LA03/DPS/0074

Antrim and Newtownabbey BOROUGH COUNCIL

Local Development Plan 2030

Draft Plan Strategy

Response Form

Consultation Period

Antrim and Newtownabbey Borough Council has published its draft Plan Strategy, the first formal stage of the new Local Development Plan 2030, for public consultation.

The draft Plan Strategy is the first of two documents, which comprise the Local Development Plan 2030. It has been developed following extensive engagement with the public, stakeholders and our elected Members, including the publication of our Preferred Options Paper.

The draft Plan Strategy sets out how our Borough will grow and change up to the year 2030. It puts forward our Plan Vision for the future. It also contains a Spatial Growth Strategy indicating at a strategic level where growth should go in the Borough. It also sets out a range of Strategic Policies and Detailed Management Policies, which together will guide future planning decisions.

The draft Plan Strategy is published for formal public consultation over an 8-week period and the Council is inviting the submissions of representations, beginning on **Friday 26 July and closing on Friday 20 September 2019 at 5pm**.

The submission of representations in relation to the Council's draft Plan Strategy provides an opportunity for the public to influence the policies and proposals for the future planning and development within Antrim and Newtownabbey.

Please note that representations received after the closing period will not be accepted and will be subsequently returned.

Published alongside the draft Plan Strategy are a range of assessments including Sustainability Appraisal (incorporating the Strategic Environmental Assessment), a draft Habitats Regulation Assessment and an Equality (Section 75) Screening and Rural Needs Impact Assessment Report. These assessments are also subject to public consultation during the formal public consultation period closing on Friday 20 September 2019 at 5pm.

Copies of the draft Plan Strategy and all supporting documents are available to view and download from our website at: www.antrimandnewtownabbey.gov.uk/draftplanstrategy.

Copies of all documents are also available for inspection at the Council Offices in Mossley Mill, Newtownabbey and Antrim Civic Centre, Antrim from Monday to Friday 8.30am to 5pm. Hard copies of the draft Plan Strategy are also available upon request.

Soundness Testing

A key feature of Northern Ireland's new Planning System is 'Soundness' which requires the draft Plan Strategy document to be tested at Independent Examination (IE) in terms of content, conformity and the process by which it has been prepared. Derived from established practices in England and Wales, it is considered that 'Soundness' testing will provide a more effective basis for examining Local Development Plans and consequently contribute towards a shorter IE process.

The purpose of the IE is to determine if the draft Plan Strategy satisfies statutory requirements and is 'sound'. The presumption will be that the draft Plan Strategy is 'sound' unless it is shown to be otherwise as a result of evidence considered at the IE stage.

The tests of soundness are based upon three categories which relate to how the draft Plan Strategy has been produced, the alignment of the document with central government regional plans, policy and guidance and the coherence, consistency and effectiveness of the content of the draft Plan Strategy. The tests of soundness are set out below:

Procedural Tests	
P1	Has the DPD* been prepared in accordance with the Council's timetable and the Statement of Community Involvement?
P2	Has the Council prepared its Preferred Options Paper and taken into account any representations made?
P3	Has the DPD been subject to sustainability appraisal including Strategic Environmental Assessment?
P4	Did the Council comply with the regulations on the form and content of its DPD and procedure for preparing the DPD?
Consistency Tests	
C1	Did the Council take account of the Regional Development Strategy?
C2	Did the Council take account of its Community Plan?
C3	Did the Council take account of policy and guidance issued by the Department?
C4	Has the Plan had regard to other relevant plans, policies and strategies relating to the Council's district or to any adjoining Council's district?
Coherence and Effectiveness Tests	
CE1	The DPD sets out a coherent strategy from which its policies and allocations logically flow and where cross-boundary issues are relevant it is not in conflict with the DPDs of neighbouring Councils.

CE2	The strategy, policies and allocations are realistic and appropriate having considered the relevant alternatives and are founded on a robust evidence base.
CE3	There are clear mechanisms for implementation and monitoring.
CE4	It is reasonably flexible to enable it to deal with changing circumstances.
***Development Plan Document (DPD) – Comprises of the draft Plan Strategy**	

Further information on Soundness can be found in Development Plan Practice Notes published by the Department for Infrastructure (DfI). Of particular relevance is Practice Note 6 'Soundness' (Version 2) and Practice Note 9 'Submission and Handling of Representations', both are available to view at https://www.infrastructure-ni.gov.uk/publications/development-plan-practice-notes.

In addition, the Planning Appeals Commission has also produced guidance entitled 'Procedures for Independent Examination of Local Development Plans' available at https://www.pacni.gov.uk/procedural-guides.

Making a Representation

As the main purpose of the IE is to determine whether the Development Plan Document (DPD) is 'sound', any person(s) wishing to make a representation to any part of the Plan should do so on the grounds of soundness. Any representation proposing a change to the Plan must demonstrate why the document is not sound having regard to the tests of soundness. Every representation should say precisely how the Plan should be changed in order to achieve soundness and should be supported, succinctly, by all the evidence thought necessary to justify the proposed change. Once the public consultation period has closed, **there will be no further opportunity to submit information unless the Commissioner requests it**.

Where several people share a common view on how the draft Plan Strategy should be changed, we encourage you to co-operate with each other, pool resources and make a single representation, for example, a local community group.

Those who make representations to the draft Plan Strategy should state whether they wish to have their representation considered at IE in writing or as an oral hearing. Unless people specifically request an oral hearing, the Commission will proceed on the basis that you are content that your representation will be considered in writing. The Commissioner will give every representation the same careful consideration regardless of whether the person who made it is heard orally or in written form.

Points to Remember:

- Representations will be made publicly available for inspection at the Council's Offices and online for counter-representations;
- Complete all relevant sections of the response form;
- Clearly state why you consider the draft Plan Strategy to be 'unsound', having regard to the soundness tests;
- There will be no further opportunity to submit information once the public consultation period closes unless the Commissioner requests it;
- We would encourage you to submit separate forms for each representation you wish to submit;
- Every representation should say precisely how the draft Plan Strategy should be changed in order to achieve soundness;
- Representations should be supported, succinctly, by all the evidence thought necessary to justify the proposed change; and
- Clearly, state whether you wish for your representation to be heard orally or in writing.

Submitting Your Representation

We recommend that you submit your representation via our on-line consultation hub, at www.antrimandnewtownabbey.gov.uk/consultations, as this is the most efficient way to make a representation.

However, you can make a representation by completing this form and returning to us by **5pm on Friday 20 September 2019** either by email or by post.

Representations received after the closing period will not be accepted and will be subsequently returned.

What Happens Next

When the consultation has closed, the Forward Planning Team will collate the representations received and as soon as reasonably practicable, publish these online for a further 8-week period of consultation to allow counter-objections to be made. The representations will also be available for public inspection during this period at the Council's Offices in Mossley Mill, Newtownabbey and Antrim Civic Centre, Antrim from Monday to Friday 8:30am to 5pm.

Once this period of counter-representations has closed, the Forward Planning Team will collate the counter-representations and publish these online. They will also be made available for public inspection at the Council's Offices in Mossley Mill, Newtownabbey and Antrim Civic Centre, Antrim from Monday to Friday 8:30am to

5pm. The next anticipated step will be for the Council to contact the Department for Infrastructure to request an Independent Examination of the draft Plan Strategy.

Contact Us

For further assistance, please contact the Forward Planning Team at Mossley Mill, Newtownabbey:

By Post – Forward Planning Team

Mossley Mill

Carnmoney Road North, Newtownabbey

BT36 5QA

By Email – planning@antrimandnewtownabbey.gov.uk

By Telephone – 0300 123 6677

SECTION A – DATA PROTECTION AND CONSENT

Antrim and Newtownabbey Borough Council complies with the General Data Protection Regulation (GDPR) by producing a specific Local Development Plan Privacy Notice, which lets you know how we manage any personal information we receive from you. It contains the standards you can expect when we ask for, or hold, your personal information and an explanation of our information management security policy.

The Local Development Plan Privacy Notice can be found on our website at www.antrimandnewtownabbey.gov.uk/gdpr/planning-gdpr/.

Please note that when you make a representation (or counter-representation) to the Local Development Plan your personal information (with the exception of personal telephone numbers, signatures, email addresses or sensitive personal data) will be made publicly available on the Council's website.

Copies of all representations will be provided to the DfI and an Independent Examiner (a third party) as part of the submission of the Local Development Plan for Independent Examination. A Programme Officer will also have access to this information during the IE stages of the Plan preparation

DfI, the Programme Officer the Independent Examiner will, upon receipt, be responsible for the processing of your data in line with prevailing legislation.

1. Please tick to confirm that you have read and understood the Council's Local Development Plan Privacy Notice.

   ☑ I confirm that I have read and understood the Local Development Plan privacy notice and I give my consent for Antrim and Newtownabbey Borough Council to hold my personal data for the purposes outlined.

You can contact the Council's Data Protection Officer via:

Post - Antrim Civic Centre, 50 Styles Way, Antrim BT41 2UB

Email - DPO@antrimandnewtownabbey.gov.uk

Phone - 028 9446 3113

SECTION B – YOUR DETAILS

2. Please specify if you are responding as an individual, as an organisation, or as an agent acting on behalf of an individual, group or organisation?

   If you are responding as an agent or representing an organisation you will be the main point of contact for your client/organisation.

   (Please select only one item)

   - ☐ Individual
   - ☑ Organisation
   - ☐ Agent

	Personal Details	Agent Details (If Applicable)
Title	DR.	
First Name	DANIEL	
Last Name	KANE	
Job Title (where relevant)		
Organisation (where relevant)	DRUMADARRAGH AND DISTRICT RESIDENTS ASSOCIATION	
Client Name (where relevant)		
Address		
Post Code		
Telephone Number		
Email Address	[redacted]	

SECTION C – REPRESENTATION

Your comments should be set out in full. This will help the Independent Examiner understand the issues you raise. You will only be able to submit further additional information to the Independent Examination if the Independent Examiner invites you to do so.

3. To which part of the draft Plan Strategy does your representation relate?

   i) Paragraph Number: 3.8, 3.10, 3.12

   ii) Policy Heading: DRAFT PLAN STRATEGY.

   - Strategic Policy (SP) Paragraph Number:

     13.1, 13.2.

   - Detailed Management Policy (DM) Paragraph Number:

     ____

   iii) Page Number in Document: 56 & 57   278

   iv) Proposal Map (if relevant state location): ________________

4. Do you consider the draft Plan Strategy to be:

   ☐ 'Sound' (*i.e. support*)

   ☑ 'Unsound' (*i.e. object*)

5. If you consider the draft Plan Strategy to be **'SOUND'** and wish to support the draft Plan Strategy, please set out your comments below.

[redacted]

(Continue on a separate sheet if necessary)

6. If you consider the draft Plan Strategy to be **'UNSOUND'** please identify which test(s) of soundness your representation relates to having regard to the Department for Infrastruture's published Development Plan Practice Note 6 'Soundness' (Version 2).

Soundness Tests:

☐ **P1 -** Has the DPD[1] been prepared in accordance with the Council's timetable and the Statement of Community Involvement?

☐ **P2 -** Has the Council prepared its Preferred Options Paper and taken into account any representations made?

☐ **P3 -** Has the DPD been subject to sustainability appraisal including Strategic Environmental Assessment?

☐ **P4 -** Did the Council comply with the regulations on the form and content of its DPD and procedure for preparing the DPD?

☐ **C1 -** Did the Council take account of the Regional Development Strategy.

☐ **C2 -** Did the Council take account of its Community Plan?

☐ **C3 -** Did the Council take account of policy and guidance issued by the Department?

☑ **C4 -** Has the DPD had regard to other relevant plans, policies and strategies relating to the Council's district or to any adjoining Council's district?

☑ **CE1 -** Does the DPD sets out a coherent strategy from which its policies and allocations logically flow and where cross-boundary issues are relevant it is not in conflict with the DPD's of neighbouring Councils?

☑ **CE2 -** Are the strategy, policies and allocations realistic and appropriate having considered the relevant alternatives and are founded on a robust evidence base?

☑ **CE3 -** Are there clear mechanisms for implementation and monitoring?

☐ **CE4 -** Is it reasonably flexible to enable it to deal with changing circumstances?

---

[1] Development Plan Document (DPD) – Comprises of the draft Plan Strategy

Details

7. Please give details of why you consider the draft Plan Strategy to be **'UNSOUND'** having regard to the test(s) you have identified above. Please be as concise as possible.

Please Note: Your representation should be submitted in full and cover succinctly all the information, evidence, and any supporting information necessary to support/justify your submission. ***This representation will be considered during the IE and here will be no further opportunity to submit information unless the Commissioner requests it.***

SEE ENCLOSED DVD DISC

(Continue on a separate sheet if necessary)

Modifications

8. If you consider the draft Plan Strategy to be **'UNSOUND'**, please provide details of what, if any, modifications do you think should be made to the section, policy or proposal which your representation relates to? What specific modifications do you think should be made in order to address your representation? Please briefly state how your proposed alternative would meet the requirements of the Sustainability Appraisal and other published assessments.

SEE ENCLOSED DVD DISC

(Continue on a separate sheet if necessary)

9. If you are seeking a change to the draft Plan Strategy, please indicate how you would like your representation to be dealt with at Independent Examination:

Please Note: Unless you specifically request an oral hearing, the Commission will proceed on the basis that you are content to your representations considered in written form only. The Commissioner will give every representation the same careful consideration regardless of whether the person who made it is heard orally or not.

Please select only one item;

- ☐ Written Representation
- ☑ Oral Hearing

Signature: [redacted]

Date: 18/09/2019.

Thank you for your response.

A COMMON SENSE, EVIDENCED AND PRECAUTIONARY APPROACH

Response to the Antrim & Newtownabbey Borough Council
Local Development Plan 2030
Draft Plan Strategy

By

Drumadarragh & District Residents Association

18 September 2019

1. Introduction – establishing the starting point

Since 2015, when the Drumadarragh & District Residents Association provided a Statement of Community Involvement, no response has been received from the Council. Even our becoming aware of the Draft Plan was purely fortuitous.

As a result, this response is perhaps more comprehensive than it might otherwise have been, as it seeks to bring forward evidence at this late stage that might have been included earlier if we had been involved.

Although much of what follows relates to renewable energy and, in particular, wind energy, We believe our long experience of the failings of the planning process in this regard has wider application, helping to identify the problems the new planning policies must address if they are to be successful.

2. Why a precautionary approach must be foundational

As a community that has suffered greatly from the depredations of the predecessor planning system and to a degree since, we have a great interest in righting the wrongs of the past and ensuring that no one else in this borough suffers from planning decisions based on ideology rather than evidence. These have displayed a total disregard for the health and wellbeing of those forced to live with the results, since, due to the 'fire and forget' nature of parts of our planning system, those results are never systematically assessed or lessons learned.

Throughout the Draft Plan, the term 'precautionary' is used. It is therefore reasonable to expect the Council to apply the fundamental principles of public health in its activities, including application of the precautionary principle .

The precautionary principle was characterized in the 1998 Wingspread consensus statement thus (Roffensperger 1999): "when an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically."
The statement goes on to list four central components of the precautionary principle:

1. taking preventive action in the face of uncertainty

2. shifting the burden of proof to the proponents of an activity

3. exploring a wide range of alternatives to possibly harmful actions; and

4. increasing public participation in decision--making.

Kriebel (2007) in commenting on Martuzzi's editorial, commends the precautionary principle and notes that public health too often works on the reactionary principle whose key components are:

1. requiring incontrovertible evidence of harm for each hazard before taking preventive action

2. placing the burden on the public (or government agencies) to show that each chemical, material or technology is harmful

3. not considering potential health and environmental impacts when designing new materials and technologies, and

4. discouraging public participation in decision--making about control of hazards and introduction of new technologies.

This community can witness that the reactionary principle noted here by Kriebel has governed both planning and public health in this borough in the past. Indeed at the end of a meeting at Mossley Mill at which our previous and current members of parliament were also present, a nationally-recognised noise expert stated that he had never in a very long career come across a situation anywhere in the UK before where both planners and environmental health saw it as their role to protect the developer against the community.

This is the legacy the Draft Plan needs to address.

There are innovative and welcome proposals such as the Strategic Landscape Policy Areas within the plan and perhaps a more robust approach to the claimed economic benefits of proposals. However, there appear to be a number of problematic issues that need to be addressed and will significantly strengthen the document. This response is a positive attempt on our part to help in that process by making our experience and knowledge available to the Council. We have therefore included a series of annexes which contain an evidence resource which it is hoped will support this outcome.

3. The Soundness test – problems to be considered

It is unfortunate that 'soundness' tests are, by their very nature, prescriptive. If soundness is not achieved, a document is adjudged 'unsound', even if a minor part only, requires to be altered.

We have felt the soundness tests to be a distraction, making a response much more difficult for ordinary members of the public going about their lives. In our opinion they do not address the environment and attitudes in which the plan is conceived and will then be applied. In particular, they do not put 'people' at the heart of the process.

Since a response in such terms is required, the Draft Strategic Plan may have failed the Soundness tests in the following areas:

Consistency Test C4 and Coherence and Effectiveness Tests CE1, CE2 and CE3.

However, in our estimation, the following needs to be considered.

Firstly, there are difficulties created by the continued adherence to the SPPS in its present form, particularly to those parts of PPS 18 'Renewable Energy' which can be shown to be factually incorrect. It is suggested that transitional amendments should be made to take account of evidence that reveals these factual errors and thus improve both decision-making and protection of the Council's residents;

Secondly, there is an absence of proposals to repair the impacts from past bad planning decisions and for which the Council has inherited responsibility under The *Planning General Regulations (NI) 2015*. Not only was PPS 18 a seriously flawed document from its inception, but it was often not properly applied in the case of separation distances for single wind turbines. *The Draft Plan* makes no proposal for scrutiny of these past disasters. Further, there is no reference to the fulfilment of commitments given in the past by predecessor bodies. These legacy issues are important when impacts, we are told, will now be looked upon differently and when attempts at renewal or replacement are being considered;

Thirdly, these legacy issues also apply to boundaries with neighbouring councils, the past and present decisions of which have a continuing impacts on this council's residents, for example in such decisions as U/2011/0351/F, T/2012/0118/F and G/2013/0198/F;

Fourthly, there does not appear to be a recognition of the responsibility to comply with the fundamental rights protected by the Convention for the Protection of Human Rights and Fundamental Freedoms (the European Convention on Human Rights).

The Convention rights involved are those protected under Article 8: the right to respect for private and family life; and under Article 8 read in conjunction with Article 1 of the First Protocol: the right to protection of property. Note that under Article 6 (1): It is unlawful for a public authority to act in a way which is incompatible with a convention right;

<u>4. Not founded on a robust evidence base?</u>

Unfortunately, examples abound of a slavish application of PPS 18 and the successor SPPS in place of evidence-based decision-making. An examination of Professional Planning Reports reveals that poor or aberrant planning decisions are excused by woodenly quoting sections of PPS 18 which are demonstrably wrong or outdated. Indeed, in some cases they were erroneous when originally written. These are not simply assertions, but are based on evidence to accompany this response.

How we got to this situation is covered in detail in Annex 1, 'Devastation & Delusion – Sacrificing Rural Communities for unfulfilled promises', presented to the Assembly's Environment Committee in 2014. The document is modular and a contents listing has also been provided. Later updates to some of the evidence contained therein, will be referred to later in this response. Note also the comments by Paul Girvan MP in the conclusion to this response.

5. Future planning decisions must be evidence-based

It should be recalled that in law any planning judgement must be evidence-based (quoted Cathco Property Holdings judgement para 61). And if there are economic benefits then they must be fully acknowledged.

Too many instances have occurred in which inaccurate, incomplete and misleading information on costs, benefits, impacts and procedures have been presented as part of the introduction of a scheme to the public. This usually minimises impacts on, and exaggerates benefits to, the host community.

It is heartening to see a different approach being proposed in the Draft Plan in DM 9.10(d) (p105) that satisfactory information must be submitted for proposals in the countryside to demonstrate a robust business case, and even more strongly in 11.3 1 (p248) A development proposal which could adversely affect a habitat, species or feature of natural heritage importance may only be permitted in exceptional circumstances and that, 'Short-term economic interests will not be considered sufficient...'

This approach should be extended to all renewable energy applications. For example, since there is no post-construction monitoring of completed applications except on foot of a complaint, how far the claimed benefits and impacts reflect reality is not being revealed and lessons are not being learned to inform future decisions. Thus claims that wind energy would be a major employer in Northern Ireland have been demonstrated to be spurious. For example:
NIRIG had originally claimed 1300 people were working in the wind industry here, but this was only 239 according to DECC and only 77 according to DETI. This latter figure is itself believed to be an exaggeration.

Indeed,at the individual project approval stage, European law is clear in that the planning authority cannot simply rely on the developer's documentation, such as his Environmental Impact Statement. The 1985 Directive on Environmental Impact Assessment, which regulates all significant projects, including wind farms, is very specific in Article 3 of this Directive, that the competent environmental authority must undertake both an investigation and an analysis to reach as complete an assessment as possible of the direct and indirect effects of the project concerned on the factors:
(a) Human beings, fauna and flora;

(b) Soil, water, air, climate and the landscape;
(c) Material assets and the cultural heritage;
(d) The interaction between the factors referred to in points (a), (b) and (c).

6. The Public Interest and Renewable Targets

The Draft Strategic Plan introduces in SP 1.3 (p62) the welcome adoption of the precautionary principle. Where, therefore, there are significant risks of damage to the environment, its protection will be paramount, unless it has been adequately demonstrated that there are imperative reasons of overriding public interest.

Similarly in 12.10 (p264) making appropriate use of renewable energy sources is supported by wider government policy. The RDS emphasises the need to increase the contribution from renewable energy, supported by the SPPS which, it is claimed, '…seeks to facilitate the siting of renewable energy proposals in appropriate locations in order to achieve Northern Ireland's renewable energy target…'.

This recourse to the public interest and renewable energy targets itself requires a precautionary approach which is not fully recognised in these statements.

7. The Public Interest test

Taking wind energy as an example, the following judgement should be borne in mind:

"If the state considers wind turbines are public policy, then the minority interest should be compensated. If wind turbines are not state policy, then decision makers may be challenged when they use the balance in favour of the state to justify giving an approval that risks a violation of basic human rights." (Justice Buckley in Dennis & Dennis v. MoD, 2003).

Thus if wind farms are public policy, then the lesser interest, i.e., you and I, must be compensated by the greater interest. If there is no mechanism as part of the policy to do this, then the public interest defence cannot be used by public servants. Since, therefore, there is no compensation mechanism mentioned in the Draft Plan, recourse to public interest arguments cannot be made.

8. Absence of Public participation in the setting of targets

In implementing renewable programmes at such a rapid pace, the legally binding procedures related to environmental assessment and democratic accountability were simply by-passed. As a legal ruling from the United Nations Economic Commission for Europe (UNECE) has demonstrated, major failings have occurred in relation to the obligations under the Aarhus Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters, which is a binding component of EU and Member State law.

Thus the public were not consulted in the setting of any renewable energy targets in Northern Ireland. Even if they had been, there is a further constraint.

In a judgment handed down at the Administrative Court in May 2012, Judge Laing found that:
"As a matter of law it is not correct to assert that the national policy promoting the use of renewable resources … negates the local landscape policies or must be given 'primacy' over them," she said.
Sea & Land Power & Energy Ltd v Secretary of State for Communities and Local Government and Great Yarmouth Borough Council [2012] EWHC 1419 (Admin).

Since developers will often attempt to pressure planners by reference to the need to achieve renewable targets and their definition of what constitutes the public interest, as in for example the Drumadarragh wind farm application U/2005/0281/F, these constraints should be noted in the Draft Plan.

9. Differential treatment in Health & Safety?

The use of the precautionary principle introduced in SP 1.3 (p62) above, should underpin the approach to all applications claiming to produce beneficial environmental results.

It is encouraging that, 'The Council recognises the link between the quality of our environment and the health and wellbeing of our population.' Yet SP 10.6 (p281) and 13.9 (p284), seem to extend this recognition only to major hazards and contaminated land, levels of pollution or negative impacts on the health and safety of our residents' Relating to those matters, and to which 'Public safety will be the overriding priority…', and health and safety risks.

It is therefore apparent that the neighbours of existing and future wind energy installations throughout the borough are not being extended this same level of protection.

It is suggested that, due to a continued adherence to the specific sections of the SPPS dealing with health and safety-related matters such as accidents, shadow flicker and noise, assessment of adequate preventative separation distances, and a refusal to engage with the latest research in this area, the Draft Plan is discriminating in favour of one particular form of renewable energy – see evidence contained in Annexes 1, 2, 3 and 4. Evidence for significant errors in the renewable energy section of the SPPS will be discussed below.

10. SPPS problems caused by continued use without amendment or updating

The Draft Plan notes in 2.24 (p31), that once the Council's Plan Strategy is adopted, its policies will replace the existing suite of Planning Policy Statements.

This is very welcome news for the future. However, the statements in 12.22 (271) that the aim of ensuring full consideration of environmental, landscape, visual and amenity impact of such schemes, is achieved by taking account of and being consistent with the provisions of the SPPS and, DM 45.4 (p273) that, 'In assessing renewable energy proposals the Council will take account of the guidance set out in the Best Practice Guidance to PPS 18 (DOE, 2009)', is far less welcome, and seems to make the assumption that the former policies were effective.

It would not be wise to uncritically base a successor planning system on one recognized as containing fundamental flaws. Such an approach would only expose the Council to defending an evidence base and policies which it did not originate or might be unable to authenticate. In such cases, as Mr. Justice Matting stated with respect to the noise standard applied in a judicial review brought by the Renewable Energy Foundation (CO/9686/2007): "It will always be open to any objector to an application for permission to develop a site as a windfarm, to contend that the statement is technically inadequate or erroneous."

Therefore, use of a flawed policy can only lead to flawed planning decisions.

11. Factual errors in PPS 18

It is futile to insist on robust evidence from applicants, if the standard against which they will be measured itself makes erroneous claims, such as the statements in PPS 18 that a separation distance of either 500 metres or 10 times the rotor diameter, would resolve all problems of noise, shadow-flicker and safety relating to wind turbine construction and operation.

12. Ten times the rotor diameter – a meaningless measurement

This metric is used to calculate what are claimed to be adequate separation distances to address issues of health and safety, shadow flicker and noise. It makes the incorrect assumption that there is a straight line relationship between the degree of impact and the size of a turbine blade and distance. No account is taken, for example, of land form, meteorological effects or season.

As Annex 2 on Shadow impacts and its appendices will demonstrate, the single piece of research on which the ten times the rotor diameter is based was completely misconstrued. Indeed, recent research for the Scottish government concluded as follows:

> "Key issues: ten rotor diameter distance Scottish guidance should not include reference to the ten rotor blade diameter distance in relation to shadow flicker. As further discussed in the literature review, there is a lack of robust evidence for the use of this figure, and it appears more appropriate to identify the factors which influence when shadow flicker is more likely to occur and when it is less likely to occur. The guidance should focus on avoidance of harm and nuisance, which should be established by exposure thresholds, and not on limiting the extent of assessment."

> "3.26 Although duration and exposure to shadow flicker are related to distance, this study has found insufficient evidence to support the use of distance alone to define areas of search for the impacts of shadow flicker, unless new data can be provided which supports the use of distance."

Review of Light and Shadow Effects from Wind Turbines in Scotland
Stage 1 and 2 Final Report for ClimateXChange, March 2017, (Annex 2, Appendix 6, pp 13 & 14).

The Scottish study was also unable to find any evidence from the source of the 10 times the rotor diameter method, to give support to a simple relationship between rotor diameter and impacts from noise. It must be abandoned as a method of protecting residents since it has no evidential basis whatsoever.

13. Already inadequate separation distances should not be reduced further

The use of the proposed 25 metre hub height will without doubt reduce the already minimal protection to wind turbine neighbours

There is now a large body of evidence, anecdotal reports, case control studies, observational reports and small controlled studies, ALL of which point in the same direction; wind turbine noise adversely effects sleep and health at distances permitted by Council regulations as they stand. This is more than sufficient evidence for action.

Related to the foregoing section on how the use of an unsupported metric has left residents unprotected from the harmful effects of wind energy, is the matter of how close to residents should they be permitted. The Draft Plan makes the following statement in DM 45.6 (p274):

For all wind turbine development with a hub height over 25m, a separation distance of 10 times the rotor diameter to all occupied properties, with a minimum distance of not less than 500m, will generally apply.

Whilst a clear statement of a minimum separation distance for some single turbines is useful, the application of this protection only to turbines with a hub height of 25 metres or greater is of serious concern. Indeed, it appears to be repeating the original errors in PPS 18 in it's calculation of buffers without adequate evidence in support and by excluding certain types of impact. It also does not address the application of the minimum separation distance to existing turbines.

Further, the proposed separation distance runs counter to trends in other countries, who are finally accepting that industrial wind turbines can pose a significant public health and safety risk. In June 2014, the report of the Finnish Ministry of Health called for a minimum distance of 2 km from houses by concluding: "The actors of development of wind energy should understand that no economic or political objective must not prevail over the well being and health of individuals" (sic). In 2016 Bavaria passed legislation requiring a minimum 2km distance between wind turbines and homes. The Scottish government has proposed increasing the separation distance between wind farms and local communities from 2km to 2.5kmetre

None of the previous separation distances applied in Northern Ireland have been the product of practical research, experimental fieldwork or the result of the measurement of impacts on those living nearby. Even the most cursory investigation would reveal that small wind turbines has caused many problems in the past from lack of maintenance and structural failures. It would not be difficult to identify single turbines below the proposed height limit of 25 metres, which regularly exceed the noise limits in ETSU-R-97 or the shadow flicker limits in the Best Practice Guide and which are causing other recorded health effects, for example I/2012/0398/F.

When permitted development for certain sizes of wind turbines was being considered in Northern Ireland, the final report recommended that no permitted development be agreed until "…issues of noise, vibration, health and aircraft safety and other critical communications systems are resolved". The turbines in question were of up to 15 metres to tip height.

The proposal to increase the height of turbines to which a minimum separation distance will not apply to 25 metres at hub height, more than doubles the size of this group of turbines and is a significant reduction in amenity and protection for the neighbours of turbines of this category. It clearly demonstrates a disregard for the health and amenity of those forced to live around wind turbines.

A separation distance must be based only on evidence from high quality research by independent experts with relevant expertise in acoustics, sleep medicine and other relevant clinical disciplines, preferably funded by the wind industry, which had demonstrated safe external and internal noise levels so as to protect the health of surrounding residents.

Instead of creating another category of turbine, the original minimum separation distance of 500 metres for all turbines, should be rigorously applied until adequate independent evidence is available to set a more realistic minimum.

As will be seen in Annex 3 on Single Turbine Separation Distances, there has been an improper application of this policy ever since the early days of PPS 18 and it's Best Practice Guide. The annex will also demonstrate that there is a clear distinction between turbines with a hub height of up to 15 metres and those of a greater size. It was only to turbines of the former size that the fall over plus 10% safety margin was to be applied. There is no justification for introducing a further discrimination into an area of impact already wrongly calculated and inadequately monitored after construction.

14. The absolute necessity of adequate separation distances

In two typical examples of professional planning reports, U/2014/0065/F and LA03/2015/0041 /F, the statements from the Best Practice Guide to PPS 18 on the safety of wind turbines are quoted, specifically 1.3.50 'There has been no example of injury to a member of the public', and 1.3.51 'The only source of possible danger to human or animal life from a wind turbine would be the loss of a piece of the blade… Blade failure is therefore most unlikely.'

More detail will be given in the section on 'Demonstrable fallacies in PPS 18 BPG', in Annex 8 but before these documents had even been completed, the Planning Service and it's then minister had been advised that by 30th June 2008, a minimum of 48 people had been killed and 22 seriously injured as a result of wind farm operations.

Yet, to continue the first of the above professional planning reports, the planning officer, having quoted the above sections of the BPG, concludes as follows:

"Consequently the objectors concerns in relation to safety aspects I find non-determining as it has not been sufficiently substantiated that there will be a demonstrable harm created by the erection of a turbine at this location."

It is a concern that such slavish adherence to untrue or obsolete statements, in the face of evidence to the contrary still occurs. This underlines the need to have adequate separation distances based on a clear identification of impacts on the public and not on some notional 'rule of thumb' with no scientific or evidential basis to support it.

Since Neither the Health & Safety Executive, Environmental Health or any other local agency have responsibility for recording accidents, policy will continue to be unrealistic, and uninformed by the results of experience. Even the most cursory examination would have revealed that the government's own Health & Safety Laboratory report entitled 'Numerical Modelling of Wind Turbine Blade Throw', demonstrated that blade fragments were being thrown distances of up to1,462 metres. In fact, contrary to the claims of the Best Practice Guide, blade failure is the most common cause of wind turbine accidents. The May 2015 edition of Wind Power Monthly admits that in 2014 alone, blade failures amounted to no less than 3,800, of which only 28 had been reported in the press. See Annex 4.

The turbines in use in Northern Ireland are no different from other countries except that they include a much higher proportion of 'second-hand' turbines. Due to the unpredictability of such accidents, their significant scale and the high number of dwellings surrounding many wind turbine sites, it is clear that safe separation distances are not being achieved. For example, the turbine that collapsed in January 2015 at the Screggagh wind farm between Fintona and Fivemiletown, sent a mass of fragments over 315 metres from the turbine and across a major road.

To maintain, as many officials still do, that 'it has not been sufficiently substantiated that there will be a demonstrable harm' when there is an abundance of contrary evidence readily available, demonstrates an absence of due diligence and a failure in their duty of care. It also illustrates the 'mechanical' tick box approach to promotional planning policies in the past that have placed adherence to a faulty statement enshrined in policy above reality. How can the public feel protected by such an approach?

Certainty is not necessary before taking action to prevent harm to the public health. In considering the evidence, planners have adopted inappropriately strict evidential criteria, but only for those opposing a development. This is the reactionary approach to public health risks noted in section 2., above, and is clearly not in the public interest. Action in defense of the public health does not require certainty. Further, the burden of proof has been turned on its head. It is the developer's duty to prove the safety of its activities and not that of the public to have to go to extraordinary lengths to disprove it.

15. Differential treatment in landscape and visual impact?

As noted above, it is encouraging that, 'The Council recognises the link between the quality of our environment and the health and wellbeing of our population.'

The Draft Plan proposes in DM 40.2(c) (p251) and DM 43.5 (p267), to protect the landscape from visual impacts by applying special requirements to 'any structure in excess of 15m in height' and, in the case of mineral workings, 'will not support development where proposed structures, machinery, land-banking or waste materials will interrupt the skyline.'

These precautionary restrictions can only be contrasted to the removal of a minimum separation distance for wind turbines of up to 25 metres hub height and the application of an inadequate separation distance to the remainder. Apparently, the neighbours of existing and future wind energy installations do not warrant the same degree of consideration in terms of the proximity of tall structures or the breaking of their skyline.

16. Differential treatment in protection from noise?

It is the Council's Preferred Option to retain the approach of the SPPS, updating Policy RE 1 of PPS 18 by adopting a cautious approach within designated landscapes.

However this retention includes the noise standard known as ETSU-R-97 which is used for wind energy applications. It is the only noise standard in the world that permits a higher noise level at night than during the day and is set significantly above World Health Organisation recommended levels and even above noise levels permitted for other types of renewable energy.

The shortcomings of the noise standard used in the original PPS 18 and now the SPPS was considered by the Assembly's Environment Committee report of the Committee for the Environment [NIA 226/11-16] on its Inquiry into Wind Energy in Northern Ireland, the second term of reference of which focused on wind turbine noise and separation distances from dwellings.

The Committee concluded that 'the current guidelines on permissible levels of noise are no longer adequate', and 'therefore recommended that the Department urgently review the use of the ETSU-R-97 guidelines with a view to adopting more modern and robust guidance for the measurement of wind turbine noise. The Committee also recommended that the Department specify a minimum separation distance between wind turbines and dwellings.'

These recommendations were adopted by the Assembly on 3 March 2015.

17. Was ETSU-R-97 written to protect amenity?

The background to the use and abuse of this inadequate standard can be found in the noise-related sections of Annex 1 and further related documents in Annex 5 and comments in Annex 8. However, without ever providing any evidence in support, a restriction in noise to a level which would actually protect amenity, was seen as being very restrictive on the development of wind energy.

It is known that wind turbine noise emissions can disturb sleep and impair health, otherwise set back distances would be redundant.

The body which formulated ETSU-R-97 has no brief for the protection of the environment or for the protection of the public from nuisance or loss of amenity. By it's own admission, it is not a method of assessing impact, but chose noise levels which they "thought" would afford the public "reasonable" protection. No certainty, just assumptions, only "reasonable" protection, with no definition of "reasonable". No margin for error.

In addition, the permitted noise levels were raised in order to facilitate the development of the wind industry. In the 22 years since ETSU was published, wind turbines have increased in size from around 1MW with a hub height of 32m to 7.5 MW, with a hub height of 135 m, with a concomitant increase in noise, particularly low frequency noise. These facts, which demonstrate the capacity for harm, should have been known to the acoustician advising the panel and should have provided the basis for an understanding of the potential for harm from wind turbine noise.

So, to answer the question, ETSU-R-97 was not written to protect amenity, but to ensure that the development of wind energy, which itself, we are told, has other environmental benefits, was not restricted. Indeed, it should be understood that when the term 'amenity' is used, this does NOT have the same meaning as the defined term in planning.

18. A concealed reduction in amenity for wind turbine neighbours?

During the public consultation process for Draft Planning Policy Statement 18 - Renewable Energy, the Chief Environmental Health Officers Group (CEHOG) voiced concern at the mismatch between the planners stated responsibility for the protection of amenity and their proposed use of a noise standard they considered to provide a lower level of protection. To quote from their response:

> "Protection of amenity

The document advises that the planning policy aims to prevent unacceptable detrimental effects upon the locality and amenity. Page 36, paragraph A37 states,

"The planning system exists to regulate the development and use of land in the public interest. The material question is whether the proposal would have an unacceptable detrimental effect on the locality generally, and on amenities that ought, in the public interest, to be protected."

"However the level of protection afforded by the current ETSU-R-97 standard referenced on page 45 would be considered to provide a lower level of protection against "unacceptable detrimental effects on the locality generally, and on amenities…". Page 45, paragraph A79 states,

"The report, 'The Assessment and Rating of Noise from Wind Farms' (ETSU-R-97), describes a framework for the measurement of wind farm noise and gives indicative noise levels calculated to offer a reasonable degree of protection to wind farm neighbours, without placing unreasonable restrictions on wind farm development."

The Department should give careful consideration to the possible interpretation of such terminology and references and should ensure that the final wording of the Statement will ensure that local amenities are adequately protected. Accordingly, the Department may wish to align the wording of paragraph A37 with that used within paragraph A79."

CEHOG Northern Ireland Pollution Sub-Group response to:
Draft Planning Policy Statement 18 - Renewable Energy: Consultation Paper February 2008. See Annex 5, CEHOG & amenity protection.

Note that we have underlined the key passage for convenience. It is, therefore, very relevant to ask if the Department heeded this recommendation from CEHOG. The final published version of PPS 18 in 2009 for the same paragraphs, now numbered 1.3.4 and 1.3.46, shows that the text remained unchanged and a noise standard was adopted that greatly weakened the level of protection from noise on a locality generally and on individual amenities.

Finally, ETSU-R-97 does not fulfil the requirements in the EU 1985 Directive on Environmental Impact Assessment, were It is a legal requirement that a noise assessment forming part of an Environmental Statement must supply "the data required to identify and assess the main effects which the project is likely to have on the environment", and that the "direct effects and any indirect, secondary, cumulative, short, medium and long-term, permanent and temporary, positive and negative effects of the project must be described".

ETSU-R-97 does not fulfil the requirement of a description of the likely significant effects of the development and so residents do not know whether the impact is small or great – merely that it meets a target noise level.

19. Noise and negative health effects

It is an unfortunate fact that the regulations on wind turbine noise are not fit for purpose. They take no account of relevant earlier research, excessive amplitude modulation and low frequency sound emissions and were formulated to favour the industry rather than the public health.

There is a large body of evidence to show that wind turbine noise cannot be equated with road, rail and traffic noise. It is more annoying, less easily masked by background noise, has a greater low frequency noise content, propagates further and is greater at night.

This needs to be recognized since Directive EIA 2014/52/EU1 which amends EIA law in a number of respects by amending Directive 2011/92/EU2, introduces the aspect of human health into the consideration of projects, as stated below:

"The characteristics of projects must be considered, with particular regard to:
...
(g) the risks to human health (for example due to water contamination or air pollution)."

There is now very considerable evidence to suggest that wind turbines disturb sleep and impair health at distances and external noise levels that are permitted in Northern Ireland. Experts in the field identify that ILFN is particularly disturbing to sleep thanks to its Impulsive, Intrusive and Incessant nature. Sleep is arranged in 90 minute batches with 'Arousals' in between when the subject wakes up but not to full consciousness, and then reverts to slumber. The presence of ILFN, especially with Amplitude Modulation, which is particularly annoying, tips the balance in favour of full awakening, and therefore sleep disturbance and deprivation.

Robust independent research into the health effects of existing wind farms is long overdue, as is an independent review of existing evidence and guidance on acceptable noise levels. Little account seems to have been taken of individual situations where those living near operating turbines have had to abandon their homes, such as in LA03/2016/0797/F.

There is a virtual deluge of recent research articles supporting the health impacts on both humans and animals near wind turbines, and the mechanisms of how the various forms of noise are translated into negative health outcomes is becoming clearer.

Rather than extending an already long response by detailing each set of research findings, other recent evidence is instead provided as a resource in Annex 6 on noise and health. Note particularly the submission for the Doraville wind farm application dated 2 September 2019 by Dr. Mariana Alves-Pereira and the major article by Prof. Alun Evans on Environmental Noise Pollution from 2017. Additional recent articles are included that will be incorporated into a later revision. Note also the comments by the Planning Appeals Commission on the effect of noise from the

Wolf Bog wind farm on sleep at distances of over 2500 metres in Planning Appeal 2013/A0169.

20. Economics, CO2 and employment

The Draft Plan proposes , in SP 1.16 (p68) and SP 1.17, an option to require developers to agree a financial guarantee or bond to ensure that decommissioning, restoration, aftercare or mitigation measures actually do take place in the case of minerals workings or renewable energy schemes.

We would urge the Council to stand fast on this proposal, which we ourselves made as long ago as 2008, and not be dissuaded by vested interest to the contrary.

There is a real danger that many renewable energy projects will become financially unviable. As you will see in Annex 7, 'Insolvency of Irish Wind Farms', this is not just speculation but is already happening on a significant scale. The Council must protect itself and its residents from the financial implications by introducing a bond system for renewables and related projects so that it is not left financially exposed.

Similarly, it needs to be appreciated that expensive electricity drives industry away and makes an area unattractive. So benefits claimed by developers must be tangible and not accepted on the basis of speculative unevidenced assertions.

Looking at our neighbours south of the border, in early 2019 there is approximately 3,500 MW of wind energy now installed in the Republic of Ireland. It would be expected that from the period from 2010, when there was an installed capacity of only 1,379 MW, there would be a significant reduction in carbon emissions from the Irish energy sector.

This period saw little or no growth in Irish electricity demand, yet greenhouse gas emissions attributed to the energy industries, has altered little in that period.

Despite this, no less than €1.2 billion per year has been paid by the electricity consumer in Ireland. Indeed, even in 2014, the Irish Academy of Engineering identified that the cost of electricity was 50% higher simply to fund the renewable investment programme. (see Annex 7, 'Public Consultation on the Draft Statutory Climate Change Adaptation Plan for Electricity & Gas').

The seriousness of such considerations is highlighted in a new report just published by consulting giant McKinsey who found that Germany's Energiewende, or energy transition to renewables, poses a significant threat to the nation's economy and energy supply. One of Germany's largest newspapers, Die Welt, summarized the findings of the McKinsey report in a single word: "disastrous."

"Problems are manifesting in all three dimensions of the energy industry triangle: climate protection, the security of supply and economic efficiency," writes McKinsey. (Annex 7, 'Renewables threaten German economy & energy supply').

The existence of climate change is not the issue here. What is at issue is the use of the climate change ‘bogieman’ to excuse bad planning decisions. Hard questions must be asked of any renewable proposal instead of being panicked into doing anything for the sake of doing something. Not every renewable solution has the same cost or result and neither do they all have the same impact on their neighbours.

In the absence of any proper cost/benefit analysis of renewable applications and the lack of any regular post approval assessment of results, the planning system stands wide open to applications based on unverified assertions – so many jobs, cheaper electricity, reduction in CO2, etc., all made by those who stand to gain from the naiveté of the planning system.

Thus, in the case of wood pellets, we find reports now such as this:

“Britain is wasting hundreds of millions of pounds subsidising power stations to burn American wood pellets that do more harm to the climate than the coal they replaced, a study has found. Chopping down trees and transporting wood across the Atlantic Ocean to feed power stations produces more greenhouse gases than much cheaper coal, according to the report. It blames the rush to meet EU renewable energy targets, which resulted in ministers making the false assumption that burning trees was carbon-neutral.” Annex 7, ‘Wood Pellet Problems’.

There are many statements within the Draft Plan that indicate the same kind of ‘groupthink’. For example, 12.2 ‘Renewable energy production reduces our dependence on imported fossil fuels and brings diversity and security of supply to our energy infrastructure.’

Such statements are embarrassing in their ignorance and clearly identify their origin. Intermittent renewables such as wind and solar can never bring security of supply and their reliance on ‘spinning reserve’ to take over when the wind does not blow or the sun does not shine, is not included in the calculation of their environmental gains and losses. Neither is their supply chain and the devastation they leave behind in other parts of the world to place that turbine on an Antrim & Newtownabbey Borough hillside included in the equation. Renewable energy applications tend to be deliberately myopic when it comes to the downside of their activities and as long as our planners equate ‘promotional’ with ‘the industry knows best’, this will continue into the new planning regime.

21. Conclusions – putting people first

With regard to renewable energy, the present planning system has displayed an ideological approach in which fact-based evidence and direct experience have played little part in the decision-making process. Indeed, it would not be too strong to characterize the approach to planning guidance as theological since it’s statements are never questioned no matter how dated, contrary evidence is disregarded and it’s tenets are not subjected to any post-approval assessment of positive and negative effects to inform future decision-making. In short, up until now, the planning system has refused to learn.

How did this incredible state of affairs happen? Our present Member of Parliament provides the answer from a meeting at Stormont with the then Environment Minister Sammy Wilson on 16 June 2009, at which members of this Association were also present:

"Alderman Girvan reminded Mr. Wilson that they had both previously attended an event at the Ross Park Hotel sponsored by the wind industry. Although the Department had made a presentation on that occasion, he noted the apparent absence of any significant underpinning knowledge and the Department appeared to be depending very much on the industry guiding them on the issues associated with PPS 18. In effect, the industry seemed to be telling the Department what to include and therefore was basically permitted to write its own charter."

"The department, in his opinion, had started from an initial position of overreliance on the industry to come up with their policies as opposed to a balance of the industry position and contrary arguments proposed to protect the public interest from these facilities and there were a number of questions that had to be answered as to the economic benefits."

What resulted in Northern Ireland in the period from 2009 to 2015 can only be characterized as a 'goldrush' for renewable energy schemes, principally wind, with remarkably low or even no rejection rate when compared to the rest of the UK. Much of the scenic character of the province was lost in this unstructured grab for subsidies, with professional planners ignoring both councilors and the rural public in their unquestioning commitment to a 'promotive' policy. Nor has any attempt been made in the aftermath to assess the post-goldrush impact on the rural public. In other words, the general public does not count.

We have stated in Section 3 our opinion that the soundness tests do not address the environment and attitudes in which the plan is conceived and will then be applied. The most perfect plan in the world will not address the needs of the public if that public is not at the heart of the plan. It has not been in the past, being treated simply as 'collateral damage' from a planning system operating a 'fire and forget' approach to approvals in particular policy areas. There is nothing in the present document, which has many 'grey areas' and caveats, to prevent this happening again. So our question is, 'How is this going to change what has happened before?'

A serious engagement with the issues would require a restructuring of some of the activities around the planning process itself.

There is a clear need, particularly for larger projects, to introduce as standard post-construction assessment. This must include involving those living around the development to adequately assess positive and negative outcomes from those it was claimed would result;

There must be a recognition of internal conflicts of interest. Post-construction policing must not be undertaken by the department who approved or otherwise recommended the original decision, including consultees within the Council itself. For example, assessment of impacts from shadow flicker reside with the planners themselves, but they do not have competence in this area. Yet it is they who assess the applicant's shadow flicker report and recommend acceptance or rejection;

Expertise is required or should be readily available in key areas to be assessed in an application. Reliance on the application itself must be avoided and independence must be credible, not relying on the industry from which the application originates;

Recognize that advice from an industry comes with a price. Vested interests are only too willing to help the planning process come to the 'right' conclusions;

Promotive policy still require rigorous scrutiny to assess accurately the balance between benefits and adverse impacts, and should not leave the public unprotected. These must be based on evidence and not assertion. Unacceptable adverse impacts cannot be claimed as 'public policy' unless there is a compensation mechanism for the lesser interest;

Only the most recent information should be used in considering applications. If the statements in the current policy are known to be out-of-date or defective, the Parliamentary Ombudsman's Principles of Good Administration will support the use of evidence resulting in an improved decision;

[redacted]

There has been instances where the number of consultees responding positively to an application has been used to over-rule objectors concerns, even though the expertise to make such a comment resides with only one of the respondents;

Notification distances for large renewable and other projects are completely inadequate in relation to landscape and visual impacts. If people are to be at the heart of this planning process, this must include those viewing the impact from some distance away on a daily basis, e. g.to avoid approvals such as this - U/2011/0351/F;

Policies and their impacts, informed by post construction assessment and policing, should be reviewed on a regular basis, such reviews to include not just independent experts and public representatives, but also members of the public affected by the policies in question;

Finally, we would once again urge the importance of the constant application of four principles:

Decision-making must be evidence-based;

That evidence must be recent and capable of independent verification;

It must put people first; and

It must apply, as far as humanly possible, "primum non nocere" ("first, do no harm").

Daniel Kane (Dr.)
On behalf of
Drumadarragh & District Residents Association.

LA03/DPS/0074

ANNEX 1

Contents

Devastation and Delusion

Sacrificing Rural Communities for unfulfilled promises

Response to the Environment Committee Inquiry into Wind Energy

by

Windwatch NI

28 February 2014

Devastation and Delusion

Sacrificing Rural Communities for unfulfilled promises

Response to the Environment Committees investigation into Wind Energy

Windwatch NI

About Windwatch NI

Windwatch NI is a collective title for a rapidly expanding network of numerous groups and individuals across Northern Ireland who are suffering from, or are threatened with the destruction of their amenity, health and well-being by the imposition of industrial wind energy in their midst either against their will or with consent obtained through a failure to adequately disclose the true nature and scale of the impacts.

Amongst its aims and objectives we would emphasise two for the current review:

To represent, lobby and promote the views of all who are affected by existing or future wind energy development and to promote the introduction and advantages of a citizen-centred approach to all scales of wind development;

To promote a presumption in favour of the protection of the health and well-being of the public who will be exposed to the impacts of wind energy developments, such presumption to take precedence over economic benefits - Health before Wealth, and the application of the precautionary principle.

Daniel Kane
On behalf of
Windwatch NI

Introduction

There is an unexpected parallel between our energy policy and the self-deception and wishful thinking exhibited by the mishandling of intelligence in the run-up to the invasion of Iraq in 2003. The Blair government ignored warnings about the reliability of sources, some of whom were fantasists, and "sexed up" whatever evidence it thought it did have. In an alarmingly similar fashion, successive British governments since the White Paper of the same year have been basing energy and climate change policy on questionable evidence, much from visionary green NGOs, dubious assumptions about future oil and gas prices and flawed reasoning about the beneficial effects of current renewable generation technologies. The thrust of this policy — unfortunately supported by all three main parties on the mainland— is to offer heavy subsidies, mostly for wind power, by means of levies on energy bills: a regressive wealth transfer from consumers to investors in renewables and to large utilities. The scale of these burdens, already significant at about £2.2 billion a year, is set to grow dramatically as we struggle to reach the 2020 targets set by the European Union's Renewables Directive.

"Instead of a science-based approach, our energy and environmental policies are typically written by those who stand to economically or politically profit from them. As a result, anything genuinely science-based in these policies is usually inadvertent and accidental."

Democratic deficit and inhuman treatment

The emergence of a democratic deficit can be traced to a general belief amongst local politicians that wind power gives us "energy security", that it creates jobs and that it reduces CO_2 emissions. To achieve such 'benefits', it seemed acceptable to subordinate the need for planning policy and Government to protect the quality of life of communities and rural dwellers from the adverse consequences of the technology. The only role for the general public in Northern Ireland, it seems, is to swallow the propaganda, pay those ever-soaring bills — and wait for our lights to go out. It would also appear on the face of it that little attention was given to the possible implications of renewable energy policies on Human Rights law, European law, European Environmental law and the principles of the Aarhus Convention. An addendum on this issue is attached to this section.

Perhaps the most perplexing aspect is the failure to recognise the effect of energy price on the resilience and competitiveness of economic activity and the impacts on well-being, employment, creativity and, for those on low incomes, the more immediate threat of premature death or illness from cold. Sacrificing the population here on the altar of expensive electricity, when it is known that the most vulnerable can lose their lives in cold winters due to the fuel poverty in a weakened economy, is a sure recipe for ruin and is utterly immoral.

The Northern Ireland government aspires to human rights ideals, yet they indirectly endorse the inhuman treatment suffered by some families, stemming directly from Government policy that allows construction of wind turbines in close proximity to family homes. The protection of family life and its amenity and health are less important to Government and its policy-makers than corporate welfare, which is favoured over human and environmental well-being.

The lack of debate, and information about the negative effects of wind power, means that people and the environment in Northern Ireland are being treated by the government as a form of collateral damage. Due regard is not being given to the growing scientific evidence which shows that wind turbines have a profoundly damaging effect on the local ecology and on people's health. The industry has also successfully diverted attention away from its 'dirty little secret' - the true cost of the technology in terms of the pollution it causes in parts of the world from source materials such as rare earth metals. The wind industry are the true NIMBYs since the worst polution has been displaced out of sight to China's 'backyard', not to ours.

Planning system 'not fit for purpose'

The nature of wind energy as a technology has also exposed long-standing tensions in the institutional design of planning. Participation is often identified as a core value of planning, yet it is just this openness to wider viewpoints that most seems to threaten the narrow, instrumental, unaccountable delivery of renewable energy under PPS 18. Decision-makers lack the specialist knowledge to effectively weigh the impacts caused by the technology, or to judge the efficacy of the information provided by many developers. Planners have been politicized to the extent of subordinating professional planning judgement to renewable targets, since the application of the same professional judgement on the mainland results in significantly higher rejection rates.

One particularly disappointing aspect is the absence of any principled independence amongst government departments and agencies, consultees, NGOs and those charged with the protection of the public. Consultees are straitjacketed by the Planning Service in how they can consider and respond to wind energy applications,usually following a desk top exercise on their part, and in some cases are compromised by accepting financial contributions from the wind industry. Any form of independent judgement that does not promote the wind paradigm is rejected outright and the assurances of the wind industry as to the benign nature of its activities are left unchallenged. Indeed, the whole system is perceived as being subservient to the goal of achieving the unproved assertions of economic, environmental and social benefits of wind energy, and no one is prepared to establish the reality of these claims. As Ed Milliband once said, 'The wind industry knows best'.

Our broken planning system has undoubtedly failed rural communities, who see it as a 'rubber stamping exercise' which does not protect members of the public from the residential amenity, health or safety impacts of wind energy. Indeed, Planning is seen as an Agency of the wind industry, and this was humorously confirmed by a recent example involving a local resident from mainland Europe, who rang the wind energy section at Planning Service headquarters. Before he could even state the purpose of his call, he was literally assailed and brow-beaten by a sales pitch on the advantages of bringing his wind farm proposal to Northern Ireland, on the mistaken assumption that he was a possible incoming developer!

However, in a clear abandonment of the precautionary principle, not only do the majority of decision-makers and consultees display a disturbing renewables sycophancy, thus maximizing approval rates for wind energy, but they have failed to put in place a robust methodology for addressing any reported adverse impacts on the rural public. For example, both planners and Environmental Health claim that they cannot monitor or police or enforce any issues relating to noise from wind farms because of the Penalty that would be applied to the developers by Power NI for interrupting the supply – a strange argument for an energy source characterized by intermittency. So the affected residents are left to suffer. Similarly, both planners and Environmental Health have admitted to having no competence in the assessment and resolution of problems caused by shadow-flicker.

By ignoring the history of such community experiences with renewable energy, therefore, the message is sent that there is an unwillingness to listen to the public at large, no matter how loud they shout, or research their grievances.

The burden is real – what about the benefits?

This response does not comment on every aspect of how wind energy interacts with people and the environment. Other colleagues will comment in more detail on the effects on health, the electricity grid, habitat and wildlife and other aspects in separate submissions. However, we wish to make the point that the burden placed on rural communities by the administration of the present renewables policy under PPS 18 is not matched by any commensurate benefits to the community as a whole.
As Dr. Patrick Moore, co-founder of Greenpeace, told more than 1,000 farmers in Ontario in 2012, the industry destroys more jobs than it creates, and causes energy prices to climb for all users. "The industry is a destroyer of wealth and negative to the economy."

There are two words that should be tattooed on the chest of every energy minister: cheap and reliable: subject all policies to those criteria. Who will invest in an economy that can't guarantee its electricity or gas supply or in which the price is no longer competitive?
Those who forget history are destined to repeat it. Catastrophe can be avoided but only with a clear understanding of the failures of the past.

One seminal failure is highlighted by Professor Tony Trewavas of Edinburgh University, and very relevant to this review. Prophesies of the end of 'scarce' fossil fuels were made without looking at the available information, but these views, were widely distributed in newspapers and magazines.

"From EIA assessments, we are several centuries away from any substantive depletion in gas, oil or coal.
Shale and methane hydrates between them put gas even longer term. There are 7 trillion tonnes of world-wide coal and even in the UK, gasification of the known 17 billion tonnes of off-shore coal offers over three centuries worth of energy.

99% of world uranium lies dissolved in the oceans and can be recovered, thus powering the future well beyond the survival of our species. Nuclear currently is the real future. And then there is thorium. We need not be complacent, oil substitution seems the most pressing because so much technology depends on it; but equally we should not descend into meaningless hysteria. Look at the facts, not the hubris."

It is simply facile to say, as the wind industry often does, that "the wind is free". Coal and gas are free in the ground; but we have to extract, convert, and deliver the usable energy to a consumer, all of which have costs.

Exactly the same is true of wind power, and for renewables the extraction, conversion, and delivery costs remain extremely high compared to fossil fuels.

The crude subsidy levels confirm this point. Even onshore wind, a relatively cheap renewable, needs a near 100% income top-up, and if systems costs, extra grid and balancing costs (a hidden subsidy since these costs are socialized over the entire system), are taken into account the cost to the consumer of onshore wind is three times that of fossil fuels, and offshore wind is still more expensive, perhaps four or five times as expensive as conventional energy. Furthermore, these cost estimates may well be too low, since there is emerging evidence to suggest that the economic life of current wind turbines is only half that claimed by the industry, roughly doubling the levelised costs of the energy generated.

Conclusion – Don't Panic!

The symptoms of decay are only too obvious, threatened blackouts, failure to advance replacement of old power stations when needed, policies constructed out of hysteria and ideology, grossly expensive electricity with bills threatened to rise for another decade, a dysfunctional market system dependent on public subsidy for its survival, inadequate gas storage, etc.

It is likely that George Washington was killed by his doctors. With good intentions they met each new symptom with the routine of blood-letting and almost certainly bled him to death.
There are certain parallels with the present feeble state of our generating policy: Ideological meddling, poor leadership and failure to act on expertise have all taken their toll and without some radical changes we too may end up like Washington, remembered but no longer extant.

Can we therefore make a heartfelt plea to our politicians to take a more detached view of the whole energy issue. There is time to look at the costs and benefits of the various alternative policies available, and, indeed, this is a requirement of the Aarhus Convention. We ask that people and the 'real' environment are placed at the centre of deliberations. Even if global warming is true - and the temperature has not risen over the last 17 years - the feared increase of two degrees over a century for a species that can acclimatise to temperature differentials of 50 degrees, or more, does not require that simply any solution, no matter how costly and injurious, is applied. We do have time to take a more balanced approach to climate change and the future of our energy supply. Therefore, as an organisation that sees the effects of hurried and irrational planning policy on families and communities in the countryside, in all sincerety we would ask the Environment Committee to accept the advice given on the front cover of Douglas Adam's famous book, 'The Hitchhiker's Guide to the Galaxy', and DON'T PANIC! There is still time to take good decisions that will benefit ALL the members of the community.

Breach of European law and other international agreements and standards

Introduction

PPS 18 does not fulfill the requirements of, and is in conflict with, a number of European and international laws and agreements.

Public participation

In this regard, two main considerations apply. Firstly in implementing these renewable programmes at such a rapid pace, the authorities have by-passed the legally binding procedures related to environmental assessment and democratic accountability. As the recent legal ruling from the United Nations Economic Commission for Europe (UNECE) has demonstrated, major failings have occurred in relation to the obligations under the Aarhus Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters, which is a binding component of EU and Member State law.

With regard to the implementation of the renewable energy programme, the EU is now required to put in place the necessary measures, such that they ensure that the arrangements for public participation in a Member State are transparent and fair and that within those arrangements the necessary information is provided to the public. In addition, such a legislative framework must ensure that the requirements of the Convention are met, in relation to reasonable time-frames, allowing for sufficient time for informing the public and for the public to prepare and participate effectively, allowing for early public participation when all options are open, and ensuring that due account is taken of the outcome of the public participation.

Implications of failure to complete an environmental assessment

1. European Directives

While this effectively demonstrates the planning approvals and funding arrangements for renewable energy projects to date have been implemented without 'proper authority', and hence are open to legal challenge, there are further implications related to the failures to complete the necessary environmental assessments. Since 2004 EU legislation required that a programme, which led to the development consent of wind farms, should have been subject to Strategic Environmental Assessment. This required the preparation of a detailed Environmental Report, followed by an in-depth public consultation. This was by-passed, a situation which also occurred in other Member States. Therefore in Northern Ireland, no such Environmental Report exists.

The Environmental Report should have addressed the effects of the renewable energy programme on biodiversity, population, human health, fauna, flora, etc. It should also have addressed the measures envisaged to prevent, reduce and as fully as possible offset any significant adverse effects on the environment of implementing the programme. Member States should have monitored the significant environmental effects of the implementation of the programme in order to identify at an early stage unforeseen adverse effects, and to be able to undertake appropriate remedial action.

Requirement to undertake an independent environmental assessment

Not only did none of this happen, but at the individual project approval stage, European law is clear in that the planning authority cannot simply rely on the developer's documentation, such as his Environmental Impact Statement. The 1985 Directive on Environmental Impact Assessment, which regulates all significant projects, including wind farms, is very specific in Article 3 of this Directive, that the competent environmental authority must undertake both an investigation and an analysis to reach as complete an assessment as possible of the direct and indirect effects of the project concerned on the factors:

(a) Human beings, fauna and flora;
(b) Soil, water, air, climate and the landscape;
(c) Material assets and the cultural heritage;
(d) The interaction between the factors referred to in points (a), (b) and (c).

However, Northern Ireland failed to transpose and implement this measure. It also adopted a noise standard in PPS 18 that does not fulfil the requirements in the EU Directive. It does not appear to be recognised that it is a legal requirement that a noise assessment forming part of an Environmental Statement must supply "the data required to identify and assess the main effects which the project is likely to have on the environment", and that the "direct effects and any indirect, secondary, cumulative, short, medium and long-term, permanent and temporary, positive and negative effects of the project must be described".

ETSU-R-97 does not fulfil the requirement of a description of the likely significant effects of the development and so residents do not know whether the impact is small or great – merely that it meets a target noise level.

Failure to transpose Article 3 of the EIA Directive

According to settled case-law, the transposition of a directive does not necessarily require the provisions of the directive to be enacted in precisely the same words in a specific, express provision of national law and a general legal context may be sufficient if it actually ensures the full application of the directive in a sufficiently clear and precise manner (see, to this effect, inter alia, Case 29/84 Commission v Germany [1985] ECR 1661, paragraph 23, and Commission v Ireland, paragraph 54).

In particular, where the relevant provision is designed to create rights for individuals, the legal situation must be sufficiently precise and clear, and the persons concerned must be put in a position to know the full extent of their rights and, where appropriate, to be able to rely on them before the national courts (see, to this effect, inter alia, Case C-233/00 Commission v France [2003] ECR I-6625, paragraph 76).

As the European Court of Justice stated in its March 2011 ruling in case C-50/09 against Ireland; the competent authority may not confine itself to identifying and describing a project's direct and indirect effects on certain factors, but must also assess them in an appropriate manner, in the light of each individual case. While Ireland's failure to comply with this ruling has now led to the situation where the European Commission is calling for it to be fined, there are other implications. Namely countless wind farms have been approved throughout the country, where both at the national level and at the individual project level, there has been a complete failure to assess properly the environmental impacts associated with these turbines and ensure that the necessary mitigation measures are in place.

Further confirmation of illegality

It should be noted that, on 13 February 2014 the European Court of Justice declared that:

"by failing to transpose correctly Articles 3(7) and 4(4) of Directive 2003/35/EC of the European Parliament and of the Council of 26 May 2003 providing for public participation in respect of the drawing up of certain plans and programmes relating to the environment and amending with regard to public participation and access to justice Council Directives 85/337/EEC and 96/61/EC, inasmuch as they provide that the judicial proceedings referred to must not be prohibitively expensive, the United Kingdom of Great Britain and Northern Ireland has failed to fulfil its obligations under that directive;"

Renewable energy projects in Northern Ireland to date have been implemented without 'proper authority', and hence are open to legal challenge under the access to environmental justice procedures through the courts, with the assistance of the Costs Protection (Aarhus Convention) Regulations (NI) 2013, which may now require further amendment to the benefit of appellants.

2. World Health Organisation

Noise is also about residential amenity. Many noise complaints made about wind turbines relate to sleep disturbance. Yet the noise standard used by PPS 18 is the only noise guidance in the entire world that recommends higher levels of noise during the night than during the day;

This guidance is quite unsuitable for quiet rural areas because, particularly at night, it sets noise limits not by what is acceptable or reasonable to protect amenity but by what is the upper limit that can be tolerated. For example it often permits turbine noise levels four times as loud as the background noise level at night and just into the region where the World Health Organisation says that it may cause sleep disturbance. Since it was written, the WHO has revised its guidance 5dB lower. So the PPS 18 night standard is now higher than WHO says is required to get back to sleep;

This updating of the night time level to 38dB as a result of the later WHO guidance was recently confirmed by the reporter in the Spittal Hill decision in Caithness in his recommendation to Scottish Ministers who accepted his recommendation to refuse the application.

The British Institute of Acoustics (IOA) will soon be the only organization left trying to defend a night time level of 43dB, and this is included in their recent 'Good Practice Guide', which has just been accepted by the Environment Minister in Northern Ireland. There is no credibility in this position or in the document supporting it.

3. <u>The United Nations Aarhus Convention</u>

The international legal basis for wind energy disappeared in December 2012 when the Kyoto Protocol ceased being legally binding and now the Aarhus committee have ruled the UK is acting illegally.

The Aarhus Convention Compliance Committee has ruled unequivocally that the UK is non-compliant with Article 7 of the Convention.
That ruling will have a profound effect on planning applications for wind farms right across the UK. This will call into question the legal validity of any further consents.

As noted by environmental lawyer, David Hart, QC,:
'This ruling means that consents and permissions for further wind-farm developments in Scotland and the UK are liable to challenge on the grounds that the necessary policy preliminaries have not been complied with and that, in effect, the public has been denied the chance to consider and contribute to the NREAP [National Renewable Energy Action Plan]':

Until such time as the NREAP is fully compliant with the requirements defined under National and Community law and International Treaty Arrangements with regard to environmental democracy and public participation, there should now be a moratorium on such consents.

The opportunity to comment on a planning application is not "public participation" since neither Planning Authorities nor appeals mechanisms will countenance any discussion, never mind criticism, of "Government Policy".
A halt to further consents until recommendations are implemented should now be automatic.

drk 27 Feb 2014

History of PPS 18 'Renewable Energy'

Three documents were published in the PPS 18 process. The policy statement itself is a general criteria-based approach for all forms of renewable energy development. It is accompanied by a Best Practice Guide and, specifically for wind energy, Supplementary Planning Guidance about how the technology looked on the landscape."

How balanced was this policy?

The section of PPS 18 relating to wind energy is in our view a seriously flawed and unbalanced policy which has resulted in effects on the health and wellbeing of everyone living adjacent to industrial wind turbines in Northern Ireland. This lack of balance is particularly evident in the inadequate protection given to the general public in relation to amenity, noise, shadow flicker and health and safety. Why was this the case?

As well as submitting a substantial document to the consultation exercise, including the most recent research on health and safety, Dr. D. Kane had also written to Environment Minister Mr. Sammy Wilson on 16 October 2008, and, in addition to raising the issue of the unrepresentative stakeholders group, two paragraphs of his letter are particularly relevant to the minister's position versus that of the Department of the Environment:

"...I fear that in the frantic desire to appear to be acting against global warming, wind energy with all its problems, will be presented to you as an issue free and effective panacea. In particular, it may be claimed that the safeguarding of the health and safety of the general public has been adequately addressed when it most certainly has not."

And, further:

"I have had much contact with the planners on wind farm applications over the last four years, and they have openly admitted to a general ignorance on many of the core issues. It is my observation that, with respect to wind farm applications, they have been acting in the role of facilitators rather than as guardians of the public interest."

It is against these statements, that Mr. Wilson's response, dated 29 October 2008, should be understood:

"Thank you very much for your letter regarding the draft PPS 18 on Renewable Energy. You may well be aware from press comments that I have made that I am not totally sold on the renewable energy argument and feel that planning

policy needs to ensure that our landscape and the interests of those who live close to wind farms are taken into full consideration when deciding on the policies which will apply to wind farms. You are quite right that there is an attempt to try and have policy written so that it is much more favourable towards wind farms but I believe that we have got to get the right balance. We cannot allow the arguments about climate change to result in a policy which gives the wind farm industry a relaxed set of rules." (Emphasis added).

Who originated the wind energy section of PPS 18?

This is a critical question given the general perception that PPS 18 is an 'industry-friendly' policy, whose restrictions are only loosely adhered to and through which approval is usually expected with confidence by developers – not without reason.

It is in this context that we would draw to your attention comments made by Mr. Stephen Hamilton on behalf of the Department of the Environment on 11 November 2010 to the Committee for Enterprise, Trade and Investment as part of its Renewable Energy Enquiry and officially recorded in Hansard.

"The project was initiated mainly by the wind industry, which was aware that the existing policy was old and had to be revised. There was lobbying of different Ministers, and DOE formed an internal working group — internal to government, not just to DOE."

It is worth noting here that a local lack of balance had already emerged in an unstructured but promotive approach to the assessment and approval of wind farm applications, as demonstrated by the very low rejection rate when compared to the rest of the UK. In 2007 some 24.8% of wind farm applications across the UK had been rejected, compared to 1.6% in Northern Ireland. In 2008 the position worsened considerably with a 41% rejection rate across the UK, but 0% in Northern Ireland. As a result, with only 3%of the population of the UK and 5.7% of the land area, we had 14% of the operating turbines. It is therefore difficult to identify what problem PPS 18 was designed to address, since the approval rate was already 100%. Any pretence to applications being subjected to rigorous scrutiny had already been exposed as disingenuous.

Mr. Hamilton continues:

"separate criteria were produced for wind technology to accompany the generic criteria for all forms of renewable energy. Those were brought together through a stakeholder group. The wind industry sat on that group and provided invaluable help and advice to those of us who did not have the competencies to deal with certain issues."

It should be noted that amongst those not invited to participate in the stakeholders group, were representatives of Environmental Health, the only consultee used by the Planning Service for issues related to noise from wind energy applications. It would appear that the wind industry was able to write its own policy in this regard, unchallenged by any other competent authority. It is therefore no surprise to learn from Mr. Hamilton that:

"Generally speaking, the wind energy industry has been very content with the policy throughout the entire consultation process."

The reasons for this 'contentment' were revealed by the minutes of a meeting held at Stormont on 16 June 2009 at which Dr. Kane, Alderman Paul Girvan, now an MLA himself, and the then Environment Minister, Sammy Wilson, were present.

"Alderman Girvan reminded Mr. Wilson that they had both previously attended an event at the Ross Park Hotel sponsored by the wind industry. Although the Department had made a presentation on that occasion, he noted the apparent absence of any significant underpinning knowledge and the Department appeared to be depending very much on the industry guiding them on the issues associated with PPS 18. In effect, the industry seemed to be telling the Department what to include and therefore was basically permitted to write its own charter.

The department, in his opinion, had started from an initial position of overreliance on the industry to come up with their policies as opposed to a balance of the industry position and contrary arguments proposed to protect the public interest from these facilities and there were a number of questions that had to be answered as to the economic benefits."

Mr. Girvan's opinion is fully borne out by a further statement by Mr. Hamilton to the Committee for Enterprise, Trade and Investment on 11 November 2010:

"One issue that really put the cat among the pigeons was that of the supplementary planning guidance, which related to how the technology looked on the landscape. When it was published, it was felt that it was too prescriptive. It went into policy issues when it was only meant to supplement the policy. As a consequence, when the Minister published PPS 18 in August 2009, he asked that the SPG be held pending some analysis of how it would impact on the then draft SEF [Strategic Energy Framework]. Colleagues from NIEA and I have worked very hard with the industry to make sure that we have something that can protect the amenity of third parties but can still help the industry realise the targets set in the SEF. The SPG was published in August 2010, and the industry has sent letters to the Minister thanking him for the process that he has brought forward and for producing a guide that they feel they can work with while still protecting the amenity of Northern Ireland."

How the Wind Industry censored the SPG

Although the public consultation on the SPG had concluded on 5 June 2008, the wind industry continued to have full access to the process of creating the final version. The nature and degree of that involvement has been uncovered from their own documentation, and reveals a disturbing and completely inappropriate level of influence on the creation of public policy and guidance. Their timetable went as follows:

5 June 2008 submission to DoE on SPG
28 July 2008 present findings of Enviros report to DETI and DoE
August 2008 submit comments on draft SPG text
4 September 2008 meet with DoE Planning Service and NIEA to discuss text of SPG
October/November 2008 DoE response to industry position expected
November 2008 expected final meeting with DoE

According to their own information, the industry engaged the Department at these meetings with a list of 'Key issues':

"The publication of the draft SPG raises a number of key issues for the Wind Industry in Northern Ireland
Policy is extremely prescriptive in terms of turbine heights and groupings
Planning policy is prepared without due regard UK energy policy
Policymakers do not appreciate industry constraints in terms of turbine size, availability and the commercial viability of small turbines
Policymakers do not treat the Wind Industry as an indigenous industry to be promoted
Policymakers did not adequately consult the industry during the preparation of policy".

The industry then set out a series of objectives to be achieved before they saw the SPG as being suitable for publication:

"Industry objectives
Changes to draft SPG to include:
Remove turbine height constraints
Removal of turbine grouping specifications
Revisions to negative language used in draft SPG
Significant changes to LCA sensitivity ratings
Alignment of SPG and PPS 18 with energy policies
Acknowledgement of the role of EIA in design and planning process".

PPS 18 and its Best Practice Guide were published in August 2009, but at the insistence of the Industry, the SPG was held back until August 2010. When it was finally published, the scale of the wind industry's influence can be gauged by their achieving all of the above objectives and more. For example, under the 'key principles of good siting, layout and design', given in Table 8 on page 50 of the draft SPG, the two statements below are given. Compare this with the final version of the SPG, were Table 5 on page 48 shows the underlined portions to have been removed:

Siting

"Optomise separation of commercial wind farm sites from settlements to reduce impacts on the amenity of residents. At distances less than around 2 km. wind turbines are likely to be prominent in the landscape and turbine movement will be clearly visible."

Layout

"Adequate separation from walking, riding and other recreational routes is important to prevent adverse impacts in the landscape experience, amenity and safety of recreational landscape users. 500 m. is generally regarded as a sensible mimimum."

As can be seen, the wind industry have an aversion to any form of separation distances that might impinge on their activities. It is also clear that the trade associations of this industry have a degree of control over the creation and final form of public policy that is inimical to the public good.

Broken Promises on adverse impacts

At the meeting on 16 June 2009 alluded to above with Sammy Wilson, then Minister for the Environment, concerns about the health and safety issues for neighbours of wind farms were raised through the medium of a detailed presentation by a delegation from residents, accompanied by Dr. William McCrea, MP and Ald. Paul Girvan. At the conclusion of that meeting, concrete assurances were given by the minister that he would consider a number of suggested alterations and that the draft policy would be released for further public consultation in which we were to be specifically involved.

In clear breach of that commitment, PPS 18 in its final form, was published on 14 August 2009 without further consultation and apparently without even the knowledge of the Assembly's Environment Committee.

Conclusion

It can now be more easily understood why the results of the meeting of 16 June 2009 were not to the liking of those whom Mr. Wilson stated were attempting '... to try and have policy written so that it is much more favourable towards wind

farms' within the Department of the Environment. The proposals submitted in writing by Dr. Kane and his colleagues and then presented by their delegation to Mr. Wilson, would have provided significant support for his expressed desire that, '...We cannot allow the arguments about climate change to result in a policy which gives the wind farm industry a relaxed set of rules.' Our proposals in relation to noise, shadow-flicker and health and safety, proper definitions and adequate separation distances would have had a significant impact in curbing the excesses of the more irresponsible elements of the wind energy sector operating in Northern Ireland, without unduly hampering responsible development.

It may be seen that the observations and concerns expressed by Dr. Kane, Mr. Wilson and Alderman Girvan in 2008 and 2009 are fully borne out by Mr. Hamilton's statements to the Committee for Enterprise, Trade and Investment. The final version of PPS 18 and its Best Practice Guidance was not published by a skeptical Mr. Wilson, but by his much more accepting successor and thus we have the unbalanced, seriously flawed and promotive policy of today. The equivalent policies on the mainland have resulted in approximately 50% of wind farm applications being rejected. In Northern Ireland in 2009 to 2011 inclusive, only one application was rejected.

After fruitless efforts to obtain a response from Sammy Wilson, attempts were made in 2009 to bring the fallacies in PPS 18 to the attention of the Assembly's Environment Committee. No acknowledgement or reply was received to the three letters sent.

A meeting was sought and eventually obtained on 26 October with Edwin Poots, successor to Sammy Wilson as Minister of the Environment. He claims that PPS 18 was 'slipped through' by civil servants in the hiatus between Sammy Wilson's departure and his arrival as Minister to replace him and that they never advised him of the commitment he had inherited. However he was not prepared to fulfil the obligation entered into by Sammy Wilson that further public consultation should take place. Indeed, Mr. Poots believes that we needed to 'grin and bear it' with wind farms because of planning mistakes in the past which pepperpotted housing development across the province preventing larger separation distances. He ignored evidence of health and safety issues when these were presented to him.

Further attempts to bring new research on health and safety matters to the attention of the next Minister of the Environment, Mr. Alex Attwood on 7 November 2011, brought the response that

"I remain satisfied that the safeguards contained within PPS 18 are adequate to ensure that the health, safety and amenity of occupants are adequately assessed through the planning process; and from the consultation responses received from statutory bodies to wind energy developments, that significant harm to the safety or amenity of any sensitive receptors arising from noise: shadow flicker; ice throw; and reflected light will not result."

This is a breathtakingly complacent statement and contrary to the evidence provided to him. For example, the noise standard which is supposed to protect amenity, itself states that its noise limits are set above those required to protect amenity and, by its own admission, it is not a method of assessing impact. Indeed, in terms of night time noise standards, it allows a level substantially higher than the World Health Organisation say is necessary to permit return to sleep.

Mr. Attwood's comments on shadow-flicker and reflected light are also baseless since the appropriate section of PPS 18 misquotes the research it is apparently based upon. Finally, with regards to safety, instead of the "very few accidents" causing "injury to humans", stated by PPS 18, there had by that time in fact been at least 133 fatalities and the annual accident rate was increasing.

To therefore summarise, this history of PPS 18, after a slow start in which the planners did little to develop their understanding of the issues surrounding wind energy over 16 years, the industry itself asked for a new policy which they had a major part in creating. This policy has the same outcome as before in assuring a tiny rejection rate and the industry remains the main source of advice to the planners on any research that challenges the paradigm that it is a clean, green and safe supplier of cheap electricity and CO2 reductions. In the same way, at the most basic local level, communities are being exposed to the health and safety impacts of wind energy partly because no one feels able to challenge the wind industry paradigm and because local authority officers do not have the expertise or working knowledge of the noise standard to establish why it is limited and should not be applied directly. They also automatically apply it as the developer's consultants use it, therefore permitting the developer to become the arbiter in its interpretation.

Terms of Reference 1:

"To assess the adequacy of PPS18 and related supplementary guidance in regulating proposals for wind turbines on a consistent and strategic basis, with due regard for emerging technologies and independent environmental impact assessment;"

"To assess the adequacy of PPS18 and related supplementary guidance in regulating proposals for wind turbines on a consistent and strategic basis, with due regard for emerging technologies and independent environmental impact assessment;"

<u>Introduction</u>

The most striking aspects of the planning procedures for wind energy are the absence of knowledge amongst decision-makers, and the absence of principle amongst the agencies tasked with advising them. There is no element of caution, no application of due diligence and no acknowledgement of a duty of care. At no time have the underlying assumptions ever been submitted to independent scrutiny. The rural public have been abandoned to the depredations of an unscrupulous industry which is permitted to be the arbiter in its own court.

<u>Context and constraint in wind energy policy</u>

It is important to briefly remind ourselves of the key aspects of the policy set out in PPS 18 for wind energy, in order to appreciate how this is being so blatantly disregarded. These can be seen in the two passages from PPS 18, below, with underlining added for emphasis:

Policy RE 1

Renewable Energy Development

Development that generates energy from renewable resources <u>will be permitted provided the proposal, and any associated buildings and infrastructure, will not result in an unacceptable adverse impact on:</u>

(a) public safety, human health, or residential amenity;
(b) visual amenity and landscape character;
(c) biodiversity, nature conservation or built heritage interests;
(d) local natural resources, such as air quality or water quality; and
(e) public access to the countryside.

The wider environmental, economic and social benefits of all proposals for renewable energy projects are material considerations that will be given significant weight in determining whether planning permission should be granted.

Wind Energy Development

<u>Applications for wind energy development will also be required to demonstrate all of the following</u>:

(i) that the development <u>will not have an unacceptable impact on</u> visual amenity or landscape character through: the number, scale, size and siting of turbines;

(ii) that the development <u>has taken into consideration the cumulative impact of</u> existing wind turbines, those which have permissions and those that are currently the subject of valid but undetermined applications;

(iii) that the development will <u>not create a significant risk</u> of landslide or bog burst;

(iv) that no part of the development will give rise to <u>unacceptable electromagnetic interference</u> to communications installations; radar or air traffic control systems; emergency services communications; or other telecommunication systems;

(v) that no part of the development will have <u>an unacceptable impact</u> on roads, rail or aviation safety;

(vi) that the development <u>will not cause significant harm to the safety or amenity of any sensitive receptors</u>[1] (including future occupants of committed developments) arising from noise; shadow flicker; ice throw; and reflected light; and

(vii) that above-ground redundant plant (including turbines), buildings and associated infrastructure shall be removed and the site restored to an agreed standard appropriate to its location.

Any development on active peatland will not be permitted unless there are imperative reasons of overriding public interest.

For wind farm development a separation distance of 10 times rotor diameter to occupied property, with a minimum distance not less than 500m, will generally apply.

The policy is obviously promotive, but there are to be certain constraints. Renewable Energy Development, including wind energy, <u>will be permitted provided the proposal will not result in an unacceptable adverse impact. To this constraint for all technologies, wind must also demonstrate that the proposal will not cause</u> 'Unacceptable impacts' and 'significant harm'.
<u>Unacceptable adverse impacts are now acceptable.</u>

<u>The Planning Service have turned this policy on its head and removed all protection from the rural public in the manner revealed in these statements from a recent Professional Planning Report:</u>

"Following additional training and guidance from the headquarters in February 2012 staff were advised to adopt a more flexible approach and it was emphasised that as RE1 states ; "The wider environmental, economic and social benefits of all proposals for renewable energy projects are material considerations that will be given significant weight in determining whether planning permission should be granted."

"The amplification of the Policy also explains even though there may be unacceptable adverse impacts - these can still be outweighed by the local and wider environmental, economic and social benefits of the proposal.
"This includes wider benefits arising from a clean, secure energy supply; reductions in greenhouse gases and other polluting emissions; and contributions towards meeting Northern Ireland's target for use of renewable energy sources."

The Powerpoint slides for this 'training and guidance' continually emphasise that PPS 18 is a 'promotive' policy, and this has been used to justify the elevation of the material considerations of 'wider environmental, economic and social benefits' to be given significant weight, to the level of being the decisive arbiters. This is critical to an understanding of why PPS 18 has failed so completely in preventing unacceptable adverse impacts and significant harm.

Quite simply, there are two very different standards applied to how the costs and benefits of an application are assessed. On the one hand, there is a refusal to apply robust measures to fully reveal the cost to be paid by an individual or community from the location or operation of a wind energy proposal, for example, from noise, health impacts and property devaluation. We find that even that detriment will be reduced further through comparison with purported benefits, primarily economic. The burden of proof for the economic benefits to be set against those costs is much lighter. For example, economic considerations often cannot give rise to effective planning conditions. Similarly, if we do not assess or otherwise audit, carbon payback claims made by developers, how can we verify the carbon footprint of their turbines?

Yet in the absence of such economic and environmental evidence, communities and individuals are being exposed to 'unacceptable adverse impacts' from noise, shadow-flicker and loss of amenity, impacts that are both easily measured, and very, very real.

Abandonment of minimum separation distances

PPS 18 seems clear when it states that "...a separation distance of 10 times rotor diameter to occupied property, with a minimum distance not less than 500m, will generally apply."

But it would appear that this is getting in the way of the 'promotional' aspects of the policy. Take, for example, the following statement dated 24 February 2014 from the Western Area Planning Office:

"Planning Policy Statement 18 'Best Practice' suggests a minimum separation distance of 500m between proposed wind farms and the nearest noise receptor. This proposal however is for a single wind turbine and as such this suggested separation distance does not apply in this instance."

It would be simple to prove the error of this statement from the original draft PPS 18 responses to the public consultation and other subsequent correspondence with its authors, but this will only prolong this document. Suffice to say:

Definition of a wind farm

"The Planning (Environmental Impact Assessment) Regulations (Northern Ireland) 2012 Schedule 2, Category 3(j) defines wind farms as "Installations for the harnessing of wind power for energy production (wind farms)" where:

- "the development involves the installation of more than 2 turbines; or
- the hub height of any turbine or height of any other structure exceeds 15 metres."

Thus the definition of a wind farm has already been established in Northern Ireland's legislation as having either more than two turbines or where the hub height of any turbine or height of any other structure exceeds 15 metres. This means that a single turbine is classed as a wind farm if its hub height is more than 15 metres, and thus the 500 m. minimum separation distance in PPS 18 must apply.

Freedom to depart from 'Guidance'?

The Western Area Planning statement, and this is a common practice, treat the guidance in PPS 18 and its associated documents, as somehow optional. The complete lack of logic in their argument that only policy that uses the term 'wind farm' applies solely to wind farms and not to single turbines, was again demonstrated in their statement dated 10 December 2013:

"Planning Policy Statement 18 (PPS 18); Policy RE 1 states that for wind farm development, a separation distance of 10 times rotor diameter to occupied property, with a minimum distance not less than 500m will generally apply. For operational purposes, in applying PPS 18 the Department regards a planning application for more than 2 No. wind turbines to constitute a wind farm, not a single wind turbine."

Now compare this to the noise methodology applied by PPS 18 to both wind farms and single turbines:

"1.3.46 The report, 'The Assessment and Rating of Noise from Wind Farms'

Recommended Good Practice on Controlling Noise from Wind Turbines From 'The Assessment and Rating of Noise from Wind Farms' (ETSU for DTI 1997).

The current practice on controlling wind farm noise by the application of noise limits at the nearest noise-sensitive properties is the most appropriate approach."

So if ETSU-R-97 referring to wind farms, can be applied to single wind turbines, separation distances for wind farms in PPS 18 can also be applied to single wind turbines.

It is a concern that the guidance is treated in such a cavalier fashion and that by simply using a non-defined term such as 'operational purposes', the planning guidance can be simply set aside. There is also an unacceptable ignorance of the provisions of The Planning (Environmental Impact Assessment) Regulations (Northern Ireland) 2012.

It is a common claim by professionals of all kinds, which obscures the reasoning for some of their more controversial decisions, that they are applying 'professional judgement'. It should be pointed out that the same planning professionals applying the same planning judgement in England, reject a far higher proportion of wind energy applications than in Northern Ireland.

The Planning Service is one of the organisations which falls under the jurisdiction of the Office of the Northern Ireland Ombudsman and it is therefore bound by the Parliamentary Ombudsman's Principles of Good Administration. The Ombudsman is clear that these Principles are intended to promote a shared understanding of what is meant by good administration and to help public bodies provide adequate and efficient public service to citizens. What is important is that they have been accepted as a benchmark by government representing the standard of performance expected of public officials. They are not aspirational but must be followed. They are therefore a benchmark of good administrative practice against which the standard of service provided by a public body can be tested.

The first Principle of Good Administration is called, "Getting it right". This states that the public body must act in accordance with its policy and guidance (published or internal). There is no flexibility here, it is an obligation. The Ombudsman further goes on to state that a novel approach should only be followed when this will bring a better result or service, and that when public bodies decide to depart from their own guidance recognised quality standards or established good practice they should record why?

These are clear rules that do not allow the Planning Service to cherry pick what part of Policy or guidance they choose to follow or not. They must follow all of it.

The issue is not whether it right or wrong that a wind turbine should be erected, nor is it that the Ombudsman should challenge the opinion of the Planning Service but whether the Planning Service have followed their own processes correctly. A finding of maladministration against the planning service, defined as delay, wrong action, inaction or decisions arrived at due to improper consideration or motives, would raise the issue of compensation for financial loss.

Material Factors

As the residents of rural areas across the province have found to their cost, when an application for wind energy is considered by the Planning Service, different material considerations are given different weight with different burdens of proof.

It is not proposed to examine every material consideration, but some examples will illustrate these problems.

Noise

If we consider noise as an example, the methodology applied is ETSU-R-97, 'The Assessment and Rating of Noise from Wind Farms'. This openly states that its noise limits are set above the level required to protect the amenity of residents, since a level to protect amenity was seen as being very restrictive on the development of wind energy. This noise methodology is therefore in conflict with the part of Policy RE 1 entitled Wind Energy Development, where an applicant will also be required to demonstrate, "vi) that the development will not cause significant harm to the safety or amenity of any sensitive receptors arising from noise;"

Other renewable sources such as biomass plants may have to meet levels of 25dBA at night in quiet countryside whilst wind turbines can operate at over 40dBA when background noise may be well below 30dBA. Usually this would be an accepted cause for complaint, but wind noise receives special treatment. The most bizarre result is that night time noise can be up to 8dBA more than the day time noise. No other standard anywhere in the world has a night time limit higher than a day time limit, and often permits turbine noise levels four times as loud as the background noise level at night. The ETSU night standard is now higher than the World Health Organisation says is required to get back to sleep. We could postulate, therefore, that if the noise level was predicted to be likely to give rise to complaints then this would constitute a major loss of amenity.

However, by using the ETSU standard instead of the more protective BS 4142, rural residents are already being asked to pay a noise penalty for wind turbines. There is no recognition of this in the weighing of material considerations.

Shadow-flicker

The claim that 'flicker effects have been proven to occur only within ten rotor diameters of a turbine' is one of a number of unsubstantiated statements made in the Best Practice Guide to PPS 18.

The research paper on which the statement is based, does not prove the ten rotor diameter claim. In fact its recommendation is 'that turbines should be sited at least ten diameters distance from habitations, and more if sited to the East/Southeast or West/Southwest, and the shadow path identified' (emphasis added). The research also contains a fundamental and demonstrable error that restricts its application.

So the standards on which the preventative separation distance are based, if properly applied, would actually considerably increase those distances. Again, the rural community is being asked, in this case through a misapplication of the research and the German standards with which it has been associated, to bear a heavier adverse impact than they will be given credit for in the weighing of material factors.

Residential Amenity and Human Rights

Whilst it is acknowledged that the planning system must seek to balance competing interests, and that Paragraph 52 of PPS 1 states that 'the planning system does not exist to protect the private interests of one person against the activities of another', this point has been explored in some detail by the Planning Appeals Commission.

In the 'Langley Hall' Appeal (Ref: 2000/A127 & 2000/A128) Commissioner Rue commented:

'The first sentence of Paragraph 52 of PPS 1 seems to suggest that the planning system will not protect private interests. I consider any such suggestion to be unlawful in the light of the Human Rights Act. It seems to me that the possibility of occupiers of neighbouring properties experiencing financial or other loss from a particular development must be a consideration material to the determination of a planning application for development. There is, in any event, an obvious connection between the devaluation of, or the loss of a view from, a property and the amenity of that property. It follows that a development that would unacceptably affect the right of an owner or occupier of adjacent land to the peaceful enjoyment of his or her possessions would not measure up to the yardsticks of good neighbourliness and fairness referred to in the last sentence of paragraph 52'.

Two very important points emerge from this.

First, financial loss is a material consideration in planning decisions. In relation to financial loss, it has been enough in the past for a developer simply to state that no financial loss would occur from property devaluation, and the planners took no account of it in any case. The Advertising Standards Authority (ASA) have upheld complaints about such claims made by developers, who have then had to withdraw them. A heavier burden of proof should not be placed on residents, some of whom have now obtained independent valuation reports by RICS registered valuation surveyors. These conclude that the proposed wind energy proposals will have an impact upon the amenity of their properties and will reduce the value by, in some cases, 25% if permission is granted. This is incontrovertible evidence that residents right to their possessions and the peaceful enjoyment of their property will be significantly affected, contrary to the provisions of the Human Rights Act.

Second, development which will unacceptably impair the peaceful enjoyment of a person's property would clearly be contrary to the policy requirements of paragraph 52 of PPS 1, and would provide a sustainable reason for refusal.

There is an increasing list of cases in GB where applications for turbines have failed because of the impact upon residential amenity. These include:

i) - APP/X2220/A/08/2071880 - Enifer Downs - 'an unpleasantly overwhelming and unavoidable presence in the main view from a house or garden, there is every likelihood that the property concerned will become regarded as an unattractive and thus unsatisfactory (but not necessarily uninhabitable) place in which to live. It is not in the public interest to create such living conditions where they did not exist before'(Para 66)

ii) - APP/E0915/A/12/2168121 - Newlands, Carlisle - 'the presence of a commercial wind turbine, with no intervening screening and in such proximity to dwellings (c400 metres) would be likely to undermine the enjoyment of domestic properties to such an extent as to result in intolerable living conditions for residents of the farm complex'. (Para 21-26)

iii) - APP/D0515/A/12/2181777 and APP/A2525/A/12/2184954 - Fenland and South Holland - 'At The Birches, a bungalow, the main living area window looks directly east towards T2 at 695 metres........I consider the occupants would suffer an overwhelming adverse impact on their outlook and their day to day lives that could not be adequately mitigated'. (Para 27)

iv) - APP/X1118/A/12/2189089 - Tiverton, Devon - the determining issue was the 'severe and unacceptable impact' upon living conditions in a bungalow 400 metres from the site. (para 11)

Residents of rural properties have an expectation that the planning system will protect not just their health, but their amenity. As PPS 1 notes, 'good neighbourliness and fairness are among the yardsticks against which development proposals can be measured'. This major detriment to amenity has generally been ignored completely in the weighing of material considerations in the past.

The wider economic benefits

The burden of proof for the economic benefits to be set against some of the costs discussed above is much lighter than for them. For example, economic considerations often cannot give rise to effective planning conditions. It is not possible to secure through planning conditions how many people can be employed in a business or its profitability, yet these may become reasons that form the basis of an approval.

Several Planning Policy Statements and guidelines have been published recently that align planning policy with an overly narrow concept of conventional economic development. The definition of 'economic benefits' is unclear as it has not been defined and neither are its objective intentions. There must be a clear definition of what the economic and social benefits actually are. These must be real, as opposed to aspirational, since the adverse impacts are real. It is not enough to permit a certain level of noise because an applicant claims that the proposal will create 100 jobs. Such claims are often aspirational and unfulfilled. The planning system has no role in ensuring that those 100 jobs actually appear. It is solely about land management.

In Planning (Statutorily) the definition of 'development', ties it specifically to development of land [Pyx Granite vs Minister of Housing and Local Government 1958]. In this sense development or promotion of economic development generally implies an identified area of development whether that is national, regional or local. Does this mean, for example, that the cost a community will be asked to pay from additional noise, will be compared with an increase in the GDP of that area?

There is a need for a complete review of what constitutes an economic benefit to provide a robust cost/benefit analysis of the tangible and realistic factors relevant to the application. Expected benefits must be based on realistic assumptions about future economic activity resulting from the project, and against which adverse impacts can be measured. The Addendum on Economic Considerations at the end of this section lists basic flaws and faulty assumptions, including a number identified by the Economics Branch of the DRD, that should be taken into account when considering the robustness of claimed economic benefits.

Similarly, a second addendum addresses the issue of supposed CO2 savings, which not only form part of the environmental assessment, but since carbon is assigned a monetary value, has an effect on the balance sheet.

Need for an audit of the past

There is an increasing suspicion in rural communities about the veracity of the claimed benefits from a proposal for which they are being asked to sacrifice their environment, amenity and health.

On the basis of job creation alone, the more than 70 wind farms already approved seem to have grossly exaggerated the numbers to be employed on a permanent basis. There is therefore an urgent need for a retrospective audit of claims about economic, environmental and social benefits of specific wind farms. This must be carried out by an independent consultant with no links either to the wind industry, the government or the various consultees whose impartiality has become so compromised. The object would be to establish if the future benefits projected by the applicant and accepted by the planners, ever materialize, and was this cost effective for the community as a whole?

Terms of Reference 2:

"To compare the perceived impact of wind turbine noise and separation distances with other jurisdictions and other forms of renewable energy development;"

The Problem of Noise from Wind Turbines

"Only when the public can trust the Government and wind farm developers on noise issues will there be a chance that the public will accept them without a fight ..." (Editorial, Noise Bulletin, Issue 15, Aug/Sept. 2007).

Preamble – Why so much emphasis on Noise?

The Committee will note that a very substantial part of this response concerns aspects of noise from wind turbines, as we see this as one of the major adverse impacts on those living around them. In an attempt to make this lengthy response more palatable, it has been broken up into an introductory section ending in our proposed solution to the problem, and seven major questions and answers (numbered 1 to 7 with an addendum), each with a short supporting rationale and a more detailed commentary.

Surely Noise is just Noise?

For years, the scientific community looked on noise as only affecting a person's ears. That is why what is termed the '(A)-Weighted decibel',.or dB(A), unit was created to measure noise, since there was an interest only in measuring the noise that will cause hearing damage.

If we compare noise with light, we find that we separate light into, for example, x-rays, Ultra Violet and infra-red,. We know that x-rays are a form of light that cannot be seen but, in sufficient quantity, can cause harm. We know that ultra violet is not visible yet harms the skin. If we use dark glasses for x-rays or ultra-violet light, they will not protect the eyes. Thus different types of 'light' can cause harm in different ways. This is similar to what happens with noise.

The present noise methodology applied in PPS 18 does not take this same approach to acoustics. This has two main effects.

Firstly, in identifying if a noise problem exists. If analysts are measuring for one type of noise, on a particular scale, but what is being heard is not recognised by this scale, this will underestimate any problems.

Secondly, if we treat noise as a single entity, how do we measure the agent of disease to identify which part is affecting, for example, a person's heart, or his lungs?

If we consider low frequency noise, it is about 10 keys below the lowest note on a piano and does not cause hearing damage. Very low frequency noise, known as infrasound, is characterized by very long wavelengths that stimulate the outer hair cells, the ear's amplifiers. The inner hair cells, responsible for hearing, do not respond to infrasound. Therefore, like ultrasound, infrasound is generally outside

the range of human hearing. It is still stimulating the ear and the brain, but is doing it in a way that is not auditory. Even though it is affecting the body, it is not measured by the dB(A) unit used in PPS 18.

Neither does PPS 18 adequately protect residents from aerodynamic modulation noise, because the specified noise descriptor ignores the noisiest 90% of each ten-minute measurement period and gives a result based on the loudest noise during the quietest 10% of the period.

These are just two examples of categories of noise that are not adequately addressed under PPS 18, but which give rise to marked physiological effects, disturb sleep and impair health.

Currently the Northern Ireland Planning Service do not require measurement of the full sound and vibration spectrum, do not require measurement inside homes and workplaces, do not require evaluation of sleep or other disturbances, but instead limit almost all assessment to audible noise (dBA) only, outside homes and workplaces. Obviously they are either under the misapprehension that the population of Northern Ireland sleeps outside at night, or they have no inclination to identify and resolve the adverse impacts they have inflicted on wind turbine neighbours.

Introduction

Adverse health effects in people living near or within the footprint of industrial scale wind turbines are being reported by researchers and medical professionals from countries around the world. These reinforce the self-reported descriptions from people living around wind turbine sites who commonly report high levels of annoyance and sleep disturbance. In some cases the reports are of other adverse health effects. In response to this information, the wind industry uniformly disclaims any responsibility. Instead, the problems are blamed on sublimated fear and anxiety; disapproval of the "visual" impact; concern about property value loss; or other issues that cause the symptoms. It is never the sound from the wind turbines that might be the cause.

Is there an explanation for this conflict between the developers safety assurances and the subsequent widespread complaints from those affected by wind farm noise? How can wind turbine noise be both 'unbearable' and 'undetectable'?

Why is the full impact of wind turbine noise not properly assessed?

It is important to appreciate that the guidelines applied to wind energy applications are problematic and controversial in themselves, since they were not just about noise measurement, but reflected an implicit political agenda when they were written. Their method of assessing the noise effects of their developments is not based on generally accepted acoustical measurement and prediction procedures, but is based instead on a 1996 document entitled 'The assessment and rating of noise from wind farms by the Working Group on Noise from Wind Turbines' and more commonly known as 'ETSU(Energy Technical Support Unit)-R-97'. Independent acoustical consultants across the world have found it to be seriously flawed and its use in place of the generally accepted procedures codified in ANSI and ISO standards, explains why projects that appear to be compatible with a community during the planning process later produce complaints of noise annoyance, sleep disturbance and other adverse health effects once operation commences.

For example, the noise standard which is supposed to protect amenity, itself states that its noise limits are set above those required to protect amenity and, by its own admission, it is not a method of assessing impact.
. Indeed, in terms of night time noise standards, it allows a level substantially higher than the World Health Organisation say is necessary to permit return to sleep.

This deniability does not end with the Wind Industry and the authors of the methodology. , as can be seen by a report in the Sunday Times on 13 December 2009:

"Civil servants have suppressed warnings that wind turbines can generate noise damaging people's health for several square miles around.

The guidance from consultants indicated that the sound level permitted from spinning blades and gearboxes had been set so high — 43 decibels — that local people could be disturbed whenever the wind blew hard. The noise was also thought likely to disrupt sleep.

In their draft report the HMP researchers recommended that "Consideration be given to a revision of the night-time absolute noise criterion", noting that this would fit with World Health Organisation recommendations on sleep disturbance.

It has now emerged that officials removed the warnings from the draft report in 2006 by Hayes McKenzie Partnership (HMP), the consultants. The final version made no mention of them.

It has also been used by ministers and officials to support the view that there was no need to revise official wind farm noise guidelines and that erecting turbines near homes posed no threat to people's health and wellbeing.

In Northern Ireland, Planning Policy Statement 18 on Renewable Energy (PPS 18) requires that ETSU-R-97 methodology be used. However, this 'industry best practice', promoted by the Wind Industry, can be seen as permitting the

introduction of wind farms into inappropriate low background noise locations where they and other comparable industrial installations could not meet planning conditions derived from the long established BS 4142 standard. This has led to wind turbines being built too close to residential areas resulting in an increasing amount of noise nuisance, whilst preventing local authorities from exercising duty of care responsibilities with respect to wind energy.

Obscuring the Impacts to the Environment Committee?

When the Environment Committee met with NIRIG on 12 September 2013, thus avoiding the possibility of an informed challenge to their statements by Windwatch NI, questions were asked of them by members about the ETSU-R-97 noise methodology used in PPS 18. The following excerpts from Hansard are of particular interest:

Ms Hitchins: I ask you to remember that the ETSU noise limits during the day are set to protect people's amenity of their gardens, so that, on a Sunday afternoon, after a good lunch, you can have that snooze in your garden or on your patio. However, at night, the guidelines assume that you will be indoors asleep — with an open window. So, that is all taken into account in the guidelines.

To show just how disingenuous this statement is, we reproduce from a document on these same points, comments by renowned independent acoustician, Dick Bowdler, a former member of the Noise Working Group:

"it is a thoroughly flawed document and does not deserve the prominence it has been given." Its conclusions are '...so badly argued as to be laughable in parts (the daytime standard is based on the principle that it does not matter if people cannot get to sleep on their patio so long as they can get to sleep in their bedrooms). It is the only standard where the permissible night time level is higher than the permissible day time level" and it "bears no resemblance to standards used for other industrial developments."
the compromise reached by the NWG is so lacking in basis, so full of unfounded assertions and so badly thought out and argued that it comes up with standards for wind farm noise that are quite unlike any other noise standards. It cannot, therefore, even by its own admission, be used as a standard to protect the health and amenity of those most affected by wind farm development, as this was not part of the DTI's remit. Yet that is how PPS 18 attempts to use it.

Turbine noise has a character that makes it far more annoying and stressful than other sources of noise at the same A-weighted sound level. The reasons for this include the amplitude modulation associated with the blade passage past the tower, the quiet rural environment in which turbines are placed, the turbulence of the air that blows past the blades, the variability of manufacture and assembly, and the dominance of low frequencies in the received sound spectrum.

Community noise studies consistently show that public annoyance increases substantially when there is a noise source with unpredictable variability and unusual sounds. Wind turbine noise satisfies these criteria. It has a unique and visceral sound character, which may be perceived as being twice as loud as measured.

The Industry 'Filter'

When public attention first turned to smoking as a health hazard, the tobacco industry tried to defend itself by pointing to the fact there were no large-scale studies that "proved" a direct causal connection between smoking and illness. Making a causal link between a health hazard and its impact can be difficult, costly, and time-consuming. As a result of these obstacles, Big Tobacco was able to hold its critics at bay for decades. The strategy of insisting on almost absolute certainty also provided Big Tobacco with the time it needed to mount a massive PR campaign and aggressively lobby policymakers for legal protections. Meanwhile, despite public posturing to the contrary, Big Tobacco knew full well just how dangerous and addictive its product truly was.

Similarly, Big Wind's call for indisputable certainty about turbine health impacts has bought years for its epic lobbying campaign to extend the government subsidies. It too, knows that there are side-effects resulting from its product.

In the summer of 2011, a crack in the wall of silence surrounding wind turbine low frequency noise emissions occurred as a result of the Danish EPA intention to add low frequency criteria to their wind turbine noise regulations. A letter dated 29 June 2011 from CEO of Vestas Wind Systems A/S to the Minister of Environment for Denmark's Department of Environment (DoE) sheds some light on why the wind industry directs permitting authorities away from regulations requiring low frequency or C-weighted analysis. Denmark's DoE had been undergoing the steps of the regulatory process to include a requirement limiting low frequency sound from wind turbines. This requirement is the same one that Denmark uses for general industry and is a well conceived and tested method although it does not utilize the dBC scale. The Danish government had concluded that larger utility scale wind turbines shift sound energy downward and increase the potential effect of low frequency noise on people inside their homes. This is consistent with the Vestas letter, which acknowledges that it will take some time to make the design changes needed to reduce the low frequency sound emissions. It states:

> "In fact according to our analyses the most economical turbines, the 3 MW category, are the ones that will be strongly affected by the new rules. This applies to open terrain in particular, where in future low frequency noise will dictate and increase the distance requirements to neighbours for close to half of the projects that we are already aware of over the next 2 to 3 years.".

> "At this point you may have asked yourself why it is that Vestas does not make changes to the wind turbines so that they produce less noise? The simple answer is that at the moment it is not technically possible to do so, and it requires time and resources because presently we are at the forefront of what is technically possible for large wind turbines, and they are the most efficient of all.".

The recent discovery of a 2004 Powerpoint presentation, demonstrating that Vestas knew a decade ago that safer buffers are required to protect neighbours from noise, that their pre-construction noise models are not accurate and that "we know that noise from wind turbines sometimes annoys people even if the noise is below noise limits" is a disturbing contradiction to their rhetoric. It is also confirmation that the global wind industry have in fact been peddling misinformation rather than facts.

When NIRIG met with the Environment Committee on 12 September 2013, in answer to a question by Mr. McElduff they gave assurances that there was conclusive evidence that there are no negative health impacts from low-frequency noise, specifically citing the Hayes-McKenzie (HMP) Report from 2006.

However, as noted earlier in this introduction, in their draft report the HMP researchers recommended that "Consideration be given to a revision of the night-time absolute noise criterion", noting that this would fit with World Health Organisation recommendations on sleep disturbance. It later emerged that officials removed these warnings from the draft report and the final version made no mention of them. It is, therefore, clear that relying on the conclusions of this report, as published, is unwise as they are, at best, misleading.

Even so, this final version has been used to support the view that there was no need to revise official wind farm noise guidelines and that erecting turbines near homes posed no threat to people's health and wellbeing.

The lack of physiological expertise in the investigators was a major methodological flaw rendering the conclusions in the original draft unreliable. Even with this weakness, and there are others, for NIRIG to suggest that there is no health problem when faced with the large body of evidence presented in the original draft of the Hayes-McKenzie 2006 report is perverse.

Since this apparent attempt to mislead the Environment Committee is so serious, an Addendum has been added to Question 2 dealing with Low Frequency Noise to directly address this claim that there is no evidence to support health impacts from this source.

Even so, this tedious digression has one salutary outcome. It demonstrates the dangers of permitting the Wind Industry to remain the main source of advice to the planners on any research that challenges the paradigm that it is a clean, green and safe supplier of cheap electricity and CO2 reductions. In the same way, at the most basic local level, communities are being exposed to the health and safety impacts of wind energy partly because no one feels able to challenge the wind industry paradigm and because local authority officers do not have the expertise or working knowledge of the noise standard to establish why it is limited and should not be applied directly. They also automatically apply it as the developer's consultant use it, therefore permitting the developer to become the arbiter in its interpretation.

Industry Acousticians acting beyond their roles

Governments continue to rely on acoustic engineers to prepare official guidance both on exposure to wind turbine noise, including the upper limits of dosage and duration, and on the separation distances of wind turbines from homes. It is ironic that several experts on noise and health are on faculty at British universities -- yet perplexingly, Britain continues to rely upon acoustic engineers to advise on the complex problem of noise and health.

Acousticians acting for developers routinely exceed their area of expertise in noise assessments; their reports often contain claims in relation to wind farm power output, meteorological factors or impacts of noise on sleep and health of neighbours. The acoustician's role is to do no more than gather and interpret the necessary acoustic data, providing the public and decision makers with a clear and accessible description of the noise impacts.

It is not the acoustician's role to make value judgements about the merits or otherwise of applications in the planning system. Similarly, calculating power output does not lie within the area of expertise of acousticians and should not form part of their deliberations.
Acousticians instead should concentrate on quantifying the likely duration and level of exposure by calculating the percentage of time in a year that complaints would be likely or marginal based on the BS4142 metric. This information could then be used by the Planning Service or local authority to decide if a proposal is satisfactory and what noise limits would be acceptable given the site-specific results.

The Solution

The constant refrain of, 'this is what is done in England', by policymakers in the Department of the Environment and by the Northern Ireland Planning Service , is the strongest argument imaginable for not having an Assembly in Northern Ireland at all. It displaces responsibility for the protection of residents living around wind turbines onto anonymous officials in England, or on Ed Davey, Secretary of State for Energy and Climate Change. When the origins of the

policies uncritically espoused by these principals are uncovered, they usually reside with lobbyists from the wind industry. Thus at times indirectly, but at others through direct intervention, the wind industry has constructed a framework that is permitted to control the amenity, health and wellbeing of everyone residing around a wind turbine.

On behalf of the increasing number of people in Northern Ireland, suffering acute and chronic health damage from living near wind turbines, Windwatch and its many constituent groups across the province demand that the Northern Ireland Assembly take the following action as a matter of urgency:

- Initiate full frequency spectrum acoustic monitoring inside and outside the homes and workplaces of people claiming health problems caused by the proximity of operating wind turbines;

- The monitoring must be conducted for sufficient time, under the weather and wind conditions indicated by victims as being contributive to their symptoms;

- Measurements must specifically include, amplitude modulation, infrasound and low frequency noise, (dBZ or dBLin, dBA, dBC, & dBG);

- The noise monitoring must be performed by accredited acousticians demonstrably independent of the wind industry, approved by the sufferers, and in a manner that will avoid any deliberate manipulation of turbine operation to reduce the acoustic emissions during testing. The results (including all the raw data and associated sound files) must be made available to all parties;

- Excess Amplitude Modulation (EAM) of the aerodynamic turbine noise is neither rare nor minor. Planning conditions following the Den Brook metric should now be applied to all future approvals;

- Wind energy and the wind industry have flourished in Germany with noise limits of 35 dBA at nighttime and, where applicable, 40 dBA for daytime, despite a population density twice that of Northern Ireland. At the very least, the World Health Organisation's night-time noise limits of 38dB LA90 (40dB LAeq) in the absence of Amplitude Modulation must be implemented. This will help bring setbacks to those recommended by health authorities;

- Initiate parallel assessment between the methodologies for assessing noise impacts contained within ETSU-R-97 and BS4142, to identify the additional noise burden on rural communities from wind turbines;

- Regulation without compliance testing is unethical. Therefore, urgently initiate independent routine testing for post-construction noise compliance. A fully automatic environmental noise measurement system for compliance testing of wind turbine noise is currently available.

- Initiate as a matter of urgency an independent academic, epidemiological clinical study of the effects of wind turbine noise on host communities;

- Introduce a mandatory 2 kilometre minimum separation distance from any wind turbine, and a greater distance for turbines over 2 MW, until robust and independently-assessed evidence is produced that a smaller distance will not have health impacts;

- Introduce a requirement that applicants for wind energy projects should provide tangible proof that their applications will not cause any short or long-term health impacts to the host community.

The plight of people made ill by wind turbine acoustic pollution has been generally ignored in many jurisdictions, including Northern Ireland, as have other negative medical impacts from this technology. The current noise assessment practices and standards in the province, based on the discredited and obsolete document known as ETSU-R-97, are incompetent and unacceptable, and must be urgently reviewed. Future procedures must include full spectrum acoustic monitoring inside homes and workplaces with separation distances being applied that are appropriate to increasing turbine scale and acoustic emissions. Both the allocation of modest funding for independent research and an adherence to the precautionary principle, are an urgent necessity. Only in this manner will the health of those living around wind turbines be adequately protected.

1. Noise Levels

Question: Is the noise standard in PPS 18 adequate to protect residents from wind turbine noise?

Answer: No.

Reason: Noise from wind turbines is permitted to be far greater than for any other renewable source and the noise guidance on which it is based is seriously flawed, thus exposing the public to even greater noise levels.

Comment: The guidelines applied to wind energy applications are problematic and controversial and the noise assessment methodology is not based on generally accepted acoustical measurement and prediction procedures, but is based instead on a 1996 document known as 'ETSU-R-97'. Independent acoustical consultants across the world have found it to be seriously flawed and it's use in place of the generally accepted procedures codified in ANSI and ISO standards, explains why projects that appear to be compatible with a community during the planning process later produce complaints of noise annoyance, sleep disturbance and other adverse health effects once operation commences.

Other renewable sources such as biomass plants may have to meet levels of 25dBA at night in quiet countryside whilst wind turbines can operate at over 40dBA when background noise may be well below 30dBA. Usually this would be an accepted cause for complaint, but wind noise receives special treatment. . The most bizarre result is that night time noise can be up to 8dBA more than the day time noise. No other standard anywhere in the world has a night time limit higher than a day time limit.

There are a number of difficulties with the ETSU-R-97 guidance.

It is out of date and it stated in 1996 that a revised report would be required in two years time. No such review has ever taken place, yet turbines are at least five times larger than those on which ETSU-R-97 was based;

The guidelines state that there should be separate noise limits for day and night time, and that the permitted noise level from turbines can be higher at night than during the day; yet many noise complaints made about wind turbines relate to sleep disturbance. ETSU-R-97 is the only noise guidance in the world that recommends higher levels of noise during the night than during the day;

The main difficulty with ETSU-R-97 is that it is quite unsuitable for quiet rural areas because, particularly at night, it sets noise limits not by what is acceptable or reasonable to protect amenity but by what is the upper limit that can be tolerated. For example it often permits turbine noise levels four times as loud as the background noise level at night and just into the region where the World Health Organisation says that it may cause sleep disturbance. Since it was written, the WHO has revised its guidance 5dB lower. So the ETSU night standard is now higher than WHO says is required to get back to sleep;

Consultants working for the Business Department (now the DECC) in 2006 indicated that the sound level permitted from turbines had been set so high — 43 decibels — that local people could be disturbed in particular wind conditions and likely to disrupt sleep. The report said the best way to protect locals was to cut the maximum permitted noise to 38 decibels, or 33 decibels if the machines created discernible "beating" noises as they spun. However, it later emerged that officials removed the warnings from the draft report by the consultants. The final version made no mention of them;

Any measurements at night are underestimated due to incorrect assumptions about the masking effects of wind near ground level, and turbines will therefore be producing more noise precisely when background noise levels are low. Atmospheric conditions at night mean higher pulse levels (producing 'thumping' noises), but investigations generally take place during the day. Likewise, the guidelines state that measurements should be taken outside properties, whereas complainants are usually more troubled by noise penetrating inside their homes;

Absolute noise level is less important than the character of the noise produced. Similarly, research suggests that wind turbine noise has special characteristics which are easily perceived, even as low sound pressure levels. This is also something that noise measurements do not take into account. Rather than noise being simply related to volume, perception of a noise as unpleasant, neutral or pleasing is much more complicated;

The Best Practice Guide to PPS 18 compares the likely noise levels from a wind turbine to those from a car or an office environment, missing the critical points that the quality of the sound, the appropriateness of the noise, and the source from which it arises are just as important as the level;

The current noise assessment practices and standards in the province, based on the discredited and obsolete document known as ETSU-R-97, are incompetent and unacceptable, and must be urgently reviewed. Future procedures must include full spectrum acoustic monitoring inside homes and workplaces with separation distances being applied that are appropriate to increasing turbine scale and acoustic emissions. Both the allocation of modest funding for independent research and an adherence to the precautionary principle, are an urgent necessity.

drk 9 Sept 2013

2. Low Frequency Noise

Question: Does the noise standard in PPS 18 protect residents from the effects of low frequency noise?

Answer: No.

Reason: The noise methodology ignores this type of noise.

Comment: As turbine sizes increase, pushing the blades into increasingly turbulent winds, the associated low frequency sounds increase and shift downward in the frequency spectrum. Because of this downward shift some larger wind turbines have lower dBA ratings than their smaller siblings. This has led to the incorrect conclusion that larger turbines are quieter.

One of the criticisms of the noise standard used by PPS 18 is that the 'A'-weighted scale it uses to measure noise mostly excludes low frequency noise. But much of the noise produced by wind turbines is low frequency and it seems strange to use a scale that does not take into account fully, noise from an offending source.

Large wind turbines generate very low frequency sounds and infrasound (below 20 Hz) when the wind driving them is turbulent. The amount of infrasound depends on many factors, including the turbine manufacturer, wind speed, power output, local topography, and the presence of nearby turbines (increasing when the wake from one turbine enters the blades of another). The infrasound cannot be heard and is unrelated to the loudness of the sound that can be heard. Infrasound can only be measured with a sound level meter capable of detecting it (and not using the A-weighted scale). Infrasound at the level generated by wind turbines cannot be heard, but the human ear is indeed detecting and responding to it, as research clearly demonstrates.

The situation has been exacerbated by bad siting, poor measurement, and the fact that the ear is most sensitive to infrasound when other audible sounds are at low levels or absent. It has been known for many years that maximum stimulation of the ear with infrasound will occur inside the home, because the audible sound of the turbine is blocked by the walls of the house, but infrasound readily passes through. The infrasound will be strongly stimulating the ear even though this is unheard. But it can be felt as a resonance, typically in the chest or through the feet etc.

This problem has been recognised by the World Health Organisation, which has said that special attention should be given to noises in an environment with low background sound levels, where there are combinations of noise and vibrations; and where there are noises with low frequency components.

The factors listed above can lead to differing views about the existence of noise problems. If analysts are measuring for one type of noise, on a particular scale, but what is being heard is not recognised by this scale, this will underestimate any problems. What has been revealed by recent research is that wind turbines do produce significant levels of infra and low-frequency sound at great distances, even when the sound pressure levels do not rise to the thresholds of audibility, and that the greatest effect is indoors.

drk 20 Feb 2014

Spinning the Environment Committee a Low Frequency Yarn?

Addendum to Question 2 on Low Frequency Noise

When the Environment Committee met with representatives of NIRIG on 12 September 2013, the following exchange took place between Mr. McElduff and Ms Hitchins of NIRIG, as recorded by Hansard. This is such a distortion of the actual position concerning the adverse health impacts of low frequency and other categories of noise, that a full rebuttal is given in an excerpt by Dr. Christopher Hanning, the acknowledged expert on Sleep Disorders Medicine in the UK, and in a fully-referenced consideration of The growing evidence of the health impacts of wind turbines.

Mr McElduff: Could Gail point us in the direction of conclusive reports that say that there are no negative health impacts from low-frequency noise?

Ms Hitchins: Yes. Numerous reports reach those conclusions. I refer you to probably the most cited of those, which is the 2006 report that was issued on behalf of the then Department of Trade and Industry and carried out by the Hayes McKenzie Partnership. It concluded that, yes, low-frequency noise can be measured indoors at properties in the vicinity of wind turbines, but that it is well below the guidelines that are permitted by the Department for Environment, Food and Rural Affairs (DEFRA). Wind turbines are not the only source of low-frequency noise. There are guidelines that aim to control it from a variety of sources. Wind turbines are not unusual in that regard, and, as I said, the levels measured were well below the DEFRA guidelines.

Statement byDr Christopher Hanning. BSc, MB, BS, MRCS, LRCP, FRCA, MD, Honorary Consultant in Sleep Disorders Medicine to the University Hospitals of Leicester NHS Trust, based at Leicester General Hospital having retired in September 2007 as Consultant in Sleep Disorders Medicine.

Hayes McKenzie Report 2006

The UK Department of Trade and Industry (DTI) commissioned a report from the Hayes McKenzie Partnership (HMP) in 2006 which investigated low frequency noise at three UK wind farms. As far as can be determined, no medical or physiological expertise was used in the design of the study. Sound measurements were taken at three of five sites where complaints had been recorded over periods from 1-2 months. Communication with residents other than those who complained was minimal. However, they did confirm that "some wind farms clearly result in modulation at night which is greater than that assumed with the ETSU-R-97 guidelines". Measured "internal noise levels were insufficient to wake up residents at these three sites. However, once awoken, this noise can result in difficulties in returning to sleep.

The lack of physiological expertise in the investigators in not recognising that noise can disturb sleep without actual recalled awakening is a major methodological flaw rendering the conclusions unreliable, as is the short recording period. It is well recognised also that not every resident affected by a nuisance such as noise will actually register a complaint (Health Protection Agency 2009). Many will not be sufficiently literate or confident so to do and others may wish to avoid drawing attention to the problem to protect property prices. They may assume also that protest is futile, which seems to be the experience of many with wind turbine noise. The WHO and other research by DEFRA suggest complaints may represent between 5-20% of sufferers with others seeking alternative coping strategies. Recorded complaints are thus the tip of the iceberg.

It will be claimed also that only 5 of 126 wind energy developments at the time of the study had attracted complaints of noise and thus the matter is trivial. This assertion is, to say the least, disingenuous. Many of the developments at that time were of small turbines set in isolated areas of the countryside, well away from habitation. In addition, as noted above, the proportion of those affected by wind turbine noise who formally complain to their local authority is very small. Research into wind farm noise and health issues in the UK is virtually non-existent and of poor quality. To suggest that there is "no problem" when faced with the large body of evidence presented here is perverse. The conclusion is also contradicted by Moorhouse's study (vide infra) which showed a complaint rate of 20%.

Draft versions of the report (DTI 2006 a,b,c) have recently come to light as a result of Freedom of Information requests. They show that HMP had recommended a reduction of the ETSU-R-97 permitted night time limits to 38dB LA90 (40dB LAeq) in the absence of AM with a further penalty of up to 5dB in the presence of modulation. These recommendations were removed from the final version of the report. No scientific explanation for their removal seems to have been offered. An example of removed text follows:

"The analysis of the external and internal noise levels indicates that it may be appropriate to re-visit the issue of the absolute night-time noise criterion specified within ETSU-R-97. To provide protection to wind farm neighbours, it would seem appropriate to reduce the absolute noise criterion for periods when background noise levels are low. In the absence of high levels of modulation, then a level of 38 dB LA90 (40 dB LAeq) will reduce levels to an internal noise level which lies around or below 30 dB LAeq with windows open for ventilation. In the presence of high levels of aerodynamic modulation of the incident noise, then a correction for the presence of the noise should be considered."

Similarly, references to WHO guidance for the protection of sleep disturbance which supported HMP's recommendations for a reduction in ETSU-R-97 night time noise limits were removed. The removed text follows:

"If one takes the guidance within the WHO for the protection against sleep disturbance of 30dB LAEq, and apply a 5 dB correction for the presence of high levels of [aerodynamic] modulation within the incident noise, then this gives rise to an internal noise criterion of 25dB LAeq. Based upon the measured building attenuation performances at Site 1 & 2, then an external level between 35 – 40dB LAEq (33-38 dB LA90) would provide sufficient protection to neighbouring occupants to minimise the risk of disturbance from the modulation of aerodynamic noise."

It is quite clear that relying on the conclusions of this report, as published, is unwise as they are, at best, misleading.

Dr. Chris Hanning, 'Wind Turbine Noise, Sleep and Health', November 2010.

The growing evidence of the health impacts of wind turbines

- Most health practitioners are well aware of the links between chronic severe sleep deprivation[1] chronic stress[2] and poor physical and mental health. This is exactly what residents living near wind turbines are experiencing[3] together with other specific symptoms strongly correlating with acute exposure to this sound energy[4,5,6,7].

- Knowledge of the damage to health from exposure to infrasound[8] and low frequency noise [9] (ILFN) has been known for many years. Despite this, little is known about the current ILFN exposure levels inside people's homes since this is not required for wind turbine planning applications.

- The link between chronic exposure to low frequency noise and chronic physiological stress, even when asleep, was clearly highlighted by Professor Leventhall et al in 2003 [10].

- Most medical practitioners have been unaware of the problems associated with exposure to ILFN. This ignorance has not been helped by acousticians and others calling such problems "annoyance" without any accurate clinical diagnoses[11].

- These symptoms have been reported to occur specifically with exposure to wind turbine noise by medical practitioners since 2003 [12,13,14,15,16,17]. Symptoms have been reported by acousticians, health practitioners and residents from countries including Denmark, Sweden, Germany, United Kingdom, France, United States, Canada, New Zealand and Australia.

- Symptoms have been reported up to 4 km from the nearest wind turbine, and more recently characteristic symptom patterns have been reported at distances of up to

10km [18]. These are associated particularly with larger wind turbines (e.g. 3MW), and on occasions are reported at even greater distances, where turbines are sited on hills above dwellings [19] or near expanses of water.

- These health problems consistently worsen over time, until the exposure ceases. A relationship between reported adverse health effects and distance has now emerged [20]. Families in other jurisdictions are being advised by their medical practitioners to leave their homes in order to regain their health. Others remain trapped due to lack of an economic alternative, unable to move to reduce exposure [21].

- Professors Moller and Pedersen, from the University of Aalborg in Denmark, have confirmed that larger more powerful wind turbines emit more low frequency sound waves as a proportion of their sound emissions [22, 23] and this has been confirmed by the world's leading turbine manufacturer [24]. These emissions are known to easily penetrate the walls, foundations, roofs, and windows of homes and workplaces, due to the lesser transmission loss of low frequencies.

- In Falmouth, USA [25], Australia (NSW) [26] and Shirley,USA [27] low frequency noise and pulsatile infrasound emitted by wind turbines have been measured inside the homes and workplaces of people suffering ill health effects. Both LFN and infrasound are present when they are experiencing the symptoms of what has been termed 'Wind Turbine Syndrome'.

- Professors Salt and Lichtenhan have shown that inaudible low frequency sounds do indeed stimulate the ear and produce marked physiological effects [28]. A large body of evidence now exists to suggest that wind turbines do disturb sleep and impair health at distances and sound pressure levels that are permitted in the United Kingdom [29].
  In Canada the research team headed by Roy D. Jeffery, MD, advised family physicians to recognize the symptoms of patients complaining about adverse health effects from wind turbines. "The documented (medical) symptoms are usually stress disorder-type diseases ... and can represent serious harm to human health," [30].

- Currently the Northern Ireland Planning Service do not require measurement of the full sound and vibration spectrum, do not require measurement inside homes and workplaces, do not require evaluation of sleep or other disturbances, but instead limit almost all assessment to audible noise (dBA) only, outside homes and workplaces.

References

1. Capuccio F et al, "Sleep Duration predicts cardiovascular outcomes: a systemic review and meta-analysis of prospective studies" European Heart Journal, (2011)32,1484-1492

2.McEwen, Bruce "Protective and Damaging Effects of Stress Mediators" NEJM 1998, 338 171-179

3.Shepherd, Daniel et al "Evaluating the impact of wind turbine noise on health-related quality of life" Noise & Health, September-October 2011, 13:54,333-9

4. Pierpont, Dr Nina "Wind Turbine Syndrome, A report on a Natural Experiment" Published by K Selected Books, Santa Fe NM 2009 www.windturbinesyndrome.com see also http://www.wind-watch.org/documents/wind-turbine-syndrome-excerpts-from-the-executive-summary/

5. McMurtry, Professor Robert "Toward a Case Definition of Adverse Health Effects in the Environs of Industrial Wind Turbines: Facilitating a Clinical Diagnosis" Bulletin of Science Technology and Society 2011 31:316

6. Phillips, Prof Carl V "Properly interpreting the Epidemiological evidence about the health effects of Industrial Wind turbines on nearby residents" Bulletin of Science, Technology and Society vol 31 No 4 (August 2011) pp 303 - 315

7. Leventhall, Benton & Pelmear May 2003, A report for DEFRA "A review of published Research on Low Frequency Noise and its Effects"

8. NIEHS (National Institute of Environmental Health Sciences) November 2001, "Infrasound Brief Review of Toxicological Literature"

9. Leventhall, Benton & Pelmear, May 2003 op cit

10. Leventhall, Benton & Pelmear, May 2003 op cit Section 10

11. Pederson & Waye, "Perception and Annoyance due to wind turbine noise - a dose-response relationship" in J Acous. Soc. Am. 116 (6) 2004 pp 3460-70

12. Harry, Dr Amanda "Wind turbines, Noise and Health" 2007 http://www.wind-watch.org/documents/wind-turbines-noise-and-health/

13. Iser, Dr David personal communication to the Waubra Foundation

14. Pierpont, Dr Nina "Wind Turbine Syndrome, A report on a Natural Experiment" Published by K Selected Books, Santa Fe NM 2009 www.windturbinesyndrome.com

15. McMurtry, Professor Robert "Toward a Case Definition of Adverse Health Effects in the Environs of Industrial Wind Turbines: Facilitating a Clinical Diagnosis" Bulletin of Science Technology and Society 2011 31:316

16. Hanning, C & Evans, A BMJ 2012: 344 e 1527 http://www.windwatch.org/documents/wind-turbine-noise-editorial/

17. Laurie, Dr Sarah Medical Director, Waubra Foundation, Submission to the Australian Federal Senate Inquiry into Rural wind Farms, February 2011, accessible via www.waubrafoundation.com

18.Waubra Foundation Submission to the NSW Department of Planning, March 2012, at http://www.wind-watch.org/documents/response-to-nsw-planning-department-draft-guidelines-for-wind-developments/

19.Personal communication, Hubert De Bonneville to Waubra Foundation, see also http://www.windturbinesyndrome.com/2012/french-writer-going-nuts-from-wind-turbines-france/

20. Nissenbaum, Michael A., Aramini, Jeffery J., Hanning, Christopher D., "Noise and Health: The Effects of Industrial Wind Turbine Noise on Sleep and Health", October 2012.

21. Letter to Australian prime minister from Dr. Sarah Laurie 2012/03/09

22. Moller & Pedersen "Low Frequency Noise from Large Turbines" J Acoustical Society America 2011 129: 3727 - 3744

23. Moeller, Henrik, Petersen, Steffen, Staunstrut, Jan Kloster and Petersen, Christian Sejer, " Assessment of Low Frequency Noise from Wind Turbines in Maastricht", Albert University, Denmark, 2012.

24. Letter from Ditlev Engel, Chief Executive Officer of Vestas Wind Systems to Karen Ellemann, Minister of Environment, Copenhagen, dated 29 June 2011.

25.Ambrose, Stephen & Rand, Robert "Bruce McPherson Infrasound and Low Frequency Noise Study" 2011

26. Cooper, Steven "Review of Draft NSW Guidelines" March 2012 http://www.wind-watch.org/documents/review-of-nsw-draft-wind-farm-guidelines/

27. A Co-operative Measurement Survey and Analysis of Low Frequency and Infrasound at the Shirley Wind Farm in Brown County, Wisconsin prepared co-operatively by Channel Islands Acoustics, Hessler Associates Inc., Rand Acoustics and Schomer & Associates Inc., 24 December 2012.

28. Salt AN, Hullar TE. Responses of the Ear to Low Frequency Sounds, Infrasound and Wind Turbines. Hearing Research 2010; 268: 12-2 1

Salt AN, LichtenhanJT. Responses of the Inner Ear to Infrasound. Proceedings of the Fourth International Meeting on Wind Turbine Noise, Rome Italy April 2011

Salt AN, Kaltenbach JA. Infrasound from Wind Turbines Could Affect Humans. Bulletin of Science, Technology & Society 31, 296-302, 2011

Salt AN, Lichtenhan, JT. Perception-based protection from low-frequency sounds may not be enough. Proceedings of InterNoise 2012, New York, 2012.

Salt AN, Lichtenhan JT, Gill RM, Hartsock JJ. Large endolymphatic potentials from low-frequency and infrasonic tones in the guinea pig. J Acoust Soc Am. 2013 133 :1561-1571.

Lichtenhan, J.T. Salt, A.N. (In Press) Amplitude modulation of audible sounds by non-audible sounds: Understanding the effects of wind turbine noise. Proceedings of Meetings on Acoustics by the Acoustical Society of America.

29. Farboud, A., Crunkhorn R., and Trinidade D., "'Wind turbine syndrome': fact or fiction?", in Journal of Laryngology & Otology, / Volume 127, Issue 03, March 2013, pp 222-226.

30. Jeffery, Roy D., Krogh Carmen, Horner, Brett, "Adverse health effects of industrial wind turbines", in Canadian Family Physician, May 2013 vol. 59 no. 5, pp.473-475.

3. Amplitude Modulation

Question: Is Excess Amplitude Modulation from turbines rare and will PPS 18 protect residents from it?

Answer: No to both.

Reason: All wind turbines generate AM and PPS 18 misrepresents the noise it measures.

Comment:

1. The noise most commonly associated with wind turbines, and frequently complained of, is the repetitive swishing beat occurring at turbine blade rotation frequency, which is known as Amplitude Modulation (AM) of the aerodynamic turbine noise. This becomes audible at a considerable distance from the wind turbines.
2. The fluctuating (amplitude modulated) noise caused by aerodynamic modulation is more noticeable and annoying than broadband noise of the same sound level.
3. The noise monitoring recommended in ETSU-R-97, the noise standard used in PPS 18, is totally ineffective in protecting residents from aerodynamic modulation noise, because the specified noise descriptor LA90, 10min) ignores the noisiest 90% of each ten-minute measurement period and gives a result based on the loudest noise during the quietest 10% of the period.
4. ETSU-R-97's recommendation that noise monitoring is carried out at the nearest noise sensitive properties fails to take account of the fact that aerodynamic modulation noise can be heard at considerable distances from a wind farm and can be difficult to detect closer to the wind farm.
5. It is highly likely that one form of aerodynamic modulation is caused by stable atmospheric conditions.
6. The noise limits recommended by ETSU-R-97 will over-estimate the level of wind-induced background noise near ground level during stable atmospheric conditions. Therefore, when the atmosphere is stable, the ETSU-R-97 noise limits will allow wind turbines to generate noise significantly above the background noise level.
7. During stable atmospheric conditions wind turbines will generate higher levels of noise than would be predicted from the wind speed at 10 metres above ground level and the logarithmic wind speed profile equation.

Recent research presented at three Planning Inquiries in England that were conducted in September, October and November 2013 (Starbold, Bryn Lleweln and Shipdham - decisions awaited) have hopefully exposed the misconceived arguments made by the Industry's acousticians' which have successfully avoided controls over wind farm noise impact for many years.

After more than 4 years of smoke screens, obfuscation and erroneous objections raising unrealistic concerns and placing barriers in the way of necessary controls over the wind farm noise called "Excess Amplitude Modulation", industry acousticians have finally admitted a planning condition is "necessary" and "reasonable". Excess AM is now shown to be neither rare nor only causing minor effects as claimed over the last few years, arguments that have successfully blocked planning controls leaving many communities exposed to serious noise impact. Research by noted British acoustician, Mike Stigwood, and a three-year Japanese study of 34 wind farms by a team under Hideki Tachibana Chiba Institute of Technology have exposed this as a common and serious problem.

Dr Matthew Cand of Hoare Lea is part of the Renewables UK research team on EAM who were due to report their findings over 2 years ago but have continuously deferred this. He finally admitted after 2 hours of cross-examination, when being questioned over the need for a condition at the Shipdham Inquiry, that one was both 'necessary and reasonable'. Dr Cand was also questioned over the Den Brook condition metric which was accepted in 2009 but rejected ever since and that was formulated by MAS Environmental with a 3dB(A) EAM limit. This has been subject to widespread industry attacks over the last four years, leading to its rejection by planning inspectors ever since the Den Brook decision. In response Dr Cand said "If I had to pick a number I don't think 3dB(A) is...a bad number". In effect the Renewables UK research must support what Mike Stigwood's team found four years ago.

These admissions follow years of unpublished work by Renewables UK, coupled with statements that no one knows the appropriate level. In September at the Starbold Inquiry arguments that the Den Brook condition was triggered by extraneous noise were dropped by the appellants and they accepted it was an incorrect argument. Following the Bryn Llewelyn appeal in October 2013 Dr Jeremy Bass of RES, the main opponent of the Den Brook condition said during a meeting:

> "foolishly ... we went along the industry line that amplitude modulation is rare". He accepted the argument that it can be dealt with by statutory nuisance was wrong. He continued "I think that argument is completely exploded by the weight of evidence presented by Mike Stigwood in particular .... we are in a difficult position now ... the landscape has changed and I suspect .... in the future developers will no longer try the argument that AM is rare".

It is hoped decision makers will no longer receive erroneous arguments about the control of EAM and that conditions following the Den Brook metric are now applied to all future consents. There also needs to be a mechanism developed by Government for applying it to existing wind farms. Emerging evidence from the Japanese studies suggests a stricter limit may arguably be necessary but at the present time it is safe to consider the Den Brook metric as a means of controlling wind farm noise.

We also hope decision makers will now exercise particular caution with respect to arguments made by wind industry acousticians and that those who raise concerns over wind farm noise, in the main, do so legitimately.

These findings should be welcomed by both wind-farm neighbours, developers, and decision makers in the planning process. AM noise provokes complaints and heated debates, and an enforceable, objective, condition to cap such noise gives all parties clarity, as well as sparing neighbours and developers the trouble, expense, and uncertainty of private nuisance actions. The Den Brook condition appears to be a readily workable solution to this very real problem.

It should now be accepted that a planning condition to prevent excessive AM noise is both necessary and reasonable in every turbine approval. If AM does not exist, it will never be called upon.

Drk 26 Feb 2014

4. Good Practice Guide to ETSU-R-97 'The Assessment and Rating of Noise from Wind Farms'

Question: Does the Institute of Acoustics Good Practice Guide improve the protection of neighbours from wind turbine noise?

Answer: No. It weakens it substantially.

Reason: The data on which it is based does not support its claims.

Comment: After nearly two decades of insisting that ETSU-R-97 'The Assessment and Rating of Noise from Wind Farms', is fit for purpose DECC commissioned the Institute of Acoustics (IOA) to carry out a review of this standard and develop good practice guidance (GPG). However, this was not a proper independent review by the IOA as the limits which, we were told, "are government policy", were excluded from it's remit.

Pre-determined Outcomes

Indeed, the review was not truly independent from it's inception since, as was stated by the chair of the working group itself at the Wind Farm meeting in January 2013, the work of the group "would be in vain if government did not feel they could endorse it at the end of the day".

Flawed Remit

This absence of real independence and the exclusion of the indicative noise limits from consideration, were not the only problems faced by the review. The character of turbine noise was also placed outside the remit and the actual environmental impacts of the noise standards in terms of audibility and likelihood of complaints were not addressed. Moreover, the guidance diverges from ETSU-R-97 in a number of key areas resulting in a reduction in protection from noise for wind farm neighbours.

The working group was, therefore, not able to tackle the real problems of the assessment of wind farm noise.

The very restricted remit from DECC, was describe in the following terms by the IOA itself:

> "The terms required us to look at the technical elements of the methodology, but did not allow us to consider the noise limits, which are a matter for Government, or to discuss the potential health effects."

Flawed Membership

A major concern with the consultation process was the lack of transparency and potential conflict of interest, since the working group was dominated by the wind industry supply chain.

The working group had no statisticians, meteorologists or others not involved with wind farm planning applications to provide balance or a check mechanism. Further, the majority of members had previously signed up to a method that had not been tested and so were committed to a particular method before taking on the role.

Flawed Methodology

Contrary to the IoA's own professional Code of Conduct, the primary data relied on in the report is not publically available, so the claims concerning the validity of the recommended guidelines cannot be independently verified.

It appears that none of the members of the working group (other than Matthew Cand as part of Hoare Lea) saw the research data they say supports the main element of the GPG. Independent acousticians have been refused the data contrary to IoA rules and now have good evidence to show it does not support its findings. In essence the GPG should not rely on research that cannot be validated but in fact it does appear to do so.

Flawed Scrutiny

The GPG has allegedly been peer reviewed but, incredibly, the reviewers have also not actually seen the research data on which it is based. They appear to have accepted its findings on trust! Thus the peer reviewers, as well as the other members of the working group, appear to simply accept the unverified statements of Industry acousticians on the efficacy of their methods, whilst meekly accepting their exclusion by those same Industry acousticians from the raw data that would allow them to test the validity of those claims.

Undue Influence?

As if all of the above was not enough to invalidate any reliance in the GPG, as journalists discovered, the lobby group for the turbine industry was able to influence the final wording of the guide.

Internal energy department emails released following a freedom of information request show the lobby group met ministry officials and were assured that their input was "reflected in guidance". In particular, an e-mail from an energy department official to RenewableUK on May 10 said: "I understand you met with [name removed] and [...] to discuss your concerns about the IoA noise good

practice guidance – in particular sound power levels and cumulative impacts. I'm aware that [...] has spoken to [...], who has confirmed that the majority of R-UK's input has been reflected in the guidance."

Indeed, RenewableUK was invited on to a peer review panel.

Failure to Meet Legal Requirements

The purpose of the GPG is to help ensure that local planning authorities and planning inspectors receive reliable information on the noise impacts of a proposed wind farm in order that a robust planning decision may be made.

The GPG does not appear to recognise that it is a legal requirement that a noise assessment forming part of an Environmental Statement must supply "the data required to identify and assess the main effects which the project is likely to have on the environment" (EIA Directive 2003/35/EC, Article 5 paragraph 3) and that the "direct effects and any indirect, secondary, cumulative, short, medium and long-term, permanent and temporary, positive and negative effects of the project must be described". (Annex IV, paragraph 4)

A noise assessment is required to describe the 'levels and effects of noise from the development'. (Environmental impact assessment: guide to procedures DCLG) There is an obligation that the 'democratic right of a member of the public to make representations must be meaningful and therefore the information which is made available must be sufficient to enable a member of the public:
a) to respond to the significant effects on the environment to which it is suggested the project may give rise;
b) to examine the project to see whether it is likely to give rise to significant effects which have not been identified.' (Newman J. in R(Burkett) v London Borough of Hammersmith and Fulham, [2003] EWHC 1031 para 8 (vii)

As a consequence of this fundamental flaw, a developer who followed the guidance indicated in the GPG would nevertheless fail to comply with over-arching legal requirements, and neither the neighbours of the proposed application, nor the decision maker, would have access to non-technical noise information that would allow them to understand the effects that would result. This is obviously an absurd outcome.

Not Fit for Purpose

We also believe that the IoA document, like ETSU-R-97 itself, is not fit for purpose. The GPG allows more noise than ETSU-R-97.

Every wind farm causing complaints (over about 80 we know about and probably double that) is considered to comply or be within 0.5dB with ETSU limits and especially when using the GPG. Thus either everyone living near them is unreasonable or ETSU and the Guide are both wrong.

The major deficiencies are as follows.

- The new guidelines deviate from the previous guidance by recommending a change of methodology which permits wind farms to make more noise during quiet evening and night hours when high wind shear conditions prevail.

- The IoA's - suggested noise condition permits additional headroom for wind farms to make more noise under specific wind conditions that are common during quiet evening and night hours.

- The IoA guidance on theoretical turbine noise predictions at neighbouring dwellings permits turbines to be built even closer to dwellings.

There are also a significant number of unsubstantiated assertions throughout the IoA documents.

Research by independent acousticians similarly confirms the data on which the GPG is based does not support its claims and as time goes on the evidence grows. A paper to be presented on this is imminent.

Dr John Constable, director of REF, said: "Almost unbelievably, the IoA's wind farm noise committee report has actually increased the risk of serious noise problems for neighbours to new wind farms, and the risks were already quite unacceptably high."
Dr Constable continued: "The report may represent current wind industry practice but it is very poor guidance and fails in its duty of care. The government and the acoustics profession should ignore it, as should responsible wind developers who do not wish to antagonise wind farm neighbours."

There can be no confidence in good practice guidance unless it is rigorous and its claims are capable of independent verification using publically accessible data.

Drk 26 Feb 2014

5. ETSU-R-97 and the protection of residential amenity

Question: Does the noise methodology in PPS 18 protect the amenity of residents?

Answer: No.

Reason: A level to protect amenity was seen as being very restrictive on the development of wind energy.

Comment: ETSU-R-97 was written by a Noise Working Group (NWG) of developers, noise consultants, environmental health officers and others set up in 1995 by the Department of Trade and Industry through ETSU (the Energy Technology Support Unit). The DTI's mission was prosperity for all by working to create the best environment for business success in the UK. It has no brief for the protection of the environment or for the protection of the citizen from nuisance or loss of amenity.

As Dick Bowdler notes, "The first paragraph of the executive summary says this document describes a framework for the measurement of wind farm noise and gives indicative noise levels thought to offer a reasonable degree of protection to wind farm neighbours, without placing unreasonable restrictions on wind farm development or adding unduly to the costs and administrative burdens on wind farm developers or local authorities. It is thus, by its own admission, not a method of assessing impact. What is more, the compromise reached by the NWG is so lacking in basis, so full of unfounded assertions and so badly thought out and argued that it comes up with standards for wind farm noise that are quite unlike any other noise standards."

Thus comments will be seen such as that underlined below:

It is proposed that the background noise levels upon which limits are based, and the noise limits themselves, are based upon typical rather than extreme values at any given wind speed. An approach based upon extreme values would be difficult to implement as the difference in measurements between turbine noise and background would depend upon the length of time one is prepared to take data. A more sensible approach is to base limits upon typical or average levels, but to appreciate that both turbine and background noise levels can vary over several dB for the same nominal conditions. (Page 61).

This is one example of how protection of amenity is set aside in the document. It is the spikes in noise that frequently cause the annoyance to neighbours of wind turbines. People's perception of intruding noise is based on what they hear in the quiet times, not what they hear on average.

Another example of this process is seen in the two sections below, parts of which are underlined for emphasis:

Margin above background

It is proposed to limit the noise from a wind farm relative to the existing background noise but with special consideration given to the very low noise limits this would imply in particularly quiet areas. Noise from the wind farm will be limited to 5dB(A) above background for both day and night time (with the exception of the lower limits and simplified method described below), remembering that the background level of each period may be different. (Page 62).

Lower limit

Applying the margin above background approach to some of the very quiet areas in the UK would imply setting noise limits down to say 25-30dB(A) based upon background levels perhaps as low as 20-25dB(A). Limits of this level would prove very restrictive on the development of wind energy. As demonstrated below, it is not necessary to restrict wind turbine noise below certain lower fixed limits in order to provide a reasonable degree of protection to the amenity. (Page 62).

For someone living in a rural environment, the level of background noise would be very low, yet the minimum level of noise for a single turbine is permitted to be 35 dB(A). Immediately you will be exposed to a noise increase of probably 10 or more decibels, which is certainly a loss of amenity. Indeed, the reasonableness of the degree of protection is not defined, nor should it be assumed that the use of the term 'amenity' refers to the defined term in planning.

The document then resorts to 'sleight of hand' by introducing the night-time noise limit of 43 dB(A) before it addresses the day-time noise limits, thus giving the impression that they are somehow being generous by having a lower day time limit. In fact, the reverse is the case. The result is that night time noise can be up to 8dBA more than the day time noise, and up to four times higher than the original background noise level. No other standard anywhere in the world has a night time limit higher than a day time limit.

The document then attempts to set up 'straw men' such as in the following statement:

The Noise Working Group believes that the external levels around 50dB(A) suggested by some of these documents for the protection of external amenity would be entirely inappropriate in the quiet rural locations of the UK. Furthermore, even the 43dB(A) limit ($L_{A90,10min}$) derived above to protect sleep disturbance inside the property does not offer sufficient protection to the external amenity in quiet areas of the UK during the day.

It is also the opinion of the Noise Working Group that there is no need to restrict noise levels below a lower absolute limit of $L_{mo,10min}$ = 33dB(A); if an environment is quiet enough so as not to disturb the process of falling asleep or sleep itself then it ought to be quiet enough for the peaceful enjoyment of one's patio or garden. This level would however be a damaging constraint on the development of wind power in the UK as the large separation distances required to achieve such low noise levels would rule out most potential wind farm sites. There are however the following justifications for relaxing this limit:

- Wind farms have global environmental benefits which have to be weighed carefully against the local environmental impact.

- Wind farms do not operate on still days when the more inactive pastimes (eg sunbathing) are likely to take place. Etc.

- The absolute lower limits will only come into force when the turbine noise is more than 5dB above the background noise level and when this level of 5dB above background is below a figure in the range discussed below. The period of greater exposure to noise will therefore be limited and on some sites will not occur at all. (Page 64).

For periods during the day the Noise Working Group has adopted the approach that external noise limits should lie somewhere between that required to avoid sleep disturbance even if the occupant is outside of the property and the higher level that would still prevent sleep disturbance inside the property.
The Noise Working Group has therefore concluded that in low noise environments the day-time level of the $L_{mo,10min}$ of the wind farm noise should be limited to an absolute level within the range of 35-40dB(A). We believe that limits within this range offer a reasonable degree of protection to wind farm neighbours without placing unreasonable restriction on wind farm development. The levels are low compared to some of the advisory documents reviewed and this is because of our concern to properly protect the external environment. (Page 65).

As Dick Bowdler again comments, "The conclusions of ETSU-R-97 are so badly argued as to be laughable in parts (the daytime standard is based on the principle that it does not matter if people cannot get to sleep on their patio so long as they can get to sleep in their bedrooms)...

ETSU-R-97 bears no resemblance to standards used for other industrial developments. Other renewable energy developments have to meet stricter standards. At several points the Noise Working Group that drew up the document decided that a particular standard was appropriate and then, without putting forward any evidence said that such a standard would restrict development of wind farms and so relaxed it further."

This is only an introductory look at the document, but it will be seen that the abandonment of protection of amenity is quite subtle in places and this is only a selection.

Drk 22 Feb 2014

6. BS 4142 – An alternative to ETSU-R-97 that works

Question: Does the noise standard in PPS 18 enable local authorities to exercise duty of care responsibilities concerning wind turbines?

Answer: No.

Reason: The noise standard used by PPS 18 permits the introduction of

wind turbines into inappropriate low background noise locations where they and other comparable industrial installations could not meet planning conditions derived from the long established BS 4142 standard.

Comment: A standard does exist for the assessment of the impact of environmental noise that both complies with EU law and UK regulations, and sets out the impact of noise from the development on people and the environment. It also provides a more robust methodology than that used in PPS 18, known as ETSU-R-97.

BS 4142 Method for Rating Industrial Noise Affecting Mixed Residential and Industrial Areas is a British Standard that has been in existence for over 40 years. It is widely used throughout the UK as an assessment tool for planning purposes. It is so widely used that hardly any local authority in the country does not use it for some types of assessment and most require it for assessments of developments where a new non-transportation noise is introduced into an area – even such noise sources as football pitches. It has been and is still regularly used to assess noise impact and experienced practitioners know of no case where it has been suggested that BS4142 gave an anomalous result.

The standard was endorsed by DEFRA in September 1998, the department of government concerned with the environment at that time. They submitted their Noise and Nuisance Policy under Health Effect Based Noise Assessment Methods to the EU. This said that BS4142:1997 provides a technical means of assessing whether or not 'complaints are likely'. The result of an assessment carried out to BS4142 would normally be relevant to the deliberations of any court considering whether or not a nuisance exists.

It seems common sense that the impact of a new noise on existing residences is related in some way to the background noise. For example if the background noise level at present is 45dBA then a level of 35dB from a new industrial source would probably be inaudible. If the background noise level at present is 20dB then an industrial noise of 35dB will clearly be heard and would be very likely to produce complaints. Indeed it is normal to set a noise limit relative to the pre-existing background noise when a new industrial noise is to be introduced into a residential area. Typical planning conditions imposed by rural local authorities require that the new noise be no more than 5dB above the pre-existing background.

BS4142 indicates that a difference of around 10dB or higher will likely result in complaints. We could postulate that if the noise level was predicted to be likely to give rise to complaints then this would constitute a major loss of amenity. BS4142 also includes a penalty to reflect the nature of the noise. If it is tonal, has clicks and bangs or is otherwise likely to attract attention then a penalty is applied of 5dB.

This then must be accompanied by a narrative to describe the likely subjective impact that the noise will have on each sensitive receptor. That narrative will include those factors that are not taken into account by the objective test – for example for how long do particular levels of impact last, is the noise likely to be masked by the background noise or are the frequency characteristics quite different, does the intruding noise have significant levels of low frequency. This is all set out in such a way that everyone understands the position and then a proper planning decision can be made.

The critical advantage in using BS 4142 is that it enables local authorities to exercise duty of care responsibilities denied to them under ETSU-R-97.

In summary, BS 4142 can be characterized as follows:

- First published in1967, amended 1975, 1980, 1982, and revised 1990, 1997

- Concise 19 page document easily understood and applied by local authorities and developers (compared to 175 pages for ETSU)

- Applicable for a range of wind speeds up to 5m/s

- Applicable when rating levels are above about 35dB

- Background surveys not required if rating level is below 35dB

Overall BS 4142 provides enforceable, robust noise assessment guidance and reintroduces the concept of protection for residents living adjacent to wind turbines.

Drk 26 Feb 2014

7. Separation Distances and Noise

Question: Does the noise standard in PPS 18 ensure adequate separation distances between turbines and rural residents?

Answer: No.

Reason: The need was ignored for epidemiological and laboratory research by health professionals and acousticians concerned with public health and well-being to develop effective and precautionary setback distances for industrial wind turbines that would protect residents from wind turbine sound.

Comment: The normal Noise protocol is to base the siting of turbines on the prediction of the noise at a receptor. There is no routine testing for compliance postconstruction and therefore no feedback on the planning of future wind farms. In cases where complaints have led to noise audits that have demonstrated noncompliance, the receptors have sometimes been compensated but no feedback has informed the compliance process.

Applicants and regulators should have foreseen the very negative noise response from neighbors living near wind turbine sites. By their not adequately understanding the sound character generated by wind turbines, appropriate corrections to prevent annoyance were not included in the noise predictions.

Residents are being annoyed, are suffering sleep deprivation and disturbance, and in many cases, are suffering adverse health effects.

Yet, in comparison to other sources of environmental noise, annoyance due to wind turbine noise was found at relatively low noise exposure levels, which for other noise sources appeared reasonable.

We now know that turbine noise has characteristics that contribute to this situation. We also know that there are factors not considered when applying the noise regulations. Finally, there is a reluctance to test for compliance. Unlike industrial machinery there is no possibility of shielding the noise at source. Nevertheless, regulation without compliance testing is unethical.

The characteristics of turbine noise that contribute to annoyance and sleep disturbance are as follows:

The sound from turbines is amplitude modulated at the blade passage frequency. The modulation level is typically 3 to 5 dBA (van den Berg, 2005) but higher levels have been measured (Moorhouse, Hayes, von H.erbein, Piper, & Adams, 2007). Two things arise: The peak sound is higher than the average used for noise regulation and the modulation enhances the audibility of the sound to such an extent that the turbine noise can be detected even when the sound is below ambient (Hanning, 2010). The noise emitted by a turbine is broadband; however, at a distance of 500 meters and more, the higher frequencies have been absorbed by the atmosphere so that it is predominantly low-frequency noise that reaches a receptor. This low-frequency noise enhances annoyance and is more readily able to penetrate walls and resonate inside rooms. Many people report a thumping, rumbling, or impulsive character to the turbine noise (e.g., Frey & Hadden, 2007, 2012; Harry, 2007); the reason is not clear.

Deficiencies With Present Noise Regulation

As noted above, the character of turbine noise makes it especially intrusive. This is exacerbated by the fact that wind turbines are sited in rural areas where the ambient noise level can be 25 dBA or less. An intrusion of 15 to 20 dBA is too large. Germany has a night time noise limit of 35 dBA; this should be the international absolute maximum, but that in Northern Ireland is 43 dBA.

Also, the standard algorithm for predicting noise at a receptor is ISO-9613-2. But, this was never designed for turbine noise. The ISO manual is specific in limiting its use to noise sources close to the ground such as "road or rail traffic, industrial noise sources, construction activities, and many other ground-based noise sources." Turbine noise derives from blades rotating, typically, between 35 to 125 meters above ground level. When used without compliance, testing the results of the predictions have little meaning.

The authors of noise prediction algorithms appreciate that there is uncertainty in the calculations. For instance, the manual for ISO 9613-2 puts the uncertainty at 3 dBA for a source to receptor distance in the range 100 to 1,000 meters.

The turbine makers know that there is variability in manufacture; this is put at 1 or 2 dBA.

Combining these, the predictions can be no better than 4 dBA. This uncertainty is ignored by the wind energy developers and by the regulatory authorities. This is despite the fact that the final siting plans are signed off by professional engineers and approved by professional engineers.

All prediction algorithms assume spherical spreading of the sound from the turbines. This is not necessarily always so, especially when more than one turbine is involved. Sound propagation experiments over hard surfaces, such as water or packed sand, have demonstrated a transition from spherical to cylindrical spreading even for distances of less than 1 kilometer (Bou 2007; Hubbard & Shepherd, 1991). Packed snow would be another example of a hard surface. The cylindrical spreading is a result of refraction of sound in the atmosphere and channeling of sound between the atmosphere and the ground (S dergaard & Plovsing, 2005).The distance at which the transition occurs

depends on the wind speed and temperature gradients in the low atmosphere and will vary with time of year, time of day, and weather.

Turbines leave behind them a turbulent wake and a wind speed deficit. Turbulence is known to exacerbate turbine noise (Amiet, 1975; Moriarty, 2004; Moriarty, Guidati, & Migliore, 2004, 2005; Moriarty & Migliore, 2003; Romera-Sanz & Matesanz, 2008). Turbulence occurs naturally in the atmosphere but the wake turbulence can equal this natural turbulence out to 5 blade diameters (Barthelmie et al., 2003). Experiments with an isolated turbine at the National Renewable Energy Laboratory in the United States have demonstrated this excess noise for measured natural turbulence and compared it with turbulent inflow noise calculations (Moriarty, 2004). Below 200 Hz, the turbulent inflow noise dominates over all other aerodynamic sources for turbulent intensities above 10%. No account of this excess noise is included in any noise regulation.

The use of masking noise to justify an increase of the noise limit with wind speed was laid to rest by the pioneering work of van den Berg (2004). He argued that in a stable atmosphere there can be a large vertical wind speed gradient such that the turbine is generating power and noise while at ground level there is insufficient wind to generate masking noise. He supported his argument with meteorological tower wind speed measurements. The pity of it is that so many wind farms have been built with setbacks based on the allowance years after van den Berg had so clearly made his case.

The Way Ahead

At a minimum, the following need to be introduced into noise regulation of wind turbines.

The noise limit needs to be reduced to 35 dBA at night time and, where applicable, reduced to 40 dBA for daytime. This is still intrusive in rural areas but will help bring setbacks to those recommended by health authorities. Wind energy and the wind industry have flourished in Germany with these regulations, despite a population density twice that of Northern Ireland.

A penalty of 5 dBA needs to be added to the time-average predicted noise levels; this is to compensate for the enhanced audibility of the amplitude-modulated and impulsive character of turbine noise.

Uncertainty in design calculations is the norm in engineering practice. The 4 dBA is real and should be tolerated in the noise prediction calculation. For the wind developers, erring on the side of caution could protect their very large investments when testing for compliance does become the norm.

A great deal is known about the excess noise due to turbulent inflow. Wind energy developers need to make test tower measurements of local natural turbulence and make calculations of wake turbulence to predict this excess noise.

Compliance is not so difficult. It is common practice to check for compliance in all manner of industrial situations. Atkinson & Rapley Consulting (2011), in association with Astute Engineering, in New Zealand has developed a fully automatic environmental noise measurement system. This is in service in New Zealand for compliance testing of wind turbine noise. Compliance testing is vital because it leads to reconsideration of noise prediction calculations. Where noise audits have been done, such as that at a home near Shelburne in Ontario, turbine noise well in excess of the noise limit has been demonstrated. In such cases, the wind energy company pays compensation or buys out the home-owner; no iterative use is made of the audit.

With the above changes to the regulation of noise:

- a 35 dBA night time noise limit;
- penalties of 5 dBA for the periodic or impulsive character of turbine noise;
- 4 dBA for uncertainty in noise prediction, and;
- a penalty for turbulent inflow noise;

the setback from homes will approach the 1.5 to 2 kilometres recommended by health authorities.

Drk 26 Feb 2014

The Inadequacy of Separation Distances

Introduction

There are a number of aspects that must be considered in setting an adequate separation distance. To simplify this document, it has been divided into a main discussion, ending with a proposed minimum separation distance, and three major questions and answers (numbered 8 to 10), each with a short supporting rationale and a more detailed commentary covering Residential amenity, shadow-flicker and reflected light, and safety impacts. All of these have significance in deciding how close to a residence a turbine should be permitted to approach, as do a number of those already considered under the earlier section on 'Noise'.

Separation distances in PPS 18 - Origins and Faulty Basis

It is surprising but true that there is no scientific basis to the statement within PPS 18 that, "For wind farm development a separation distance of 10 times rotor diameter to occupied property, with a minimum distance not less than 500m, will generally apply."

As will be seen below, the statement is the result of the conjunction of three errors:

- Failure to fully understand the application of the noise standard adopted by PPS 18;
- Failure to identify the limitations and shortcomings inherent in a restricted piece of research concerning shadow-flicker, not capable of verification or repetition; and
- Failure to objectively examine wind industry assertions concerning the safety of their technology.

No research had been conducted nor was independent expert advice ever sought to assess if these separation distances would be adequate to protect residents from the effects of noise, shadow-flicker and component failure. In short, it appears to be a civil servant's approach to controlling impacts by combining two misread and misunderstood standards, the adequacy of which individually and in concert, have never been established, and ignoring a third impact completely.

Why a 500 metre minimum separation distance and what does it apply to?

This is first stated in the summary of consultation responses to the draft of PPS 18 in 2009:

"In response to points raised through the public consultation, the Department has decided to amend the policy text to include reference to a recommended separation distance that should be applied as a general rule to applications for wind energy development. The distance is expressed as 10 times rotor diameter or a mimimum distance of 500 metres to occupied property."

Note in particular that this minimum is to be applied '...as a general rule to applications for wind energy development', and not only to wind farms. However, the reason for the size of the actual distances themselves is not given.

Further investigation into the efficacy of these separation distances brought the following clarification from Stephen Hamilton, one of the authors of PPS 18, on 14 May 2010: It is partly reproduced below without correction:

'I would like to draw your attention to the complementary Best Practice Guidance to PPS18. This guide was initially published as Annex 1 to draft PPS18 and provides guidance for other amenity considerations outside of the established ETSU noise standards applied across the whole of the UK. Paragraphs 1.3.76 and 77 of the Guidance (paragraphs A107/8 in the consultation draft) provides a separation distance to mitigate against the potential for shadow flicker. While this document is referenced in the text of policy RE1, only limited weight can be applied to this in setting a minimum standard in the protection of public safety, human health or residential amenity. Taking the comments received to the public consultation exercise from the Chief Environmental Health Officers Group (CEHOG) proposing a minimum distance of 500m on the issue of noise, the policy wording requiring a separation distance of 10 times rotor diameter separation distance not less than 500m was written to encapsulate a general separation distance on amenity grounds.

So the separation distance is the combination of two methodologies, applying to noise and shadow-flicker respectively, and slightly increased at the recommendation of CEHOG. Note also that '...the policy wording requiring a separation distance of 10 times rotor diameter separation distance not less than 500m was written to encapsulate a general separation distance on amenity grounds' and does not refer specifically to wind farms.

This understanding of the sources from which the separation distances were derived, is further confirmed in correspondence dated 18 June 2010 with Anne Lockwood, Deputy Director of the Planning and Natural Resources Division.

In her reply, Ms. Lockwood states:

'In your email, you stated "You have not revealed the origin of the "10 diameters is sufficient to prevent noise impacts". The department FEELS that this is right. Have they conducted research? Have they sought expert advice? Or is it just in

their bones? Perhaps you would advise us of the basis for this intriguing assertion". In response, I would like to refer you back to Mr Hamilton's email dated 14 May 2010. Taking on board the CEHOG comments to the PPS 18 public consultation, a minimum separation distance of 500m has been introduced to accommodate the differences in noise emissions between different types of turbine. Generally speaking, 500m is approximately the same distance as10 times rotor diameter to a turbine of 80m in height. On general amenity grounds, the 10 times rotor diameter separation distance has been introduced with particular regard to taller turbines. This increases the separation distance to sensitive receptors beyond what is required by national guidelines set out in ETSU.'

In this regard it is useful to record what ETSU-R-97 actually says on the matter of separation distances:

"The difference in noise emissions between different types of machine, the increase in scale of turbines and wind farms seen today and topographical effects described below all dictate that separation distances of 350-400 metres cannot be relied upon to give adequate protection to neighbours of wind farms", (ETSU-R-97, page 46).

In effect, what the Chief Environmental Health Officers and Anne Lockwood are saying is that, because turbines are now bigger and noisier than those considered under the adopted noise standard of ETSU-R-97 which was written in 1996, then the separation distance should be increased above the 350 to 400 m. which ETSU-R-97 states is not adequate to resolve noise problems. The CEHOG recommended a minimum of 500 m. Although ETSU-R-97 clearly applies also to single turbines, neither the CEHOG nor Ms. Lockwood refer to any lesser distance for these. So 500 m. is the minimum separation for any turbines, either singly, in clusters or farms.

Unfortunately, neither the Chief Environmental Health Officers Group nor the Planning and Natural Resources Division, seem to have been aware that, in a major presentation to the British Wind Energy Association and the Department of Trade and Industry in 2004, Andrew Bullmore, one of the original authors of ETSU-R-97, the noise methodology applied under PPS 18, advised his audience:

"All other things being equal, original 350 m. separation distance on grounds of noise should now be 700 m."

So, in summary, even by the time the minimum separation distance of 500 m. was inserted into PPS 18 to address all adverse impacts, it was already five years out of date as a protection of noise from larger turbines. Further, in adopting a minimum separation distance related to rotor diameter, no scientific corroboration had been obtained that there was a direct relationship between rotor size and noise output.

Separation distances on the Mainland

When NIRIG met with the Environment Committee on 12 September 2013, thus avoiding the necessity of having to substantiate their statements before the public at Omagh, they portrayed the position relating to separation distances in the following two exchanges with members, as recorded in Hansard. Our response is given after each exchange.

Mr Elliott: Apologies for missing part of your presentation. If this point has been addressed, that is fine. One of the issues that came up consistently at the Omagh meeting was the distance from which wind turbines can be built from a dwelling. People referred continually to the Scottish policy and guidance. I cannot remember; was it 3 kilometres or something like that? It was quite a long distance anyway. I am sure that you are very much aware of that policy and guidance. How do you react to the suggestion that Northern Ireland should move to a policy similar to Scotland's?

Ms Whitford: I think that that is under consultation at the moment. I will have to triple-check with my colleagues in Scotland, but, as far as I am aware, it is a consultation and it relates to villages. My understanding is that it is not individual properties; it relates to villages. It is an ongoing consultation. As far as I know, there is not a set policy anywhere for a separation distance, apart from what is detailed in PPS 18 and policy RE 1 for residential amenity, which is 10 rotor diameters, and a minimum of 500 metres.

This statement is contradicted by the following, from 18 April 2009:

The Stop Highland Windfarms Campaign wrote to Jim Mather, Minister for Enterprise, Energy and Tourism, for clarification. In reply, the Directorate for the Built Environment wrote: "The 2km separation distance is intended to recognise that, in relation to local communities, visual impacts are likely to be a prominent feature and this should be taken into account when identifying the most suitable search areas. However, impacts will clearly vary considerably depending on the scale of projects and the proposed location. That is why SPP6 confirms that, in all instances, proposals should not be permitted if they would have a significant long term detrimental impact on the amenity of people living nearby. This principle applies to houses within and outwith 2km of the proposed development and regardless of whether they are single dwellings or part of a settlement."

Similarly, NIRIG do not appear to be aware that The Welsh Affairs Select Committee, after investigating wind farms concluded, "for existing wind farms we are satisfied that there are cases of individuals being subject to near-continuous noise during the operation of the turbines, at levels which do not constitute a

statutory nuisance or exceed planning conditions, but which are clearly disturbing, unpleasant and may have some psychological effects". "We recommend that such limits should be set both in respect of a standard distance from the development and separately for all dwellings within a certain radius (say 1.5 km). It should be the intention of those limits that wind farm noise of mechanical origin is inaudible at any neighbouring dwelling."

Moving on now to the second exchange:

Ms Hitchins: I am aware of local authorities in England that have tried, in the context of their local plans and development frameworks, to introduce stand-off distances of varying amounts, but those have been rejected when the policies have gone for examination. They have been found not to be appropriate.

Mr Elliott: By whom? Was it the courts?

Ms Hitchins: I will have to check. Milton Keynes is the example that I am thinking of. We can certainly get back to you on who exactly rejected it.

In fact, in contrast to this misrepresentation, the real outcome of the Milton Keynes case is neatly summarised below, and has a totally different meaning for the introduction of separation distances :

"The Renewable Energy Foundation (REF) regrets the misreporting of the High Court ruling on the RWE Judicial Review of Milton Keynes Borough Council's attempt to set a minimum separation distance between wind turbines and residential dwellings. Milton Keynes Borough Council is to be congratulated on the judgment reached in the High Court case on their Wind Turbine Supplementary Planning Document (SPD) on Monday 15 April 2013. The judgment confirms that local authorities can set exclusion zones to protect local people from inappropriate development. Press reports and press statements from the wind industry suggesting that the judgment prevents local authorities from doing so are incorrect."

"The judgment in the Milton Keynes case shows that the law in fact supports Local Authorities that wish to set minimum separation distances, although it also shows that these must be designed and worded carefully."

Milton Keynes is not the only English council to adopt significantly larger separation distances. Stratford-on-Avon, Cherwell, in Oxfordshire, Wiltshire and Staffordshire councils are using the planning system to create "separation zones", banning new turbines within up to 2 kilometres

A particularly good example is Lincolnshire County Council, aspects of whose Wind Energy Position Statement of June 2012, is reproduced below:

c) Residential Amenity

Amenity of existing residential occupants must be maintained at an acceptable level, therefore the following criteria shall be applied:-

no wind turbine developments shall be constructed in close proximity of a residential property (the accepted distance for separation is 700 metres) however, noise and amplitude modulation issues can be present up to 2km away. Therefore, unless through assessment, it can be demonstrated that there would be acceptable noise levels within the 2km radius of a residential property, the minimum distance should be 2km:

no wind turbines shall be constructed within a distance of a factor of ten times the diameter of the blades of a residential property to mitigate against flicker, unless intervening topography/structures negates the impact.

wind farm developments must demonstrate that they would have no unacceptable impact due to noise, amplitude modulation, low frequency sound or vibration on residential amenity.

Wiltshire county council has gone further. Its draft "core strategy", awaiting approval by the government's planning inspectorate, has proposed separation zones of 2km for turbines up to 150 metres high and 3km for anything taller. South Cambridgeshire district council has brought in a 2km separation zone while others considering similar moves include Rutland, Staffordshire, and Northumberland county councils. South Kesteven, in Lincolnshire, has proposed a 2km "search area" around any proposed wind-farm site, where prospective developers must prove turbines will not generate disturbance or visual intrusion.

This is enough to demonstrate that the desire for greater separation distances, usually at least 2 kilometres, is not confined to Milton Keynes, and has not been denied by the courts or the government.

What is happening in other jurisdictions?

Table II (see below) shows recommendations for setback distance by a number of authorities, although some of these have increased the recommended minimum distance and more have emerged since then. In general, noise engineers recommend lesser setback distances than physicians. The former rely more on measured and/or calculated sound pressures and the latter on clinical reports. It is logical to prefer the actual reports of the humans subjected to the noise rather than abstract calculations, even if the latter accurately measure ambient noise and allow for the low frequency components of wind turbine noise. Calculations can not measure annoyance and sleep disturbance, only humans can do so.

Sleep disturbance and wind turbine noise November 2010

Table II. Recommendations for setback of residential properties from industrial wind turbines

Note 1: The 2km limit from edges of towns and villages seems to have been set more for visual than noise reasons
Note 2: [illegible] and colleagues (2009) report a review of the recommendation by AFSSET. They concluded that the 1.5km setback was "not relevant" and would compromise wind park development

Authority	Year	Notes	Recommendation	
			Miles	Kilometres
Frey & Hadden	2007	Scientists Turbines >2MW	>1.24	>2
Frey & Hadden	2007	Scientists Turbines <2MW	1.24	2
Harry	2007	UK Physician	1.5	2.4
Pierpont	2008	US Physician	1.5	2.4
Welsh Affairs Select Committee	1994	Recommendation for smaller turbines	0.93	1.5
Scottish Executive	2007	See note 1	1.24	2
Adams	2008	US Lawyer	1.55	2.5
Bowdler	2007	UK Noise engineer	1.24	2
French National Academy of Medicine	2006	French physicians See note 2	0.93	1.5
The Noise Association	2006	UK scientists	1	1.6
Kamperman & James	2008	US Noise engineers	>.62	>1
Kamperman	2008	US Noise engineer	>1.24	>2
Bennett	2008	NZ Scientist	>0.93	>1.5
Acoustic Ecology Institute	2009	US Noise engineers	0.93	1.5
NSW General Purpose Standing Committee	2009	Legislators	1.24	2
Thorne	2010	Aus/NZ acoustician	1.24	2
Horonjeff	2010	US acoustician	1.5-2	2.4-3.2

Are the separation distances in PPS 18 being adhered to?

The situation NIRIG are attempting to portray can be seen in this further comment to the Environment Committee on 12 September:

Ms Whitford: PPS 18 sets out a minimum of 500 metres or 10 rotor diameters. If a project goes forward for approval, it has to put its case for anything that is going to be under that, and then it is for the Planning Service to look at. That is certainly the policy context of PPS 18.

In fact, in contrast to this attempt to portray the existence of a regime of probity, scrutiny and quality assurance on the part of both planners and developers, we find that both the minimum and general separation distances are regularly ignored. Indeed, with respect to single turbines, the 500 metre minimum separation distance to sensitive receptors is being ignored by most Divisional Planning Offices.

Further, following additional training and guidance from headquarters in February 2012, planning staff were advised to adopt a more flexible approach even though there may be unacceptable adverse impacts. These can apparently still be outweighed by the local and wider environmental, economic and social benefits of the proposal, which although not calculated or evidenced, always appear to outvalue proximity to homes. Members of staff were reminded that PPS 18 is a promotive policy. So bad is the current situation, that turbines are being erected at a little over 100 metres from some homes.

There is no post-construction compliance testing, audit or 'policing for any aspect of turbines after erection, no assessment of the relationship between the range and severity of impacts occurring against those predicted by the developers in their original application, and no feedback from situations were problems have been identified. There remains a general subordination of due diligence and overarching duties of care to the achievement of targets for renewable energy AT ANY COST amongst planners, consultees and politicians

<u>What separation distance should be used in future?</u>

The original 10 times the rotor diameter, with a minimum of 500 metres, was a general separation distance on amenity grounds with no scientific basis. Since turbines are now substantially larger, with a range of adverse effects, this is no longer adequate and must be reviewed. Similarly, the use of the ETSU-R-97 methodology for the assessment of noise, has been shown to have numerous weaknesses that do not adequately identify, for example, the impact of amplitude modulation and low frequency noise, which travel further than higher-frequency broadband noise.

We have also seen that the research on which the use of the 10 times the rotor diameter for shadow-flicker is based, does not support the assertion that this will remove the problem. Further, research by Aston and Essex universities has demonstrated that seizure risk of flicker does not decrease significantly until the distance exceeds 100 times the hub height.

The effects of noise on sleep disturbance and symptoms of inner ear problems appear to be related to distance from the turbines. In addition, the night-time noise level remains above the level the World Health Organisation says is required to permit return to sleep. Finally, turbine component failures and accidents are much more common than the industry will allow, and blade throw distances identified by the government's own Health and Safety Laboratory, demonstrated that blade fragments were being thrown distances of up to1,462 meters.

All of these factors call for a significant increase in the minimum separation distance applied in Northern Ireland.

There are two other possible approaches to judging an appropriate setback distance.

The first is to determine a dose-response relationship between turbine noise and a health concern, for example, sleep disturbance. A dose level (turbine noise) that minimises the measured response (sleep disturbance) would be identified.

Examination of data from Swedish and Dutch studies suggests that an external predicted noise level of no more than 35dB(A) LA90 would be appropriate. This view is supported by a presentation by members of RIVM, the widely respected Dutch National Institute for Public Health and Environment, which recommends an outdoor Lden limit of 40dB(A) which corresponds to an external noise level of about 35dB(A). Thorne in 2010, from an analysis of noise complaints concludes that unreasonable noise occurs at noise levels above 30dB(A)LA90 in the presence of excess amplitude modulation. Together with van den Berg he states: "We believe annoyance and loss of amenity will be protected when the wind turbine noise limit would be 30 dBA L95 in conditions of low wind speed at the dwellings and modulation restricted to 3dB".

Overall, as stated by Hayes-McKenzie in their 2006 report before it was emasculated by anonymous civil servants, it is apparent that the present ETSU-R-97 night time noise limits are too high to protect receptors from severe annoyance and sleep disturbance and that a level of 35dB(A) LA90 is appropriate, in the absence of excessive modulation.

The second approach is to correlate reports from those living in proximity to wind turbines to their distance to the turbines. This has the disadvantage that symptoms are generally self-reported and subjective. Nevertheless, it can be argued that it is logical to rely on the actual reports of human receptors in the same way that human opinions are used to judge visual amenity. It has the advantage also that it may better detect those subjects that are most sensitive to turbine noise than surveys. It has the merit also of simplicity. The New South Wales Legislative Council General Purpose Standing Committee No 5, under the Chairmanship of Mr Ian Cohen, a member of the Green Party, has recently published the report of an inquiry into rural wind farms (NSW 2009). Recommendation 7 to the NSW Planning Minister is for a minimum setback of 2 km. In the UK, Mr Peter Luff, MP for Mid-Worcestershire, was given leave to introduce a Bill to Parliament to establish a legal minimum setback distance. This Bill was unfortunately lost with the dissolution of Parliament and election.

Based on the reports cited in the table, and the introduction of a 2 km. minimum separation distance by more and more councils in England, the application of the precautionary principle would indicate a minimum setback of 2.0 km is appropriate.

8. Separation Distances & Long Term destruction of Amenity

Question: Are separation distances in PPS 18 adequate to protect residential and visual amenity?

Answer: No.

Reason: Minimum separation distances are totally inadequate, frequently ignored, often falsified and not policed.

Comment: For a single or group of turbines, The general rule in PPS 18 is that the minimum separation distance is the greater of 500 metres or 10 times the rotor diameter. This is being blatantly ignored by planners, Environmental Health Officers and developers, some turbines being placed just over 100 metres from a home. This compares badly with the situation in Scotland, where 'in all instances, proposals should not be permitted if they would have a significant long term detrimental impact on the amenity of people living nearby', and a general rule of 2000 metres applies.

Accuracy in the measurement of separation distances is fundamental to noise estimation, shadow casting and shadow flicker analysis and visual impact assessment. Yet many developers obscure the definition of the separation distance they are applying and there is no guidance in PPS 18.

The present planning system includes no proper vetting of applications for deliberate falsifications or accidental inaccuracies. In short, an applicant with a vested interest, is trusted, and is only required to state a 'candidate' turbine, not the turbine type and model that will finally be erected. Note also that some single turbine applications are for turbines bigger than in some wind farms.

Due to all the uncertainties involved, it is critical to introduce a mandatory 2 kilometre minimum separation distance from any wind turbine, and a greater distance for turbines over 2 MW, until robust and independently-assessed evidence is produced that a smaller distance will not have impacts on amenity and health.

PPS 18 fails in its stated intent to protect the amenity of those living in and using the countryside. For example, the noise standard used by PPS 18 itself clearly states that it is set above the level necessary to protect amenity, a statement corroborated by the Chief Environmental Health Officers Group. Similarly, no competent authorities are involved in the measurement of the impacts from shadow flicker, reflected light and safety hazards. Both Environmental Health and the Health & Safety Executive deny their responsibilities in such matters and the planners admit to having no expertise in all such areas, including noise.

The cavalier and uncaring attitude within PPS 18 to the amenity of neighbours of wind farms can be encapsulated in just two quotations. These demonstrate a fundamental disregard in Northern Ireland to the effects of visual impact.

Firstly, from PPS 18, section 4.14 (underline added):

'Of all renewable technologies, wind turbines are likely to have the greatest visual and landscape effects. However, in assessing planning applications, the Department recognises that... some of these impacts may be temporary if conditions are attached to planning permissions which require the future decommissioning of turbines.'

Thus the term 'temporary' to the department means the expected life of the wind farm from approval to decommissioning.

Contrast this to the recognition of the human cost of such impact in Scotland where the Directorate for the Built Environment wrote in April 2009 under the direction of Jim Mather, Minister for Enterprise, Energy and Tourism (underline added):

"The 2km separation distance is intended to recognise that, in relation to local communities, visual impacts are likely to be a prominent feature and this should be taken into account when identifying the most suitable search areas. However, impacts will clearly vary considerably depending on the scale of projects and the proposed location. That is why SPP6 confirms that, in all instances, proposals should not be permitted if they would have a significant long term detrimental impact on the amenity of people living nearby."

In Scotland, with many more turbines, the life of a wind farm from birth to death is described as 'long term'. In Northern Ireland, it is described as 'temporary'. In landscape terms such structures are 'temporary', as are all man made structures. In human terms, they are most definitely not.

drk 9 Sept 2013

9. Shadow-flicker and reflected light

Question: Does 10 times rotor diameter prevent shadow flicker at a home?

Answer: No.

Reason: The original research on which this is based does not state this.

Comment: The claim that 'flicker effects have been proven to occur only within ten rotor diameters of a turbine' is one of a number of unsubstantiated statements made in the Best Practice Guide to PPS 18.

In correspondence with DECC, the source from which this statement was derived was confirmed as being from a paper by A.D. Clarke 1991 for Open University. However, this paper does not prove the ten rotor diameter claim. In fact its recommendation is 'that turbines should be sited at least ten diameters distance from habitations, and more if sited to the East/Southeast or West/Southwest, and the shadow path identified' (emphasis added). The research also contains a fundamental and demonstrable error that restricts its application.

This 10 rotor diameter assumption has also been decisively challenged by research from Delft University of Technology in the Netherlands, who, concluded that "there is no rule-of-thumb regarding the distance from a turbine where shadow flicker may be an issue", and by other comprehensive study. This is also confirmed locally, using the restrictive PPS 18 definition, identifying shadow flicker effects at distances of beyond 22 times the rotor diameter, the worst affected property being at 15 times the rotor diameter.

Other claims, such as the policy being based on a survey by PREDAC, an EU sponsored organisation, when examined, reveal a selective approach to the German model recommended by Predac itself. For example, not only does shadow-flicker occur inside a dwelling, German guidance clearly shows its existence outside the dwelling too. The 30 hours per year limit set by PPS 18 for shadow flicker through one window only, applies in the German standard to cumulative indoor and outdoor flicker.

The evidence indicates that the statement that only dwellings within 10 rotor diameters need to be considered likely to suffer shadow flicker is not correct and must be amended.

Finally, it should be highlighted that light nuisance powers held by councils within Northern Ireland under the Clean Neighbourhoods and Environment Act (NI) 2011 only relate to 'artificial light' produced by a luminaire (a light fixture or source) and hence cannot be used to address complaints of shadow or light flicker caused by a wind turbine. As a consequence, issues regarding shadow or light flicker associated

with wind turbines would fall outside council's sphere of expertise. No competent authority therefore exists to scrutinize the often minimalist claims made by developers, in clear breach of EU legislation.

drk 22 Feb 2014

10. Safety Impacts.

Question: PPS 18 states that 'There has been no example of injury to a member of the public.' Is this true? (BPG 1.3.50)

Answer: No. It was not true when it was written and is even more untrue now.

Reason: By 30th June 2008, a minimum of 48 people had been killed and 22 seriously injured as a result of wind farm operations. By 30 June 2013, this had risen to 136 deaths and 121 serious injuries. In the five years to 2011, 1,500 accidents occurred in the UK alone.

Comment: One impact of wind energy that has been generally ignored as almost irrelevant is that of the threat of injury due to a failure in the structure or components of a turbine. This is much more common than is generally known, and bears directly on the issue of separation distances.

Many accidents are not reported and examples of industry cover-ups abound since it is standard policy to obscure the frequency of turbine accidents. The lengths to which the industry will go to divert attention from the dangers of living too close to turbines were well illustrated on 10 February 2009 by Dale Vince of Ecotricity. As the Daily Telegraph noted at the time, he has been assiduous in spreading the story that the turbines which suffered catastrophic blade failure at his Conisholme power station might have been struck by a UFO or some other mysterious external agent:

Blade failure is particularly dangerous for neighbours of wind turbines because detached blades can 'plane' for long distances and fragments are cast using the velocity of the spinning blades to travel significantly further. As an example of the potential damage, a one centimetre slice through a 40 metre long turbine blade weighs 2¼ kg. Or 5 lbs. But how likely is this to occur?

According to the PPS 18 Best Practice Guide, 'Blade failure is therefore most unlikely. Even for blades with separate control surfaces on or comprising the tips of the blade, separation is most unlikely.' (BPG 1.3.51)

However, in one year in Germany, 36% of turbines suffered component failure.

A recent piece of EC - funded research by Loughborough University had the aim of identifying the problems of component failure and offering support to address it. This piece of UK based research estimated that from 8 to 10% of wind turbine blades will fail in some manner, the brakes controlling the speed of the blades will fail in another 7% of turbines, and the structure of 3% of turbines (which obviously support the blades) will fail.

A total of 265 separate incidents of blade failure were found to 30th June 2013, and pieces of blade are documented as travelling up to one mile. In Germany, blade pieces have gone through the roofs and walls of nearby buildings. This is why we believe that there should be a minimum distance of at least 2km between turbines and occupied housing or work places - in order to adequately address public safety and other issues including noise and shadow flicker.

The government's own Health & Safety Laboratory report entitled 'Numerical Modelling of Wind Turbine Blade Throw', demonstrated that blade fragments were being thrown distances of up to1,462 metres. The turbines in use in Northern Ireland are no different from those used in Germany or Denmark or England. Due to the unpredictability of such accidents, their significant scale and the high number of dwellings surrounding many wind turbine site, it is clear that safe separation distances are not being achieved.

Finally, neither the Health & Safety Executive, Environmental Health or any other local agency is prepared to take any responsibility for ensuring that accidents are recorded and that policy is informed by the results of experience.

drk 9 Sept 2013

Terms of Reference 3:

"To review the extent of engagement by wind energy providers with local communities and to ascertain how this engagement may best be promoted."

"To review the extent of engagement by wind energy providers with local communities and to ascertain how this engagement may best be promoted."

Introduction – Distraction by Misdirection

The greatest tool of an illusionist, by means of which he seems to be able to perform the impossible, is through the misdirection of his audience, so that his 'sleight of hand' is not observed. The present preoccupation with community benefits, is a similar attempt at misdirection with the object of distracting attention from two signal failures.

Firstly, the entire community, rural and urban, were promised lower electricity prices from the introduction of wind energy. Secondly, if it is public policy that wind energy installations be 'hosted' by communities irrespective of their wishes, then it is a legal requirement that a compensation mechanism be put in place to address the adverse impacts they will suffer.

In the Programme for Government, the Northern Ireland Executive has committed to:

1. growing a sustainable economy and investing in the future;
2. tackling disadvantage;
3. improving health and well being;
4. protecting our people and building a strong and shared community; and
5. delivering high quality service.

It should be emphasised that Priorities 2, 3 and 4 have relevance here, which, taken together in the context of this review, can be summarized as stating that no citizen of Northern Ireland should be 'disadvantaged' by the imposition of unacceptable levels of adverse impacts.

In the effort to misdirect attention away from the failure to reduce electricity costs and protect those living around wind turbines, it would appear that these commitments have been abandoned.

Who are the 'community' and who decides?

As noted above, the entire community, rural and urban, were promised lower electricity prices from the introduction of wind energy.

The extent of the 'community' is defined by international law and by the application of other limiting factors.

Firstly, the Aarhus Convention and the Environmental Impact Assessment Directive apply to national units. Aarhus requires that an assessment of the alternative types of renewable energy, along with their costs and benefits, be provided before public consultation begins to finalise what will make up the Strategic Energy Framework. This has never been done, with an immediate move to wind energy taking place instead.

Within the national unit of the UK, regional targets have been completely removed. Indeed, as can be seen from the statement by Rt Hon Ed Davey MP, the Secretary of State in the Department of Energy and Climate Change, in the House of Commons on Thursday 8th March, 2012, the targets have already been achieved:

Mr Davey: "I thank my hon. Friend for his question. He and I may disagree about the significance of onshore wind, but I appreciate the measured way in which he has engaged with me and the Prime Minister on this issue. I can tell him that 5 GW of onshore wind power generation has already been built, that there is planning consent for a further 6 GW and that planning permission is being sought for 7 GW-worth of projects, only some of which will be approved. Given that the ambition was for 13 GW, most of the development that the country needs is indeed already on the table."

This gives substantial freedom to the Northern Ireland government in deciding what burden it is necessary to impose on its communities. However, with respect to local applications, the EU requirement (that full and meaningful community consultation is completed and that member state governments carry out independent Environmental Impact Assessments (EIA's) prior to approving major strategic infrastructural projects, has also been ignored.

When considering what constitutes the 'community', a number of other factors aid definition:

At what scale are economic and CO2 benefits calculated? Although developers will often present figures to support their application, the 'benefits' from CO2 savings and additional economic activity are usually set, with some local commentary, at national levels, since there are no measureable targets applied, for example, to each district council area. Indeed, no district council is considered in terms of having an individual gross domestic product. There is thus no adequate cost /benefit analysis below the national level.

Further, it can be argued that the entire population bears the costs of renewable energy through taxation and higher electricity bills. The population of Belfast, for instance, should not be disqualified from the 'benefits' of the renewable energy they have subsidized simply because they do not live in a rural location.

The Irish Wind Energy Association stated in 2009:

"More wind on the system will also result in lower and more stable energy prices for consumers while helping us achieve our energy and emissions targets."

Such unequivocal statements were common from the wind industry, but they are now disingenuously attempting to qualify them. This is due to the cost of a unit of electricity having increased from 9.38 pence per unit in 2003 to 17.18 pence now. This burden is shared by every household in the province, and it is a heavy burden indeed. How heavy can be illustrated by asking a simple question. Has Fuel Poverty in Northern Ireland increased?

"With 42% of households in Northern Ireland spending more than a tenth of their income on energy, compared to 15% in England, we have the highest level of fuel poverty in Western Europe." Pat Austin, Chair of the NIFPC.

More than seven out of ten people have been deprived of basic essentials such as food due to rising energy bills.

Eight out of ten struggle to adequately heat their homes.

The community in Northern Ireland were promised lower electricity prices as the benefit for accepting increasing amounts of wind energy. That commitment has not been fulfilled and to offer to pay a few crumbs to some and not all members of the community is an attempt to distract attention from that failure, whilst ignoring the vast majority who are providing the funding.

Lack of a Compensation Mechanism

The second aspect is the distraction from the moral responsibility to pay compensation to the most affected individuals.

> "If the state considers wind turbines are public policy, then the minority interest should be compensated. If wind turbines are not state policy, then decision makers may be challenged when they use the balance in favour of the state to justify giving an approval that risks a violation of basic human rights." (Justice Buckley in Dennis & Dennis v. MoD, 2003).

This makes clear that, if wind farms are public policy, then the lesser interest, i.e., you and I, must be compensated by the greater interest. Community payments are simply a way of breaking democratic resistance against huge, noisy and unhealthy structures placed too close to homes. They are, in effect, an attempt to substitute token payments in place of compensation based on impacts.

Why do communities resist?

The well-known legal injunction, is that 'In any context the essence of consultation is the communication of a genuine invitation to give advice and a genuine receipt of that advice.' What communities find, however, is, to use a term now current, not 'consultation' but 'insultation'.

Because of the way wind farms are procured, people quite simply see the process as unfair and this perception has been increased over the years by the actions of developers and government. Though there are some exceptions, developers have not involved communities and have been secretive and uncooperative. They may consult but only after the design and siting of their projects has been more or less established. Government has been dismissive of wind farm objectors and has put out and still does put out inaccurate and misleading information. When a minister boasts of approval rates of well over 90%, for wind energy projects, communities might be excused for asking what account will be taken of their interests?

The whole environment in which developers, landowners, planners and consultees interact with communities is characterized by inflated claims of benefits and a reductionist approach or outright denial of any adverse impacts. Numerous instances now exist of complaints against these exaggerated claims being upheld by the Advertising Standards Authority (ASA).

There is an absence of transparency throughout, including that the planners and some of the key consultees lack the expertise and equipment to accurately judge the extent of the impacts residents will be exposed to. Further, there is an apparent disregard by planning departments of the minimum separation distances included in PPS 18 to protect residential amenity.

In the absence of an independent Environmental Impact Assessment to verify claims of costs and benefits, as required by European legislation, the testing of the veracity of the claims by developers and their trade bodies, is left to ordinary members of the public.

It does not build confidence in either the developer or the efficacy of the planning system, to see impacts being underplayed, whilst claims about job creation and the number of houses that proposed wind farms will supply are grossly exaggerated, and no proper breakdown of the methodology used is ever given. For example, NIREG states that there are 1300 people directly employed by the wind industry in Northern Ireland whereas DECC figures state there are 239 jobs - a substantial difference and a figure also believed to be inflated.

There also are a number of significant non-quantifiable adverse effects directly attributable to the operation of wind farms which are generally not brought to the attention of rural communities:

- Property devaluation and resultant loss of rates revenue for local government;
- Fall in rural tourism as has been evidenced in Scotland and Cornwall;

- Acrimonious splits in rural communities and even within families;
- 3.7 jobs lost for every one renewable energy associated job created (Verso Economic Study in Scotland);
- The loss of CO2 retention capacity where wind farms are built on areas of raised bog-land;
- Forest clearance to make way for wind farms;
- Exposure of rural communities to accidents. There have been 1500 reported accidents to 2011 (Renewables UK statistics) some of which were fatal. Insurance industry statistics indicate that every turbine has a major incident every four years. Government held Health & Safety information has reported parts of turbines travelling up to 1600 metres.

None of the above are 'confidence-building measures that will contribute to the establishment of a basis of trust by developers who dismiss all problems caused by their technology.

There is one sure test that will reveal how true the statements on adverse impacts made by a developer or landowner actually are. Ask them to enter into a legally-binding Indemnity to protect the communities against impacts.

<u>Can a community say 'NO'?</u>

The present emphasis on community benefits seems to be part of a larger context in which public participation is being restricted or suppressed. The constant emphasis on economic development is given such precedence that many see an increasing 'democratic deficit' in Northern Ireland. This view is supported in three ways:

- The concept of 'well-being' appears to be defined as economic well-being. This definition is particularly important as it was a primary characteristic of the late failed Planning Bill 2013, which included 'promoting well-being' along with furthering sustainable development, and promoting economic development. It also features in the draft Noise Policy Statement 2014;
- The proposal for a third party right of appeal in planning cases, has been excluded from any revision to planning legislation;

- There is an absence of a Localism Act in Northern Ireland. When introduced in England in November 2011, it had the aim of devolving more decision making powers from central government back into the hands of individuals, communities and councils.

Applications for wind energy routinely exaggerate the economic benefits of the proposal and play down any adverse effects on visual or residential amenity, health, wildlife and habitat.

An ignorance amongst decision-makers, or a desire to achieve targets, has led to a dismissal of any negative effects of some of the renewable energy technologies being fostered. This, in turn, has led to a narrow 'one size fits all' approach to how a community benefit should be defined and assessed.

The starting point in all cases is that rejection of an intrusive, dangerous or economically disadvantageous energy source was not a choice open to a community and, therefore, not to their benefit. Thus, for example, a community which derived much of its economic activity from tourism and which wished to protect the unspoilt nature of its principle asset, would not in these terms be seen as providing a community benefit if it rejected intrusive renewable energy infrastructure. This is a very skewed view of what constitutes community involvement.

As per the Coughlan judgment, consultation must be undertaken at a time when proposals are still at a formative stage. It must include sufficient reasons for particular proposals to allow those consulted to give intelligent consideration and an intelligent response; adequate time must be given for this purpose; and the product of consultation must be conscientiously taken into account when the ultimate decision is taken.

Governments and large renewables companies may argue about global warming and targets but, as research has demonstrated, these are nothing more than distant and rapidly decreasing backgrounds in the context of the local decisions actually being taken on real renewable projects.

Collaborative processes work much better as has been found in waste power siting in some countries. Bad communication causes endless problems but it results from the way most decision -making is framed. There should be complete openness in the process and an avoidance of presupposition and predetermination in decision making. As research has conclusively demonstrated, consultation only after a plan is instituted is more of a trigger for opposition than an incentive for the design of suitable projects.

This is the inheritance that must be understood and addressed if meaningful community engagement is to occur. By ignoring the history of previous community experiences with renewable energy, therefore, the message is sent

that there is an unwillingness to listen to the public at large, no matter how loud they shout. Thus reviews such as this are vulnerable to the charge of being part of an apparatus designed to be used as propaganda to put down opposition.

The supposition that the public will support whatever planners and industry want them to do, leads also to the simplistic belief that knowledge will change attitudes. It does not.

It is an inherent but false assumption, that when asked about the use of wind power in the abstract, the public is usually strongly in favour. Wind as a source of power is free at source (although not in exploitation) and supposedly green so is supported on that basis. But explicit (and local) proposals for wind farms in defined environments now remove it from the abstract and crystallise and focus attention on the reality of what wind power in the form of a farm or single turbine actually means to the landscape and to peoples lives. The cost-benefit analysis is no longer theoretical and distant, but factual, local and personal.

When theory meets reality, the dynamics of community engagement and the nature and perception of what constitutes a benefit to both community and individuals, changes. This review needs to demonstrate that this shift in perspective has been recognised and that communities objecting to renewable energy are no longer treated as somehow aberrant, rather than constituting the norm. While this continues to be the case, successful community engagement cannot occur.

Opposition and conflict – two effects of community payments

The existence of community benefit may in fact have the effect of increasing opposition to local wind farms. This is due to the phenomenon known as 'motivation crowding effect', where external intervention through monetary incentives is used in an attempt to undermine intrinsic motivation (in the case of wind farms to limit objections to proposals). There is compelling empirical evidence from many countries for the existence of crowding out and crowding in, based on circumstantial insight, laboratory studies by both psychologists and economists as well as field research by econometric studies.

Community benefit in the limited financial form offered by developers, fundamentally alters the perceived nature of a siting procedure. While external intervention, i.e. offering some financial recompense, manages to address some concerns regarding the costs of a noxious facility, it reduces the intrinsic motivation to permit the construction of such a facility. In some case studies, this latter effect outweighs even the benefits of external intervention, thereby reducing overall acceptance.

The ultimate objective of the community benefit payments made by the wind industry appears to be to muster support from those living further away from the wind farm hazards whilst at the same time isolating the lesser number living closest and most affected by shadow flicker, infrasound, loss of amenity and property devaluation – those who will suffer the pain whilst others gain. This is nothing less than a strategy of 'divide and conquer', with which many government agencies will be guilty by association.

That the industry is prepared to pay meagre sums to community projects within eight miles of their wind farms, appears to be an admission on their part that there are adverse effects up to that distance. The wider community in a 5 mile or 8 mile radius should not be permitted to benefit unless and until Northern Ireland's minimum separation distances between turbines and dwellings are updated and operated to safe international standards. Otherwise, this so-called 'community benefit' will prove to be merely a source of conflict and discontent. In particular, it will be seen as a lever whereby the wider community suffers no real adverse effects but is incentivised by the 'community benefit' to pressurise the unfortunate few in the centre zone whose amenity and health will suffer from the development.

Duration of community benefits

There are two major constraints that should be considered before the 'Faustian pact' of community benefits based on someone else's loss are entered into.

Firstly, the life expectancy of a wind turbine is not the 25 years of wind industry myth. Instead, as a number of recent studies have demonstrated, the life expectancy is 12 to 15 years, and there will be significant periods of 'down' time due to the need for repairs and replacement parts.

Secondly, as a recent case in Cornwall demonstrated, the agreements made between renewable energy developers and the communities they potentially damage are not legally binding. Legal opinion is that payment in any such agreement is entirely voluntary, and that the council had no lawful basis to refuse planning consent. In other words, Companies can refuse to pay and, if they change hands, their successors are certainly not liable for any commitments made. "Beware renewable developers bearing gifts."

The Sacrifice of the Rural Minorities?

Rural proofing is a process to ensure that all relevant Government policies are examined carefully and objectively to determine whether or not they have a different impact in rural areas from that elsewhere. We consider that the desire to promote community engagement through token payments, is not the way forward. Not only are the chief beneficiaries not those suffering the chief detriments from a proposal, but the amounts involved are tiny in comparison to the loss sustained by many families. A reduction in property value of even 10% cannot be accepted for an annual payment of £200 towards electricity costs.

Community benefits, as presently envisaged, are likely to have a differential impact in rural areas compared with that within any other sector of the community.

For this reason, the resistance to wind energy is growing across Northern Ireland. It is caused by a culture of false promises, lack of due diligence in identifying and preventing the adverse impacts, imposed to the disadvantage of a minority against the commitment made by the Executive.

When compared with the example of the procedures surrounding the redevelopment of housing, designed to protect the residents from the effects of planning blight in the public interest, wind energy is a policy 'on the cheap'. It is, in fact, nothing more than legalised intimidation and theft. In no other area of life in this community, can a developer freely destroy or seriously damage with impunity, the value of the single greatest asset belonging to any family – their home. That the same developer can, by the promise of tiny amounts from his vast profits, arrange for other parts of the same community to marginalise and ostracise these very victims for daring to object, is nothing more than an indirect form of bullying and harassment. The wind industry knows exactly what it is doing when it offers money to individuals so far from the wind energy installation. It has been trying to pin the perjorative term, NIMBY, on all who do not share their corporate vision for many years.

It is appalling that this is done with the complicity of a whole range of public agencies and NGOs, from those who ignore the blighting effect of nearby turbines when assessing Rates, to those who refuse to carry out research on reported health impacts, or simply look the 'other way'. Is it therefore surprising that rural communities feel abandoned by those they expected to protect them, and see themselves to be under siege?

Is there a way forward?

If wind energy is to be seen as public policy, then a robust compensation system must be introduced. But, given the disgraceful record of community engagement by the wind industry and allied government agencies and NGOs, there is presently no basis in trust. Indeed, the priority given to wind energy, and how this is manipulated through the planning process, is illegal under both the Aarhus Convention and the EIA Directive. It is expected that a judicial review will fully reveal this in the near future.

No matter what the technology chosen, there will always be occasions and locations where it is not suitable. Without an honest accounting of benefits and adverse impacts, a working relationship with communities cannot be built.

In addition, it is the role of those responsible for causing unacceptable adverse impacts and more particularly government, to ensure that these are managed properly. That is as important as ensuring that the impact levels themselves are low enough.

One way forward would be adherence, even initially on a voluntary basis, to a separation distance that will provide a significant cushion against impacts. For example, adoption of a 2 km. distance to the nearest receptor would be a major step by developers in starting to build credibility. Similarly, voluntary adherence to the World Health Organisation night-time noise guidance, would be another confidence-building move.

A system built on transparency, honesty, a realistic view of impacts and compensation for those most affected, would be the minimum for any future system. However, given the history, an 'honest broker' would be required, not only between the developers and local communities, but also between the local communities and the Planning Service, who are seen as the mouthpiece for the wind industry's demands.

Rural communities are not selfish, or inflexible. But they have found to their cost that the adverse impacts they were assured would not happen, have occurred and are sometimes impossible to live with. They have also found that the system they relied on for protection and post-construction policing, lacks both principle, integrity and belief in a duty of care. The message they are sending to the Environment Committee as part of its review, is that they do care about others who are yet to be affected. To them, NIMBY stands for, 'next it might be you'!

Addendum on Economic Considerations

Economic models often produce false or misleading outputs because (a) the model itself is faulty, and/or (b) unrealistic assumptions are "fed into" the model, with the result that the models overstate national, regional, and/or local job and other economic benefits.
In the case of wind energy models, basic flaws and faulty assumptions often include one or more of the following:

1. Ignoring the fact that much of the capital cost of "wind farms" is for equipment purchased elsewhere, often imported from other countries. An analysis by Deloitte for IWEA concerning Employment in Wind Energy identified that all investment in relation to turbine manufacture and installation is exported to continental Europe. EWEA analysis found that wind turbine and component manufacturing provides the majority of employment opportunities at circa 59% of direct employment. These elements represent 12.5 of the 15.1 jobs claimed to be created in the EU for every MW installed.

Northern Ireland has largely missed the opportunity to build a significant wind turbine and components manufacturing industry and the vast majority of turbines and components are being imported from the continent. Thus claims that wind turbines are "manufactured" in Northern Ireland when, in fact, they are merely assembled here using imported parts and components, are untrue. About 75% of the capital cost of "wind farms" is for turbines, turbine parts and components, towers and blades – so a large share of the "wind farm" cost is for imports. These add to the outflow of wealth from the UK, add to our balance of payments deficit and provide no economic or job benefits locally.

2. Assuming that employment during project construction results in new jobs for local workers. However, the international turbine companies typically install turbines in Ireland using their own internal teams rather than sub-contracting to local Irish firms.
Installation represents another 1.2 of the purported 15.1 jobs created in the EU for every MW installed. Therefore, it can be said that Ireland has not capitalised on 13.7 of the 15.1 jobs created in the EU for every MW installed.

3. Assuming that the very few permanent "wind farm" jobs are new jobs filled by local workers – when, in fact, these few permanent jobs are often filled by people brought in for short periods. Most "wind farm" construction jobs are short term (6 months or less) and the overwhelming share of them are filled by specialized workers who are brought in temporarily, usually from the Republic of Ireland or from mainland Britain. Some "wind farm" owners contracts with suppliers of wind turbines and other equipment for maintenance work with the result that no "new" jobs for local workers are added.

4. Job creation linked to renewables is subject to more and more doubt. There are now numerous reports which argue that jobs created in this sector are done so at the expense of jobs elsewhere in the economy. For example, a recent report suggests that for every job created in the UK in renewable energy, 3.7 jobs are lost or foregone in the rest of the economy. The key reasons for this are related to the grants and subsidies being paid, feed-in tariffs and the existence of the Renewables Obligation. Not only could this money have been spent on other projects (an opportunity cost), the price of electricity is artificially raised which means increased costs for households and businesses.

Wind energy applications do not analyse displacement of jobs, possible use of cross border workers, give no information on how many long term jobs will be created or how many of the jobs estimated are direct and how many are indirect. Worst of all, there is no retrospective auditing of the claims against fulfilment.

It is, however, worth recalling the oft quoted figure from NIRIG of 1,300 jobs from wind energy in Northern Ireland, a figure the Department of Enterprise, Trade and Investment seems unable to corroborate. This should be compared to the statement by Ed Davey, Secretary of State for Energy and Climate Change, that the 'industry has announced' 239 jobs in Northern Ireland. However, as Mr. Davey also announced 9,143 jobs in Scotland at the same time, and First Minister Alex Salmond was only able to confirm 2,235, the Northern Ireland figure of 239 is equally suspect.

High rates of employment are not characteristic of a highly productive energy sector, indeed quite the reverse.

5. Ignoring the fact that the higher true cost of the electricity from wind is passed along to ordinary electric customers and taxpayers via electric bills and tax bills which means that people who bear the costs have less money to spend on other needs (food, clothing, shelter, education, medical care — or hundreds of other things normally purchased in local shops), thus reducing the jobs associated with that spending and undermining local economies that would benefit from supplying these needs. The artificially raised price of electricity contributes to fuel poverty and the impact on households is another serious economic consideration, particularly in NI where fuel poverty is significantly higher than in the rest of the UK.

6. Assuming that temporary workers who are brought in for short periods live and spend their pay cheques — and pay taxes — locally when, in fact, these workers spend most of their wages where they and their families have permanent residences — where the workers spend most of their weekends and where they pay nearly all of their taxes. This was very evident with the recent Carn Hill wind farm above Belfast. The workers, including the night watchman, came from Co. Donegal, and even brought their food with them from home and cooked in their accommodation. There was virtually no benefit to the local economy.

7. Assuming that the full purchase price of the goods and services purchased locally (often minimal in any case) has a local economic benefit. In fact, only the local value added may have a local economic benefit. This truth is illustrated by the purchase of a litre of petrol, for about £1.35. Only the wages of the service station employees, the dealer's margin, and the taxes paid locally or nationally may have a local or national economic benefit. Economic benefits associated with the share of the £1.35 that pays for the crude oil (much of it imported), refining, wholesaling, and transportation generally flows elsewhere.

8. Assuming that land rental payments to land owners for allowing wind turbines all have local economic benefit. In fact, these payments will have little or no local economic benefit when the payments are to absentee landowners OR if the money is spent or invested elsewhere or is used to pay income tax or VAT that flow to the Inland Revenue.

9. Using "input-output" models that turn out "indirect" job and other economic benefits that, in effect, magnify (a) all of the overestimates identified above, and (b) use unproven formula and data to calculate alleged "multiplier" effects.

10. Ignoring the negative externalities that also need to be considered in the decision making process. Environmental and economic COSTS imposed by "wind farm" development, which include (a) environmental, ecological, and economic costs associated with the production of the equipment, and constructing and operating the "wind farm" (e.g., site and road clearing, (b) wildlife habitat destruction, noise, bird and bat kills and interference with migration and refuges, and (c) scenic impairment. From an economics perspective, these externalities have a value and only when the total cost of the proposal (including these wider costs) are compared against the potential benefits can we make a judgement about the net impact on the economy. This would ideally be done in the form of a cost benefit analysis or economic appraisal.

11. Ignoring the impact on property prices. It is now conclusively confirmed by recent research published by the London School of Economics that wind farms reduce property values for properties either in close proximity or within the range of visibility of turbines. Examination of over one million sales covering a 12-year period of properties close to wind energy installations found that values of homes within 1.2miles were being significantly affected. Independent valuation reports by RICS registered valuation surveyors in Northern Ireland, conclude that even single turbines will impact upon the amenity of nearby property and will reduce their values by some 25%. Owen Patterson MP has also commissioned research into this area.

12. Overstating the true value of payments made to local authorities. Contribution to local Councils through the payment of rates for the wind turbine is

always highlighted as bringing additional funds to the community but no account is taken of the negative benefit when sensitive receptors will demand rate reductions with a possible overall net loss in rates income. Arguably money received in rates as a result of any development may not be considered a benefit if it is used to cover the costs of servicing the site. Irrespective of being generated to local or national government, in net terms it remains unclear how much of the rates will be used to cover direct costs (e.g. road maintenance and other infrastructure costs) and how much, if any, is additional benefit locally or nationally.

13. Ignoring the fact that electricity produced from wind turbines, has less real value than electricity from reliable generating units — because that output is intermittent, volatile and unreliable. Also, the electricity is most likely to be produced at night, not during the day when demand is high and the economic value of electricity is high.

14. Ignoring the "backup power" costs; i.e., the added cost resulting from having to keep reliable generating units immediately available (often running at less than peak efficiency) to keep electric grids in balance when those grids have to accept intermittent, volatile and unreliable output from "wind farms."

15. Maintenance costs during non generation result in the wind farm taking electricity from the grid. Research confirms that wind turbines do in fact use electricity from the grid to turn the blades during periods of low wind and this is something that may need to be investigated further as it would have an impact on the perceived efficiency of the turbine and the running costs. As it stands, the Economic Statements in wind energy applications do not recognise that electricity from the grid is needed.

16. Ignoring the fact that electricity from "wind farms" in remote areas generally results in high unit costs of transmission due to (a) the need to add transmission capacity, (b) the environmental, scenic and property value costs associated with transmission lines, (c) the electric transmission "line losses" (i.e., electricity produced by generating units but lost during transmission and never reaches customers or serves a useful purpose), and (d) inefficient use of transmission capacity because "wind farms" output is intermittent and unpredictable and seldom at the capacity of the transmission line that must be built to serve the "wind farm".

For example, £44 million is being provided to upgrade the grid to accept another 800MW of wind energy. This is £55,000 per MW= £14,000 just for grid upgrade for a single 250 kW turbine.

17. The CO_2 emission savings have often been calculated using the old style fossil generation power stations as opposed to the new generation of gas power stations, resulting in an over estimate of the economic benefits. Changes in the

energy mix have reduced the claimable CO_2 savings of wind farms by over two-thirds in the past 20 years. However, even these figures are exaggerated as they make no allowance for CO_2 expended in manufacture and installation, the mining of iron ore and limestone for steel and cement manufacture, the liberation of CO_2 from peat which is damaged during construction, and the need to provide back-up of up to 90% of the installed wind capacity.

The Economic Statement usually does not disclose what the expected CO_2 savings are or how they have been calculated.

In conclusion, most economic statements in wind energy applications are fairly basic and do not provide enough information or evidence to aid in decision making. They cannot be used to give an accurate and impartial indication of the total net economic benefit or otherwise. In order to make an informed decision, a full cost benefit analysis over the realistic capital life of the turbines would need to be completed and this would need to take into account all of the elements listed above to give a robust estimate on value for money. It need hardly be stated that this would need to be independent of the developer's estimates.

The viability of a proposal, in other words whether or not there would be sufficient revenue in the longer term to enable the proposal to survive commercially, is unknown since the economic statements do not usually examine this issue. The proposal would only have a positive economic impact if it continued to operate successfully, but this would be greatly affected if turbine life expectancy was not the 25 years usually claimed, but the 12 to 15 years revealed by recent research.

Perhaps most important, ignoring the fact that the investment pounds going to "renewable" energy sources would otherwise be available for investment for other purposes that would produce greater economic benefits. Indeed, on investigation we find that modern wind turbines are still extremely capital intensive, with low load factors, very high system integration costs and relatively low operating costs compared to generating units using traditional energy sources. They also create far fewer jobs, particularly long-term jobs, and far fewer local economic benefits. "Wind farms" are simply a poor choice if the goals are to create jobs, add local economic benefits, or hold down electric bills.

drk 26 Feb 2014

Addendum on CO_2 reductions

If we consider the alleged environmental benefit of the Northern Irish renewable energy programme, then this should be; (a) related to specific verifiable reductions in greenhouse gas emissions and; (b) that these reductions should be associated with a defined environmental benefit. The combination of (a) and (b) actually amounting to something tangible is therefore of great importance. Yet when it comes to seeking data on what verified emissions have actually occurred and which can be expected to occur, no verification of emission savings with the wind energy installed to date appears to have been completed, and no estimation of greenhouse gas savings has been concluded.

Displacement of fossil fuels

It is claimed that 1 MWh input of electricity from wind energy directly displaces the emissions from 1 MWh of conventional generation using fossil fuels. In reality the power stations now have to operate in variable, stop start mode to balance the fluctuating wind energy input, such as like a car in city driving as opposed to on a motorway. As a result the fuel consumption of the power stations increases over the condition where they would otherwise be on steady load and not having to balance variable wind energy input.

Eirgrid in their 2004, engineering report on the impact of wind energy and its intermittency on the economics of operation of conventional plant concluded that:

"The adverse effect of wind on thermal plant increases as the wind energy penetration rises. Plant operates less efficiently and with increasing volatility". This Eirgrid report highlighted not only the practical limitations, but also the very high cost associated with wind energy given other far more cost effective alternatives available for carbon abatement. In fact this report predicted greenhouse savings from 1,500 MW of wind equivalent to 1 .42 million tonnes per annum, which equals 0.95 million tonnes per 1,000 MW.

Ireland is an isolated island with a limited amount of hydro-electricity available for balancing wind generation. It is therefore possible to analyse the performance of the thermal plants on its grid as the wind energy input varies, a position which is facilitated by Eirgrid, who not only publish wind energy input to the grid in 15 minute intervals, but also modelled emissions from the thermal power plants based on their theoretical loads. While this is not as precise as actual measured fuel consumption of the power plants, it is providing useful data for the interested public to analyse. This analysis of Eirgrid's data shows that emissions on the grid actually start to rise when the wind energy input exceeds 1,200 MW.

Indeed Dr Joe Wheatley, Biospherica Risk Ltd, completed an analysis of the CO_2 performance of the Irish grid based on the modelled emissions available from Eirgrid, in order to better analyse the inefficiencies on the grid with increasing amounts of wind input. This was presented in March 2013 at a Seminar organised by the Economic and Social Research Institute (ESRI). Of relevance is that emissions savings from wind power are significantly lower than expected, 0.28 tonne CO_2/MWh, relative to an implied average carbon intensity in the absence of wind of 0.53 tonne CO_2/MWh, and the savings are decreasing as more wind power is added to the grid. In other words, actual savings are only about a third of what the wind industry frequently claims in its applications, usually 0.86 tonne CO_2/MWh.

Disturbing peat releases CO_2

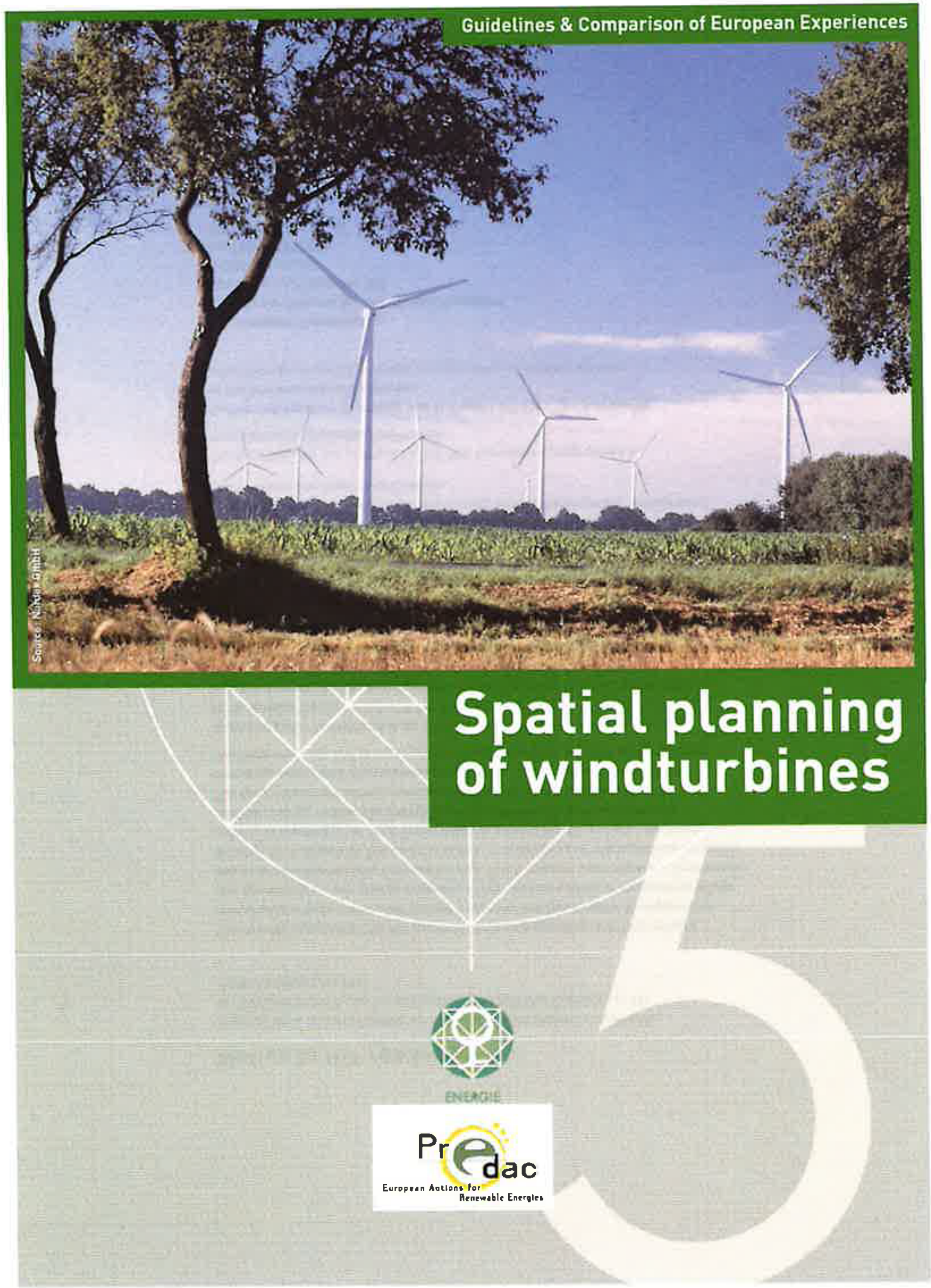
The world's peatlands have four times the amount of carbon than all the world's rainforests, but they are a Cinderella habitat, completely invisible to decision-makers. Wind farms are typically built on upland sites, where peat soil is common. But peat is also a massive store of carbon, since they both contain and absorb carbon in the same way as trees and plants — but in much higher quantities.

Wind farms, and the miles of new roads and tracks needed to service them, damage or destroy the peat and cause significant loss of carbon to the atmosphere.

Scientists from Aberdeen University, contend that wind farms on peatlands will not reduce emissions and suggest that the construction of wind farms on non-degraded peats should always be avoided.

Peat only retains its carbon if it is moist, but the roads and tracks block the passage of the water. The wind industry insists that it increasingly builds "floating roads," where rock is piled on a textile surface without disturbing the peat underneath. But peat has less solids in it than milk. The roads inevitably sink, that then causes huge areas of peatland to dry out and the carbon is released. More than half of all British onshore wind development, current and planned, is on peat soils.

ANNEX 2



This Energie publication is one of a series highlighting the potential for innovative non-nuclear energy technologies to become widely applied and contribute superior services to the citizen. European Commission strategies aim at influencing the scientific and engineering communities, policy-makers and key market players to create, encourage, acquire and apply cleaner, more efficient and more sustainable energy solutions for their own benefit and that of our wider society.
Funded under the European Union's fifth framework programme for research, technological development and demonstration (RTD), Energie's range of support covers research, development, demonstration, dissemination, replication and market uptake - the full process of converting new ideas into practical solutions to real needs.
Its publications, in print and electronic form, disseminate the results of actions carried out under this and previous framework programmes, including former JOULE-Thermie actions. Jointly managed by the European Commission's Directorates-General for Energy and Transport and for Research, Energie has a total budget of 1042 million€ over the period 1998-2002.
Delivery is organised principally around two key actions, "Cleaner energy systems, including renewable energies" and "Economic and efficient energy for a competitive Europe", within the theme "Energy, environment and sustainable development", supplemented by coordination and cooperative activities of a sectoral and cross-sectoral nature. With targets guided by the Kyoto Protocol and associated policies, Energie's integrated activities are focused on new solutions which yield direct economic and environmental benefits to the energy user, and strengthen European competitive advantage by helping to achieve a position of leadership in the energy technologies of tomorrow. The resulting balanced improvements in energy, environmental and economic performance will help to ensure a sustainable future for Europe's citizens.

ENERGIE

with the support of the European Commission
Directorate-General for Energy and Transport

Printed in France

Produced by

Comité de Liaison
Energies Renouvelables
2B, rue Jules Ferry
(33-1) 55868000
(33-1) 55868001
predac@cler.org

Notice to the reader

A great deal of information on the European Union is available on the Internet. It can be accessed through the Europa server (http://europa.eu.int).

The overall objective of the European Union's energy policy is to help ensure sustainable energy system for Europe's citizens and businesses, by supporting and promoting secure energy supplies of high service quality at competitive prices and in an environmentally compatible way. The European Commission's Directorate-General for Energy and Transport initiates, coordinates and manages energy policy actions at transnational level in the fields of solid fuels, oil and gas, electricity, nuclear energy, renewable energy sources and the efficient use of energy. The most important actions concern maintaining and enhancing security of energy supply and international cooperation, strengthening the integrity of energy markets and promoting sustainable development in the energy field.

A central policy instrument is its support and promotion of energy research, technological development and demonstration, principally through the Energie sub-programme (jointly managed with the Directorate-General for Research) within the theme "Energy, environment and sustainable development" under the European Union's fifth framework programme for RTD. This contributes to sustainable development by focusing on key activities crucial for social well-being and economic competitiveness in Europe.

Other programmes managed by the Directorate-General for Energy and Transport, such as SAVE, Altener and Synergy, focus on accelerating the market uptake of cleaner and more efficient energy systems through legal, administrative, promotional and structural change measures on a trans-regional basis. As part of the wider energy framework programme, they logically complement and reinforce the impacts of Energie.

The Internet web site address for the fifth framework programme is: http://www.cordis.lu/fp5/home.html

Further information on Energy and Transport DG activities is available at the Internet web site address: http://europa.eu.int/comm/dgs/energy_transport/index_en.html

The European Commission
Directorate-General for Energy and Transport
Rue de la Loi/Wetstraat 200
B-1049 Brussels
Fax (32-2) 2956118
TREN-info@cec.eu.int

Guidelines & Comparison of European Experiences

Spatial planning of windturbines

PREDAC Coordinator
Emmanuel Poussard (CLER, France)

WP8 consortium
Project coordinators
Yann Rochard (Avel Pen Ar Bed, France)
Bertrand Poyet (Avel Pen Ar Bed, France)

Annabelle Jacquet (APERe, Wallonia – Belgium)
Luc De Wwilde (3E nv, Belgium)
Gunnar Boye Olesen (OVE, Denmark)
Bernard van Hemert (ECOFYS, The Netherlands)

graphism Atelier des grands pêchers

Introduction

Wind energy is one of the most promising renewable energy sources (RES). As a consequence, ambitious targets are defined for it at European level.
It is also the most noticeable one. So, if wind energy could be a good advertisement about green electricity for public opinion, it also causes strong resistance among citizens. Indeed, if wind production is part of a sustainable development, implementation of turbines on any territory is not neutral on its environment, in particular from a landscape point of view.
So the first statement is that wind energy is subject to spatial planning procedures. More, we consider spatial planning, or land-use planning as crucial for the successful integration of windpower in populated areas. Successful spatial planning is part of the accomplishment of windpower in Germany and Denmark. Problems with spatial planning have delayed the developing of windpower in a number of countries including Denmark, The Netherlands, Belgium and France (see the matrix in annex).

Lack of involvement of neighbours in spatial planning can create opposition against it. A more frequent issue is that opposition against wind turbines must be handled correctly in the spatial planning processes.

As a consequence, the general objectives of a wind energy spatial planning are:

- to take the maximum advantage of the wind energy potential, planning it in a coherent way for its correct development from territorial, energetic, environmental and socio-economic point of view.
- to both rationalise and accelerate the development of wind energy throughout the EU streamlining the current processes of project selection by developers and project judgement by planners.
- to optimize and at facilitate the territorial integration of the projects, beyond the only energy concerns and by holding account of local specificities.

More information on www.cler.org/predac.

This paper proposes guidelines for spatial planning for windpower, based on experience with spatial planning in Belgium, Denmark, France and The Netherlands. In addition experiences from Germany and Ireland has been used. In this guidelines, we tried to quote all decisive criteria for successful implementation of wind energy. For the different aspects of spatial planning recommendations for a European framework for spatial planning are made. In addition, a summary of the situation for Belgium, Denmark, France, and The Netherlands are given for each of the aspect. To complete the descriptions, detailed reports are available for these countries, as well as a summary report for Ireland, on the PREDAC website (www.cler.org/predac).

The guidelines are meant for larger wind turbines and groups of larger wind turbines; mainly land-based. For smaller wind turbines, e.g. household wind turbines, a simpler planning regime is recommended. Thus, these guidelines should not be applied to turbines of 25 m total height or less.

This publication is part of the PREDAC project with support from EU Commission, 5th RTD Framework Programme, 2002-2004. The recommendations in this paper are from the expert group working on Work Package 8 of PREDAC.

This publication is downloadable for free on PREDAC website: www.cler.org/predac

PART 1
DIFFERENT ASPECTS OF SPATIAL PLANNING FOR WINDPOWER

Spatial planning regulates human activities to minimise adverse effects on other human activities, as well as on nature. Windturbines, like any infrastructure projects, have considerable impact in their immediate neighbourhood. They are visible, throw shadows, and give noise. On the other hand, they take up very little ground and can co-exist with other activities such as most types of farming.

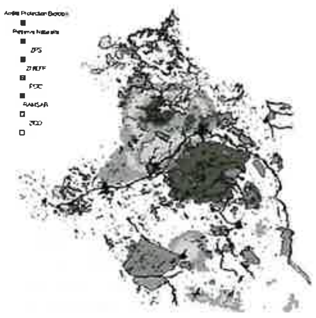
In this paper the aspects of spatial planning considered are:

Planning framework:
- Integration of windpower in regional and local planning
- Environmental impact assessment (EIA) requirements
- Other authorities involved
- Permits needed
- Involvement of stakeholders
- Period to obtain all permits
- Costs required for studies and permits
- Relations with grid connection

Environmental and spatial criteria and recommendations:
- Noise
- Shadow flicker
- Distance from housing
- Distance from roads, railways and waterways
- Distance from high voltage lines
- Aviation servitude
- Distance from radio communication
- Distance from radar and navigation beacons
- Piping and tubes
- Defence constraints
- Ground occupation (access roads, sheds)
- Landscape
- Harmonisation of turbines in parks
- Distance to historical sites and buildings
- Distance to natural reserves and other protected areas (incl. EU wildlife protection areas)
- Distance to water bodies
- Distance to forests
- Distance to silent areas
- Fauna
- Distance between turbines and parks
- Lighting and marking of turbines

PART 2
PLANNING FRAMEWORK

Integration of windpower in regional and local planning



Source: Avel Pen Ar Bed

Recommendations

- **The participation of both regional and municipal authorities in the planning process is important. Planning should not be limited to municipal level that cannot maintain sufficient expertise (too few projects), nor to the regional scale that does not have the same direct contact with locally involved citizen's as municipalities usually have**
- **It is recommended that national and regional wind power planning be linked via regional indicative minimum targets that add up to national targets. Such targets MUST be minimum targets; otherwise they can be counterproductive in regions with success in windpower development.**
- **It is recommended that people living in areas with potential for windpower be encouraged to get involved in the regional and local planning process, in particular if a detailed site-planning is made (e.g. with designation of sites as part of the planning).**
- **It is recommended that the planning authority give as clear criteria as possible to limit risks for developers of preparing project that cannot be granted a building permit.**

- While some countries have had success with a detailed planning for windturbines, leading to designating windpower areas or even designated sites, such detailed planning is not necessarily the best solutions in all cases. The benefits of the detailed planning are clear: it gives certainty for developers, it makes windpower projects simpler once the planning is in place, and it separate the planning process from the rush of project development.
  The problems are:
  - that it delays general development with 1-2 years,
  - that it is costly, in particular if wind conditions are not evaluated in advance (high costs are particular a problem in areas where the opportunities for windpower is small as the potential benefit of the development is limited), and
  - that it can contribute to land speculation.

National experience

Belgium

The regions –Flanders and Wallonie– have major responsibilities on spatial planning, also for windturbines. In Wallonie are set criteria for windpower and a regional facilitator is established, while for Flanders a wind plan has been developed as a basis for the development of wind energy. Based on this windplan designated areas are now created in order to implement wind energy.. Municipalities can assist the regional approach through programming and planning at a municipal level and implement a programme for a municipal structure (in Flanders they can take actions for smaller project).

Denmark

The most important planning for windpower is in the regional plans that include designated sites for windturbines. Some counties have used indicative wind capacity targets that were derived from national targets. These county-targets seem to have been supporting the development, but they have also been used as a reason to limit the development once the target was achieved.
Municipal plans for windpower follow regional plans in almost all cases but can be more specific. Local plans are made for specific projects.
The clear definition of sites in regional and municipal planning made a fast development possible in the late 90's as they made windpower investments easier. This approach did create some local opposition, mostly because of lack of local involvement in planning and in projects.

France

Windturbines can be included in spatial plans of municipalities or groups of municipalities that have made their own spatial plans (PLUs), but it is generally considered that wind exploitation is suitable with agricultural zones in PLUs if no specific or opposed prescriptions are mentioned in the attached rules. Wind energy is not included in general in the spatial plans of French Regions or Departments, but they can have activities to promote windpower and they are also involved in the part of the permission-procedure. In certain cases (e.g. Finistere Department in Brittany), Departments have made recommendations for windpower that is close to overall spatial planning (The Finistere Wind energy Charter).The lack of integration of windpower in municipal and regional spatial planning makes increases the uncertainty for developers about identification of possible sites.

A new law of the 3 January 2003 (n° 2003-8) about gas and electricity markets and the public utility of energy introduces the idea of a regional plan to enhance the development of wind energy.
This kind of plans are intended to precise geographically the areas adapted to the establishment of wind parks.

The Netherlands

Regional plans indicate globally the land use and can create possibilities for windpower. The provincial authorities make wind strategy plans, indicating how they want to reach a windpower target. Municipal zoning plans lay down land use. The plans can create possibilities for windpower, and they can also prohibit or limit windpower in certain areas.

Examples of integration of wind power in regional & local planning

France: The Finistery charter

In France, the legal process for wind turbines building agreement gives entire ability to the Prefect of each department (representative of the State). In Finistery, the Prefect asked for the elaboration of a charter to «organise» wind energy development, to prevent the territory from too strong impacts due to an anarchic development of wind farms. This charter is expected to be progressively replaced by local specific rules included in the SCOT (planning coherency schemes at an intercommunal level) and the communal urbanism documents. Meanwhile, charter vocation is to avoid «prejudicial nuisances for territory and population», especially on a landscape consideration.
So the document is composed of general instructions about the team project, the choice of the location regarding to landscape and environmental considerations etc. About ecological and landscape considerations, maps of major interest's sites and of emblematic landscape zones have been elaborated. All these areas have been indexed with an analysis of their capacity to receive wind turbines.

In the areas identified as «emblematic landscapes», the principle is «to preserve imperatively their emblematic characteristic, what is possible either preserving these areas from any significant mutation, or accepting only projects which quality allows a successful integration». The objective is to avoid any significant mutation of the emblematic areas or areas which particular characteristic could justified :
- unbroken landscapes
- landscapes of particular local interest

In the other areas, «principle is not to refuse wind turbines, but to avoid the effects of multiple implementations».

This document has a connotation rather dissuasive about wind energy development, which does not appear in conformity with the indications of the EU directive of September 2001 and the national law of January 2003.

The File is downloadable on PREDAC website: www.cler.org/predac

Example

France : The wind energy development spatial planning of the community of communes of Châteaulin and Porzay : landscape matter and harmonisation of wind projects

Whereas the department of Finistery has published a charter of the wind mills to have a framework about the development of the projects, the community of communes of Châteaulin and Porzay decided to launch the realisation of a wind development spatial planning. The community of communes wishes to validate a wind scheme among the scenarios suggested, in order to optimise landscape, environmental and social integration of the projects.
The analysis of the territory under a Geographical Information System (GIS) made it possible to gradually reduce the area of the study and show the potential sites by applying the following criteria :

- exclusion of the protected areas (registered sites and monuments, Natura 2000...),
- exclusion of zones of constraints of public utility,
- application of a buffer distance to the buildings and roads networks

Some areas were also described as areas of constraints. Their statute is not incompatible with wind energy, but have a particular sensitivity (ZNIEFF, ZICO ...). The taking into account of the uses of the territory (coasting flight...), of the town planning documents, of the wind resource and the surface of the potential sites made it possible to carry out the cartography of the whole suitable sites.
In parallel, a landscape analysis was carried out. 3 landscape units emerge on the territory (Aulne's valley, mountainous masses and the basin of Porzay). Independently of the research for potential sites, this analysis makes it possible to imagine a theoretical scenario of establishment.
The correlation of the 2 approaches (highlighted of the potential sites and landscape analysis), carried out in an independent way, made it possible to propose 3 scenario of wind development at the steering committee.

These 3 scenario are now used as support together with the debate and the dialogue within the framework of this innovating step of spatial planning.

Communauté de Communes de Châteaulin et du Porzay
30 Quai Charles de Gaulle,
29 150 Châteaulin, France
tel : (+33) (0)2 98 16 14 00
email : ccpcp@wanadoo.fr

Energies et Territoires Développement
Pôle d'innovation de Mescoat,
29 800 Landerneau, France
tel : (+33) (0)2 98 30 36 82

scénario 1

scénario 2

scénario 3

SOURCE : ETD

Environmental impact assessment (EIA) requirements

Recommendations

EIA's are made according to a EU directive (Council Directive 85/327), and the structures of the EIA's are generally similar across the countries analysed. [windpower related issues of directive included here: 20MW/10 turbines]. The EIA can be a tool to increase the confidence in the quality of a project and so can be a factor of social acceptance.
An EIA should only be a requirement for larger projects, as experience show that smaller projects can be planned well without an EIA, and because of the costs involved in developing an EIA. A developer should be able to choose to make a voluntary EIA to increase confidence in a project.
To maximise the confidence in EIAs, they should be made or verified by an entity that is independent from project interests.

SOURCE : NORDESE GMBH

National experience

Belgium

In Flanders region an EIA is only necessary for wind farms with a rated power >20MW or >10 turbines. In some case an IEA may be rquired in sensitive area's.
For all ather projects an short notice describing the project and the environmental effects is necessary.

In Walloon region an environmental impact assessment (EIA) is compulsory for all projects whose power generation is greater than or equal to 3 MW. Under 3 MW, the project developer has to fulfil and add to his demand of permit an evaluation notice on environmental impacts. The EIA shall begin with a consultation meeting with the local population. Questions and Opinions raised at this meeting have to be examined in the impact assessment in addition to the minimal content fixed by the law. This content covers the evaluation of social, economical and environmental impacts, with a particular attention to the landscape integration. The undertaking of the impact assessment also requires a public enquiry to be undertaken. The impact assessment completes the impact assessment phase. The project developer pays the complete process. The EIA report must be added to the form of request of the permit, so this have to be done before to ask the permit.
EIA costs between 15000 and 25000 € for middle size projects (under 10 turbines).

Denmark

An EIA is required for sites with more than 3 turbines or total height above 80m (approx. 1 MW turbines). The EIA starts with a public «idea phase» where the public and stakeholders are invited for comments to the project idea. This phase usually include a public meeting. The EIA report is made with inputs from this phase. In a following public phase are invited comments to the report and usually a public meeting is held. The EIA is organised by the county, but the project developers are often requested to finance the studies.
Costs of EIA depend on project, in a recent example the costs were 40,000 €. The county makes the EIA, but it usually requires that the project developer pay for all EIA studies.

France

The EIA is the major part of the Building Permit.
Before the EIA, preconditions about numerous constraints have to be fulfilled (civil and military servitude's, environmental constraints...). The new law of January 2003 about gas and electricity markets and the public utility of energy introduces that wind projects above 2,5 MW are subordinated to the preliminary carrying out of an EIA and also requires Public Inquiry.
Another new law of the 2 July 2003 relative to town planning and habitat (n°2003-590) maintain this obligation that projects above 2,5 MW requires a public enquiry and an EIA. For projects below 2,5 MW, only the realisation of an «Impact Evaluation Note», (simplified EIA) is needed.

The landscape impact analysis is the most important part of the EIA. It generally requires:

- Map of Visual Influence Zone (means from where turbines are visible) and of eventual co-visibility with existing or planed projects.
- Analysis of the views from roads, pedestrian paths, from highest points that are frequented and from houses of neighbourhoods.
- Illustrated analysis (photos, maps, sketches...) of landscape's components of the site and its surroundings.
- Explanation of the developments choice (research of visual harmony, limitation of access..) from the point of the concerned landscape.
- Explanation of treatments of the direct surroundings of the site: technical room, compensatory measures on reshaped areas (access path, connection cables...)

EIAs are required for project with an output of 2,5 MW and are paid by developers.

The Netherlands

An EIA is only required when the initiative exceeds 15 MW or is larger than 10 turbines and if there are circumstances, which can lead to negative environmental impact. The EIA starts with public comments to the directives of the EIA. After this phase the directives are set by the competent authority –usually the province- and the project promoter makes the EIA. When the project promoter has finished the EIA, the competent authority assesses if it conforms to the directives. When this is the case, it sent for public hearing together with the draft decision [or verdict] about approval/not approval of the project.
EIA costs 50,000-200,000 € and is paid by developer.

SOURCE: NEG MICON

Other authorities involved

(power utilities are not included in as an «authority» in this paper)

Recommendations

It is recommended that all authorities and power utilities are involved via the regular planning and permitting authorities: the region/county and the municipality. Authorities should be involved as early as possible.
It is specifically recommended that:

- **Ministry of Defence is involved only within a pre-defined distance from military installations, e.g. 12 km, and in zones of special military interest such as low-flying zones. This is a restriction of consultation of military compared with some countries, but seems to work well in Denmark. The Ministry of Defence must answer without delay whether proposed projects are in above-mentioned zones of military interests.**
- **Civil aviation authorities are consulted only in projects nearby airports, e.g. within 5 km from airports, and in projects where turbines are above 100 m in total height.**
- **In projects near national borders, including off-shore projects bordering international seas, the authorities of neighbouring countries must be involved following the Espoo Convention.**

National experience

Belgium

In addition to the municipalities and regional authority, a developer should in both regions as part of project development:

- Request for an unofficial opinion from the eronautical authorities and National Defence;
- Request for an unofficial opinion from the Institute Belge des Postes et Telecommunications concerning radio waves.

In Wallonie those authorities are also officially consulted in the process of instruction of the permit as well as the following authorities:

- The Municipal or Regional Commission of Spatial Planning
- The Walloon's Commission of Sustainable Development
- The concerned administrations (environment, spatial planning and energy)
- The «wind energy cell»
- The Regional Commission of Monuments and Sites if the project is close to a classed site of monument
- The competent authority if the project is close to a natural reserve or Natura 2000 site
- The Park's Commission if the project is in a natural park perimeter

In Flanders a wind plan has been made and this has been followed by development of spatial zoning planning maps (so called RUPs) that are designated area's for larger projects.
The IWW (Interdepartmental Workgroup Wind energy) was formed as part of this planning procedure to come to a consensus on planning issues. The IWW has to give his advice on all projects.

In Wallonie a developer should as part of project development:

- Request for an unofficial opinion from the aeronautical authorities and National Defence
- Request for an unofficial opinion from the Institute Belge des Postes et Telecommunications concerning radio waves

Denmark

The region will involve other relevant authorities, such as:

- Ministry of defence if there is a military installation nearby (e.g. within 12 km). In addition the defence has to be involved in turbines installed in special military low-flying zones.
- Airport authorities if there is an airport nearby (e.g. within 5 km)
- For turbines > 100 m, aviation authorities.

Other authorities can be involved if they have jurisdiction of neighbouring natural, economic or cultural values. They can have authorities because they are landowners or because they are in charge of protection of special natural or cultural values.

France

Depending on the project a large number of authorities are involved in addition to the municipalities/groups of municipalities:

- The Prefect (the states representative in a district), must approve the building permit adopted by the municipality/group of municipalities
- The Departments Architecture & Patrimony Offices, advice about nature and landscapes
- Civil and Military Aviation offices oversees that the project is conforming with aeronautical rules and limitations
- The Departments «Sites Committee» (SDC). Gives advice to the Prefect, upon his request
- The ministry in charge of energy gives an exploitation declaration (projects below 4.5 MW) or an exploitation agreement.
- The power company (EdF) accepts a grid connection agreement

Other authorities can be involved in special cases: Ministry of Environment becomes involved if the project is in a nature protection are, The Architect of Ancient Monuments (AAM) becomes involved if the project is less than 500 m from protected monuments

The Netherlands

When placing windturbines on infrastructure, which is under maintenance of the District Water Board and/or the Department of Public Works, an additional authorisation is required.

The Ministry of Defence has to give authorisation if windturbines are placed in low-fly zones or bordering military areas.

Permits

Recommendations

It is recommended that the regular planning regime only require one permit that should be issued once the planning and permitting procedures are concluded.

It is recommended that time to obtain all permits should not exceed 6 months. Authorities that are consulted as part of the project should respect deadlines for responses. Lack of reply should be treated as no objections from the given authority.

National experience

Belgium

Flanders:

A building permits is necessary according to the law and a exploitation permits is required. A building permits is delivered by the commune and the exploitation permit is granted by the commune, province or regional authorities depending on the size of the project and the type of project developer (public or private). The procedure takes normally between 6 months and one year.

If the location is situated in an agricultural zone a so called RUP (designated area) has to be made before the project developer can apply for a permit. The procedure for the RUP takes one year and incorporates a period of public enquiery.

Wallonie:

A unique permit is necessary. It includes both environment and building permit. This Permit is given by the municipality in first authority and by the regional minister in second authority. For the application form to be complete, the project developer has to add the results of the EIA (project of 3 MW or above) and of the public enquiry or the impact evaluation's note (project under 3 MW). A declaration must be made to the federal Secretary of Energy when the project is realised. Concerning the grid connection, the acceptation of the grid manager is needed and a contract must be conclude with this authority to carry out the connection and to be authorised to inject the produced electricity.

Eventually, for projects from and above 3 MW, the complete permit process will take 4 to 6 month after the realisation of the public consultations and of the EIA, so that is around 9 month altogether. For project less than 3 MW, the total process to obtain the permit takes 2-3 months. The time to carry out the connection depends on the planning of activities of the utilities. Usually, it takes 3 to 15 months.

Denmark

The regional wind energy plan must include the windturbine site. This plan is approved by the country council and requires in certain cases an EIA (see above).

There must be a local plan for the site. The local plan is approved by the municipal council and must conform to the regional plan.

The building permission can be issued administratively by the municipality once the local plan is approved.

Projects that require EIA and amendment of regional plan can be developed in one year, if work on EIA is fast and no problems occur, but often the entire procedure will take 1.5-2 years.

For projects that are already in designated areas, the remaining planning process can be made in 3-6 months, if no problems occur.

France

New law of January 2003 precises that the establishment of an installation producing electricity from the mechanical energy of the wind, at height higher or equal to 12 metres, requires a building permit from the Prefect.

The obtaining of the building permit occurs after the consultation of the "Commission des Sites" (regrouping the representatives of each ministries at the local level and of local associations or interests).

Other Permissions required are:

- Agreement with aeronautical rules (Civil and military)
- Agreement from Radio-electricity & Telecom services
- Agreement from Forest & Agriculture department
- Agreement from Architecture & Historic Buildings department
- Exploitation agreement or declaration by the DRIRE (Regional Direction for Industry, Research and Environment)
- Authorisation of grid connection by power company (ARD : Access to the Distribution Grid)

Time to obtain permissions is often 15-20 months. In projects where grubbing agreement does not give delay, the time is decided by the grid connection procedure (12 months). The development time of a project also includes time to make the EIA and other project documents, at least 5 months, if the wind conditions are known. Many projects take longer time because of specific obstacles and/or because wind measurements has to be made.

From a general point of view, the time needed for the development of a project is often delayed because of the complex and long administrative process.

The Netherlands

The required permits are:

- Building permit,
- Environment permit, for projects above 15 MW and in some special situations
- Waterworks permit (if the project involves use of dikes or other land under the jurisdiction of the waterworks),
- Defence: certificate of incorporation from Ministry of Defense, indicating that the project does not interfere with military interests

Permits can be obtained in 1.5– 2.5 years (average), while project development takes 3 – 6 years.
The costs of building and environmental permits are 40,000- 60,000€.

Example

France : Permits needed & period to obtain : the French case

It is common to hear that « everybody can build a wind mill in its garden without authorisation ». This is clearly not true, a permit building is necessary, as an exploitation authorisation signed by the ministry of Industry. Since January 2003, the procedure of public inquiry is needed for all projects of more than 2,5 MW.
Besides, the EIA must include acoustic, landscape, fauna specific studies. The expenses of development are quite huge and there is a rate of extremely high failure of the projects.
Obtaining a permit building requires about 30 opinions or administrative authorisations.
The administration often blocks building permits, when it is not the prefect, it is the Grid system of electricity (RTE), when it is not the RTE, it is the regional Directions of environment (DIREN) and the legislative framing still being weighed down.
The lawful obstacles accumulate, according to the developers. Like the public inquiry, that a disposition, added to the January law, made compulsory for any wind mill equal or higher than 25 meters. If the public investigation is necessary to facilitate the dialogue with the local populations, but to fix a limit of 25 meters is rude since the smallest wind mills are 40 or 50 meters.
It is important to also quote a recent decree imposing a minimal distances between sites of « clean » production of electricity. Still a text trying to limit the development of wind power because two connections to the network will be necessary where only one would be enough.

Involvement of stakeholders

Recommendations

It is recommended that there is a total of 2 public consultation phases of 4 weeks length. The consultations must be outside holiday periods or extended accordingly. At the start of each consultation phase the planning authority should inform stakeholders including neighbours up to 2-5 km from the project site. A good, complete, and transparent communication is recommended during the consultation phase. It's not only necessary to present the project or proposed plan, it is also important to explain the process. Therefore, it can be convenient to invite a delegate from the ministry or public authority involved in the permit process for public meetings.

Source : Avel Pen Ar Bed

National experience

Belgium

Flanders :
Public consultations are an important element once an EIA is finished for large projects, and designated area's (RUPs). Stakeholders can and do use these public consultations to voice their comments and eventual objections to projects.

Wallonie :
Public consultations are made before the EIA and after it. The population can ask to add certain point in the EIA. Every question or comment of the population has to be analysed and answered in the EIA. For project that doesn't require an EIA, a public consultation has to be made during the permit process. If the municipality decide to adopt a municipal planning, the population is also consulted in the process of adoption. Furthermore, an opening of the project developer to the social participation in the investment in the project is often asked and proposed.

Denmark

Public consultations are made for EIA's, regional plans and local plans. Stakeholders can and do use these public consultations to voice their comments and eventual objections to projects. Projects involving EIA's will have at least three separate for public consultation periods: two for the EIA and at least one for the spatial plans. Smaller project typically have two public consultation periods.

France

The local authorities have a large freedom to decide upon the involvement of the different stakeholders in windpower planning, including discussions on individual projects. A new legislation is under preparation, which will require that local stakeholders are invited to a consultation in the EIA process.

The Netherlands

Two public consultations are made for EIA's and for changing the municipal plans, and one to obtain the building permit. For projects that do not require an EIA, only one consultation round is requested.

Relations with grid connection authorities

Recommendations

It is recommended that once a building-permit is obtained, the distribution company should provide the grid-connection as highest priority extension and within no more than 3 months.
Relevant power utilities must be involved in windpower planning and should include future windpower developments in their planning of line extensions and reinforcements.
The grid-connection costs paid by the investor must be transparent and non-discriminatory. The advantage given to the grid by the windpower producer has to be taken in consideration. (These requirements follow the EU Directive 201/77/CE on the promotion of electricity from renewable energy in the internal electricity market.) The advantages given to the grid include other use of the extension by current and future consumers and generators. The utility should co-finance or reimburse investments proportionally to the benefits given to the grid by the extension. It is recommended that the grid-connection costs paid by the investor only cover connection to the nearest medium voltage grid (10-15 kilo Volt line). It is also recommended that the developers can choose to use open tender procedures for his grid-connection and extension investments. It is further recommended that the distribution companies pay reinforcement of grid and substations and that these costs are distributed to all consumers in the country.

National experience

Belgium

Installations should be connected to «sub-station», i.e. a transformer between the high voltage (over 70 KV) and medium voltage (between 11 and 15 KV) lines or between medium voltage and low voltage (11 KV and under).
Applicants are recommended to submit the connection request as soon as possible to the grid operator in order to be assured of the project's compatibility with the existing grid. This applies to Wallonie only; a new regulatory body is currently developing rules for Flanders.
Connection charges vary according to the station, voltage level and connection type. The tariffs are fixed and revised every year by the Commission of Regulation of Electricity and Gas after a consultation of the grid manager and of the grid users.
The costs for the connection (study only, no works) are about 10,000 to 14,000 €.

Denmark

When the building permit is obtained, the power distribution company has to provide a 10 or 15 kV line to the site while the investor(s) pay transformer from lower tension and cables from the individual turbines to the transformer. The distribution companies share the grid-connection costs; so all consumers will pay the same share for this as part of their grid distribution costs.

France

Project's developers have to pay for connection costs between turbines and connection point on the network. Costs for possible grid reinforcement is supported by the power utility EdF (in fact, final consumers and producers).
The connection procedure is long and organised into a queuing system:

- Connection inquiry by developer.
- Exploratory study (sent under a delay of 6 weeks by the network operator). This answer gives indications about the connection costs and the rank of the project in the waiting list.
- The operator has 4 months to prove the building permit deposit (administrative and technical information). If not, the project is excluded from the waiting list.
- Network operator then answer with a detailed connection study within 3 months (called technical and financial propositions).
- The operator has then 3 months to discuss and sig the proposition with the network authority (If not, the wind operator is removed from the waiting list)
- Acceptation by EdF

Before the principle of amortising the network reinforcement costs amongst the final consumers was retained, the cost for reinforcement of the network was often very high and lead sometimes to the renunciation of the projects because developers couldn't afford the expense.
Now that this principle is specified on the law, for certain projects located in areas where a grid reinforcement is needed, we observe that the delay announced for reinforcing the network (several years sometimes) makes the project unrealisable.
This situation could lead to a general location of projects where the network does not require to be reinforced (but also often in less windy areas).
There is also a contribution for all producers to the funds of «public utility of the production of electricity». A decree fixed the contribution at 0,33 c€/kWh for the year 2003, that is to say approximately 4% of the first 5 years tariff (8,38 c€), which is far from being negligible. Moreover this amount is revised regularly so therefore unforeseeable.

The Netherlands

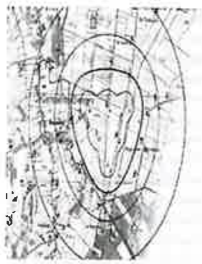
The investor(s) pay the connection to the (nearest) substation (60/10 kV transformer). The distribution company mostly does the installation of this line, but this is not a requirement by the law. Grid reinforcement costs are born by the distribution company.

PART 3
ENVIRONMENTAL AND SPATIAL CRITERIA AND RECOMMENDATIONS

Noise

Recommendations

Danish and Dutch noise norms work satisfactory; thus both can be recommended (see below). German norms are similar to Danish norms.
The norms should apply in all areas (including industrial areas), except in and near areas with special requirements for low noise (e.g. silent areas). At such areas windturbines should respect the local noise limits, but scaled with the wind, preferably according to the WindNormCurve 40. If e.g. the permitted noise level is 5 dB(A) below the standard of 40 dB(A), the curve should be reduced 5 dB, i.e. start with 35 dB(A) at wind speed of 1 m/s. Windturbines siting should not be limited with fixed distances to low-noise areas.



Source: OVE

National experience

Belgium

The respecting of conditions is imposed everywhere in the emission zones and the threshold has been fixed at 40 dB(a) in Wallonie Regions. Measurements are taken outside housing constructions, if possible at least 3.50 metres from any reflective structure other than the ground. With wind speeds of less than 5 m/s (for higher wind speeds, measurements are distorted by the noise of ambient wind). Though wind turbines only produce noise when the wind operates them, which is above wind speed of 5 m/s, the Dutch noise curve is applied in practice to estimate the real noise impact.
In the Flemish region, the local authority can decide on the permitted noise level depending on background noise.

Denmark

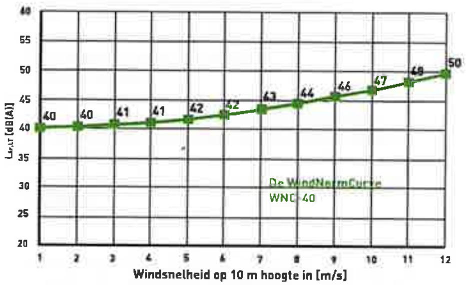
The limit is 45 dB at single houses and 40 dB at dwelling areas, summerhouse areas, and recreation areas, with 8 m/s wind speed 10 m above ground at the site of the turbine. The noise is calculated at the neighbours based on a noise measurement 1-2 times hub height downwind of the turbine; thus the noise limit is effectively for a situation with the wind from the turbine to the neighbour(s).

France

According to the law about noises of vicinity of the 31st of December 1992, there is no maximum value indicated, but a maximum noise emergence authorised from an initial measured surrounding noise.
This means that a noise measurement (at nearest neighbour) is required before wind turbines implementation. The maximum authorised emergence (difference between noises measured before and after the turbines are implemented) is fixed up to 3 dbA at night and 5 dbA during daytime.
It is specified that this should be measured with a wind speed of 5 m/s, but this is not representative as most wind turbines are not operating with this wind speed, and thus it is expected that this will be revised.

The Netherlands

The Limiting value is 40 dB(A) on the nearest house. The Correction with Wind Norm Curve:



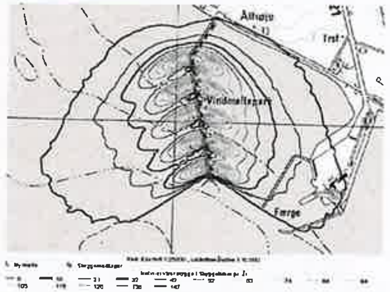
Using this curve the noise can be 44 db(A) at wind speed of 8 m/s and 50 dB at 12 m/s.

Shadow flicker

Recommendations

It is recommended at neighbouring dwellings and offices that flickering shadows are not exceeding 30 hours /year or 30 min. per day with normal variation in wind directions and with clear sky. (This follows the German norm of 30 hours a year at clear sky).

Source: Neg Micon



Source: OVE

National experience

Belgium

In Wallonie, the government recommends to apply the threshold of tolerance that are fixed on the German pattern, that is 30hrs per year and 30 min per day. In practice, they are always applied as condition to obtain the permit and must be studied in the EIA.

Denmark

Recommendation: max. 10 hours/year allowed at neighbouring dwellings with average cloud cover.

France

No recommendation are fixed, but the calculation of the occurrence of the shadow flicker at the nearest neighbours should be indicated in the EIA.

The Netherlands

When there is more than 20 minutes per day, 17 days per year (5 hours 40 min/year calculated, with clear sky), at neighbours it is regarded as a nuisance, which is unacceptable, and a standstill device is requested

Landscape

Recommendations

Windturbine siting must consider the influence on the landscape and windturbines should be integrated into the landscape. Where feasible this can include creation of links between the windturbines and other landscape elements. These links can be made with lines or clusters of windturbines that follows natural or man-made structures in the landscape. Where relevant (in open landscapes), it is recommended that windturbines are not closing a large part of the view; certain permeability should be maintained in the landscape.

In preparation of projects must be made correct visualisations of windturbines in the landscape, seen from different viewpoints, including viewpoints where many people will see them. These visualisations must be well distributed locally as basis for the local consultation before the development.

It is recommended that a relevant authority gives criteria and advice on landscape issues at the start of projects to project developers without delay, to minimise project development risks.

SOURCE : AVEL PEN AR BED

National experience

Belgium

In Flanders landscape integration is a major issue. Windturbines should not affected the open space and therefore wind turbines are preferably located near existing infrastructures like harbours, industrial area's etc.

As one of the only regions in Europe it is in general not allowed to locate wind turbines in agriculture area's except if a designated area has been created. This is normally only done by the regional authorithies (although it is also possible at province or commune level) in area's close to existing infrastructure.

For some provincies a landscape integration study was made to define designated areas and the procedure to evaluate the landscape. The zone of visual influence is normally defined up to 5 km.

The integration in the built site and not built is a major condition for the permit. This point will be one of the biggest parts of the EIA and can be analysed in a study in addition to the EIA, before the determination of the turbine installation's place.

The following guidelines have been retained for the Walloon's Region:

- To guarantee harmony and visual balance by giving preference to an «organic» type installation in natural sites and a «geometric» type installation in urban environments.
- Giving priority to parks whose wind turbines are of a grey-white colour, of similar model or equal proportions and to only accept three-blade propellers with slow blade rotation speeds.
- Same proportion of the turbines and same direction of rotation of all turbines

The siting of wind turbines is not advisable within the perimeters of remarkable viewpoints, landscape interests, cultural, historic or aesthetic interests.

Regarding harmonisation of windturbines in parks, it is recommended for the Walloon's Region that:

- The «grouping» principle: priority is given to groups of production units, rather than the dispersion of individual wind turbines.
- Combined use through which the space available for several compatible functions is also one of the essential principles of this policy.
- The recommended distance between wind turbines is equal to 7 times the diameter of the propeller when in line with the prevailing winds and 4 times this diameter for those perpendicular to the line of the prevailing winds.
- To guarantee harmony and visual balance by giving preference to an «organic» type installation in natural sites and a «geometric» type installation in urban environments.

Recommendations to promote integration (Wallonie):
- Limit the park to wind turbines only

Denmark

Windturbine plans must consider the influence on the landscape. New windturbine groups must be clearly separated from existing groups. Considerations must include the character of the landscape, the new turbines maximal height and the sites of existing turbines.

A harmonic relation between hub height and rotor diameter is recommended, e.g. that they are within 10 % from each other.

Windturbines should primarily be placed in groups, but single turbine developments can be permitted. Windturbines in groups should be ordered in an easily recognizable geometrical pattern. New windturbine groups must be clearly separated from existing groups.

SOURCE : WINDPOWER.COM

France

The landscape consideration is among the most important of the EIA. In this document the project developer must give an explanation of the choice, including research of visual harmony from the point of view of the concerned landscape.

The landscape is a major stake of land planning and the choice of a site to establish a project should be studied and justified from landscape considerations.

From a general point of view, French Administration fears the multiplication of the operations that «can lead to phenomena of covisibility and in certain cases with landscape changes». It is thus essential that the choice of a site, naturally directed towards spaces having an exploitable wind potential, should be preceded, as of the first investigations, of a study of the sensitivity of spaces concerned and their aptitude to accommodate turbines.

As a consequence, each carrier of project must carry out a landscape analysis on a big area, presenting several possible sites of establishment. This surface should not stop with administrative limits, and should integrate the possible wind parks already carried out or for which the request for authorisation to build is known.

SOURCE : ECOFYS

In practice, this means that the location of a wind project should be defined on the basis of a landscape analysis, after the comparative study of the level of integration of several different options.

The Netherlands

Development may not have harmful consequences of the landscape, windturbine parks have to harmonise with the landscape. This is regulated in the zoning plan or in the landscape or urban plan.

The Ministry of Housing, Spatial Planning and the Environment recommends:

- As far possible, concentrate wind turbines on lines and clusters.
- As far possible, combine wind turbines with industrial sites
- As far as possible, strengthen large-scale man-made cut-through of the landscape like rail-, high-, and / or waterways.
- Because of their size, wind turbines cannot be placed individual in the landscape near farms.
- Preferably site wind turbines in young and large-scale developed landscapes.
- Preferably site wind turbines on the border of open areas in the landscape. Note: the effect of a visual fence around an open area has to be avoided.
- New wind turbines should preferably not be placed in open landscapes, unless they should fit in the landscape very well.
- For the placing of wind turbines in «green contour areas» counts the «no, unless...»-consideration.

In addition, the various provinces have developed their own guidelines, with little difference though compared to the national guidelines. Most additional restrictions refer to mast height, number of wind turbines and number of wind turbines in a cluster or line.

Regarding harmonisation for windturbines in parks/groups there is a preference for single or eventually double line configurations along existing infrastructure.

SOURCE : ECOFYS

Distance between turbines and parks

Recommendations

It is recommended that windturbines are integrated in the landscape including harmonisation with existing turbines and coming windturbine projects that have started the process to get permits. Only windturbines within a reasonable distance, proposed to 3 km, must be considered in this process.

National experience

Belgium

In Flanders region there are no rules regarding to distances. The recommended distance between wind turbines is equal to 7 times the diameter of the propeller when in line with the prevailing winds and 4 times this diameter for those perpendicular to the line of the prevailing winds (see 3.12).

Denmark

If two groups of windturbines are closer than 2.5 km apart, both groups must be included in landscape planning.

France

As described before (see 3.3. landscape), the concept of co-visibility – the area where more windturbine groups can be seen must be described in EIA.
Since July 2003, the new law (law n°2003-590 about Town planning and Habitat) stated that 2 wind parks should be at least 1,5 km distant.

The Netherlands

The required distance varies. It is regulated in regional and (municipal) zoning plans.

Distance from housing

Recommendations

It is recommended that there is not fixed a specific minimum distance, but that the distance is decided according to noise, shadow flicker, and landscape considerations.

Source: Ecorys

National experience

Belgium

No special rules are applied in general the distance depends on the calculated noise or shadow criteria
In Flanders an indicative minimum distance is used of 250 m from nearby houses

Denmark

4 times total height, sometimes 500 m

France

Windturbines are generally not allowed in zones for housing as defined in municipal spatial plans (PLUs). There is no special rules, the distance from nearest housing is established on the basis of the noise nuisance and the notion of noise emergence (see 3.1. Noise)

The Netherlands

No special rules. Minimum distance depends on noise and shadow nuisance.

Distance from roads, railways and waterways

Recommendations

It is recommended that turbines be placed at a distance of at least the rotor radius from the edge of roads, railways or waterways to the turbine tower (no overhang). In countries and areas with risk of over-icing, turbines closer than their total height from the infrastructure should be stopped automatically in case of risk of icing, or otherwise protect neighbours from ice from turbine blades. For main railways, highways and major intersections, special risk analysis can be required.

Source: Ecorys

Source: Ecorys

National experience

Belgium

In the Walloon Region, a distance equal to the height of the turbine is recommended in relation to national roads and railways. No distance is pre-defined from waterways that are rare and often inappropriate for the wind power because located in valleys or other boxed zone.
In the Flemish region, a risk analysis can be required for projects near highways and railways.

France

There is no special rules for wind turbines, but each roads, according to its category (communal, main roads, motorway) has a defined distance back from the road in which no construction at all is allowed.
The rules of constructibility and distance from the roads are included in the local documents of town planning. Generally, the roads are classified in various categories according to their importance.
In all the cases, prohibition of overhang and in certain case, application of the law Barnier (distance back to motorways of 100 m but with possible exceptions locally).
This means that there is no single rule, but that the constraints vary according to the roads but also to geographical areas for the same road.
About the distance from railways and waterways, it seems that only the prohibition of overhang is applied.

Denmark

This is decided on county level, but often is used a distance of 4 times total height to major roads and total height to other roads and to railways. Denmark has very few inland waterways.

The Netherlands

Half the rotor diameter, or at least 30 meters, from railways, highways and waterways. Special risk analysis required at intersections. Risk analysis show that only under the rotor is any considerable risk, except for ice, where the risks are mainly at a distance up to total height of the turbine

Distance from high voltage lines

Recommendations

It is recommended that the distance from windturbine tower to the nearest high-voltage line is at least equal to the rotor diameter.

Belgium
In the Walloon Region, a distance equal to the height of the turbine is recommended in relation to power lines.

Denmark
No general rules, the distance is decided by the county in connection with planning permissions.

France
There is no clear rules. A distance equal to the total height of the machine at least should be respected between turbines and lines. Sometimes, a distance is given in local planning documents.

The Netherlands
The rotor diameter from the center of the windturbine to the nearest line, otherwise at least 30 m.
[refer to risk analysis study]

Distance from radio communication, radar and navigation beacons

Recommendations

Windturbines must not cause nuisance with radio and radar equipment including navigation beacons. It is recommended that authorities or suppliers of the different radio technologies specify required distances to reduce interference to an acceptable level, and that they give technical documentation for these distances.
It is recommended that a windpower project that will give nuisance to radio wave communication can decide to pay compensatory measures, if technically feasible.
Because of the very different distance requirements in different countries, it is recommended an exchange of information between competent authorities of European members states.

National experience

Belgium
In the Walloon Region, as a precautionary measure, wind turbines should normally be positioned at a distance of 100m from telecommunication lines. Furthermore, a distance of 600m appears to be required from major emitter antennas and radars, sometimes a distance of 7 km is applied to navigation beacons.
In the Flemish Region, the project developer must prove that the turbines will not affect the radio equipment. Therefore additional studies are sometimes necessary in the vincinity of radio, radar or other telecommunication devices.

France
There is not distance fixed. Each project should receive the agreement of implementation from aeronautical authorities, and from Radio-electricity & Telecom services.

Denmark
Wind turbines may not cause nuisance, distance to radio-beam centreline typical 200 – 350 m.
[aviation beacons, rules to be explained]

The Netherlands
Wind turbines may not cause nuisance. Typically 30m from rotor tip to centreline of beam is used.
In case of proximity of navigational radar, an analysis may be requested; these analysis mostly show that no distortion takes place..

Example

The Netherlands, telecommunication lines
On a former rubbish dump site, a combined windfarm with PV-system was planned. Five 1.3 MW turbines would be erected, together with 800 kWp of PV panels. However, a radio beam link crosses the site. After consultation with the competent authorities (KPN), it was resolved in August 2000 that: ...In principle, the protection zone extents to 100 m from each side of the heart line of the beam connection. However, regarding wind turbines, a smaller value can be adopted: 25 meters from the tip of the blade. With a rotor diameter of 60 m, the turbine mast should thus be positioned 25 + 60/2 = 55 m from the centerline of the beam. In case this numerical value would allow insufficient room for positioning the turbines, more detailed calculations should assess whether a closer distance is also possible. In any case, placing of turbines in the heart of the beam connection must be avoided. The allowed distance of 55 meters provided enough space to locate the turbines in an optimal configuration, as can be seen in the photomontage above.

Distance to historical sites and buildings

Recommendations

It is recommended to consider historical sites and buildings in the landscape evaluation, to avoid that windturbines negatively dominate these places.
It is recommended that relevant authorities should give their advices on this matter to project developers without delay, to minimise project development risks.

National experience

Belgium
The siting of wind turbines is not advisable within the following perimeters, owing to their a priori incompatible nature (Wallonie): remarkable viewpoint, cultural, historic or aesthetic interest. Across and close to these area's, the advise of the competent authority (Regional Commission of Monuments and sites) is needed.

Denmark
100 m, sometimes more, e.g. 300 m, or dependant on landscape considerations based on visualisations. Turbines at short distances to churches have been seen as a problem, because they can dominate the site.

France
Projects nearer than 500m from historical monuments require an approval from the «Architect of Ancient Monuments (AAM)» to obtain a building permission.
In practice such distance is applied from every historical sites and building for wind turbines.

The Netherlands
Distances are regulated in zoning planes, made by the municipalities

Distance to natural reserves and other protected areas

The includes EU wildlife protection areas, RAMSAAR, Natura 2000, ...

Recommendations

It is recommended that windturbines are not placed in Ramsaar and bird protection areas. For other protection areas, for surroundings of areas (buffer zones), and for offshore developments is recommended an assessment of the effect of the development on the fauna and flora that is protected. Experience shows that negative effects on protected bird life are usually found in distances up to 200-300 m from bird protection areas.
More research is (still) needed on how birds adapt to wind turbines and how this can influence distances required.

National experience

Belgium
The siting of wind turbines is not recommended within the following perimeters, owing to their a priori incompatible nature(Wallonie): ecological connection, foreseeable natural risk or major geotechnical constraint and protection perimeter in the sense of legislation for the protection of fauna. It can however be permitted if the EIA shows that there is no unacceptable impact. The advise of the competent authorities or of experts is always needed.
In Flanders region siting close to area's with important natural wildlife or fauna. Additional research has to be carried out by the institute of nature conservation (IN); In general exclusion area's of 200 to 700 m are applied.

Denmark
300 m is the usual distance to forests, but to some areas e.g. RAMSAAR areas, are often required 500-800 m.

France
Projects located in protected areas require permission from the Ministry of Environment, but no distance from these sites is mentioned.
Nevertheless, some distances to respect are sometimes mentioned in documents such as departmental charter or guidelines. This is the case for the «Côtes d'Armor» guidelines which defines «sensitive areas» in which any turbine, because of its characteristics, is expected to have a big environmental impact. Such areas include zones of ecological or landscape interests and crowded sites from a tourism point of view. Areas close to the shore of the sea are also attached to it, significant natural spaces as well as the surroundings of the «incompatible sectors» on a distance of at least 2 km

The Netherlands
Wind turbines are not allowed in the EHS, unless... (Ecologische hoofdstructuur; Ecological main structure is a protected area). It is not allowed to develop wind turbines in birds directive areas, except nearby highways and/or railways through those area's.

Distance to water bodies

Recommendations

It is recommended that distance to water bodies should not be based on fixed exclusion distances, but on landscape considerations.

National experience

Belgium

In Flanders waterways are often used as location to install turbines (preferably along canals). The distance is in general at least the rotor radius.
In Wallonie, the impact and the risk of siting a wind turbine along water bodies must be carefully studied in the EIA. Nevertheless, because of their location (not adapted for windy conditions), there will be rarely a demand to install turbines at those places.

Denmark

150 meters to lakes above 4 ha, sometimes also to rivers.
Special planning for 3 km from sea, require special landscape consideration to permit turbines in this zone, but it is possible.
Windturbines should be at least 100 meters from the coast except in industrial areas (e.g., harbours)

France

No construction is allowed at a distance of less than 500 meters from sea or lakes in application of the littoral law. The rules of constructibility and distance from the water bodies could be locally adapted and are included in the local documents of town planning.
The «Côtes d'Armor» guidelines also excludes areas close to the sea (see the previous chapter).

SOURCE : CAUE DE L'AUDE

SOURCE : NEG MICON

The Netherlands

50 meters to waterways. No limit for waters bodies which are not waterways.

Distance to forests

Recommendations

It is recommended to integrate windturbines into the landscape and minimise harm to nature, in particular to protected species and areas. It is not recommended to exclude forests from windpower developments (though most forests are not suited for windpower development).

National experience

Belgium

In flanders the distance is dependant on the «value» of the forest regarding to wildlife, birds etc. It is a part of the evaluation of the IN.
In Wallonie, the legal criterion of integration in the built and not built site is interpreted by the Government as incompatible with a location of windturbine in forests and silent areas. No buffer zone is clearly indicated.

Denmark

300 m to forests
Special silent areas are not used as planning criteria in Denmark, but noise regulation is stricter to recreation areas than to other areas and single dwellings.

France

No distance is indicated, but a distance could be possibly included in town planning documents. However, a good site is generally a relatively released space. When a potential zone is located in a context characterised by a rather strong vegetable cover (forests or wood), roughness is rather strong and wind potential not so good.

The Netherlands

The distance varies. It is regulated in regional and zoning plans.
Wind turbine placing in silent areas is prohibited.

Protection of flora and fauna

Recommendations

Fauna and flora studies should be part of the environmental assessments to be made before development of windpower projects, also when a full EIA is not required. Particular caution should be taken in bird migration routes and around bird protection areas.
Since most effects are often caused during construction, special measures should be taken to reduce negative effects of construction on flora and fauna.

© Gunnar Britse

SOURCE : WINDPOWERPHOTOS.COM

National experience

Belgium

Impact on wildlife, particularly birds (Walloon's Region): The EIA have to evaluate the impact in the area's breeding population, to identify the species which use it as a resting or feeding spot, or if it contains resting and feeding areas or is part of a migration corridor for migrant species and assess the potential losses of biotopes and other permanent disruptions suffered by birds. To do this, the author of the EIA must make references to existing study or advice of experts. If the project is localised in a bird's resting, feeding or reproduction area or in an important migratory corridor, a special study has to be conduct. In general, those areas are better avoided. If there is no EIA required, a special study has to be done on those topics. The compatibility of wind turbine with other species is recognized, but must be checked in the EIA. In Natura 2000 areas and natural reserves, the authorisation of the competent authority is requested. The installation of turbines in those sites is not always refused, but will be refused in the sensitive locations of the site, according to the kind of species protected and its sensibility.
In Flanders region the Institute of nature conservation will give a recommendation per site.

Denmark

The required EIA includes a fauna study. For smaller developments environmental impact study should include fauna impacts. Placing in bird migration routes needs a special consideration, and can be a reason for rejection of a project.

France

In every case, a preliminary verification of the environmental constraints beside the DIREN (Environmental Regional Direction) is necessary for the location of the project. Then, the study of the impacts on wildlife is part of the EIA. A flora and fauna (especially birds) impact analysis is required on a period of one year!

The Netherlands

The initiator has to do a fauna study before developing wind energy. Placing in bird migration routes or in meadow bird grazing areas is not prohibited

Example

Impacts on birds : France, the case of « Port la Nouvelle » wind park

The wind problems with birds appeared in Europe at the beginning of the Nineties, that is relatively recent. Reserves as for methodologies used accommodated the first alarming results of follow-ups carried out in California, on the site of Altamont (1988) in particular. In France, the follow-ups of « Port La Nouvelle » (1997) and « Garrigue Haute » (2002) are the only studies completed. Follow-ups of wind parks under operation are in hand and the years which come should enable us to better know the risks.

The impacts can be direct or indirect and can relate to the nesting (N) and the migrating (M), as the table summarises it below :

Direct impacts	Indirect impacts
Collision risk (N and M)	Behavioural disturbances (N and M)
Loss of biotope (N)	Modification of the trajectory of Migrating
Failure of the reproduction (N)	Reduction in the food resource (N)

The study of the wind farm of « Port La nouvelle » (5 turbines with a mast of 40 m and blades of 19,5 m) shows no direct impact (no bird wounded or killed by direct collision in 5 years), but more precise follow-ups are recommended (dense covered vegetation).
The follow-up of the migration pre and postnuptial on the wind park was carried out over one year (Abies/Géokos/LPO Aude 1997). The wind mills implemented perpendicular to the principal migratory axis were considered as a dangerous establishment. The follow-up did not allowed to discover corpses on the wind site. Besides, very few flights were observed through wind mills when they all are moving. An increase in these passages is noted when one or more wind mills are stopped.

Various studies and observations show that the birds establish strategies of flight plan adapted to the wind mills. Nevertheless, The identification of the wind mills by birds implies :

- Change of the axis of the flight (about 75 % of the birds reacted to the presence of a wind turbine running.
- A higher flight or at the opposite, a flight under the turbines (in Tarifa, the overflight of migrating is 100 m to the top of the wind mills against 60 m above the ground in the zones without wind mills).

So there is not so much problems with birds, but these reactions result in :

- An additional expense of energy for the bird
- A deviation of the flight sometimes though areas with infrastructures (train, power lines...) with more significant impacts

From a general point of view, the studies undertaken in France and throughout the world show that birds and wind turbines can cohabit.
But direct and indirect impacts on birds are not negligible and the sites chosen must take care of the bird's context at local and regional level.
On the whole, it is strongly advised not to set up wind turbines in the corridors of the migration flights and near the areas of rare / threatened nesting species.

Defence constraints

Recommendations

It is recommended that the military be consulted for developments nearer than 12 km from defence installations and in zones of special military interest such as low-flying zones. The Ministry of Defence must answer without delay whether proposed projects are in above zones of military interests.

National experience

Belgium

The military authorities are always consulted in the permit process and their authorisation is needed in area devoted to military activities. A non-official map is available by the Army that give indication on excluded areas.

Denmark

Within 12 km from defence installations, the military must be consulted

France

In France a developer must consult the military aviation authority that will give its approval or rejection of a development on a given site, based on interference with military activities. No more information is given.

The Netherlands

A special authorisation is required within 15 km around defence airfields.

Aviation Constraints

Recommendations

It is recommended that turbines are excluded from airport in fly funnels; but are permitted around airports, where they do not interfere with aviation.
It is recommended that windturbines can be permitted in low fly zones, also military. Restrictions on low-fly zones must be negotiated with the relevant authorities on a case-by-case basis.
It is recommended that windturbines less than 100 m have no lights or markings.
For turbines above 100 m total height is recommended no obligatory marking on the tower.
It is recommended that a process be started to develop European recommendations for lighting of turbines above 100 m total height in a dialogue among windpower interests, aviation authorities and nature protection interests.

National experience

Belgium

In addition to the requirement that windturbines do not interfere with aviation, the aeronautical authorities can request the marking of wind turbines, when necessary. In the Walloon Region, the type of marking requested consists of a white type A flash, with 360° visibility and a red light (for night visibility) on the nacelle and red marking along the last 2 metres of the blade. In the zones for the helicopters, also white flash and red marking along the mast (1/7th of the mast height).

Denmark

No turbines in airport in fly funnels. Some counties set exclusion zones around airports. Turbines above 100 m total height are subject to special analysis, in particular in low fly zones; but permissions have been given even to turbines above 100 m in low fly zones.
The aviation authority can demand that turbines with total height above 100 m should be marked (with light). Turbines above 150 m should always be marked. Different warning lights are tested, including lights on top of nacelle, lights on wing-tips that only light up when the wing-tip is above a certain height. Some of these lights are only visible from the air, not from the ground.

France

Windpower projects must obtain permits from civil and military aviation authorities. They can set limitations on height and demand lights for increased visibility from the air. In certain cases the military have limited the permitted total height to 75 m in so-called low-flying zones. These zones are quite large in some parts of France (especially in Finistery).

The Netherlands

Turbines in military low fly zones or in airport in fly funnels are not encouraged, but according to the law, can be assessed.
No requirements for lights below 100 m mast height (not total height)

Ground occupation (access roads, sheds)

Recommendations

It is recommended that access roads be kept to a minimum to preserve farmland.
It is recommended that land under windturbines can be used for agricultural and appropriate industrial purposes, such as storage of non-risk materials.

Belgium
In the Walloon and Flanders regions it is recommended to bury the foundations and keep access roads to a minimum, in particular by using the existing roads. Site remediation is required at the end of its lifetime.

Denmark
It is recommended that these should be minimised to preserve farmland. As part of that some counties recommend to use existing farming roads and field borders.

France
As part of the EIA, the project developers must give an explanation of the treatments of the direct surroundings of the site: technical local, compensatory measures on reshaped areas (access path, connection cables, etc.). Generally, it is recommended to use the existing access paths and to avoid levellings of slope or other significant impact on the initial area (most of the time with an agricultural destination).

The Netherlands
No universal recommendations. Some municipalities operate their own guidelines, these vary.

Conclusion

From WP8 partners' experiences and within strong differences both on level of development and growth of development between the countries, some relevant conclusions could be extracted.

Public support is generally strong in surveys as sustainable development also for energy production is beginning to be of real concern among citizens'. However, some movements of radical opposition and NIMBY attitudes toward wind projects are observed.

Some factors can explain this current situation (it is the case in Netherlands, Belgium, Denmark, France and other countries): Location of wind projects is made by developers (France and Belgium in particular) with no overall background consideration at local level. Therefore, judgement of projects by administrative authorities and planners is often difficult. A case by case instruction is the rule in such situations.

Wind energy is a major planning matter at local level (mostly because of the landscape aspects). Spatial planning of wind turbines is of major interest both for elected politicians and for citizens. It is often the main obstacle for wind energy development (Germany).

Public support for windpower and the complex situations with local protests and unclear planning procedures lead to wind spatial planning with concerted effort (Denmark, Germany, Netherlands). This also means a chance for local investment, that is another major strike for public acceptance (in the field of the PREDAC project, the WP1 –www.cler.org/predac/wp1– studies this aspect in details).

This also means policy choices and institutional matters on national level (including laws to oblige municipalities or other local authorities to plan for windturbines). Is the future of a territory to be decided by anybody else but the concerned elected leaders and the citizens? We feel that spatial planning established at local level (with concerted practices) is the only way to achieve targets fixed at European level (for countries like France or Belgium especially).

These guidelines examines the wind energy spatial planning problems in the European partners' countries. From a comparative review of methods and criteria used, this guidelines propose to compile the planning procedures in different countries and make recommendations. Over the last few years, the need for a special approach for wind energy in planning policy has become more and more obvious (first in Germany and Denmark, then in Holland, Belgium and France, according to the level of development of wind energy). Nevertheless, regarding to each social and political context, some strong differences occurred, and criteria or assumptions used in wind planning are different from countries to countries. As a consequence, recommendations sometimes do not fit precisely to national context. Therefore these proposed guidelines include a minimum of recommendations, that are chosen to be useful in as many situations as possible.

contacts

Denmark

OVE
Organisationen for Vedvarende Energi
Danish association for renewable energies
European Cooperation Office
Contact Gunnar Boye Olesen
Dannebrogsgade 8A, DK-8000 Aarhus C
Gl. Kirkevej 82, 8530 Hjortshoej
Danemark
tel (+45) 86227000
fax (+45) 86227096
email ove@inforce.org
site web www.orgve.dk

Belgium

Apere
Belgium association for the Promotion of Renewable Energies
Contact Annabelle Jacquet
Rue de la Révolution
7-1000 Brussels Belgium
tel (+32) (0) 2 218 78 99
fax (+32) (0) 2 219 21 51
email info@apere.org
site web www.apere.org

3E engineering
Contact Luc Dewilde
Verenigingsstraat 39,
1000 Brussel Belgique
tel (+32) (0) 2 229 15 22
fax (+32) (0) 2 219 79 89
email luc.dewilde@3E.be
site web www.3E.be

Netherland

Ecofys
Contact Bernard van Hemert
Postbus 8408
3503 RK Utrecht
tel (+31) (0) 30 280 8300
fax (+31) (0) 30 280 8301
email info@ecofys.nl
site web www.ecofys.nl

Germany

BWE
Bundesverband WindEnergie,
German Wind Energie association
Contact Jochen Twele
Herrenteichstrasse 1
49074 Osnabruck Allemagne
tel (+49) (0) 302 848 21 05
email j.twele@wind-energie.de
site web http://www.wind-energie.de/

France

Avel pen ar bed éoliennes en Bretagne
Association for the Promotion of Wind Energy in Brittany
Contact Yann Rochard, Bertrand Poyet0
1 rue de la fontaine St-Pierre
29 470 Plougastel Daoulas
tel (+33) (0) 2 98 37 89 29
fax (+33) (0) 2 98 40 32 17
email avel@infini.fr
site web www.apab.org

CLER
French renewable energy network
Contact Emmanuel Poussard
2b rue Jules Ferry
93100 Montreuil
tel (+33) (0) 1 55 86 80 00
fax (+33) (0) 1 55 86 80 01
email predac@cler.org
site web www.cler.org

Notice to the reader

A great deal of information on the European Union is available on the Internet. It can be accessed through the Europa server (http://europa.eu.int).

The overall objective of the European Union's energy policy is to help ensure sustainable energy system for Europe's citizens and businesses, by supporting and promoting secure energy supplies of high service quality at competitive prices and in an environmentally compatible way. The European Commission's Directorate-General for Energy and Transport initiates, coordinates and manages energy policy actions at transnational level in the fields of solid fuels, oil and gas, electricity, nuclear energy, renewable energy sources and the efficient use of energy. The most important actions concern maintaining and enhancing security of energy supply and international cooperation, strengthening the integrity of energy markets and promoting sustainable development in the energy field.

A central policy instrument is its support and promotion of energy research, technological development and demonstration, principally through the Energie sub-programme (jointly managed with the Directorate-General for Research) within the theme "Energy, environment and sustainable development" under the European Union's fifth framework programme for RTD. This contributes to sustainable development by focusing on key activities crucial for social well-being and economic competitiveness in Europe.

Other programmes managed by the Directorate-General for Energy and Transport, such as SAVE, Altener and Synergy, focus on accelerating the market uptake of cleaner and more efficient energy systems through legal, administrative, promotional and structural change measures on a trans-regional basis. As part of the wider energy framework programme, they logically complement and reinforce the impacts of Energie.

The Internet web site address for the fifth framework programme is: http://www.cordis.lu/fp5/home.html

Further information on Energy and Transport DG activities is available at the Internet web site address: http://europa.eu.int/comm/dgs/energy_transport/index_en.html

The European Commission
Directorate-General for Energy and Transport
Rue de la Loi/Wetstraat 200
B-1049 Brussels
Fax (32-2) 2956118
TREN-info@cec.eu.int

Annex 2

Extracted from 'Update of UK Shadow Flicker Evidence Base', by Parsons Brinckerhoff (2011).

2.3.3 Germany

2.3.3.1 Notes on the Identification and Evaluation of the Optical Emissions of Wind Turbines, States Committee for Pollution Control – Nordrhein-Westfalen (2002)

Synopsis

This document provides a clear set of criteria for an astronomic worst case scenario. German guidance sets strict limits on the levels of acceptable shadow flicker effect, using two methods:

An astronomic worst case scenario limited to a maximum of 30 hours per year or 30 minutes on the worst affected day; and
A realistic scenario including meteorological parameters limited to a maximum of 8 hours per year.

If the above limits are exceeded, then mitigation measures should be implemented. The document makes particular reference to adopting a planning condition for automatic turbine shut-down timers, which use radiation or illumination sensors.

The following strict criteria are provided to define the astronomic worst case and realistic shadow flicker scenarios:

There is continual sunshine and permanently cloudless skies from sunrise to sunset
There is sufficient wind for continually rotating turbine blades
Rotor is perpendicular to the incident direction of the sunlight
Sun angles less than 3 degrees above the horizon level are disregarded (due to likelihood for vegetation and building screening)
Distances between the rotor plane and the tower axis are negligible.
Light refraction in the atmosphere is not considered.

The German guidance does not specifically refer to a distance limit for shadow flicker assessments. However, there is reference to a point where the contrast between shadow and ambient conditions are so low that the impact is excluded from assessment.

The 30 minutes per day rule for shadow flicker at any given receptor is based on a psychology academic survey by the University of Kiel (Pohl et al 2000).

This document also provides an example case study demonstrating how shadow flicker should be calculated. The methodology sets the indoor reference height at the centre of a receptor window, and a reference height of 2m above ground level if measured outside. This case study can be found in Appendix 1.

Relevant text

Please note – this text is a translation and is not quoted verbatim. Some elements of the translation may not reflect the exact wording of the original documents.

Scientific research [no reference given in text] has demonstrated experience that optical emissions in the form of periodic shadows can result in considerable harassment effects.

Technical measurements and limits on the time of operation are based on WEA guidance. Turbine shut down is only considered in cases where the operation is an endangerment to life or health, or will result in significant damage.

Astronomically maximum shading time (worst case) is the theoretical time when the sun is during the entire period between sunrise and sunset passing through a cloudless sky and the rotor surface is perpendicular to the solar radiation, and the wind turbine is in operation.

Actual shading time is the realistic estimate of accumulated exposure to periodic shadows. If the irradiance of the direct solar radiation in the direction normal to the incident plane is more than 120 W/m^2, then sunshine and shadows are acceptable.

Relevant emission figures that could occur are defined by ambient weather conditions. The effect of predicted periodic shadow is not considered a significant nuisance if the cumulative astronomical maximum loading at a reference height of 2m above ground level does not exceed 30 hours per calendar year and is not greater than 30 minutes per calendar day.

If the time values for the astronomical maximum shading are exceeded, there are technical measures that can be considered to impose time-limit restrictions on the operation of the wind turbine. An automatic switching unit, with radiation or illumination sensors, which record the specific meteorological situation can allow terms and conditions agreed for shadow flicker time limits to be achieved. Since the value of 30 hours per calendar year was developed using the astronomical maximum loading, automatic switch-off is an appropriate solution to mitigate the actual, real time shadows. The actual real-time shadows are limited to 8 hours per calendar year (Freund 2001).

The sun is assumed to be point-like source and appears on all day.

There is a cloudless sky, sufficient wind to turn the turbines blades. Wind direction corresponds to the azimuth angle of the sun (ie. rotor is perpendicular to the incident direction of the sunlight). Calculations are based on geographic north. Distances between the rotor plane and the tower axis are negligible. Light refraction in the atmosphere is not considered.

Sun angles less than 3 degrees above the horizon are removed from analysis because vegetation and buildings will remove shadow impact.

Annual limits

Wind turbines are only approved if the maximum astronomic shading period of 30 hours per calendar year is not exceeded. A review of complaints relating to shadow flicker at existing systems, has informed the setting of this benchmark. When using an automatic cut off system that does not takes account metrological parameters, the maximum astronomic shading is limited to 30 hours per calendar year. For systems that do take into account metrological parameters (ie intensity of the sun), the actual shading is limited to 8 hours.

Daily Limits
Shadow flicker should be limited to a maximum of 30 minutes per day. The laboratory study by the University of Kiel (Pohl et al 2000) noted that even a one-off exposure to 60 minute duration of shadows can cause stress reactions. For precaution, shading duration is therefore limited to 30 minutes per day.

For planned plants, the astronomic maximum shading period should be used, and for existing plants, the actual shadow duration is used. When this benchmark is exceeded for at least three days, appropriate measures need to be implemented to reduce the impact to guarantee a maximum duration of shading of 30 minutes.

When siting wind turbines, there is an obligation to take precautionary measures to reduce the shadow flicker, taking account of proportionality and the requirements of the planning department.

Exceedance of the allowable emission values for a wind turbine is carried out by emission-verified compliance. Reduction of shadow is carried out by an electronic circuit which calculates the time of shadows at relevant receptors. In determining exact times, the type of receptor (eg. window) should be considered. When indoors, the reference height should be set at the centre of the window. When outdoors, the reference height is set at 2m above ground level. Sunshine duration data should cover a period of at least a year, and the data should be available by a competent authority on request.

Evidence of the amount of shadow flicker needs to be calculated in the context of planning projects and monitoring systems. This allows the shut-down timings for wind turbines to be determined.

Shadow forecast is based on an algorithm which calculates the location, day and time dependent solar position. To ensure uniform implementation, widely available computational models are recommended (DIN 5034-2 1985; VI 3789 1994).

Accuracy of geometric parameters should be ±3-10m. The determination of shadow cast times should have an accuracy of 1min per day. Absolute times are in GMT or BST.

The start and end points of shadow at each relevant receptor point needs to be calculated in relation to the receptor. In the case of several wind turbines, the cumulative contributions need to be taken into account.

As part of the calculation, excerpts are required from topographical maps, as are coordinates of plant locations and receiver points. The result from the software is isoshadow contours (especially the 30 hour contour) for the plant.

Because of the complexities of the calculations, commercial computer programmes should be used to calculate shadow flicker. Forecast times should be presented in appropriate data tables.

Annex 2

Wind Farm Developments Ltd
Willowbank Business Park
Millbrook
Larne
County Antrim
BT40 2SF

02828263320

Wolf Bog Wind Farm, Tildarg, Kells, Co. Antrim

Supporting information for an application to vary condition 10 of planning approval G/2004/0597/F to allow substitution of 5 approved turbines (overall max. height of 96m) with 5 turbines with an overall max. height of 100m

26th May 2006

House	East	North	Elevation	Nearest turbine	Distance to nearest turbine (in m)
House 1	322693	398043	196	T5	1013
House 2	323439	397339	261	T5	860
House 3	323937	396955	284	T2	1191
House 4	323960	396789	276	T2	1194
House 5	324623	396410	239	T2	1883
House 6	323795	396375	248	T2	1086
House 7	323800	396120	226	T2	1199
House 8	322646	395747	242	T1	785
House 9	322036	395546	233	T1	1124
House 10	321604	395629	240	T1	1328
House 11	321229	395620	226	T1	1630
House 12	320777	395677	227	T1	1996
House 13	320071	395846	207	T1	2602
House 14	319779	396250	189	T4	2731
House 15	319864	396693	191	T4	2547
House 16	319685	397088	184	T4	2697
House 17	320382	397379	212	T4	2022
House 18	320344	398066	184	T4	1900
House 19	320711	397982	174	T4	2266
House 20	320956	398217	175	T4	1827
House 21	321313	398433	170	T4	1728
House 22	321807	398122	199	T4	1193

Table 1.1: Locations of houses near Wolf Bog Wind Farm.

Assumptions

It should be noted that the analysis was performed using the following assumptions:

- The sun will always be visible during daylight hours (conservative assumption; the location is known to encounter cloud cover approximately 70% of the year[5].
- The intensity of the shadow will not be affected by the composition of the atmosphere (conservative assumption; the distance over which shadows will be cast depends on how much the light from the sun is diffused, which is in turn dependant on any dispersants, such as humidity or aerosols, between the sun and the turbine[4]).
- The wind will always be sufficient to turn turbine blades at these times (conservative assumption).
- The alignment of the turbine rotor blades with respect to the sun's position will always produce maximum shadow casting (conservative assumption; it is unlikely that the wind, and therefore the rotor blades will track the sun in practice).
- The analysis looks at shadow casting over the complete building frontage rather than over windows only (conservative assumption).

- The intensity of the sun will be insufficient to cast strong shadows at elevations less than 5°.
- There is an absence of local shielding features such as trees (conservative assumption). Terrain shielding, however, is modelled.

Results

The results of the analysis are shown in the following table B2. The times when shadow could occur at each house have been rounded up to the nearest quarter of an hour.

House	Shadow Flicker per year			Comments	
	Days with flicker	Max time in hours	Year Total in hours	Month and time (GMT) ranges having flicker	metres
House 1	30	0.28	7.0	Dec – Jan; 1345 - 1400	1013
House 2	30	0.40	9.5	Mar; 1715 – 1730 Oct; 1645 – 1715	860
House 20	22	0.21	3.7	Nov; 0830 – 0845 Jan – Feb; 0900 - 0915	1827
House 21	70	0.34	15.3	Nov – Jan; 0900 - 1000	1728
House 22	62	0.66	29.2	Dec – Jan; 0930 - 1045	1193 *

Table 1.2: Predicted Shadow Casting of Turbines at Wolf Bog Wind Farm.

The results show that only six of the houses near the wind farm area could be subject to shadow flicker from the Wolf Bog wind farm: the local topography is such that most of the properties will be shielded from shadow by Elliott's Hill or by Big Collin, as shown by Figure 1.1. House 22 would experience the greatest effect in a single day, a maximum of 40 minutes of shadow flicker, over 62 days of the year.

In the winter the sun stays in the southern part of the sky, therefore the buildings that could be affected by shadow casting will be distributed around the north of the turbines. Houses 1, 2, 20, 21 and 22 would be subject to shadow flicker when the sun is rising at around 0900 during the winter, from turbines T2, T4 and T5.

It should be emphasised that this analysis provides an extremely conservative estimate of the extent that habitations will be affected by shadow flicker. Due to low rotational speeds, frequent cloud cover, sufficient turbine to residence separation, intervening vegetation (at houses 1 and 2) and durations of unfavourable turbine-sun alignment, it is concluded that shadow flicker will not cause a significant nuisance to nearby neighbours of the Wolf Bog wind farm.

2.0 REFLECTED LIGHT

A related visual effect to shadow casting is that of reflected light. Theoretically, should light be reflected off a rotating turbine blade onto an observer then a stroboscopic effect would be experienced. In practice a number of factors limit the severity of the phenomenon and there are no known reports of reflected light being a significant problem at other wind farms.

RES

Assessing the impact of shadow flicker from Wolf Bog Wind Farm on nearby habitations

Report No:	01224R00003
Issue No:	03
Classification:	COMMERCIAL IN CONFIDENCE

Prepared:	**Abena Poku-Awuah**	Signed Electronically	23 May 2006
Checked:	**Philip King**	Signed Electronically	24 May 2006
Approved:	**Mike Anderson**	Signed Electronically	24 May 2006

Annex 2

Wind turbines, flicker and photosensitive epilepsy: Characterising the flashing that may precipitate seizures and optimising guidelines to prevent them.

*Graham Harding, *Pamela Harding and †Arnold Wilkins
*Neurosciences Institute Aston University, Birmingham, England and †Department of Psychology University of Essex, Colchester, England.

Running title = Wind turbine Flicker & photosensitive epilepsy
Keywords: photosensitive epilepsy, flicker, rotors, visual discomfort, wind farms, wind turbines, green power.

Corresponding Author: Professor Graham Harding
The ElectroDiagnostic Centre Ltd, Greenfields, Upton Snodsbury, Worcester WR7 4NR,UK
Telephone & Fax: 01905 381 335
Email: gharding@wyenet.co.uk

Summary

Wind turbines are known to produce shadow flicker due to interruption of sunlight by the turbine blades. Known parameters of the seizure provoking effect of flicker, i.e., contrast, frequency, mark-space ratio, retinal area stimulated and percentage of visual cortex involved were applied to features of wind turbines. The proportion of patients affected by viewing wind turbines showed that seizure risk does not decrease significantly until the distance exceeds 100 times the height of the hub.

Since risk does not diminish with viewing distance, flash frequency is therefore the critical factor and should be kept below three per second, i.e., sixty revolutions per minute for a three-bladed turbine. On wind farms the shadows cast by one turbine on another should not be viewable by the public if the cumulative flash rate exceeds three per second. Turbine blades should not be reflective.

Introduction

The provision of energy from renewable sources has produced a proliferation of wind turbines. Environmental impacts include safety, visual acceptability, electromagnetic interference, noise nuisance and visual interference or flicker. Wind turbines are large structures and can cast long shadows. Rotating blades interrupt the sunlight producing unavoidable flicker bright enough to pass through closed eyelids, and moving shadows cast by the blades on windows can affect illumination inside buildings.

Planning permission for wind farms often consider flicker, but guidelines relate to annoyance and are based on physical or engineering considerations rather than the danger to people who may be photosensitive.

Photosensitive Epilepsy (PSE)

PSE occurs in one in 4,000 of the population (Harding & Jeavons 1994). The incidence is 1:1 per 100,000 per annum. Amongst 7-19 year-olds the incidence is more than five times greater (Fish et al 1993). Photosensitivity persists in 75 per cent of patients (Harding et al 1997).

Precipitants

Sunlight is a precipitant of photosensitive seizures, whether reflected from waves, or interrupted as the subject travels past an avenue of trees or railings. In 454 patients Harding & Jeavons (1994) found 33 cases where seizures had been precipitated by flickering sunlight.

Television is a common precipitant of seizures and guidelines now prevent the broadcast of programmes with flicker at rates exceeding 3 flashes per second, the frequency above which the chance of seizures is unacceptably high.

Flicker from rotating blades

The interruption of light by helicopter blades has caused seizures (Johnson 1963, Gastaut & Tassinari 1966, Cushman and Floccare 2007) but to our knowledge there are no reports of seizures induced by rotating ceiling fans.

Large wind turbines usually rotate at between 30 and 60 revolutions per minute (rpm). Many are three-bladed and operate at a constant speed, and at 60 rpm produce flicker at a rate of 3Hz; some two bladed wind turbines also exist. Turbines that rotate faster or have more blades will produce flicker at frequencies for which the chances of seizures are unacceptably high. Smaller variable-speed turbines range between 30 and 300 rpm (Verkuijlen & Westra 1984) and some have more than three blades, so their flicker is within the range for which seizures are likely.

When several turbines are in line with the sun's shadow there is flicker from a combination of blades from different turbines which can have a higher frequency than from a single turbine.

If the blades of a turbine are reflective then there is the possibility of flicker from reflected light at viewing positions that are unaffected by shadows.

Exposure to flicker from a turbine is determined by the hub height and the diameter of the blades, the height of the sun and the direction of the blades relative to the observer. These variables are affected by the time of day, time of year, wind direction, and geographical location (Verkuijlen & Westra 1984). Shadows can be cast on the windows of nearby buildings, affecting the internal illumination giving rise to flicker that cannot be avoided by occupants. Verkuijlen & Westra determined the shadow tracks of wind turbines and their effect relative to the hub height of the rotor. They assumed that the rotor diameter was 75 per cent of the hub height, but many wind turbines deviate from this ratio.

To avoid the problems of shadow flicker Verkuijlen and Westra proposed that wind turbines should only be installed if flicker frequency remains below 2.5 Hz under all conditions, and that wind turbines should be sited where buildings were not in East-NE or WNW directions from the turbine (northern hemisphere recommendations).

Modelling the effects of flicker

1. Shadow flicker

The seizure provoking effects of flicker depend on the time-averaged luminance of the flicker, its contrast, frequency and mark-space fraction, and the area of retina stimulated and are well described (Figure 1).

INSERT FIGURE 1 ABOUT HERE

The area of retina stimulated by flicker from a wind turbine might be expected to depend on the area that the rotors subtend at the eye. However, if the rotors interrupt direct sunlight casting a shadow upon the observer then the luminance of the flicker is likely to be such as to scatter sufficient light within the eye as to stimulate the entire retina with intermittent light. If the eyes are closed, the light is diffused by the eyelids and intermittent light reaches the entire retina.

The luminance contrast ratio of the flicker depends on the extent to which the blades occlude the sun. Given that the sun subtends about 0.5 degrees, it is only completely occluded when the blades subtend more than 0.5 degrees at the eye, ignoring flare. When the observer is at a distance at which the blades subtend less than 0.5 degrees, the contrast of the flicker is reduced. Flicker ceases to be provocative at luminance contrasts less than about 10%, see Figure 1. Assuming that contrasts of less than 10% occur when the width of the turbine blade subtends at the eye an angle that is 10% of the sun's diameter (0.05 degrees) it is possible to set a limit for the distance at which shadow flicker is likely to be seizure provoking. For a turbine blade 1m in width, this distance is 1.14km. Most shadows are likely to be of contrast sufficient to be provocative. It may be insufficient to restrict the siting of turbines to a distance ten diameters from habitation (Clarke).

In EEG laboratories epileptiform EEG activity is induced in photosensitive individuals by a xenon gas discharge lamp providing a series of very brief flashes. ,ie,Laboratory studie,s have not investigated the effect of very brief dark periods in an otherwise bright stimulus (such as might be provided by a wind turbine rotor) However in the case of a seizure induced by helicopter blades reported by Cushman and Floccare (2007) the dark period of the shadow flicker occurred between 24 and 27 times per second. Helicopter blades are usually narrower than those on wind turbines and would provide for a shorter dark interval that might be expected to be less provocative than for a wind turbine blade.

2. Reflected flicker

Flashing can occur by the reflection of sunlight from the gloss surface of blades (Clarke). The blades are likely to cause flicker only if the amount of sun reflected towards an observer varies with the rotation of the blades. Given the shape of the blades, such variation is likely. These considerations introduce the possibility of a danger zone different from than that provided by the shadow cast by the blades.

In the case of reflected sunlight, the flicker may be less bright than that cast by a shadow, and the light scattered within the eye may be insufficient to cause a problem. If so, the effectiveness of the stimulus will depend on the visual angle subtended by the rotor at the observer's eye. This visual angle will be directly proportional to the rotor length (radius) and the distance from which the observer is viewing the rotor.

The visual angle subtended by the flickering light determines the likelihood of seizures. From the studies of Binnie, et al (2002) or Wilkins et al (2005) it is clear that the risk of seizures is in direct proportion to the area of visual cortex stimulated, see Figure 1. For this reason, flicker that is directed at the centre of the visual field is more provocative than flicker in the visual periphery. (The central 10 degrees of vision provide for 90 per cent of the neural output from the retina to the brain.)

INSERT FIGURE 2 ABOUT HERE

Suppose a turbine with blades 75% of hub height is viewed from a distance (Figure 2). The sunlight is not simultaneously reflected from more than one blade given that the angle of the blades relative to the sun will rarely be similar. We will assume that the blades are of uniform width equal to 10% of their (radial) length. The angle at the eye of an observer subtended by any blade is maximum when the blade is at the bottom of its path. Assuming gaze is centred half way up the blade the proportionate area of the visual cortex stimulated can be calculated. According to Drasdo (1977), the proportion of visual cortex (P) to which a circular centrally fixated stimulus, angular radius A, projects is:-

$$P = 1 - e^{-0.0574A}$$

Applying this formula to angular segments of the rotor surface centrally fixated, the area of cortex to which the rotor projects can be calculated and the proportion of patients liable to seizures can be estimated, using the relationship between proportion affected and stimulated area of the cortex (Figure 1). The proportion of patients affected is shown as a function of viewing distance (expressed as a factor of the height of the hub) (Figure 3). Note that the risk of seizures does not decrease appreciably until the viewing distance exceeds 100 times the height of the hub, a distance typically more than 4km.

INSERT FIGURE 3 ABOUT HERE

The above analyses indicate that flicker from wind turbines is potentially a problem at considerable observation distances.. Over 1km, only 25 per cent of the light is expected to be attenuated by the atmosphere (Curcio et al 1953). The effects of luminance on seizure risk are likely to depend on the logarithm of the luminance (Binnie et al, 2002), so any reduction of seizure risk by virtue of the atmospheric attenuation of light is likely to be small.

Discussion

Flicker from turbines that interrupt or reflect sunlight at frequencies greater than 3Hz poses a potential risk of inducing photosensitive seizures. At or below 3 Hz the calculated risk of inducing a seizure should be less than 2? in 133,000 of the photosensitive population. The risk is maintained over considerable distances from the turbine. It is therefore important to keep rotation speeds to a minimum, and in the case of turbines with 3 blades ensure that the maximum speed of rotation does not exceed 60rpm, which is normal practice for large wind farms. The layout of wind farms should ensure that shadows cast by one turbine upon another should not be readily visible to the general public. The shadows should not fall upon the windows of nearby buildings. The specular reflection from turbine blades should be minimised.

Acknowledgements

We confirm that we have read the Journal's position on issues involved in ethical publication and affirm that this report is consistent with those guidelines. None of the authors have any associations which might affect their ability to present and/or interpret data objectively, particularly financial ties to funding sources for the work under review.

References

Binnie,, C. D. Emmett, J. Gardiner, P. Harding, G.F.A. Harrison, D. and Wilkins A. J. (2002). Characterizing the flashing television images that precipitate seizures. SMPTE J. , August: 323-329

Clarke, A.D. A case of shadow flicker/flashing: Assessment and solution. Personal communication.

Curcio, J.A., Drummeter, L.F., Petty, C.C., Steward, H.S. and Butler, C.P. (1953). An experimental study of atmospheric transmission. J. Opt. Soc. Amer. , 43 (2): 97-102.

Cushman, J.T. and Floccare,D.J. (2007) Flicker illness: an under-recognized but preventable complication of helicopter transport. Prehosp. Emerg. Care 11, (1): 85-88

Drasdo, N. (1977) The neural representation of visual space. Nature 266(5602): 554-6.

Fish, D.R., Quirk, J.A., Smith, S.J.M., Sander, J.W.A.S., Shorvon, S.D., Allen, P.J. (1993) National Survey of Photosensitivity and Seizures Induced by Electronic Screen Games (Video Games, Console Games, Computer Games). Interim Findings, London: Dept of Trade & Industry.

Gastaut, H., Tassinari, C.A. (1966) Triggering Mechanisms in Epilepsy. The electroclinical point of view. Epilepsia. 7: 85-138.

Harding, G.F.A. & Jeavons, P.M. (1994) Photosensitive Epilepsy. MacKeith Press, London.

Harding, G.F.A., Edson, A., Jeavons, P.M. (1997) Persistence of Photosensitivity. Epilepsia, 38: 663-9.

Johnson, L. C. (1963) Flicker as a helicopter pilot problem. Aero. . Med. , 34: 306-310.

Verkuijlen, E., & Westra, C.A. (1984) Shadow Hindrance by Wind Turbines. Proceedings of the European Wind Energy Conference.

Wilkins, A.J., Emmett, J., & Harding, G.F.A. (2005) Characterising the patterned images that precipitate seizures and optimizing guidelines to prevent them. Epilepsia. 46: 1212-1218.

Figure 1

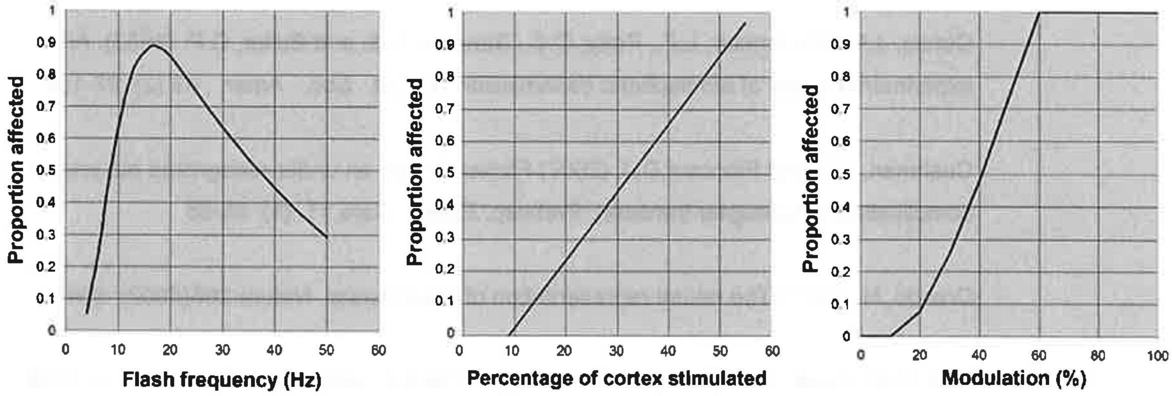


Figure 1. Proportion of patients with photosensitive epilepsy sensitive to flicker, shown as a function of the frequency, the proportion of the cortex to which the flicker projects (estimated from the response to striped patterns, and the modulation depth of the flicker (expressed as a Michelson fraction). The data are taken from Binnie, et al (2002).

Figure 2

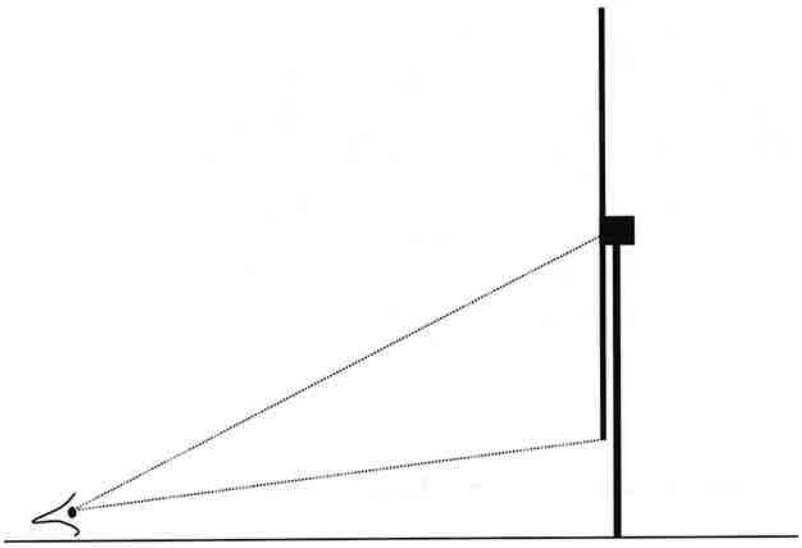


Figure 2. Maximum visual angle is subtended by blades when at the bottom of their path.

Figure 3

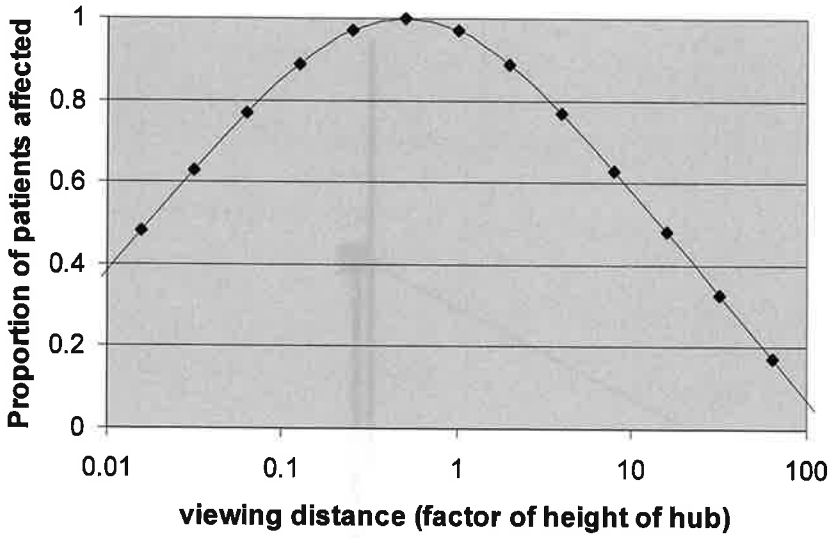


Figure 3. Proportion of photosensitive patients liable to seizures from light reflected from a turbine blade shown as a function of viewing distance. The viewing distance is given as a factor of the height of the hub.

Annex 2

Visual Health Effects and Wind Turbines

"…wind-energy projects create negative impacts on human health and well-being, the impacts are experienced mainly by people living near wind turbines who are affected by noise and shadow flicker." [1]

In addition to noise pollution wind turbines also have visual burdens. [2]

The health impact of visual burdens cannot be underestimated. An epidemiology study conducted by World Health Organization determined a "bad view out of window" increased the risk for depression by 40%. The same study also demonstrated disturbance by noise and sleep disturbance by noise increased the risk of depression 40%, and 100% respectively. [3] In addition to visual burdens wind turbines create noise pollution [4] which can cause annoyance, stress and sleep disturbance. [5], [6], [7], [8], [9] In light of these statistics it is expected that people may suffer adverse health effects from visual and noise impacts of wind turbines.

Rotating wind turbine blades interrupt the sunlight producing unavoidable flicker bright enough to pass through closed eyelids, and moving shadows cast by the blades on windows can affect illumination inside buildings. [10] This effect is commonly known as shadow flicker.

Wind turbine shadow flicker has the potential to induce photosensitive epilepsy seizures however the risk is low with large modern models and if proper planning is adhered to. [11], [12] Planning should ensure the flash frequency does not exceed three per second, and the shadows cast by one turbine on another should not have a cumulative flash rate exceeding three per second. [13]

Wind turbine shadow flicker induced adverse human health effects include annoyance and/or stress. [14], [15], [16], [17], [18]

Wind turbine noise including low frequency noise may also contribute to the overall annoyance.

"Wind turbine noise is easily perceived and annoying even at low A-weighted SPLs….Wind turbines are furthermore prominent objects whose rotational movement attracts the eye. Multimodal sensory effects or negative aesthetic response could enhance the risk of annoyance. Adverse reactions could possibly lead to stress-related symptoms due to prolonged physiological arousal and hindrance to psychophysiological restoration." [19]

No generalized dose-response curves have yet been modeled for wind turbine shadow flicker primarily due to the lack of results of published field studies.

Further investigation into the effects of wind turbine stressors including shadow flicker is required to assist in the development authoritative guidelines designed mitigate potential adverse health effects. [20]

Shadow flicker is also a safety concern. For example it can cause vehicle driver distraction. [21]

Most jurisdictions do not have explicit regulations to protect people from the adverse health effects of shadow flicker. [22]

To mitigate risk to human health wind turbines should be sited to ensure people will not be adversely affected. For example in the northern hemisphere people located East-NE or West-NW from the turbine must be protected from shadow flicker. [23]

Recommended shadow flicker setbacks for current wind turbine designs are 10 rotational diameters which would typically translate to approximately 1000 m. [24]

Greater setback distances may be required when wind turbines are sited on elevated ridges as the shadows can be cast over distances of several kilometres.

It is acknowledged that "…shadow flicker can be an issue both indoors and outdoors when the sun is low in the sky. Therefore, shadow flicker may be an issue in locations other than the home." [25] Shadow flicker modelling must consider human exposure to shadow flicker outside a building.

Protection from wind turbine shadow flicker exposure must be engineered into the design of the wind turbine facility during the planning stage. [26], [27]

To ensure protection from adverse human health effects a shadow flicker study must be conducted during the planning stage of a wind turbine facility. The shadow flicker study should:

· Calculate shadow flicker based on the actual location of the wind turbines.

· Calculate shadow flicker exposure on the entire neighbouring properties and not just the "receptor (house)".

· Calculate shadow flicker for both sun and moon induced flicker using conservative assumptions to ensure maximum protection against adverse human health effects and safety risks.

· Protect against photosensitive epilepsy by ensuring the flash frequency does not exceed three per second, and the shadows cast by one turbine on another do not have a cumulative flash rate exceeding three per second.

Conclusions: Wind Turbines and Shadow Flicker

Based on the best available science the following conclusions can be drawn.

· Wind turbines produce noise and visual burdens.

· Scientific research confirms visual impacts can adversely affect human health.

· Wind turbine shadow flicker has the potential to induce photosensitive epilepsy seizures however the risk is low with large modern models and if proper planning is adhered to.

· Wind turbine shadow flicker induced adverse human health effects include annoyance and/or stress.

· No generalized dose-response curves have yet been modelled for wind turbine shadow flicker primarily due to the lack of results of published field studies.

· Protection from wind turbine shadow flicker exposure must be engineered into the design of the wind turbine facility during the planning stage.

[1] National Research Council (NRC). Environmental Impacts of Wind-Energy Projects, 2007 NRC, Washington, DC

[2] Energy, sustainable development and health .Background document for the Fourth Ministerial Conference on Environment and Health, 23-25 June 2004, Geneva.

[3] World Health Organization, Large analysis and review of European housing and health status (LARES) Preliminary overview, 2007

[4] Energy, sustainable development and health. Background document for the Fourth Ministerial Conference on Environment and Health, 23-25 June 2004, Geneva.

[5] W. David Colby, M.D et al., Wind Turbine Sound and Health Effects, An Expert Panel Review 2009, Prepared for American Wind Energy Association and Canadian Wind Energy Association

[6] Arlene King M.D., Ontario Ministry of Health and Long Term Care Memorandum, October 21, 2009,

[7] Copes, R. and K. Rideout. Wind Turbines and Health: A Review of Evidence. Ontario

Agency for Health Protection and Promotion 2009

[8] Pedersen et al., 2008,Project WINDFARMperception Visual and acoustic impact of wind turbine farms on residents

[9] Thorne et al, Noise Impact Assessment Report Waubra Wind Farm Mr & Mrs N Dean Report No 1537 - Rev 1 - July 2010

[10] Graham Harding, Wind Turbines, Flicker, And Photosensitive Epilepsy: Characterizing The Flashing That May Precipitate Seizures And Optimizing Guidelines To Prevent Them, 2008

[11] Smedley AR et al, Potential Of Wind Turbines To Elicit Seizures Under Various Meteorological Conditions., 2009

[12] Graham Harding, Wind Turbines, Flicker, And Photosensitive Epilepsy: Characterizing The Flashing That May Precipitate Seizures And Optimizing Guidelines To Prevent Them, 2008

[13] Ibid.

[14] National Research Council (NRC). Environmental Impacts of Wind-Energy Projects, 2007 NRC, Washington, DC

[15] Copes et al, Wind Turbines And Environmental Assessment, National Collaborating Centre for Environmental Health, June 23, 2009

[16] Copes, R. and K. Rideout. Wind Turbines and Health: A Review of Evidence. Ontario

Agency for Health Protection and Promotion 2009

[17] Minnesota Department of Health (MDH) 2009 Public Health Impacts of Wind Turbines

[18] Pedersen et al., 2008,Project WINDFARM perception: Visual and acoustic impact of wind turbine farms on residents

[19] Pedersen Eja, Human Response To Wind Turbine Noise: Perception, Annoyance And Moderating Factors , May 23, 2007

[20] Copes et al, Wind Turbines And Environmental Assessment, National Collaborating Centre for Environmental Health, June 23, 2009

[21] Minnesota Department of Health (MDH) 2009 Public Health Impacts of Wind Turbines

[22] National Research Council (NRC). Environmental Impacts of Wind-Energy Projects, 2007 NRC, Washington, DC

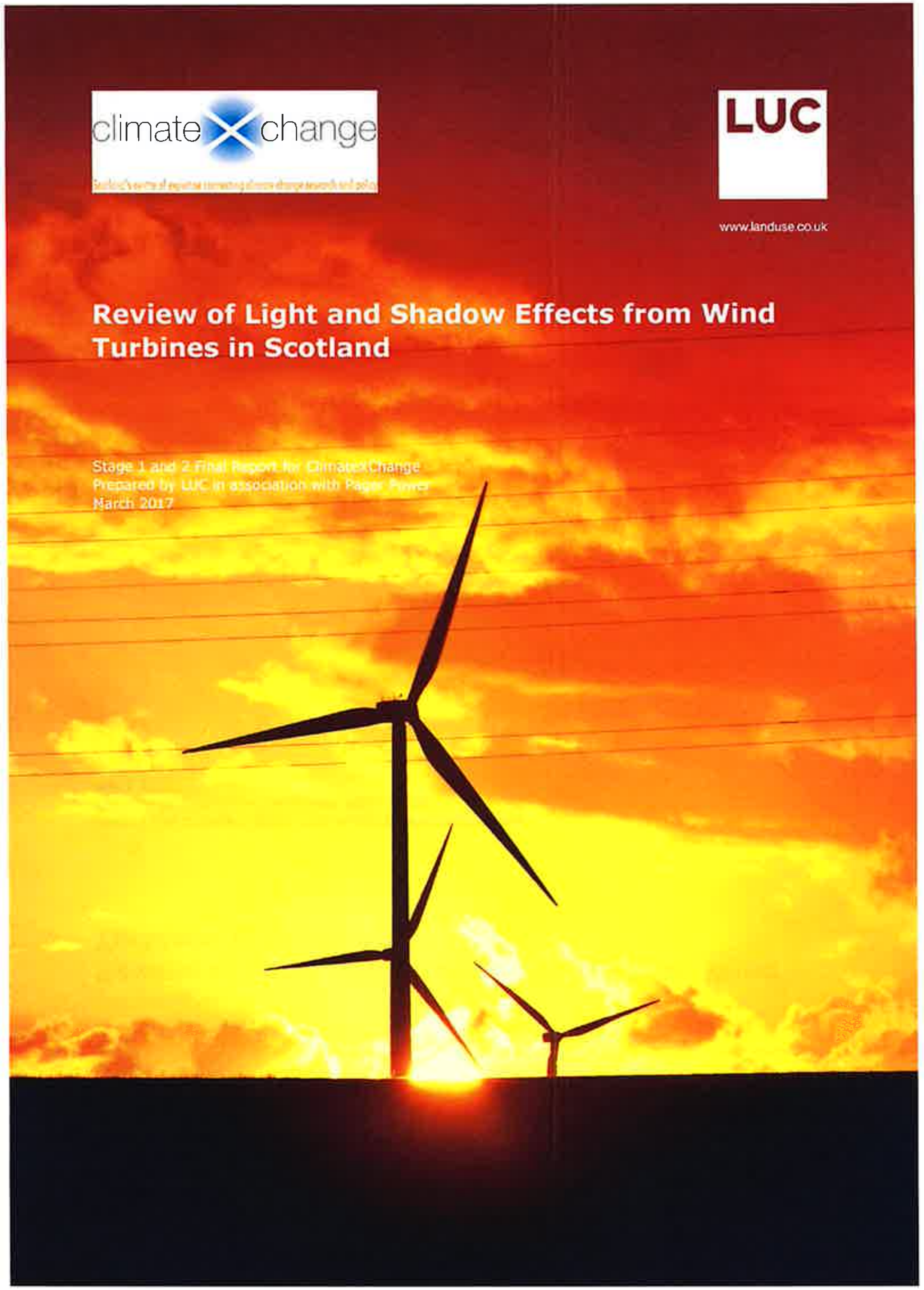
[23] Verkuijlen E, Westra CA. (1984) Shadow hindrance by wind turbines. Proceedings of the European wind Energy Conference. October 1984, Hamburg, Germany.

[24] Minnesota Department of Health (MDH), Public Health Impacts of Wind Turbines, 2009

[25] Minnesota Department of Health (MDH) 2009 Public Health Impacts of Wind Turbines

[26] National Research Council (NRC). Environmental Impacts of Wind-Energy Projects, 2007 NRC, Washington, DC

[27] Minnesota Department of Health (MDH) 2009 Public Health Impacts of Wind Turbines



Project Title: Review of Light and Shadow Effects from Wind Turbines in Scotland

Client: ClimateXChange

Version	Date	Version Details	Prepared by	Checked by	Approved by
V1	15/06/16	Stage 1 Interim Findings Draft Report	Susanne Underwood Kai Frolic	Nick James	Nick James
V2	10/03/17	Stage 1 and 2 Findings Draft Report	Susanne Underwood	Nick James	Nick James
V3	28/3/17	Stage 1 and 2 Findings Final Draft Report	Susanne Underwood	Nick James	Nick James
V4	30/3/17	Stage 1 and 2 Findings Final Report	Susanne Underwood	Nick James	Nick James

A4 Portrait Report

Annex 2

LUC

www.landuse.co.uk

Review of Light and Shadow Effects from Wind Turbines in Scotland

Stage 1 and 2 Stage 1 and 2 Final Report for ClimateXChange
Prepared by LUC in association with Pager Power
March 2017

Planning & EIA
Design
Landscape Planning
Landscape Management
Ecology
Mapping & Visualisation

LUC EDINBURGH
28 Stafford Street
Edinburgh
EH3 7BD
T +44 (0)131 202 1616
edinburgh@landuse.co.uk

Offices also in:
London
Bristol
Glasgow

Contents

Executive summary

LUC, in association with Pager Power was commissioned by ClimateXChange in March 2016 to undertake a review of how light and shadow effects from wind farms are considered in the development planning process in Scotland. ClimateXChange published the report *Wind Farm Impacts Study* in July 2015, which made a number of recommendations for better guidance on predicting and mitigating the impacts of light and shadow flicker effects from wind turbines. This report aims to contribute to meeting these recommendations.

- Stage 1 of the project involved a review of guidance and tools (including modelling software that are currently available and in use in Scotland), and a literature review to examine the following:
    - to describe the origins, rationale, and use of the 10-rotor diameter distance threshold for shadow flicker;
    - to explore the definition of different types of receptors to light and shadow related effects;
    - to understand the extent to which assessments are based on worst case and / or likely case scenarios;
    - the understand the definition of significance of exposure to effects of light and shadow related effects;
    - to understand how assessment takes latitude into account.

Stage 2 of the work examined the approach to light and shadow effects in the Scottish planning system for five case study planning authorities through:

- analysis of the approach to shadow flicker within five planning applications for wind turbines;
- analysis of the policy framework for shadow flicker within the case study planning authorities.

The second stage of the work also carried out a focused literature review of public perceptions of light and shadow effects and presentation and communication of light and shadow issues to non-specialists.

The literature review explored:

- Origins of the 10 x rotor blade diameter distance threshold;
- Other factors relevant to the 10 x rotor blade diameter distance;
    - Shadow flicker and photo sensitive epilepsy
    - Twenty percent coverage of the sun
    - Setback distances in other countries
    - Shadow dissipation and atmospheric interference
    - Relationship between noise thresholds and shadow flicker
    - Timing of shadow flicker
- Definitions of receptors;
- Significance of effects and use of worst case and likely case scenarios in assessments;
- High latitude assessments.

The Stage 2 review of practice and literature, plans and SPG for the case studies examined:

- Definition of shadow flicker;
- Definition of shadow throw;

- Night time lighting;
- Acknowledgement of reflected light issues;
- Reference to separation distances and site specific issues;
- Reference to ten x rotor diameter;
- Reference to 130 degrees either side of north;
- Significance thresholds;
- Definition of receptors;
- Impacts on receptors;
- Parameters when shadow flicker may occur;
- Reference to worst case and likely case scenarios and factors taken into account in calculating likely case scenario;
- How latitude is taken into account;
- Computer modelling used;
- Cumulative effects;
- Reference to policy and guidance;
- Mitigation.

Recommended content of guidance on shadow flicker

Recommendation 1: Definition of Shadow Flicker

There needs to be consistency between guidance documents and planning policy on the definition of shadow flicker. The most widely used definition of shadow flicker within guidance documents is as follows:

"*Under certain combinations of geographical position, time of day and time of year, the sun may pass behind the rotor and cast a shadow over neighbouring properties. When the blades rotate, the shadow flicks on and off; the **effect or impact** is known as "shadow flicker*".

Recommendation 2: Definition of Shadow Throw

The literature review identified that experience of shadows outdoors is not clearly recognised within policy and guidance, and the case studies identified limited reference to this effect. Although this is not identified as a significant issue, it is recommended a definition of the outdoor effects of light and shadow related effects is included for clarity. A possible definition is '*a moving shadow across open ground*'.

Recommendation 3: Acknowledgement of reflected light issues

It is recognised that reflected light issues are not identified as a significant issue within the guidance documents, literature or case studies. For completeness, guidance should include acknowledgement of the issue of reflected light.

Recommendation 4: Night time lighting

No significant issues associated with night time lighting were identified in the study. The guidance could acknowledge impacts of night time lighting through cross reference to Scottish Natural Heritage guidance. It is recommended that guidance should clarify the likely requirement for visible lighting, and how potential landscape and visual effects should be addressed.

Recommendation 5: Definition of parameters when shadow flicker may occur

The guidance should explicitly set out the parameters when shadow flicker may occur and which are required for likely case scenario modelling. There appears to be significant variation in the factors taken into account when calculating 'likely case' shadow flicker, and the case study review identified a lack of clarity in presentation of findings. The guidance should explicitly set out the parameters which are required for likely case scenario modelling.

Recommendation 6: Reference to the degrees either side of north affected by shadow throw

Although the Scottish guidance does not refer to the parameter of 130 degrees either side of north, some of the case study examples referenced this figure, in line with other UK guidance. Scottish guidance should not include reference to the occurrence of shadow throw 'within 130 degrees either side of north'. In line with the recommendation that shadow flicker assessment should be based on significance thresholds, guidance should avoid reference to limiting the area of assessment.

Recommendation 7: Exclusion of reference to the 10 rotor diameter distance

Although a number of other factors may contribute to the significance of shadow flicker potentially being greatest closer to the wind turbines, the ten rotor diameter distance threshold does not appear to have robust evidence within the literature examined.

Secondly, there is frequent misapplication of the ten rotor diameter distance as a limit within which shadow flicker modelling is applied.

Recommendation 8: Thresholds for exposure to shadow flicker and use of worst case and likely case scenarios

The German guidelines are clear on the exposure thresholds for both worst case and likely case scenarios of 30 hours per year or 30 minutes a day worst case and eight hours a year likely case. These thresholds are most widely quoted, although some countries have set their own limits.

The case study review has identified inconsistency in the definition and application of 'significance' in relation to predicted shadow flicker both worst case and likely case, and the application of a precautionary approach in the decision making process. There is a need for guidance on the thresholds of exposure to shadow flicker in Scotland.

Recommendation 9: Definition of different types of receptors to light and shadow related effects

The case study review identified that there needs to be clarity on the different approaches to assessing significance of levels of effect at financially involved properties. This is an established difference in noise assessment, however it is unclear how appropriate this is in relation to shadow flicker, particularly in light of the lack of clarity in assessments on 'significance'.

The study review was inconclusive in relation to the definition of different types of receptor based on other variables and their sensitivity to light and shadow related effects. There was some reference to residential and business use, and the interviews highlighted the need to consider impacts on rural businesses.

There is a need to include guidance on different factors which may affect the sensitivity of different types of receptor to light and shadow related effects.

Recommendation 10: Approach to assessing cumulative effects

The study found limited reference to the identification and assessment of cumulative effects, however it was identified as an issue covered in the case studies and an area where there was a lack of clarity or consistency in approach. The guidance should set out the need to consider cumulative shadow flicker and further guidance on how this should be approached

Role of plans and supplementary guidance

Local plans provide almost no coverage of shadow flicker issues. Supplementary planning guidance and other local authority guidance relevant to renewable energy provide coverage of some issues, and reflect national guidance in relation to the ten rotor diameter distance, but lack detail on key issues such as significance of effects. Furthermore the case study review identified a clear reversion in the Environmental Statements to national level guidance and documents in relation to shadow flicker with very limited reference to supplementary planning guidance.

Decision making and conditions

Four of the case studies demonstrated a precautionary approach to shadow flicker through the conditions attached to the decision. This was irrespective of the level of effects identified in the shadow flicker report. This supports the finding from the case study review of lack of clarity and accessibility of the shadow flicker reports, and the challenges of gaining a clear understanding of the extent and significance of shadow flicker.

Presentation and communication of Shadow Flicker to non-specialists

A number of issues have been identified in relation to the clarity of presentation and communication of shadow flicker at the technical level. It appears that some of these issues are transferred into other literature presented to non-specialists. The study also identified some confusion over the definition of the impact of shadow flicker in terms of amenity or nuisance.

Areas for future research

The project has identified a number of questions which could be addressed through modelling to provide robust findings to support the study conclusions, particularly in relation to the ten rotor diameter distance.

Thresholds of exposure: Modelling exposure thresholds as distance thresholds based on worst case scenario in terms of wind direction, cloud cover and window orientation. This would allow the definition of an area on a map of where exposure exceeds the threshold set out in the German guidance, and the distances at which these occur and if these are beyond ten rotor diameters. A sophisticated model would be required to account for these parameters, and the most appropriate model identified to date is WindPRO, although other models may be developed or improved in the future.

20% obscuration of the sun: Modelling how different turbine dimensions affect what distance from the wind turbine the threshold of 20% obscuration of the sun is reached. This would allow an understanding of whether the ten rotor diameter distance threshold potentially relates to the figure of 20% obscuration of the sun. Again, at this point in time the only model which allows the input of this variant is identified as WindPRO, although other models may be developed or improved going forward.

130 degrees of north: Modelling of the same dimension turbine at different latitudes to identify the area affected by shadow flicker.

Modelling shadow flicker extent in relation to receptors at significantly lower elevation than the wind turbines: This would allow evidence to be provided on the effects of topography on the extent and duration of shadow flicker.

1 Introduction

1.1 LUC in association with Pager Power was commissioned by ClimateXChange in March 2016 to undertake a review of how light and shadow effects from wind farms are considered in the development planning process in Scotland. ClimateXChange published the report *Wind Farm Impacts Study* in July 2015[1], which made a number of recommendations for better guidance on predicting and mitigating the impacts of light and shadow flicker effects from wind turbines. This report aims to contribute to meeting these recommendations.

1.2 This report sets out the findings of the study. The project brief outlined that these findings are intended to feed in to the Scottish Government thinking on how light and shadow effects are assessed and considered through the planning process, and potentially inform future guidance for developers and planning authorities.

Study scope

1.3 The scope of Stage 1 of the project is as follows:

- Review of guidance and tools (including modelling software that are currently available and in use in Scotland);
- Literature review to examine the following:
  - to describe the origins, rationale, and use of the 10-rotor diameter distance threshold for shadow flicker;
  - to explore the definition of different types of receptors to light and shadow related effects;
  - to understand the extent to which assessments are based on worst case and / or likely case scenarios;
  - the understand the definition of significance of exposure to effects of light and shadow related effects;
  - to understand how assessment takes latitude into account.

1.4 Stage 2 of this work follows on from Stage 1 and examines:

- Light and shadow effects in the Scottish planning system;
- A literature review of public perceptions of light and shadow effects;
- Discussions with development planners and environmental health officers.

1.5 Stage 3 of the work draws together the findings from both stages of the work to make clear recommendations on:

- definitions of light and shadow effects associated with wind turbine development;
- the requirement and content of guidance on the light and shadow effects associated with wind turbine development, for Scotland;
- tools and methods of predicting wind turbine light and shadow effects;
- distances, thresholds, receptors, making judgements about significance;
- role of development plans, supplementary planning guidance, decision making, conditions and monitoring in addressing shadow flicker issues;

[1] SLR and HoareLea consultants (2015) Wind Farm Impacts Study Review of the visual, shadow flicker and noise impacts of onshore wind farms. ClimateXChange. Available at: http://www.climatexchange.org.uk/files/3414/3578/2608/FINAL_REPORT_Wind_Farm_Impacts_Study_July_2015_ISSUE.pdf

- presentation and communication of light and shadow issues to non-specialists.

Summary of previous report findings

1.6 There have been two significant reports published in the UK on light and shadow related effects in recent years, and the key findings from these are summarised below. The second study prepared for ClimateXChange was influential on the issues being investigated through this report.

Update of UK Shadow Flicker Evidence Base, Department for Energy and Climate Change[2]

1.7 This report aimed to enable the former Department of Energy and Climate Change (DECC) to advance current understanding of the shadow flicker effect, and presents an update of the evidence base which has been produced by carrying out a thorough review of guidance, literature and assessment methodologies.

1.8 The key points are as follows:

- Planning guidance in the UK requires developers to investigate the impact of shadow flicker, but does not specify methodologies.
- The current recommendation in Companion Guide to PPS22 (2004) to assess shadow flicker impacts within 130 degrees either side of north is considered acceptable, as is the 10 rotor diameter distance from the nearest property. This is a 'one size fits all' approach that may not be suitable depending on the latitude of the site.
- There is no standard methodology that all developers employ when introducing environmental and site specific data into shadow flicker assessments.
- All computer model assessment methods (eg. WindPRO, WindFarm and Windfarmer) use a 'worst case scenario' approach and do not consider 'likely case' factors such as wind speed and cloud cover[3].
- It is considered that the frequency of the flickering caused by the wind turbine rotation is such that it should not cause a significant risk to health[4].
- Mitigation measures employed to operational wind farms have proved successful, to the extent that shadow flicker cannot be considered to be a major issue in the UK.

1.9 The DECC report contains the majority of shadow flicker related references which were identified and reviewed for this current study, however this current study asks a number of different questions of the literature sources than were posed by the DECC report.

Wind Farm Impacts Study: Review of the visual, shadow flicker and noise impacts of onshore wind farms[5]

1.10 This document explores whether the impacts predicted by wind farm developers, at the time of planning application submission, are consistent with the impacts experienced once the wind farm is operational. It aims to inform any future decisions on changes to Scottish Government online planning guidelines and good practice on managing the impacts of wind farms on local residents.

1.11 Shadow flicker was assessed at all ten of the case study wind farms for properties where it could occur based on the distance to the turbine(s). The shadow flicker related findings were as follows:

- Some participants noted that they experienced shadow flicker even though they lived in properties beyond the distance at which shadow flicker is currently predicted to occur.

[2] Parsons Brinckerhoff (2011) Update of UK Shadow Flicker Evidence Base, Department for Energy and Climate Change

[3] Note that GH Windfarmer and WindPRO can both incorporate wind direction. WindPRO can incorporate cloud cover

[4] Specifically in relation to modern, larger turbines which rotate at a lower frequency.

[5] SLR, Hoare Lea Acoustics (2015) Wind Farm Impacts Study Review of the visual, shadow flicker and noise impacts of onshore wind farms, ClimateXChange

- There are no standard significance criteria to assess shadow flicker impacts and no statutory limit or guidance to stipulate acceptable levels of shadow flicker.
- Modelling of shadow flicker that includes data gathered through a house-by-house assessment of the potentially affected properties provides a more robust approach.
- A range of lighting effects impact people living close to wind farms, none of which were found to be clearly defined.
- A clear(er) definition of all shadow and light effects with reference to parameters such as the distances, directions, light and weather conditions in which they can occur would help both assessments and public understanding of this particular impact.
- In the process of developing new guidance, it would be beneficial to carry out further research to improve understanding of light and shadow effects on residents within 2 km.

Definitions of light and shadow related effects

1.12 Within the two documents outlined above, the following types of light and shadow effect were identified and defined. The documents acknowledge that there is no standard definition of shadow flicker, but the following text has been identified from the reports as referring to the different light and shadow effects to help provide a baseline for this report. The definitions of light and shadow related effects within the wider document base are explored in the body of the report.

Table 1.1 Definitions of light and shadow related effects within the Update of the UK Shadow Flicker Evidence Base, and the Wind Farm Impacts Study

Light and shadow related effect	Update of UK Shadow Flicker Evidence Base	Wind Farm Impacts Study
Shadow flicker	Includes two definitions used within the text: 'The term "shadow flicker" refers to the flickering effect caused when rotating wind turbine blades periodically cast shadows over neighbouring properties as they turn, through constrained openings such as windows' 'blade shadows passing across windows'	generally is taken to mean shadow effects caused by the movement of rotors which occurs at distances of up to ten times the rotor diameter (10 x rotor diameter) of the relevant turbines
Shadow throw		*Includes two definitions used within the text:* 'taken to mean shadow effects which occur beyond ten rotor diameters distance' 'when individual(s) outside a building are affected by the shadow cast by turbine(s) at frequent intervals' (as defined for the questionnaire that formed part of the study)
Passing shadows	Blade shadows passing across open ground in an outdoor location	
Strobe effect / Glint and glare	'refers to the flashing of reflected light which can be visible from some distance (This phenomenon has largely been ameliorated by the development of an industry standard (light grey semi-matt) for the colour and surface finish of turbine blades, and was disregarded from the study).'	sun glinting off turbines
Night time lighting	No reference	Identified as an impact, but not explored in any detail

1.13 Night time lighting is considered as a potential source of landscape and visual impact. This is not an issue which has emerged through the literature review, and therefore is identified as more appropriately explored through the review of case studies in Stage 2 of the project.

2 Methodology

Introduction

2.1 This chapter of the report sets out the method and approach to carrying out the different stages of the research.

Stage 1: Review of current guidance

Guidance

2.2 The first task in the study involved the review of the following guidance documents in the UK:

- Scottish Planning Policy (2014)[6];
- Scottish Government (Updated May 2014) Online renewables planning advice[7];
- National Planning Policy Framework Planning Practice Guidance Renewable and low carbon energy (updated 2015)[8];
- Department of Communities and Local Government (2013) Planning practice guidance for renewable and low carbon energy 2004 (withdrawn on 7 March 2014)[9];
- Best Practice Guide to PPS18: Renewable Energy (2009)[10];
- Welsh Assembly Government Practice Guidance Planning Implications of Renewable and Low Carbon Energy (2011)[11].

2.3 These documents were reviewed in a framework which draws out how they approach or refer to the following:

- Definition of shadow flicker;
- Reference to shadow throw;
- Reference to other light related effects;
- Reference to circumstances of occurrence of shadow flicker including;
  - Reference to 130 degrees either side of north;
  - Reference to 10 rotor diameter;
  - Other references to distance and shadow flicker;
- Reference to thresholds for duration of effect.

[6] Scottish Government (2014) Scottish Planning Policy. Available at: http://www.gov.scot/Resource/0045/00453827.pdf

[7] Scottish Government (2014) Online renewables planning advice [illegible]

[8] Department for Communities and Local Government (2015) http://planningguidance.communities.gov.uk/blog/guidance/renewable-and-low-carbon-energy/particular-planning-considerations-for-hydropower-active-solar-technology-solar-farms-and-wind-turbines/

[9] Department of Communities and Local Government (2013) Planning practice guidance for renewable and low carbon energy (withdrawn on 7 March 2014) Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/225689/Planning_Practice_Guidance_for_Renewable_and_Low_Carbon_Energy.pdf

[10] Department of Environment (2009) Best Practice Guidance to Planning Policy Statement 18 'Renewable Energy'. Available at: http://www.planningni.gov.uk/index/policy/planning_statements/planning_policy_statement_18_renewable_energy_best_practice_guidance.pdf

[11] Welsh Assembly Government (2011) Practice Guidance Planning Implications of Renewable and Low Carbon Energy. Available at: http://gov.wales/docs/desh/publications/110228planimplicationsen.pdf

2.4 The next step was to identify other relevant overseas guidance, where this is referred to in UK assessments or where it has been instrumental in informing guidance or practice.

2.5 This was undertaken by identifying a number of shadow flicker assessments from within the UK, and examining their methodology to identify what guidance documents have been referred to. This examined ten assessments (see References). This review recorded the following:

- Proposal name;
- Date;
- Local authority;
- Guidance referred to.

2.6 Any guidance identified within the documents was reviewed against the framework used for the UK guidance documents. Reference to any other documents relevant to the literature review was also noted.

Review of tools and methods

2.7 The review of tools and methods was undertaken by Pager Power, and updates the review contained in the DECC (2011) review of shadow flicker. The stages included:

- Review of the use of modelling programs and add on packages. This aimed to identify the range of programs used, identify the most popular programs, and also differing perceptions on the acceptance of different programs.
- Comparative review of the inputs to the modelling programs;
- Comparative review of the outputs to the modelling programs;
- Commentary on the potential implications of the differing inputs and related outputs for the accuracy and interpretation of the model results.

Literature review

2.8 The targeted literature review focused on exploring key issues identified by the earlier ClimateXChange research and the DECC (2011) report. It involved searches of two bodies of literature.

2.9 The first involved reviewing renewable energy supplementary planning guidance from local authorities across the UK to identify references to light and shadow related effects. This identified:

- references to receptors, definition and sensitivity of different receptors;
- reference to significance of effects;
- reference to worst case/likely case scenarios;
- references to latitude, and how this is included within modelling.

2.10 The second tranche searched for journal articles/reference material, and documents referenced within these to identify source documents for:

- origins of the 10x rotor blade diameter;
- references to receptors, definition and sensitivity of different receptors;
- reference to significance of effects;
- reference to worst case/likely case scenarios;
- references to latitude, and how this is included within modelling.

2.11 As set out in the original submission the outputs from Stage 1 included a presentation of the findings to the project steering group, covering:

- Current guidance on shadow flicker;
- Current software and tools used to predict the occurrence of shadow flicker;

- Origins, rationale and use of the 10 x rotor diameter distance threshold;
- Approaches to issues including the definition of receptors, assessment of worst case or likely case, calculation of significance and high latitude practice;
- Recommendations on how Scottish guidance, definitions, assessment methodologies and tools could be improved.

Stage 2

2.12 The second stage of the work comprised a review of practice in Scotland, particularly in terms of the way that light and shadow effects are addressed in the Scottish planning system, and a review of public perceptions of light and shadow effects.

2.13 Specifically this involved the selection and review of case studies, follow up interviews and a review of literature sources related to public perceptions of light and shadow effects.

Selection of case studies

2.14 The review of light and shadow effects in the Scottish planning system was carried out through a small case study review of a planning application for a wind energy development with shadow flicker issues for each of five planning authorities. The selection of case study planning authorities was initially based on those with a higher occurrence of wind energy development with the intention of achieving a latitudinal spread.

2.15 A request for selection of possible case studies where shadow flicker was an issue was made to the Scottish Government, and the Department of Planning and Environmental Appeals (DPEA). Discussion of the possible approach to selection of case studies was also made with some of the project steering group. However approaching the planning authorities for suggested case studies highlighted the challenges of individual planners having a sufficient overview of planning applications, and the relatively low profile of shadow flicker in comparison to other wind farm related issues.

2.16 Following challenges in the identification of specific case study examples by this approach, a revised tailored approach using Geographical Information System (GIS) analysis was employed.

2.17 The case studies were identified from GIS analysis of the LUC windfarm database, which shows the mapped locations of wind turbines and wind farms across the UK. This was combined with map data on the location of buildings to the wind turbines. This allowed the identification of wind turbines with the greatest number of buildings within 500m. This provided a clearer focus to the search for case studies where shadow flicker had been assessed in relation to nearby properties, (rather than a those with shadow flicker statements concluding that there were no properties within the required threshold for assessment).

2.18 Based on the analysis, the five local planning authorities included in this stage of the work were identified as:

- Aberdeenshire;
- Angus;
- Fife;
- North Lanarkshire;
- Perth and Kinross.

Case study analysis

2.19 The case study analysis involved analysis of the relevant planning policy framework and detailed review of online planning documentation in relation to the case study planning application. This included the relevant information from the planning application (including the Environmental Statement where relevant), the Report of Handling and Decision. The analysis for each case study was structured around the following headings, as identified from Stage 1 of the study.

- Definition of shadow flicker;
- Definition of shadow throw;
- Night time lighting;
- Acknowledgement of reflected light issues;
- Reference to separation distances and site specific issues;
- Reference to ten rotor diameter;
- Reference to 130 degrees of north;
- Significance thresholds;
- Definition of receptors;
- Impacts on receptors;
- Reference to worst case and likely case;
- Parameters when shadow flicker may occur;
- Factors taken into account in calculating likely case scenario;
- How latitude is taken into account;
- Computer modelling used;
- Cumulative effects;
- Reference to policy and guidance;
- Mitigation.

2.20 The analysis was able to draw conclusions regarding the key issues surrounding each of these topics.

Interviews

2.21 Interviews were sought with the case study planning authorities and used to test out the emerging issues and recommendations from the case study review. The interviews presented some difficulties in gaining participation from all of the case study planning authorities, due to staff changes from the relevant contacts for the case studies. Contact was made with all of the case study planning authorities and interviews or written feedback provided by two planners and two environmental health officers from three planning authorities.

Public perceptions literature review

2.22 Stage 2 of the study also sought to identify and review literature on the extent to which public perceptions of shadow flicker match predicted and actual effects and to make recommendations on how future research and guidance should aim to close any gap. This involved search and review of media articles relating to shadow flicker, wind farm opposition group material and wind industry material.

2.23 The final recommendations and conclusions draw on the findings from both stages of the project.

3 Stage 1: Review of current UK guidance

Introduction

3.1 The first stage of the project separates out the findings from the review of current UK guidance, from those of the wider literature review. Although there are key issues of overlap between the two tranches of work, it was seen as important to differentiate where appropriate. Cross references to the findings of the literature in relation to the findings from the review of guidance are provided where appropriate, and the overall conclusions in Section 6, bring the findings of both elements of the work together.

Review of current UK guidance

3.2 The review of current UK guidance aims to establish the baseline parameters used in relation to the definition and assessment of light and shadow related effects.

Definition of Shadow Flicker

3.3 The purpose of the review of the definition of shadow flicker and other light and shadow related effects in current UK guidance documents is to identify consistency or differences between the definitions. This will identify if an appropriate definition exists which could be recommended as a standard definition, as no standard definition exists.

3.4 Definitions of shadow flicker were not explored within the Update of the Shadow Flicker Evidence Base DECC (2011), although the document itself did define shadow flicker. The Wind Farm Impacts Study recommended clearer definition of light and shadow related effects, and referred to the definitions in general use, but did not analyse them or provide recommendations.

3.5 Four of the national government guidance documents defined shadow flicker as set out in the following box, with some variation between the use of the word 'effect' or 'impact'.

> Under certain combinations of geographical position, time of day and time of year, the sun may pass behind the rotor and cast a shadow over neighbouring properties. When the blades rotate, the shadow flicks on and off; the **[effect[12] [13] or impact[14] [15]]** is known as "shadow flicker".

3.6 Scottish Planning Policy refers to shadow flicker but does not define it. The Welsh Government document[16] provides a simplified definition, similar to the above, '*Shadow flicker can occur when the sun passes behind the rotors of a wind turbine, which casts a shadow over neighbouring properties that flicks on and off as the blades rotate.*'

3.7 The literature review raised a number of more complex issues in relation to definitions of the effect than the findings from the review of guidance. The definition of shadow flicker (and other light related effects) needs to be comprehensive in responding to the issues which they raise for people. As such, the recommendations for the definition of shadow flicker and other light related effects is made in the conclusions, where the findings from the review of guidance and the literature review can be drawn together.

> **Key issues: Definition of Shadow Flicker and Shadow Throw**
>
> Shadow flicker and shadow throw (also referred to as 'passing shadows') should both be defined. The most widely used definition of shadow flicker within guidance documents is as follows:
>
> *Under certain combinations of geographical position, time of day and time of year, the sun may pass behind the rotor and cast a shadow over neighbouring properties. When the blades rotate, the shadow flicks on and off; the **effect or impact** is known as "shadow flicker".*
>
> A definition of the outdoor effects of light and shadow related effects was not identified within the guidance, and has emerged from the literature review and review of Supplementary Planning Guidance. A possible definition is '*a moving shadow across open ground'.*

Reference to other light and shadow related effects

3.8 Reference to other light and shadow related effects within the national government guidance documents was limited to the issue of reflected light. These were referred to by the National Planning Policy Framework Planning Practice Guidance Renewable and low carbon energy, the withdrawn DCLG Planning Practice Guidance for renewable and low carbon energy, and the Northern Ireland Department of the Environment Best Practice Guide to PPS18: Renewable Energy. The Scottish Government and Welsh Assembly Government documents do not refer to these effects.

3.9 The most detailed reference is provided by the Northern Ireland Department of the Environment Best Practice Guide to PPS18:

> *A109. Turbines can also cause flashes of reflected light, which can be visible for some distance. It is possible to ameliorate the flashing but it is not possible to eliminate it. Careful choice of blade colour and surface finish can help reduce the effect. Light grey semi-matt finishes are often used for this. Other colours and patterns can also be used to reduce the effect further. (See 'The Influence of Colour on the Aesthetics of Wind Turbine Generators' – ETSU W/14/00533/00/00).*

3.10 In response to the review finding a lack of reference to paint colour and finish in Scottish government guidance, reference to paint colour and surface finish within other relevant Scottish guidance was then sought. Scottish Natural Heritage (SNH) (2014) Siting and Designing Windfarms in the Landscape[17], states that '*paint reflection should be minimised. Texture is an important factor in reducing reflectivity and matt or light absorbent finishes are preferable*'. It also states, '*precise colour tone and the degree of paint reflectivity should be specified at the application stage.*'

3.11 The DECC report notes references to reflected light within some of the documents within the review, but does not explore this issue in any depth.

> **Key issues: Acknowledgement of reflected light issues**
>
> For completeness, the guidance should include acknowledgement of the issue of reflected light, which can be most apparent under wet or icy conditions. It should refer or cross

[12] Scottish Government (Updated May 2014) Onshore Renewables http://www.gov.scot/Resource/0045/00451413.pdf

[13] Department of the Environment Planning and Environmental Policy Group Best Practice Guidance to Planning Policy Statement 18 'Renewable Energy' August 2009 http://www.planningni.gov.uk/index/policy/planning_statements/planning_policy_statement_18__renewable_energy__best_practice_guidance.pdf

[14] National Planning Policy Framework Planning Practice Guidance Renewable and Low Carbon Energy http://planningguidance.communities.gov.uk/blog/guidance/renewable-and-low-carbon-energy/particular-planning-considerations-for-hydropower-active-solar-technology-solar-farms-and-wind-turbines/

[15] Department of Communities and Local Government (2013) Planning practice guidance for renewable and low carbon energy (withdrawn on 7 March 2014) Available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/225689/Planning_Practice_Guidance_for_Renewable_and_Low_Carbon_Energy.pdf https://www.planningportal.co.uk/directory_record/719/planning_for_renewable_energy_a_companion_guide_to_pps22

[16] Welsh Assembly Government (2011) Practice Guidance Planning Implications of Renewable and Low Carbon Energy, Welsh Assembly Government http://gov.wales/docs/desh/publications/110228planimplicationsen.pdf

[17] Scottish Natural Heritage (2014) Siting and Designing Wind Farms in the Landscape Version 2 http://www.snh.org.uk/pdfs/strategy/renewables/Guidance_Siting_Designing_wind_farms.pdf

> reference to the use of paint colour and surface finishes which reduce this effect as in the SNH guidance.
>
> The impacts of night time lighting of wind turbines should be kept under review.

3.12 No reference to impacts of night time lighting was identified in the government guidance documents, although it was referenced in relation to requirements by the Ministry of Defence (MOD) in Scottish Government (Updated May 2014) Onshore renewables. The MOD's Obstruction Lighting Guidance[18] sets out the circumstances when visible aviation lighting is required for wind farms located in areas used for low flying training. The Civil Aviation Authority's[19] policy statement outlines the likely requirement for aviation warning lights in the vicinity aerodromes and on structures which are 150 metres or more in height. The SNH guidance[14] also refers to turbine lighting, where it is required, and states '*such lighting, typically at the top of the tower of the wind turbine, may appear prominent in night views and be incongruous in predominantly un-lit rural areas. Where lighting is necessary it should be designed to minimise landscape and visual impacts whilst satisfying health and safety or navigation requirements*.' The document goes on to state that lighting is predicted to become more widespread as sites are explored within flight paths and as larger turbines are considered. It is notable that new and repowered wind farms are making increasing use of turbines in excess of 150 metres in height, potentially triggering the requirement for the use of warning lights. Impacts will be influenced by brightness of visible lighting, numbers of lights required, their design (some are upward facing only), flashing or steady and potential for reflection on turning blades, low cloud or in mist.

3.13 The approach to assessment of the landscape and visual impact of night time lighting of wind turbines through the EIA process may be an issue which requires on going monitoring, however this should be clarified in discussion with Scottish Natural Heritage.

> **Key issues: Night time lighting**
>
> The requirement for visible (as opposed to infrared) lighting should be identified at scoping stage and, where required, considered as part of the LVIA process.

Reference to parameters/ distances/ areas where it is an issue

3.14 The Scottish Government Onshore Renewables Guidance, the Welsh Assembly Government Practice Guidance on the Planning implications of Renewable and Low Carbon Energy and the Northern Ireland Best Practice Guide to PPS18 Renewable Energy all make reference to when shadow flicker will occur.

3.15 The Scottish Government Onshore Renewables Guidance states that '*It occurs only within buildings where the flicker appears through a narrow window opening. The seasonal duration of this effect can be calculated from the geometry of the machine and the latitude of the potential site.*'

3.16 The Welsh Government document states '*However, this only occurs under particular circumstances and lasts for only a few hours per day*.' The document does not expand on the circumstances when it does occur.

3.17 The most detailed explanation is provided by the Northern Ireland Best Practice Guide to PPS18, as set out in the box below:

> It only occurs inside buildings where the flicker appears through a narrow window opening. A single window in a single building is likely to be affected for a few minutes at certain times of the day during short periods of the year. The likelihood of this occurring and the duration of such an effect depends upon:
>
> - the direction of the residence relative to the turbine(s);
> - the distance from the turbine(s);
> - the turbine hub-height and rotor diameter;
> - the time of year;
> - the proportion of day-light hours in which the turbines operate;
> - the frequency of bright sunshine and cloudless skies (particularly at low elevations above the horizon); and,
> - the prevailing wind direction.

[18] Ministry of Defence (2012) MOD Obstruction Lighting Guidance

[19] Civil Aviation Authority (2010) Policy Statement: Lighting of En-Route Obstacles and Onshore Wind Turbines

> **Key issues: Definition of parameters when shadow flicker may occur**
> The guidance should explicitly set out the parameters when shadow flicker may occur, similar to the bullet points in the Northern Ireland Best Practice Guide to PPS18 above.

Reference to 130 degrees either side of north

3.18 The study brief did not specifically require an investigation of the use of figure of 130 degrees either side of north, however it is a figure which is frequently cited within the documents. The DCLG National Planning Policy Framework Planning Practice Guidance, the withdrawn DCLG Planning Practice Guidance for renewable and low carbon energy and the Northern Ireland Best Practice Guide to PPS18 all state, '*Only properties within 130 degrees either side of north, relative to the turbines can be affected at these latitudes in the UK – turbines do not cast long shadows on their southern side.*'

3.19 The DECC report noted the following in relation to 130 degrees either side of north:

> *"England's Companion Guide to PPS22 (2004) and BERR (2007), and Northern Ireland's Best Practice Guidance to PPS18 (2009) state that only properties within 130 degrees either side of north of a particular turbine can be affected by shadows. Verkuijlen & Westra (1984) confirm this assertion, stating that particularly large areas to the east-northeast and westnorthwest of the turbine experience shadows for long periods of time. Both German guidance (2002) and Verkuijlen & Westra (1984) provide figures demonstrating the azimuth extent of the shadow flicker zone. The concept of limiting the assessment to within 130 degrees either side of north is not contested (nor are any alternative assessment methodologies proposed) in any guidance documents or academic literature."*

3.20 Including reference to the occurrence of shadow flicker within 130 degrees of north does not allow for the consideration of differences between the actual shadow throw of a wind turbine in different latitudes, although the extent of this difference is unlikely to be significant. The Scottish guidance does not currently make reference to 130 degrees either side of north. This appears prudent, as it is more important that the modelling of the shadow throw is accurate, and takes latitude into account, than the guidance states a figure of 130 degrees either side of north which may or may not be technically accurate in all locations within Scotland.

3.21 The conclusions of the DECC (2011) report state that although 130 degrees either side of north and ten rotor diameters is considered acceptable, that the '*one size fits all approach may not be suitable depending on the latitude of the site*'. The shadow flicker computer models take latitude into account, however the guidance documents and SPG which use these figures as triggers for assessment or as stated limits to where shadow flicker will occur do not take the approximate nature of these figures into account.

Key issues: Reference to the degrees either side of north affected by shadow throw

Scottish guidance should continue **not** to include reference to the occurrence of shadow throw 'within 130 degrees either side of north' unless evidence from modelling proves that this statement is accurate within Scotland. An alternative approach may be to include an example of the typical pattern of shadow throw from a wind turbine, and include explanation that in northern latitudes the pattern of shadow throw is limited to the approximate area shown, but that this varies with latitude and modelling will clarify the actual area of shadow throw from a wind turbine.

Reference to 10 rotor diameter

3.22 The origins of the frequently cited occurrence of shadow flicker within ten rotor diameters of a wind turbine was one of the key issues to be investigated through Stage 1 of this study. This issue is explored in more detail in the literature review, however this stage of the work sets out how this figure is used in the guidance documents.

3.23 Only two of the guidance documents make reference to the ten rotor diameter threshold. There is no mention of a reference source for the ten rotor blade diameter in either of these documents. Scottish Government Onshore Renewables (updated May 2014) states:

'In most cases however, where separation is provided between wind turbines and nearby dwellings (as a general rule 10 rotor diameters), "shadow flicker" should not be a problem.'

3.24 The Best Practice Guide to PPS18 states that, *'Problems caused by shadow flicker are rare. At distances greater than 10 rotor diameters from a turbine, the potential for shadow flicker is very low.'* It also provides an explanation of why distance influences shadow flicker:

A105. The further the observer is from the turbine the less pronounced the effect [of shadow flicker] will be. There are several reasons for this:

- *there are fewer times when the sun is low enough to cast a long shadow;*
- *when the sun is low it is more likely to be obscured by either cloud on the horizon or intervening buildings and vegetation; and,*
- *the centre of the rotor's shadow passes more quickly over the land reducing the duration of the effect.*

A106. At distance, the blades do not cover the sun but only partly mask it, substantially weakening the shadow. This effect occurs first with the shadow from the blade tip, the tips being thinner in section than the rest of the blade. The shadows from the tips extend the furthest and so only a very weak effect is observed at distance from the turbines.

Key issues: ten rotor diameter distance

Scottish guidance should not include reference to the ten rotor blade diameter distance in relation to shadow flicker. As further discussed in the literature review, there is a lack of robust evidence for the use of this figure, and it appears more appropriate to identify the factors which influence when shadow flicker is more likely to occur and when it is less likely to occur.

The guidance should focus on avoidance of harm and nuisance, which should be established by exposure thresholds, and not on limiting the extent of assessment.

References to thresholds for duration of effect

3.25 It has emerged from the literature review that thresholds for the duration of shadow flicker are a significant consideration in determining the impact. Although duration and exposure to shadow

flicker are related to distance, this study has found insufficient evidence to support the use of distance alone to define areas of search for the impacts of shadow flicker, unless new data can be provided which supports the use of distance.

3.26 Of the documents reviewed, only the Northern Ireland Best Practice Guide to PPS18 refers to a threshold for duration of effect, *'It is recommended that shadow flicker at neighbouring offices and dwellings within 500m should not exceed 30 hours per year or 30 minutes per day.'* This statement is referenced to the research carried out by Predac, a European Union sponsored organisation promoting best practice in energy use and supply which draws on experience from Belgium, Denmark, France, the Netherlands and Germany. However it is noted by Haugen (2011) that the German guidance is often misquoted, as it refers to 30 hours / year worst case, and 8 hours / year likely case (further detail on this is provided in Chapter 4). PPS18 appears to reflect this observation, omitting reference to worst case or likely case in relation to the threshold. Therefore documents referring to the thresholds for exposure must be clear in the relevance of this to worst or likely case scenarios.

Key issues: thresholds for duration of effect

Guidance documents referring to exposure thresholds for shadow flicker must be explicit in their reference to limits relating to worst case and likely case scenarios.

Review of SPG

3.27 The review of national UK guidance documents did not identify many references to other sources in relation to light and shadow related effects. In order to identify if local planning authorities had referenced additional sources or developed a greater level of detail in relation to the assessment of light and shadow effects from wind turbines, a brief review of a selection of SPG within the UK was also undertaken. A list of the SPG reviewed in provided in the references. The following text highlights the key findings from the review of SPG.

Approach to light and shadow effects within the SPG

3.28 Light and shadow effects are sometimes grouped with the discussion of other impacts including noise, or under the wider heading of community or amenity impacts. This introduces the potential for confusion of impacts of noise with those of shadow flicker (see Section 4: Literature review)

Types of receptor

3.29 Within the 17 SPG reviewed, the following different types of receptor were identified (the wording from each SPG is shown separated by a forward slash):

- **Residential**: Dwelling house / residential properties / residential dwelling / dwellings / residential / nearby dwellings /dwellings/dwellings / Residential premises within 10 rotor diameters / Residential properties within 10 rotor diameters and within 130 degrees either side of north/ residential accommodation including future residents.
- **Work**: Workplace/ work place /neighbouring offices.
- **Buildings and properties**: All buildings (within 10 rotor diameters) / Occupied buildings / Regularly occupied buildings not associated with the development / Existing properties / Nearby properties [nearby not defined].
- **Transport**: trunk roads (within 10 rotor diameters) / public roads or paths identified in the Core Paths Plan (this would appear to be in relation to ice throw or turbine failure and not shadow flicker, as it is specified as the height of the turbine to blade tip, plus 10%) / road and rail networks.

- **Other:** sport and recreation facilities / important historic sites / community facility / other sensitive properties (although sensitive properties are not defined) / hospitals, schools and churches.

3.30 One SPG didn't refer to types of receptor, and another (Aberdeenshire) provided detail relating to the sensitivity of different receptors, which is discussed below.

3.31 The majority of the SPG primarily mentioned residential dwellings as receptors, although there is some evidence of greater consideration of other types of receptor (e.g. Rushcliffe Wind Energy Supplementary Planning Document). The basis for specific mention of these types of receptor is unclear without detailed case study analysis of the SPG.

3.32 It is interesting to note that the receptors identified include both indoor and outdoor receptors, when the definition of shadow flicker in most documents within this study specifies occurrence within a building.

3.33 The DECC (2011) report noted questionnaire respondent views on the issue of indoor and outdoor effects, and that these differed between developers and those doing the assessments and planning authorities, but did not draw any firm conclusions on how these should be addressed.

> **Key issues: shadow effects outdoors**
>
> There should be definition of shadow effects outdoors and how these should be assessed.

Sensitivity of receptors

3.34 The SPG for Wind Energy Developments in Aberdeenshire[20] provided the only example in the sample of SPG which defines sensitivity of land use adjacent to a site, as set out in the box below.

HIGH	Residential uses (including nursing houses, accommodation blocks)
MEDIUM	Non-residential uses and brownfield land within settlements
LOW	Non-residential uses and brownfield land outwith settlements

3.35 Eleven of the 17 SPG reviewed referred to receptors within 10 rotor diameters as triggering the requirement for a shadow flicker assessment, which highlights the wider use of this distance threshold within SPG.

> **Key issues: sensitivity of receptors**
>
> Further research should be carried out into the sensitivity of different receptors.

Worst case / likely scenario modelling

3.36 Worst case scenario modelling is when site specific factors such as prevailing wind direction, cloud cover etc. are not taken into account. Likely scenario modelling is when a range of variables are included in the modelling. There can be a large difference between modelled outcomes for exposure under worst case scenario and likely case scenario. The German guidance illustrates this, by its reference to exposure thresholds of 30 hours / year *worst* case modelling or 8 hours / year *likely* case.

3.37 In relation to identifying factors which influence the likely case scenario, two of the SPG refer to the types of window opening and the occurrence of shadow flicker, but no mention is made of how this should be taken into account. North Lanarkshire SPG notes that certain types of window openings can affect the degree of impact but makes no reference regarding how this should be considered during modelling or assessment. East Ayrshire SPG notes a narrow window opening will contribute to the occurrence of shadow flicker but makes no reference regarding how this should be considered during modelling or assessment.

[20] Aberdeenshire Council (2005) Supplementary Planning Guidance Use of Wind Energy in Aberdeenshire Part Two Guidance for Assessing Wind Energy Developmetnshttps://www.aberdeenshire.gov.uk/media/8107/2005_2windassessing06.pdf

3.38 Five of the SPG refer to the conditions under which shadow flicker may occur. They do not discuss the differences between likely case and worst case modelling.

3.39 The conditions when shadow flicker may occur as set out in the SPG reviewed are listed under each dark bullet point:

- *the occurrence and duration of shadow flicker at a particular occupied building is dependent on wind speed, wind direction and cloud cover.*
- *Shadow flicker is likely to be a seasonal occurrence, unlikely to occur during cloudy conditions.*
- *the magnitude of shadow flicker varies both spatially and temporally and depends on a number of environmental conditions including position and height of sun, wind speed direction, cloudiness and the position of the turbine to sensitive receptor. If there are no windows facing the direction of the turbine a shadow flicker assessment will not be required.*
- *Influences on the likelihood of shadow flicker occurring, and its severity include:*
  - *The direction of the dwelling relative to the turbine(s);*
  - *The distance from the turbine(s);*
  - *The turbine height;*
  - *The time of year (the effect is greater when the sun is lowest in the sky);*
  - *The proportion of daylight hours in which the turbine(s) operate;*
  - *The frequency of bright sunshine and cloudless skies (particularly at low elevations above the horizon);*
  - *The prevailing wind speed and direction.*
- *The likelihood of this occurring and the duration of such an effect depends upon:*
  - *the direction of the residence relative to the turbine(s);*
  - *the distance from the turbine(s);*
  - *the turbine hub-height and rotor diameter;*
  - *the time of year;*
  - *the proportion of day-light hours in which the turbines operate;*
  - *the frequency of bright sunshine and cloudless skies (particularly at low elevations above the horizon); and,*
  - *the prevailing wind direction.*

3.40 This illustrates the different levels of detail provided in the SPG. Although there is recognition of the difference between worst case and likely case, the SPG do not provide clear guidance on how assessment should relate to this, or what conditions are expected to be included within modelling.

> **Key issues: worst case and likely case scenario**
>
> Guidance should be explicitly clear on when worst case scenario or likely case scenario is being referred to and how this relates to shadow flicker calculations and thresholds of exposure. It should also clearly refer to the importance of defining 'worst- case' or likely case.

Reference to ten rotor diameter distance

3.41 Eleven of the 17 SPG reviewed make reference to the ten rotor diameter distance threshold. There is some variation in how the ten rotor diameter distance threshold is used in SPG. It is used:

- To indicate the areas of greatest potential impact from shadow flicker;

- As a separation distance between wind turbines and nearest residential dwelling;
- To indicate the area within which a shadow flicker assessment is required.

3.42 Using the ten rotor diameter distance threshold as the cut-off for the area requiring a shadow flicker assessment automatically is not precautionary as it excludes consideration of shadow flicker in areas beyond this, and any assessment of whether or not this has the potential to be significant, even if it is unlikely. This is however indicative of the weight given to the ten rotor diameter within UK guidance.

Reference to how latitude is included in the modelling

3.43 Six of the SPG make reference to properties within 130 degrees either side of north having the potential to be affected by shadow flicker. Another SPG notes that shadow flicker relates to the angle of the sun but does not elaborate, so it is unclear if this is a reference to latitude or time of day.

Summary

3.44 Overall this illustrates the level of variation in the guidelines for shadow flicker within the SPG reviewed. In particular there is inconsistency in the identification of likely scenario contributing factors to shadow flicker, and variations in the use of language which could have significant effects on how the SPG are interpreted.

Other relevant overseas guidance

3.45 A search for other relevant guidance documents which may be informing the assessment of light and shadow effects of wind turbines was also carried out. This review was based on a search of shadow flicker assessments within the UK for any references to other literature sources or guidance documents. A list of the shadow flicker assessment documents searched is available in the list of references. This review found that there is very limited reference to any guidance. Documents identified included:

- Research by 'Predac', a EU sponsored organisation promoting best practice in energy use and supply, which draws on experience from Belgium, Denmark, France, the Netherlands and Germany. 'Spatial Planning of Wind Turbines, PREDAC - European Actions for Renewable Energies'
- German Guidance: Hinweise zur Ermittlung und Beurteilung der optischen Immissionen von Windenergieanlagen, Länderausschuss für Immissionsschutz (2002), [Notes on the determination and evaluation of the optical emissions from wind turbines].

3.46 The content of these documents is explored in the findings from the literature review. One assessment also made reference to Canadian guidance, but it was insufficiently referenced to identify.

3.47 A wider internet search of other potential documents using search terms 'shadow' 'guidance' and 'wind' also found no references to other guidance documents. However, this search was focused on documents available in English, and there may be other relevant documents presented in other languages which were not identified.

Review of tools and methods

3.48 This part of the report compares the technical tools for the assessment of shadow flicker that are currently available to developers. The review of tools and methods was undertaken by Pager Power and a summary is provided below. The full text is in Appendix 1.

3.49 It considers:

- How shadow flicker is defined and what related effects are to be considered.
- The factors that influence shadow flicker effects to the greatest extent.

- The most popular tools used to assess shadow flicker effects.
- The technical differences between the available tools – and the significance of these differences.
- A summary of technical considerations pertaining to eventual formal guidance on shadow flicker and related effects.

Definitions of Shadow Flicker

3.50 Precise definitions of shadow flicker from various sources are presented explored earlier in this report. The key features identified by all sources are:

- The effect is caused by the shadow of the spinning rotor periodically obstructing a view of the sun.
- The resulting effect is periodic changes in light intensity.
- The effect occurs inside a room that is lit by sunlight through a constrained opening such as a window.

Effects to Consider

3.51 The wider project is concerned with shadow flicker and related effects. The study therefore makes reference to the potential for observed changes in light intensity as a result of periodic obstruction of the sun by a turbine's rotating blades.

3.52 Shadow flicker effects can be caused by a single turbine or multiple turbines.

Technical factors that influence Shadow Flicker

3.53 The primary mechanism behind observable shadow flicker effects is obstruction of the sun by a turbine's blade. The obstruction can be full or partial.

3.54 Shadow flicker effects therefore depend on the width of the blade and its position relative to the sun and the receptor. The relative positions, in turn, are dependent on many parameters including distance, bearing, terrain elevation, time of year and wind direction among others.

3.55 The table on the following page sets out the parameters that a comprehensive modelling tool should accommodate.

3.56 Some factors, common to all models, have not been explicitly defined in order to keep the assessment output concise. This includes the latitude and longitude of the development and the path of the sun through the sky.

Table 3.1 Comparison of shadow flicker modelling software

Category	Feature	WindFarm (ReSoft)	GH WindFarmer	WindPRO	Input required for worst case scenario?	Input required for likely scenario?
Turbine Data	Incorporation of hub height	✓	✓	✓	✓	✓
	Incorporation of rotor diameter	✓	✓	✓	✓	✓
	Incorporation of blade thickness	✗	✗	✓	✗	✓
Receptor Data	Incorporation of window dimensions	✓	✗	✓	✓	✓
	Incorporation of azimuth angle	✓	✓	✓	✗	✓
	Incorporation of vertical tilt angle	✓	✓	✓	✗	✓
Terrain Model	Incorporation of earth curvature	✓	✓	✓	✗	✓
	Incorporation of a terrain model	✓	✓	✓	✗	✓
	Incorporation of structures above ground	✗	✗	✓	✗	✓
	Incorporation of intervening terrain	*Possibly*	✗	✓	✗	✓
	Incorporation of terrain / screening on the horizon	✓	✓	✓	✗	✓
	Sophisticated terrain data interpolation algorithm	✓	✓	✓	✗	✓
Wind Direction	Incorporation of wind direction	✗	✓	✓	✗	✓
Cloud Cover	Incorporation of likely cloud cover	✗	✗	✓	✗	✓

Category	Feature	WindFarm (ReSoft)	GH WindFarmer	WindPRO	Input required for worst case scenario?	Input required for likely scenario?
Sunrise / Sunset	Incorporation of sunrise and sunset times	✓	✓	✓	✗	✓
Model Output	Quantification of hours per day / per year that effects could occur	✓	✓	✓	✓	✓

Modelling and Future Guidance

3.57 Comprehensive formal guidance on shadow flicker effects is likely to define:

- Requirements for an assessment process.
- A quantified definition of an 'acceptable' impact.

3.58 The definition of an acceptable impact may be related to one or more of the following:

- Number of hours per day.
- Number of hours per year.
- Severity of impact.

3.59 Modelling tools should therefore:

- Be able to assess worst-case scenarios based on the geometric locations of the sun, the turbines and the receptors.
- In order to evaluate the severity of the impact, the change in observed intensity must be quantified in some way. A reasonable approach would be to define this in terms of percentage of sun obscuration e.g. if the widest part of the blade obscures less than 50% of the sun under worst-case conditions, the impact is considered negligible[21].

[21] The value of 50% is for explanation purposes only, there is no recommendation within this report with regard to acceptable limits.

4 Literature review findings

Introduction

4.1 The findings of the literature review are structured around the key issues which were set out in the project brief:

- to describe the origins, rationale, and use of the 10 x rotor diameter distance threshold for shadow flicker;
- to explore the definition of different types of receptors to light and shadow related effects;
- to understand the extent to which assessments are based on worst case and / or likely case scenarios;
- the understand the definition of significance of exposure to effects of light and shadow related effects;
- to understand how assessment takes latitude into account.

Origins of the 10 x rotor diameter distance threshold

4.2 The literature review focused on references to the origins of the 10 x rotor blade diameter threshold, but through the course of the review, it was also identified that there are a number of other factors which potentially correlate approximately to the ten rotor blade diameter distance. These include:

- The distance threshold related to triggering photosensitive epilepsy;
- The inter-relationship between distance thresholds for noise and visual impact from wind turbines, and that for shadow flicker;
- The percentage coverage of the sun by the turbine blade[22];
- The reduction in shadow intensity with distance; and
- The frequency at which shadow flicker will occur. The closer a receptor is to a wind turbine (within the pattern of shadow fall) the greater the potential occurrence of shadow flicker. For distances further from a wind turbine the number of times a year and the duration of the shadow flicker effect are reduced. This seems to lead to the distinction between levels of shadow flicker which cause harm vs those that cause annoyance. This is explored under the section heading 'significance of effect' (see paragraph 4.29).

4.3 The earliest reference to the 10 x rotor blade distance threshold is found in an article by Clarke (1991)[23] . This article includes the comment that the minimum separation distance for wind turbines from habitations should be **approximately** 10 blade diameters. The synopsis for the article states that in relation to the problem of shadow flicker and flashing from the blades of a turbine; '*turbines should be sited at least 10 x diameters from habitations, and more if sited to the southeast or west / southwest, and the shadow path identified.*' The use of the words 'at least' should be noted. This is further reinforced through the following quote from the article '*Clearly it is best to avoid the problem in the first place by attention to careful siting. Wind turbines close to habitations, e.g. ten diameters distance should not be sited to the east or south east, or west or south west of habitations, unless the shadow path has been identified and does not fall on the windows of habitations or occupied buildings.*'

[22] This needs to be considered within the context of turbines with greater blade length becoming more prevalent

[23] Clarke A.D, (1991), A case of shadow flicker/flashing: assessment and solution, Open University, Milton Keynes

4.4 This highlights the need to consider the impacts at a distance greater than ten rotor diameters within different compass directions to the turbine.

4.5 The summary comments in the document on the siting of turbines states:

4.6 '*The minimum separation distance for wind turbines from habitations should be approximately 10 blade diameters. This is emerging from experience and research as a standard guideline, in order to reduce problems of visual impact, noise, shadow disturbance and safety.*'

4.7 The reference to '*visual impact, noise, shadow disturbance and safety*' illustrates the blurring of multiple impacts in relation to separation distance between wind turbines and people within this article and is an issue further explored in paragraph 4.22 .

4.8 A key point to emerge from the review of the frequently cited article by Clarke (1991) is the potential for the interpretation of the key points from the article to have been summarised and their original sense distorted. There is evidence of this within the article itself between the main text and the synopsis. The ten rotor blade distance is referred to as an approximate separation distance, not a set limit. Equally the research cited in the article as supporting the ten rotor diameter separation distance includes only one reference to documents specifically related to shadows from wind turbines (Verkuijlen and Westra[24]). The other references include studies related to the effect of flicker on people, including in relation to traffic tunnel lighting and visually induced seizures. Although the studies in relation to the effects of flicker on people are important, it is not clear from the article how these studies relate to the ten rotor diameter distance.

Other factors relevant to the 10 rotor blade diameter distance

Shadow flicker and photo sensitive epilepsy

4.9 The relationship between the 10 x rotor diameter and the effects of shadow flicker on those with photosensitive epilepsy has emerged from the literature examined. In relation to the effects of light flicker Clarke (1991) makes reference to the issue of wind turbine rotation and epileptic convulsions. He notes '*most medium and large wind turbines have a rotation rate of between 30 r/min and 60 r/min, and smaller turbines often have a faster rotation. Most turbines in use today are two or three bladed, constant speed types, producing shadow flicker rates in the range of 1-3 Hz. Variable speed turbines may produce a 2-6 Hz flicker rate. Therefore the shadow flicker from turbines has frequencies that could in the right conditions produce light flicker effects to susceptible persons.* '

4.10 Smedley, Webb, and Wilkins, (2010)[25] looked at the potential risk of epileptic seizures from wind turbine shadow flicker under various meteorological conditions. They found that large turbines rotate at a rate below that at which the flicker is likely to present a risk of epileptic seizure, although there is a risk from smaller turbines that interrupt sunlight more than three times per second. For the scenarios considered in the research, they found the risk is negligible at a distance more than about 9 times the maximum height reached by the turbine blade, a distance similar to that in guidance from the UK planning authorities.

[24] Verkuijlen E. Westra, C.A. Shadow Hindrance by Wind Turbines Proceedings of European Wind Energy Conference, European Wind Energy Association October 1984

[25] Smedley, Andrew R. D ; Webb, Ann R ; Wilkins, Arnold J. (2010) Potential of wind turbines to elicit seizures under various meteorological conditions, Epilepsia, 51 (7), 1146- 1151

Key points in relation to origins of the ten rotor blade diameter distance

The original references to ten rotor blade diameter distance separation between wind turbines and habitations by Clarke (1991) is presented as an approximate or minimum distance to avoid disturbance, and should not be interpreted as a limit at which disturbance from shadow flicker can occur.

Within the text of the original article by Clarke (1991) there is blurring of the impacts of *visual impact, noise, shadow disturbance and safety* in relation to the ten rotor diameter separation distance.

Clarke (1991) does not make reference to distance and the effect of wind turbines and epileptic convulsions commenting only on the frequency of flicker and speed of blade rotation.

Twenty percent coverage of the sun

4.11 The German guidelines (2002)[26], the Swedish guidance (2012)[27] and the WindPro User Guide (2010) all refer to the requirement for 20% coverage of the sun for shadow flicker to occur. The following paragraphs explore the context for this figure.

4.12 According to the German guidelines, the limit of the shadow is set by two factors:

- The angle of the sun over the horizon must be at least 3 degrees.
- The blade of the wind turbine must cover at least 20 % of the sun.

4.13 It is not clear from the German guidelines of the origin of the 20% reference.

4.14 An explanation and source reference for of the 20% coverage of the sun was identified within a shadow flicker assessment for a wind farm in Lempster, United States, *'Dobesch and Kury (2001) and 'out of the box' wind project analysis software packages such as WindPro, work on the basis that when less than 20% of the sun is masked by the turbine blades the difference of the radiation-intensity between shadow minimum and shadow maximum is so low that the people don't notice it unless they are looking directly at the sun.'*[28]

4.15 The source of Dobesch and Kury (2001) is referenced in other English speaking documents as Basic Meteorological Concepts and Recommendations for the Exploration of Wind Energy in the Atmospheric Boundary Layer, Central Institute for Meteorology and Geodymanics (ZAMG), Vienna, Austria. However as the document will have been written in German, and the actual wording of the document title in German has not been identified, despite considerable searching, it has not been possible to find the original article, and therefore understand the source.

4.16 It is not clear if the work by Dobesch and Kury influenced the German guidelines, although it may be possible to establish this through discussions with the German authorities. Communication with WindPRO was not able to identify this source.

4.17 Of the three shadow flicker models examined, only WindPRO allows inclusion of the figure of obscuration of the sun in the modelling. It is possible that 20% obscuration of the sun relates to rotor diameter and distance, and therefore this is put forward as a recommendation for additional modelling.

Setback distances in other countries

4.18 Haugen (2011)[29] undertook a review of wind energy policies and recommendations about wind turbine setbacks, noise, shadow flicker and other possible concerns in major wind energy producing countries outside the U.S. (not including China, India or Japan due to translation

[26] https://www.umwelt.sachsen.de/umwelt/download/laerm_licht_mobilfunk/WEA-Schattenwurf-Hinweise_LAI.pdf

[27] http://www.boverket.se/globalassets/publikationer/dokument/2013/vindkraftshandboken.pdf

[28] Superna Energy L.L.C. (2006) Lempster Wind Project Shadow Impact Assessment, Lempster Wind, LLC and Community Energy, Inc www.nhsec.nh.gov/projects/2006-01/documents/28_shadow_flicker_assessment.pdf

[29] Haugen KMB. (2011) International Review of Policies and Recommendations for Wind Turbine Setbacks from Residences: Setbacks, Noise, Shadow Flicker, and Other Concerns. St. Paul, MN: Minnesota Department of Commerce, Energy Facility Permitting (2011). p. 1-43.

difficulties). The report sought to keep the issues of setback distances due to noise impacts separate from setback distances for shadow flicker. The report concluded *'Very few countries have mandatory wind turbine setback distances between wind turbines and homes. Instead of set wind turbine setback distances, many countries regulate how close wind turbines may be located to residences through noise limits or shadow flicker limits.'*

4.19 This identifies the focus on using limits of exposure and not set distances. However, because this research focused on mandatory limits, and it therefore does not identify references to the ten turbine diameter distance within the UK. It is therefore possible that other references to distance and shadow flicker that sit within guidance documents which were not identified in relation to other countries.

Shadow dissipation and atmospheric interference

4.20 A further influence on the distance which shadow effects can be detected is air turbidity. An article by Freund (2002) [30] in the wind industry magazine DEWI[31] [English translation] highlights the causes and effects of this:

> *Depending on the concentration of aerosol particles (dust, smoke, water droplets) the atmosphere is more or less turbid. Shadows are a function of air turbidity. On a clear day, low turbidity means shadows are longer, and when turbidity is high their extent is less. The haze factor is subject to considerable temporal fluctuation, including the change in the water vapour content of air with temperature, air mass change and daily and seasonal variations. The extent of shadows also depends on the inclination of the exposed area. The direct radiation component of the sun is intense on a vertical surface. Shadows falling on surfaces of different inclination should be dealt with differently.*

4.21 The effect of light refraction in the atmosphere is also referred to in the German guidance, as a factor which is not taken into account in worst case scenario modelling. This is another factor which further contributes to a reduction in shadow effect with distance from the wind turbine.

Relationship between noise thresholds and shadow flicker

4.22 A German magazine article published in DEWI magazine 1998[32] makes reference to the interaction between shadow flicker limits and noise thresholds. It states that for the earlier generations of smaller turbines of 500 / 600kW, the noise limits seemed to be the deciding factor to define the limits in distance to the nearest dwelling. The article notes that for the larger wind turbines the manufacturers state that there is not an according increase in noise output compared to the earlier turbines, therefore noise will no longer be the limiting factor on distance, and shadow impact will play a larger role in future assessment of wind farms in planning. Wind farm technology has moved on significantly since 1998, however this article indicates that earlier research relating to the impacts of shadow flicker (in the field) may also have been inadvertently affected by the impact of noise from wind turbines.

4.23 The relationship between noise and shadows is further supported by Haugen (2011). Haugen (2011) notes that [field] studies done in Germany regarding shadow flicker which looked at shadow flicker exposure, stress, behaviours and coping found increased levels of exposure time correlated with increased stress levels and negative effects with those experiencing over 15 hours of actual shadow flicker having decreased quality of life and high levels of daily annoyance. However it was noted that stress levels and annoyance increased as the distance to the turbines decreased **in all directions**, not only the directions where shadow flicker occurs due to

[30] Freund 2002. Hans-Dieter Freund, FH Kiel/University of applied sciences. Einflusse der Lufttrubung, der Sonnenausdehnung och der Flugelform auf dem Schattenwruft von Windergieanlagen. DEWI magazin nr 20/2002 (Influences of the opaqueness of the atmosphere, the extension of the sun and the rotor blade profile on the shadow impact of wind turbines)

[31] DEWI is a performance, measurement, efficiency, research and education provider in the field of wind energy. It has been issuing a company magazine, the DEWI Magazin, twice per year since 1992. It includes articles on DEWI's research activities and other company news, but it is also used by external institutions for the publishing of their research results.

[32] Osten, T., and Pahlke, T. (1998). Schattenwurf von windenergieanlagen: wird die gebrauschabstrahlung der MW-Anlagen in den Schatten gestellt? (Shadow impact on the surrounding of wind turbines). DEWI Magazin, Nr. 13, August 1998. Pp 6-12. Shadows of wind turbines : Will the greater use of large turbines be put in the shade? http://www.dewi.de/dewi/fileadmin/pdf/publications/Magazin_13/02.pdf

sunset/sunrise. This implies that the noise from wind turbines has a greater impact on stress levels than shadow flicker.

Timing of shadow flicker

4.24 A Swedish study which aimed to understand the impact of wind turbines on noise, shadows and landscape was based on interviews of residents in three neighbourhoods with wind turbines in Gotland[33]. The study found that in one of the case study areas although none of the respondents in Klintehamn had calculated shadowing (under worst case scenario) of more than 30 hours a year and a maximum of 30 minutes a day, 24% are fairly or very annoyed by shadows. In Nasudden 17% of the respondents had more than 30 hours /year facade worst case, but only 4% are fairly or very annoyed by shadows. The text states that one possible explanation for so many of those in Klintehamn being annoyed by shadows could be that most of the respondents live south east of the turbines and will get shadow flicker in the evenings during the period April to September (90% of respondents) that is when the shadows are most intense and most people are at home. Respondents that are not annoyed by shadows, even though they have a large calculated shadow flicker duration have shadows during the morning or during winter. Respondents that are annoyed by shadows, even though their calculated shadow impact is small, experience this effect during the evening.

4.25 The study concluded that it is more important at what time of day and year the shadows fall, than the total calculated time in hours a year of shadow impact.

4.26 A new rule was introduced in Sweden by Boverket (the Swedish national agency for planning the management of land and water resources, urban development and housing), for the calculation of shadow impact, which states that the calculation should be made for the building lot (garden) instead of the window[34].

> **Key issues: other factors relevant to the ten rotor diameter distance**
>
> Impacts of noise potentially confuse reporting of nuisance with shadow flicker impacts.
>
> Time of day is potentially relevant to the experience of shadow flicker, although this depends on the lifestyle of the affected occupants.
>
> Consider shadow impacts on the garden ground of a property.
>
> Smedley et al (2010) refer to the risk of epileptic seizures and distance from wind turbines, of about nine times the height of the turbine blade. However all articles referring to wind turbines and epileptic convulsions state that large commercial sized wind turbines rotate at a rate below that likely to trigger epileptic seizures.

Definitions of receptors

4.27 Very little discussion of sensitivity of different types of receptors was found within the literature review, and this is an area where the findings from the review of SPG (see paragraph 3.34) provide a greater level of detail. The key issue seems to be the effect on people in general, and research to identify more sensitive groups has not been identified through this literature review.

4.28 Through the literature review an EIA for a wind farm in Ireland[35] identified in addition to receptors typically referred to, impacts on properties within 10 rotor diameters of a proposed turbine which included unoccupied buildings, permitted dwellings not yet constructed, and equestrian facilities.

[33] Environmental Case Study of Wind Turbines in the Living Environment(VINDKRAFTENS MILJOPÅVERKAN FALLSTUDIE AV VINDKRAFTVERK I BOENDEMILJO), Widing, A., Britse G., Wizelius T., Centrum for Vindkraftsinformation Institutionen for naturvetenskap och teknik, Gotland University, Sweden, 2004 [English translation of abstract] http://cvi.se/uploads/pdf/Kunskapsdatabas%20miljo/Ljud%20och%20Skuggor/Ljud/sammanfattning/Fallstudie%20sammanfattn050630.pdf

[34] Planering och Provning av Vindkraftverk på land och i kustnära vattenområden", Boverket, 2012, (Wind Energy Handbook, Planning and testing of wind turbines on land and in coastal waters)

[35] http://maighnewindfarm.ie/environmental/environmental-impact-study/volume-2-main-eis

> **Key issues: exposure thresholds and types of receptor**
>
> The recommendation for the threshold for sensitivity in the German guidelines appears to be based on a laboratory study of adults.
>
> The literature review has not identified any issues with different types of receptor having higher sensitivity. This would appear to be a gap in the knowledge base. It would be interesting to study the shadow flicker assessments of wind turbines within closer proximity to urban areas, to identify what issues have arising associated with exposure by different types of receptor (e.g. children, people with mental health issues etc.).

Significance of effects and use of worst case and likely case scenarios in assessments

4.29 The literature review found that the significance of effects of shadow flicker is closely entwined with the use of worst case and likely case assessment.

4.30 The literature review examined references to exposure thresholds, and this found that the use of thresholds of exposure is not widespread, but for the countries which have an exposure threshold it is often based on the German guidelines. Haugen (2011) identified the use of the threshold for exposure in Australia, Germany and Ireland.

4.31 The German guidelines are the most commonly cited, and Haugen (2011) noted that the maximum 30 minutes/day or 30 hours/year for worst case scenario, and the 8 hours/year actual amounts of shadow flicker are a nationwide requirement in Germany as they are now part of the "Federal Emission Control Act (BLmSchG)", but have been used in case law and state and federal standards as well.[36]

4.32 In Australia, only two states have addressed shadow flicker with Victoria guidelines recommending no more than 30 hours per year shadow flicker exposure, and South Australia stating that shadow flicker must be considered to a distance of 500m.

4.33 Ireland Wind Energy Development Guidelines (2006) were subject to a targeted review [37] in relation to noise, proximity and shadow flicker which set out a number of proposed revisions in 2013. The revisions require a shadow flicker study for properties within 10 rotor diameters from each individual turbine. Previous to these revisions the 2006 guidance advised that houses and workplaces within 500m of a wind turbine should not be exposed to more than 30 hours per year or 30 minutes per day of shadow flicker. The references to a separation distance of 500m between any commercial scale wind turbine and the nearest point of the curtilage of any property in the vicinity is made with regard to amenity considerations, and not specifically shadow flicker.

4.34 The literature review identified that Swedish guidance[38] also repeats the German guidelines and states, '*The theoretical shadow time of disturbance to sensitive buildings should not exceed 30 hours per year and that the actual shadow time should not exceed 8 hours per year, and 30 minutes a day.*'

[36] Haugen KMB. (2011) International Review of Policies and Recommendations for Wind Turbine Setbacks from Residences: Setbacks, Noise, Shadow Flicker, and Other Concerns. St. Paul, MN: Minnesota Department of Commerce: Energy Facility Permitting (2011). p 1-43.)

[37] Environment, Community and Local Government Proposed Revisions to Wind Energy Development Guidelines 2006 Targeted Review in relation to noise, proximity and shadow flicker – December 11th 2013 http://www.environ.ie/sites/default/files/migrated-files/en/Publications/DevelopmentandHousing/Planning/FileDownLoad%2C34769%2Cen.pdf

[38] "Planering och Provning av Vindkraftverk på land och i kustnära vattenområden", Boverket, August 2008, (Planning and testing of wind turbines on land and in coastal waters) (Boverket is Boverket is the national agency for planning, the management of land and water resources, urban development, building and housing in Sweden)

4.35 Guidelines published by PREDAC[39] provide recommendations on shadow flicker exposure, and provides examples of thresholds of exposure within other European countries. '*It is recommended at neighbouring dwellings and offices that flickering shadows are not exceeding 30 hours /year or 30 min. per day with normal variation in wind directions and with clear sky. (This follows the German norm of 30 hours a year at clear sky).*'

4.36 The report by PREDAC also identified the following thresholds:

- Wallonie, Belgium: 30 hours a year or 30 minutes a day (the PREDAC report does not clarify if this is worst case scenario);
- Denmark: 10 hours a year with average cloud cover;
- The Netherlands: When there is more than 20 minutes per day, 17 days per year (5 hours 40 min/year calculated, with clear sky), at neighbours it is regarded as a nuisance, which is unacceptable, and a standstill device is requested.

4.37 The German Guidelines provide a reference source for the threshold of 30 minutes a day exposure to shadow flicker. It refers to a laboratory study of the University of Kiel (2000)[40](Pohl, Faul and Mausfeld), it was found that even a one-off exposure to shadow effects for 60 minutes can lead to stress responses. Therefore for precautionary reasons the daily shading duration is limited to 30 minutes.

4.38 It is important to note that the laboratory study followed on from a field study by the same authors in 1999. The relevance of a laboratory study is that this removes any other variables (particularly noise influences from wind turbines) in relation a stress response. However it was noted in another document that these results were not published in a peer reviewed journal[41].

4.39 Further investigation of the origins of the exposure threshold in the Netherlands and Belgium may identify additional evidence base.

4.40 In relation to health effects of wind turbines, the University of Salford report (2013) [42] into the health effects of wind turbines stated, '*Health effects from other wind turbine related sources such as shadow flicker have been reported in several studies and guidelines to be less of a problem. Careful wind farm design and operational restrictions are suggested to be sufficient to minimise the impact.* This report did not include reference to any laboratory studies in relation to shadow flicker.

4.41 Within the UK a number of documents typically conclude that the impacts of shadow flicker are not significant because it is relatively straightforward to mitigate the effects. However this statement is based on the assumption that the impacts are accurately identified through the assessment process.

[39] Predac (undated) Spatial Planning of Wind Turbines Guidelines and Comparison of European experiences. This publication is part of the PREDAC project with support from EU Commission, 5th RTD Framework Programme, 2002-2004. The recommendations in this paper are from the expert group working on Work Package 8 of PREDAC http://www.cler.org/IMG/pdf/WP8_ANG_guide.pdf

[40] J. Pohl, F. Faul, R. Mausfeld, Belastigung durch periodischen Schattenwurf von Windenergieanlagen, Laborpilotstudie, Institut für Psychologie der ChristianAlbrechts-Universitat, Kiel 15.05.2000
http://vi.se/uploads/pdf/Kunskapsdatabas%20miljo/Ljud%20och%20skuggor/Skuggor/Utredningar/Laborstudie%20Schattenwurf.pdf

[41] Twardella D (undated) Bedeutung des Ausbaus der Windergie für die menschliche Gesundheit Consequences of wind energy for Health, Bayerisches Landesamt für Gesundheit und Lebensmittelsicherheit [Bavarian State Office for Health and Food Safety]

[42] Von Hunerbein S., Moorhouse A., Fiumicelli, D., Baguley D. (2013) Report on Health Impacts of Wind Turbines, Report for Scottish Government http://usir.salford.ac.uk/29183/1/HealthEffects_Final_IQ1-2013_20130410.pdf

Key points: significance of effects

The origins for the German thresholds for exposure to shadow flicker are based a laboratory study of adults which identified a stress response to exposure of 60 minutes to shadow flicker effects.

With the exception of the work by Pohl et al (2000) no other studies have been identified which attempt to isolate the effects of shadow flicker from other experiences associated with proximity to wind turbines.

It is important to note the German threshold relates to 30 hours / year worst case, and 8 hours / year likely case, and the need to clearly differentiate between the parameters for the two thresholds.

High latitude assessments

4.42 The models for the calculation of shadow flicker take into account the latitude of the location, therefore if latitude is factored into the model the area of shadow flicker can still be accurately predicted. However if the area of shadow calculation is limited to e.g. 130 degrees either side of north, this could result in areas which could experience shadow flicker being excluded from the calculation.

4.43 Modelling could identify how relevant the ten rotor diameter distance is at different latitudes. However, any distance based on multiples of rotor diameter will be indicative only because it does not factor in other parameters that influence potential effects.

5 Stage 2 Review of Practice and Literature

Introduction

5.1 The focus of the second stage of the work is to explore through a review of the case studies and literature:

- The findings from Stage 1, including identified uncertainties around the accuracy of current impact assessment methods;
- Definitions of light and shadow effects and impacts used in the planning process and in engagement/consultation with residents;
- The extent to which light and shadow effects and impacts are featured in pre-application consultation with residents;
- The available evidence on how residents understand and perceive light and shadow effects; and
- Recommendations of a precautionary approach to setting any thresholds for light and shadow effects.

5.2 These aspects are explored through the analysis of the five case study planning authorities of:

- Aberdeenshire;
- Angus;
- Fife;
- North Lanarkshire;
- Perth and Kinross.

Review of plans and SPG

5.1 As detailed in the methodology, the planning context for each case study was reviewed against a series of headings identified from the Stage 1 literature review. This included a review of the local plan, and relevant supplementary planning guidance (SPG) / supplementary guidance (SG). Only one local plan[43] (which was the adopted plan at the time of the case study planning application) made reference to shadow flicker, through a policy for wind energy developments and the need to demonstrate '*there is no unacceptable detrimental effect on residential amenity, existing land uses or road safety by reason of shadow flicker, noise or reflected light.*' It should be noted that due to the dates of some of the planning applications, the exact version of documents at the time of the decision making process was not always available. The following paragraphs summarise the findings of the review of the SPG / SG or other guidance relevant to renewable energy planning applications. A list of the relevant local plans and supplementary guidance is included in the references. One of the case studies included both supplementary guidance and supplementary planning guidance.

Definition of shadow flicker

5.2 The case study review examined if shadow flicker was defined, and how it was defined relative to the definitions identified through Stage 1. Two of the documents reviewed do not define shadow flicker. Other definitions of shadow flicker included:

'the strobe effect of light flashing through the moving blades'.

'where the moving shadow flicker appears through a narrow window opening.'

5.3 One document defines both shadow flicker and separates out the strobe effect.

'Shadow flicker is caused by low sun behind the rotating blades of a turbine. The shadow created by the rotating blades can cause alternating light and dark shadows to be cast on roads or nearby premises, including the windows of residences, resulting in distraction and annoyance to the residents.

A related phenomenon, strobe effect, is caused by the chopping of sunlight behind moving blades, similar to the effect of the setting sun behind trees when driving along a roadway in the winter. Both of these phenomena are factors in the visual impact of a wind turbine project, and they could also be considered a nuisance to nearby property owners.'

5.4 Only one of the documents defines shadow flicker in line with the definition used in four of the national government documents (as outlined in chapter 4): '*under certain combinations of geographical position, time of day and time of year, the sun may pass behind the rotor and cast a shadow over neighbouring properties.*'

5.5 The variation in definition of shadow flicker supports the recommendation identified from Stage 1 of the report for the need for a definition of shadow flicker.

Definition of shadow throw

5.6 Only one planning authority referred to the issue of shadow flow in planning guidance. The authority's SPG clearly defines the difference between shadow flicker and shadow throw, and makes it clear that shadow throw is experienced outside and that turbines should be sited to avoid this effect on inhabited properties.

5.7 The absence of wider references s may be indicative of a lack of awareness of issues related to shadow throw, but in line with the recommendation identified from Stage 1 of the report supports the need for clarity on this issue.

Night time lighting

5.8 Only one document refers to lighting, noting that it may be required for civil or military aviation safety for larger turbines; usually at top of towers and may appear prominent in night views, and that shields can help minimise impacts.

5.9 The lack of coverage of this issue in the other case study documents suggests it is not currently perceived as an issue in the majority of the case study planning authorities. However, the increasing size of turbines, in particular the use of turbines of 150m or more in height, is likely to mean this will be a more significant issue in the future.

Acknowledgement of reflected light issues

5.10 Three authorities' documents do not refer to reflected light. Of the remaining authorities, one refers to the preference for a semi-matt finish to reduce the reflection of light, and another to turbine colour and the use of a non-reflective finish. Another of the documents refers to turbines causing flashes of light, and that this can be ameliorated but not eliminated.

5.11 There is a lack of consistency in coverage of reflected light issues in the case study guidance documents. Where it is provided in the case study examples, coverage of this issue is more extensive than that provided in national level Scottish government planning guidance.

Reference to separation distances and site specific issues

5.12 Case study authorities' planning guidance was reviewed for any references to the need to take site specific issues into account when identifying separation distances, or the proposal of alternative separation distances to any references to ten rotor diameters. One document states; '*The desirable separation distance will be dependent on a range of factors, including topography, safety issues, noise, shadow-flicker, shadow-throw and the size of the turbines.*'

[43] Angus Local Plan Review (Adopted 2009) https://archive.angus.gov.uk/localplan/review.htm

5.13 Another document requires an assessment of potential shadow flicker and shadow throw for all dwellings within a 1000m radius[44] of the proposed location of each wind turbine. It also states that taking all other factors into account it is not anticipated that development would be less than 400m from the nearest dwelling, and it is possible that a greater separation distance will be required.

5.14 Two of the documents do not refer to separation distances or site specific issues to be taken into account when setting separation distances.

5.15 One of the documents refers to the general rule of ten rotor diameters as set out in the Scottish Government Guidance, but also states, *'Detailed information on site specific circumstances based upon the likely effects of shadow flicker as well as noise and visual impact may challenge this general approach. In any case developments will be assessed based upon their individual merits and against the criteria in section 8.'*

5.16 Illustrating a further variation, another of the documents also refers to a separation distance of 20 times height to blade tip in relation to operational impacts of wind turbines on residential amenity (including shadow flicker)[45].

5.17 The case studies show some variation in their recognition of the need to take site specific issues into account. There is an apparent awareness of the need to take this approach in the wording of two of the guidance documents.

Reference to ten rotor diameter

5.18 As discussed in relation to Stage 1 of the study, reference to ten rotor diameters is a key area of investigation, and an area of frequent misinterpretation. One of the documents states *'A distance of at least 10 rotor diameters is a general rule beyond which shadow flicker should not be a problem.'* Another document also specifically refers to the separation distances in PAN45 of 10 rotor diameters, but also states *'...although the local topography and the position of the turbine in relation to the dwelling(s) should be taken into consideration during any assessment.'*

5.19 One documents refers directly to the Scottish Government on-line guidance for Onshore Wind Turbines and that problems of shadow flicker can be resolved through separation between wind turbines and nearby dwellings (as general rule 10 rotor diameter). It then reiterates that turbines should generally be a minimum of 10 times rotor diameter from sensitive properties to avoid the potential effects of shadow flicker.

5.20 A document refers to the general rule of ten rotor diameters as set out in the Scottish Government Guidance, and another refers to the ten rotor diameter separation distance within PAN45 as a distance beyond which there should be no problem with shadow flicker.

5.21 One of the documents notes that shadow flicker can affect properties which are positioned within 130 degrees of north and located up to 10 times the rotor diameter from the turbine, which suggests shadow flicker is not an issue beyond this distance.

5.22 Overall, the case study guidance documents tend to reflect the intention of the national level guidance that ten rotor diameters is an approximate distance, with only one appearing to categorically rule out effects beyond this distance.

Reference to 130 degrees either side of north

5.23 Identification of any references to 130 degrees either side of north within the case study guidance documents was carried out to identify if this was being used as a method of defining the assessment area for shadow flicker. Of the case study guidance documents only one refers to shadow flicker within 130 degrees of north, defining it as a set area within which shadow flicker may occur.

[44] It should be noted that larger turbines now use rotors with a diameter of more than 100m, meaning this threshold is less precautionary than the usual 10x rotor diameter figure

[45] Overall turbine height is not always an indicator of rotor size and the potential for shadow flicker. Some turbines make use of larger diameter rotors mounted on shorter towers, increasing wind capture whilst limiting increases in height.

Significance thresholds

5.24 Guidance on significance thresholds provides consistency in the assessment of effects. Four of the documents do not refer to significance thresholds. One refers only to general impacts on residential amenity, including shadow flicker. Another includes a generic table for assessing the significance of impacts from wind energy, but not specifically in relation to shadow flicker.

5.25 One document states that, *'Wind turbines that result in significantly adverse, and therefore unacceptable impacts on residential amenity will not be supported'*. However the text does not provide greater detail on what level of shadow flicker is significantly adverse, other than referring to direct impacts on individual properties.

5.26 It is clear that the local authority guidance documents provide limited guidance on what levels of exposure to shadow flicker are significant.

Definition of receptors

5.27 The literature review confirmed that the severity of shadow flicker impacts varies according the nature of receptors and factors such as time of day. Definition of these different types of receptor is therefore necessary to inform the assessment of effects, although limited examples were identified within the planning authority guidance reviewed. Two of the documents do not define receptors. One refers to the sensitivity of adjoining land use based on residential or non-residential use. Another refers to sensitive properties which it defines as residential properties including care homes; educational buildings, hospitals, cemeteries; some visitor facilities and accommodation; and proposed development areas. One of the documents specifically states *'Turbines should not be sited where they are likely cause detrimental or significant shadow flicker at dwellings or other sensitive properties'*, but does not define what other sensitive properties are.

5.28 One of the documents refers to the prediction of shadow flicker on sensitive locations *'such as roads or dwellings around proposed developments.'*

5.29 There is some variation in the guidance documents which refer to 'sensitive' receptors, but it unclear how these are defined. One of the examples attempts to define a wider range of receptors, including people outdoors.

Impacts on receptors

5.30 None of the case studies refer to the types of impact on receptor.

Parameters when shadow flicker may occur

5.31 Reference to the parameters when shadow flicker may occur was identified in Stage 1 of the study as providing additional clarity on the specific circumstances required for shadow flicker to occur. However none of the case study guidance documents refer to these.

Reference to worst case and likely case scenarios and factors taken into account in calculating likely case scenario

5.32 None of the guidance documents refer to worst case and likely case scenarios.

How latitude is taken into account

5.33 Only one of the documents refers to the fact that latitude is taken into account in the shadow flicker calculation models.

Computer modelling used

5.34 Only one of the documents refers to computer modelling within the context of the assessment being undertaken by means of mathematical modelling.

Cumulative effects

5.35 Only one of the documents refers to *'...any cumulative impacts on amenity'* but not specifically shadow flicker.

Reference to policy and guidance

5.36 The extent to which other policy and guidance is referred to within the guidance documents was examined to identify which higher level documents inform the guidance. Two of the documents do not refer to policy and guidance. Two documents refer to PAN 45, and another refers to Scottish Government Guidance (but does not specify further). One document refers to national planning guidance contained within SPP (Scottish Planning Policy) (2010) and online renewables advice including 'Onshore wind turbines'.

Mitigation

5.37 The coverage of the approach to mitigation within the guidance documents was examined in order to identify how the guidance on mitigation influences the approach to mitigation in the case studies.

5.38 Three of the documents do not refer to mitigation.

5.39 Two of the documents refer to the need to avoid locating turbines where they cause shadow flicker, and refer to mitigation firstly in the form of turbine shutdown and secondly through other screening.

5.40 One of the documents also states that shadow flicker can be minimised by appropriate turbine positioning in relation to residential properties and low sun positions and separation distances from residential properties.

5.41 The inclusion of the proposed approaches to mitigation within the local guidance documents provides a clear framework to developers and planners, however the use of this approach is not consistent within the case study examples.

Review of case study planning applications

5.42 Detailed case study analysis was carried out on the shadow flicker assessments for five wind turbine / farm planning applications for the five planning authorities. The case studies included:

A) A single 94m to tip turbine, decided 2010, supported by an Environmental Report[46].

B) A single 67m to tip turbine, decided 2016, supported by an Environmental Statement.

C) A single 127m to tip turbine, decided 2013, supported by an Environmental Statement.

D) A single 127m to tip turbine, decided 2011, amended 2012, planning application supported by a separate shadow flicker report.

E) Four wind turbines 115m to tip, decided 2015, supported by an Environmental Statement.

5.43 The case study results are presented under the main headings as identified from the Stage 1 literature review, as are the findings from the interviews. The interviews involved discussions and written responses with planners and environmental health officers from three of the case studies. As set out in the methodology, the interviews discussed the emerging conclusions and recommendations from Stage 1 of the project and the findings from the case studies.

Definition of shadow flicker

5.44 Case study A Environmental Report reflects the standard definition of shadow flicker used in the four national government guidance documents.

5.45 Case study B Environmental Statement (ES) provides a definition of shadow flicker as used in the DECC (2011) *Update of the Shadow Flicker Evidence Base*, and does not reflect to wording of the planning authority's SPG which is less detailed and refers to a 'strobe effect'.

5.46 Case study C Environmental Statement provides a simple definition of shadow flicker which broadly reflects the standard definitions used.

[46] Although not a formal Environmental Statement for the purposes of the Environmental Impact Assessment (Scotland) Regulations (1999)

5.47 Case Study D shadow flicker report which accompanies the final planning application (relating to a reduction in turbine height) does not define shadow flicker, although it was defined in the report accompanying the previous planning application. The wording used in the definition does not directly reflect the standard definitions in national guidance, however it still reflects the important factors relevant to the issue.

5.48 Case study E Environmental Statement quotes the definition of shadow flicker as given by BERR, 2007, *'Shadow flicker can arise from the passing of the moving shadow of a wind turbine rotor over a narrow opening such as the window of a nearby residence'.* The Development Management Committee report also refers to the definition within the SPG.

5.49 The definition of shadow flicker demonstrates a reversion to the national guidance documents over the local documents, but also variation in the definitions used.

Definition of shadow throw

5.50 The case study A Environmental Report refers to moving shadows, but does not describe the impacts of shadow throw on amenity.

5.51 The Environmental Statement for case study B also refers to moving shadows outside, and defines that these are not shadow flicker. The ES does not reflect the SPG which identifies that shadow throw should be taken into account in the siting of the development.

5.52 None of the remaining case studies refer to shadow throw.

5.53 There appears to be limited coverage or recognition of shadow throw within the case studies.

Night time lighting

5.54 Four of the case studies make no reference to night time lighting. Case study C makes no reference within the planning policy or ES, but a condition is applied requiring lighting on the turbine, and the specifications of this. This reflects the fact that night time lighting is referenced in the planning authority's SPG.

5.55 The case study review findings suggest that night time lighting is not currently a significant issue, except in certain geographical locations. However, the trend towards taller turbines is likely to mean more frequent use of lighting to satisfy the requirements of the MOD and CAA. While this may sometimes employ infrared lighting which is invisible to the naked eye, visible lighting may be required under some circumstances.

Acknowledgement of reflected light issues

5.56 Three of the case studies make no reference to reflected light issues.

5.57 Case study C makes no reference in the planning policy or ES with regard to reflected light, but a condition is included that requires non reflective paint with a semi matt finish. Again, the condition appears to reflect the coverage of this issue within the relevant authority's SPG.

5.58 The Environmental Statement for case study E refers to the flashing of reflected light from turbines with a gloss finish, but does not expand further.

5.59 The case study review findings suggest that reflected light is not considered to be a significant issue.

Reference to separation distances and site specific issues

5.60 The ES for case study B uses a 1km distance for assessing shadow flicker, as set out in the SPG.

5.61 Three of the case studies do not refer to separation distances and site specific issues.

5.62 Case study D does not refer to separation distances, however in the final shadow flicker report for the reduction in turbine height the definition of receptors is based on a Zone of Visual Influence (ZVI).

Reference to ten rotor diameter

5.63 Case study A Environmental Report text shows the typical modification of the wording from the Scottish Government Guidance, presenting the ten rotor diameters as a limit, not a guideline; *'Flicker effects have been shown to occur only within 10 rotor diameters of a turbine. Therefore if a turbine has 71m diameter blades, the potential shadow flicker effect could be felt up to 710m from a turbine.'* The ES goes on to say, *'Therefore, for this assessment, it has been assumed that properties within 10 rotor diameters (<700m) have a high sensitivity to shadow flicker, while properties further away from the project are deemed to be outside the region of potential effect and are not included in the assessment.'*

5.64 Case study B ES includes the statement that the Scottish Government's web based renewables advice suggests that shadow flicker should not pose problems beyond a distance of 10 rotor diameters from a wind turbine. This broadly reflects the intended meaning of references to ten rotor diameters in the guidance document, suggesting this is the area of greatest impact.

5.65 The case study C Environmental Statement refers to the limitation of the assessment to within 10 rotor diameters, illustrating the transposition of what is written in the guidance as a likely distance, into a threshold; *'In line with the Scottish Government Web-based Renewables Advice and Update of Shadow Flicker Evidence Base, the assessment area was limited to a radius of 10 rotor diameters from the turbine location and to 130 degrees either side of north.'*

5.66 Case study D planning amendment refers to the limitation of shadow flicker effects, and therefore the assessment, to ten rotor diameters, *' In line with the recommendations of PAN45 and the March 2011 report, shadow flicker effects have been calculated up to a distance of 10 times the maximum rotor diameter of the proposed turbine.'* The shadow flicker report for the planning application for a reduction in turbine height does not refer to ten rotor diameters distance.

5.67 Case study E Environmental Statement simply states that *'Shadow flicker may occur up to ten rotor diameters from the turbines,'* suggesting that the ten rotor diameter distance is used as a threshold. The development management planning committee report also discusses distance and quotes BERR (2007) *'Only dwellings within 130 degrees either side of north relative to a turbine can be affected and the shadow can be experienced only within 10 rotor diameters of the wind farm.'*

5.68 The case studies highlight the frequent use of ten rotor diameters as a maximum threshold for undertaking shadow flicker assessment, and use of this to limit the assessment area, without taking any other factors, such as topography, into account.

Reference to 130 degrees either side of north

5.69 The Environmental Report for case study A makes no reference to 130 degrees either side of north.

5.70 The ES for case study B notes that properties within 130 degrees of north are included in the assessment, from which it can be assumed that properties outwith this range were excluded from the assessment, although this is not made explicitly clear.

5.71 The case study C Environmental Statement refers to 130 degrees either side of north, in relation to the *Update of the UK Shadow Flicker Evidence Base* report, but does not specify if or how it was used in the assessment.

5.72 The case study D planning amendment (2011) refers to 130 degrees either side of north; *'in the UK generally only properties within 130 degrees either side of north, relative to the turbines, can be affected.'* The shadow flicker report for the reduction in turbine height (2012) does not mention 130 degrees either side of north.

5.73 The ES for case study E states, *'Shadow flicker may occur ... within 130 degrees either side of north. Within this area there are several residential properties where shadow flicker may potentially occur and a shadow flicker assessment has been undertaken outlining potential impacts and necessary mitigation.'* This suggests that it was used as a limit for the assessment.

5.74 Therefore the case studies suggest that some of the shadow flicker reports interpret the current guidance as supporting the limitation of the assessment area to within 130 degrees of north.

There is some uncertainty in how 130 degrees of north is being applied in other case studies, although it is referred to.

Significance thresholds

5.75 The Environmental Report for case study A refers to significance thresholds, stating,

' The Danish Wind Energy Association web site suggests that in Germany up to 30 hours of actual shadow flicker during the times a property is occupied is likely to be tolerable. Therefore with similar reasoning as above it has been assumed that more than 30 hours of flicker predicted when mitigation has been taken into account represents a high magnitude of impact, while more than 30 hours without mitigation represents a medium magnitude. Below 30 hours of predicted flicker without mitigation, the magnitude is low, becoming negligible when mitigating factors are applied.'

5.76 However this is another example of the recurrent mis-application of the German threshold without careful reference to worst case or likely case exposure.

5.77 The case study B Environmental Statement refers to the Northern Ireland's Best Practice Guidance to Renewable Energy, which recommends that shadow flicker at neighbouring offices and dwellings within 500m should not exceed 30 hours per year. The ES clearly demonstrates the exposure levels at the affected properties.

5.78 Case study C makes no reference to significance of shadow flicker effects in general or the significance of the predicted shadow flicker levels within the ES, which appear high.

5.79 The case study D (2011) planning amendment refers to the significance of effects but does not define them for the purpose of the report. The shadow flicker report for the reduction in turbine height (2012) does not refer to significance, which makes the interpretation of the assessment findings difficult.

5.80 The case study E Environmental Statement makes reference to significance thresholds in some detail:

'There is no national planning policy or guidance in Scotland which deals with 'exposure' to shadow flicker effects in terms of acceptable of duration. In Northern Ireland guidance recommends that shadow flicker at offices and dwellings within 500m should not exceed 30 hours per year or 30 minutes per day (DOENI 2009). This is based on research by Predac, a European Union sponsored organisation promoting best practice in energy use and supply which draws on experience from Belgium, Denmark, France, the Netherlands and Germany. Although there is no policy or guidance which sets out the limits it is generally considered that exceedance of 30 hours over the course of a year or 30 minutes in a single day is considered as significant under the EIA Regulations.'

5.81 However, as with the case study B example noted above, no reference is made to worst case or likely case scenario.

5.82 The case studies make it clear that greater clarity on significance of effects is required and in particular definition of when worst case and likely case scenarios are referred to.

Definition of receptors

5.83 Two of the case study ES both differentiate between financially involved or not financially involved properties.

5.84 Case study A does not make specific reference to receptors and their sensitivity.

5.85 Case study C refers to receptors, making reference to *The Update of UK Shadow Flicker Evidence Base.* The ES refers to the assessment of non-residential receptors, and refers to the varying sensitivity of receptors. The ES states that it does not attempt to vary the sensitivity of receptors, in order to reduce uncertainty created by making assumptions about sensitivity. This highlights the need for guidance on sensitivity of different receptors.

5.86 The case study D planning amendment does not define receptors. The later shadow flicker report relating to the reduction in turbine height identifies receptors based on a ZVI but does not otherwise define them.

5.87 The case studies highlight a lack of clarity in the definition of receptors to shadow flicker, and how this would affect sensitivity to effects. The case studies also raise the issue of the different treatment of financially involved properties, and the challenges of establishing the financial involvement.

Impacts on receptors

5.88 Case study a highlights inconsistencies within the Environmental Report between the text showing the periods when shadow flicker may occur, and the tables showing the length of time each day shadow flicker may be experienced. For example the maximum hours per day exposure to shadow flicker is shown as 0.6 hours (which is 36 minutes) but the times of day shown in the text when shadow flicker could occur (only in the late afternoon) are for time periods of less than 36 minutes.

5.89 The case study B Environmental Statement summary text on shadow flicker excludes reference to financially involved properties, one of which experiences more than 30 hours per year worst case, and 6 hours per year likely case, which is illustrated in the table within the document. It appears misleading to exclude reference to this property in the summary text on the basis of financial involvement. It is unclear how the cumulative shadow flicker has been calculated.

5.90 Case study C assessment of shadow flicker impacts on receptors is poorly presented, with no reference to the types of receptor, the significance of the effect, or to exposure thresholds.

5.91 Comparing the figures presented in the ES with the threshold (identified in the Stage 1 report for this study) of 30 hours per year worst case shows that 15 of the properties experience more than 30 hours per year worst case cumulative effect. It is not possible from the ES findings to identify daily exposure. The ES presents the shadow flicker exposure as total hours and also as a percentage of time, which appears to be an unusual approach.

5.92 Furthermore, the figures in the text about the percentage of time which shadow flicker would be experienced appear to be based on the number of hours in a year, and not the number of daylight hours in a year. Percentage time exposure to shadow flicker at these properties is given as 2.8%, 4.4% and 3.8%. However to put these figures in context, given 8760 hours in a year, the worst case threshold of 30 hours a year equates to 0.34% of annual hours.

5.93 Case study D identifies one property which could experience shadow flicker effects (based on a search area of ten rotor diameters). It is unclear if the levels of exposure to shadow flicker are worst case or likely case, as the text in the shadow flicker report (2011) does not use the terminology 'worst case'. The impacts on receptors are over 30 hours a year, 30 minutes a day. The shadow flicker report for the reduction in turbine height (2012) identifies the property most affected, and worst case the property most affected receives 6 hours of shadow flicker a year, over 26 days, at a maximum duration of 0.20 hours a day, which is not defined as significant.

5.94 The case study E Environmental Statement identifies four properties as having more than 30 hours a year worst case, and three properties as having more than 30 hours a year shadow flicker (realistic –based on sunshine hours only) experiencing 41 hours, 37 hours and 36 hours.

5.95 The ES goes on to add; *'It should be noted that all four properties which could theoretically* [worst case] *experience significant effects are financially involved with the project and three of which are under the ownership of the site landowner'.* The case study also raises additional issues in relation to financial interest of affected properties. For this case study a report (commissioned by the council) reviewing the noise impact assessment, raised queries over some of those properties noted as having a financial interest as not having any formal agreement in place.

5.96 Although carried out in relation to noise, the query over actual financial interest would also appear to apply to all of the properties which could experience shadow flicker for more than 30 hours a year worst case. A condition was included requiring any change of owner or occupier of properties deemed as having a financial interest in the development to be notified to the Planning Authority, and confirmation of continuing financial involvement verified. The condition, although put in relation to noise, also implicitly applies to properties experiencing high levels of shadow flicker, although it is unclear if this is intentional.

5.97 The case studies identify there are a variety of approaches taken to presenting shadow flicker effects. Opportunities to improve the clarity and consistency of the presentation of effects would be helpful in ensuring clear understanding of the results.

Parameters when shadow flicker may occur

5.98 Two of the case studies include text on the parameters when shadow flicker may occur, which reflects that in the Northern Ireland Best Practice Guide, and also refers to the effect of distance on shadow dissipation and proportion of the sun covered by the turbine blade.

5.99 Case study C refers to the parameters required for shadow flicker to occur including turbine dimensions, weather and other mitigating effects and the trajectory of the sun.

5.100 Case study D defines the factors which influence shadow flicker as relevant to worst case experience of shadow flicker for the shadow flicker reports for both 2011 and 2012, but does not define the parameters for shadow flicker to occur in the same way as the other case studies. The shadow flicker report (2012) is the only case study example which refers to the fact that shadow flicker calculations are only made when 20% or more of the sun is covered by the blade (this reflects the WindPRO computer model parameters).

5.101 Case study E Environmental Statement broadly reflects the parameters set out in the other case studies but excludes some of those included in the longer list, as illustrated in Table 5.1 overleaf.

Table 5.1 Parameters used in the case studies to define when shadow flicker may occur

Parameters	Case study A	Case study B	Case study C	Case study D	Case study E
The direction of the residence relative to the turbine(s)	✓	✓	✓		
The distance from the turbine(s)	✓	✓	✓		✓
The turbine hub-height and rotor diameter	✓	✓	✓		✓
The time of year	✓	✓	✓ (trajectory of the sun)		
The proportion of day-light hours in which the turbine operates	✓	✓	x		
The frequency of bright sunshine and cloudless skies (particularly at low elevations above the horizon)	✓	✓	✓ (weather and other mitigating effects)	Sun is always shining with sufficient intensity to cast clear shadows	✓
The prevailing wind direction.	✓	✓	✓ (weather and other mitigating effects)	Refers to worst case assumption that wind direction is always parallel to the sun-turbine-receptor alignment	
Window sizes and orientations			✓ (taken into account in computer programme)	Properties have windows at north, south, east and west.	✓
Landform and elevation differences between the turbine and receptors			✓(taken into account in computer programme)		
Speed of blade rotation					✓

5.102 The case studies are not always clear on setting out the parameters required for shadow flicker to occur.

Reference to worst case and likely case scenarios

5.103 Two of the case studies provide the likely case and worst case scenario. One case study does not appear to present likely case exposure figures. Case study D identifies that the results in the planning amendment (2011) shadow flicker report are worst case, and the shadow flicker report

for the reduction in turbine height (2012) clearly refers to the worst case scenario. Case study E presents both worst case and 'sunshine corrected' hours [taking only sunshine hours as the additional factor].

5.104 The case studies illustrate the need for clarity in the presentation of both worst case and likely case scenario results. However they also highlight the need to link this to significance, as when levels of exposure to shadow flicker are presented without any discussion of significance, reference to worst case and likely case scenario has less meaning.

Factors taken into account in calculating likely case scenario

5.105 Case study A sets out the same factors for calculating likely case scenario as for case study A below, using location specific data to inform the annual hours of sunlight (35%). The property which experiences 25.7 hours worst case shadow flicker, and is then calculated as 5 hours for the adjusted scenario, which works out at a correction factor of 19% similar to case study B.

5.106 Case study B Environmental Statement sets out the correction factors used in calculating the likely case scenario. These include:

- *Average sunlight hours for the location (32% of daylight hours);*
- *% of time the wind turbine can be expected to turn (90%);*
- *According to the Danish Wind Energy Association website, shadow flicker is reduced to 63% of the maximum possible if the wind turbine is assumed to be randomly yawed relative to the sun position.*

5.107 The shadow flicker report then calculates that 0.32 x 0.90 x 0.63 gives a correction factor of 18%, indicating that likely case shadow flicker is 18% of the calculated total.

5.108 Case study C provides information on what information could be taken into account in the likely case scenario, but does not then appear to apply it. The shadow flicker report mentions a figure of 35% of worst case shadow flicker hours being realistic. Even applying this figure to the predicted hours of shadow flicker, ten of the receptors would still experience in excess of 30 hours a year likely case, well in excess of the 8 hours a year likely case set out in the German guidelines.

5.109 Case study D does not specify factors to take into account in calculating likely case scenario in either shadow flicker report, although it defines the assumptions which inform the worst case.

5.110 Case study E likely case calculations only take sunshine hours into account, and not the percentage of time the blades are rotating, although this is mentioned. The ES references 15% of the time as the blades not rotating, for comparison the case study A example uses 10%. It is unclear from the case studies where these figures are sourced.

How latitude is taken into account

5.111 Latitude is taken into account in the computer modelling.

Computer modelling used

5.112 Case studies A, B and D (2011) used REsoft WindFarm. Case studies C and D (2012) case studies used WindPRO and case study E used WindFarmer.

5.113 The shadow flicker reports for case studies A and E both set out the factors taken into account in the computer modelling. The use of all of the different models illustrates that there does not appear to be a strong preference for the use of one computer model (within the small sample of case studies examined).

Table 5.2 Computer modelling used in the case studies

Case study	REsoft WindFarm	WindFarmer	WindPRO
A	✓		
B	✓		
C			✓

Case study	REsoft WindFarm	WindFarmer	WindPRO
D (2011)	✓		
D (2012)			✓
E		✓	

Cumulative effects

5.114 Case study B includes consideration of cumulative shadow flicker effects with a nearby wind farm. Cumulative receptors are identified as those within 1km of the neighbouring wind farm, and within 1km of the applicant's wind turbines. The two properties are not predicted to show any increase in shadow flicker cumulatively, but it is unclear from the text how the cumulative shadow flicker was calculated. The use of 1km distance for calculating cumulative effects reflects the guidance in the SPG, however it is unclear if this is a direct relationship.

5.115 Case study C presents cumulative shadow flicker in the ES in text form and in tables but it is unclear as to how exactly it has been taken into account.

5.116 Case studies A and D do not mention cumulative impacts in relation to either shadow flicker report. It may be that there are no turbines which could contribute to these, but it is not clear if these have been considered.

5.117 Case study E clearly states that there are no cumulative shadow flicker impacts expected from the proposed development, due to sufficient separation distance from any operational or proposed developments.

5.118 The case studies demonstrate a varied approach to the consideration of cumulative effects and also a lack of clarity and consistency in the approach.

Reference to policy and guidance

5.119 References to policy and guidance were reviewed to identify which documents were informing the approach to shadow flicker assessment within the case studies. Case study A ES only refers to PAN 45 (2002), not the wider range of guidance, however the original application was submitted in 2009, and therefore pre-dates several of the other guidance documents.

5.120 Case study B Environmental Statement refers to the whole suite of relevant guidance: Scottish Executive Planning Advice Note, PAN 45 (revised 2002) (now revoked): Renewable Energy Technologies, the planning authority's Supplementary Planning Guidance, Best Practice Guidance to Planning Policy Statement 18: Renewable Energy, Department of the Environment (Northern Ireland), (2009) and the UK Shadow Flicker Evidence Base, DECC (2011).

5.121 Case study C only refers to the Scottish Government web based Renewables Advice.

5.122 Case study D (2011) refers to PAN 45 (2002), and the UK Shadow Flicker Evidence Base, DECC (2011), but the 2012 shadow flicker report does not refer to policy and guidance.

5.123 The case study E Environmental Statement refers to The Scottish Government web-based guidance on Onshore Wind (2014), replacing PAN 45, the report by consultants Parson's Brinkerhoff for the Department of Energy and Climate Change (DECC 2011) reviewed the UK evidence base on Shadow Flicker and Planning for Renewable Energy: A Companion Guide to PPS 22 (2004).

5.124 The case studies demonstrate a varied approach to referencing other relevant policy and guidance.

Mitigation

5.125 The overall duration and significance of the effect of shadow flicker in case study A Environmental Report is assessed as negligible. The condition applied to the decision takes a precautionary approach which provides protection for any experience of shadow flicker that has not been identified through the assessment process, requiring shut down during conditions conducive to shadow flicker.

5.126 In case study B Environmental Statement no mitigation is proposed. The ES identifies that one property experiences more than 30 hours a year worst case, but that the duration of exposure is below 30 hours a year for the 'realistic' adjustment. This is misleading because the likely case threshold according to the German guidelines should be eight hours, not thirty.

5.127 The report of handling and decision take a precautionary approach and include a standard condition requiring the shut down of turbines following a complaint. Interestingly, the reason given in the report of handling for the inclusion of the condition is given as, *'In the interests of retaining a level of control over any changes in the shadow flicker from the wind turbines, or any differences in the actual shadow flicker from that projected for the site.'*

5.128 The case study C wind turbine appears to generate a high level of shadow flicker. The ES text does not appear to recognise the significance of this potential effect. It states that shadow flicker mitigation is not required in UK policy. The ES text sets out a mitigation strategy which places the burden of proof of the experience of shadow flicker on the receptor and not the developer. The condition included in the decision although covering *'any of the surrounding residential properties to the site of the wind turbine'*, does not appear to offer a high level of protection to residents as it refers back to the text in the ES requiring the receptor to log all occurrences of shadow flicker.

5.129 The developer proposed the shadow flicker mitigation for the case study D wind turbine (2011) as only to be implemented in the event of a complaint. Contrary to this, the condition in the decision requires the mitigation for shadow flicker to be implemented before the turbine is operational. This represents greater emphasis by the planning authority on mitigating impacts on the potential receptors, and not in favour of the developer. There is no mitigation proposed in relation to the 2012 shadow flicker report, or in the planning report as the shadow flicker impacts were not assessed as significant [and are below eight hours a year].

5.130 Case study E Environmental Statement explores in some detail possible approaches to turbine shutdown based on predicted shadow flicker and the use of control systems which respond to light conditions. They also refer to vegetation planting and provision of blinds. The development management committee report includes a planning condition requiring the developer to submit a scheme for an operational protocol for the assessment of any complaints of shadow flicker. This is recognised in the development management committee report as not being an ideal condition, but reflecting that of a condition applied by a Scottish Government reporter to another wind farm. As with the previous case studies, this condition appears to attempt to compensate for any deficiencies in the assessment, including the locations affected by shadow flicker occurrence (including locations beyond ten rotor diameters), and deficiencies in the assessment of significance of shadow flicker. However the efficacy of the operational protocol would be dependent on its content.

5.131 The case studies present some clear examples of the planning authorities compensating for the potential deficiencies in the shadow flicker assessment.

Summary of issues from the case studies

5.132 To summarise the issues from the case studies:

- Apparent differences in the ways information is presented in different parts of the shadow flicker report.
- Frequent mis-application of the 30 hours a year worst case threshold for experience of shadow flicker as a likely case threshold (therefore underestimating the significance of impacts, as it should be 8 hours likely case if referring to the German guidelines).
- Some variation in distance thresholds applied in guidance documents (SPG for two of the case studies use distances greater than ten rotor diameters), but general use of ten rotor diameters within ES (with one exception which uses a ZTV to identify receptors). This illustrates a reversion to national guidance over local guidance documents.
- Use of the ten rotor diameter threshold as a limit, not an approximate distance within the shadow flicker assessments.
- Lack of reference to what levels of shadow flicker are 'significant' within assessments.

- Differentiation between discussion of significance shadow flicker effects at financially involved and not financially involved properties (reflecting what is common in noise assessments).
- Lack of clarity in how cumulative effects of shadow flicker are calculated.
- Variation in the factors taken into account in calculating 'likely case' scenarios, and how this is actually calculated, (definite need for guidance to make this more consistent).
- Variation between planning authorities in approaches to conditions. Example of one case study taking a precautionary approach to the robustness of the assessment results and applying conditions to allow issues of future shadow flicker to be addressed even where predicted effects are negligible. The case study E example also provides a 'catch all' condition which allows any future complaint to be addressed. Another example (case study C) where the condition simply repeats proposed mitigation from an ES which seems heavily biased against any potential receptors providing a burden of proof.

Interview findings

5.133 The interviews were based around the emerging conclusions from the Stage 1 literature review and informed by the results of the case study review.

Definition of shadow flicker

5.134 All of the respondents agreed a need for a clear definition of shadow flicker in order to provide clarity and consistency. One respondent noted that the definition needs to clarify indoor effects and outdoor effects, and that clarity on the parameters where shadow flicker is likely to occur would be useful including reference to latitude.

5.135 Another respondent noted use of the definition in the Scottish Government Guidance and lack of awareness of the inconsistency between documents.

Definition of shadow throw

5.136 The respondents for two case studies did not have experience of the issue of shadow throw. One respondent suggested that it would need to have an amenity impact if it was something to be further explored. An EHO agreed it would be helpful to have a definition and know how to deal with it.

5.137 One of the case study EHO has received complaints regarding what would be termed shadow throw. Some residents complain/comment on shadow throw affecting their enjoyment of their garden or the effect on roads/driving. Some residents also comment that their horses are adversely affected/spooked. It was suggested that residents may consider shadow throw to be shadow flicker and that further clarification would help.

Night time lighting

5.138 One development planner was not aware of issues relating to night time lighting, but mentioned the night time impacts of shadow flicker from the Little Raith wind farm and the Mossmorran flare stack.

5.139 A development planner had no experience of complaints regarding night time lighting post development, although he noted that this is a concern when developments are proposed. It was noted that these impacts are easily mitigated through the use of infrared lighting.

5.140 An Environmental Health Officer noted that they had received adverse comments in respect of the lighting used on the top of the nacelle for aircraft warning purposes. Giving the example of a very small number of cases commenting that this lighting makes them feel "uneasy" in the dark and that it is like "two eyes" looking down on you.

Acknowledgement of reflected light issues

5.141 One respondent was not aware of any examples of reflected light issues and suggested that it was not a planning issue, pertaining to amenity or safety, and questioning the different between light

reflection from a wind turbine and any other structure. It was also suggested that if the SNH guidance provides coverage of this issue, there is perhaps not a need for further guidance.

5.142 One of the case studies had not received any complaints regarding reflected light but noted that they routinely request a matt finish in conditions for wind turbine developments.

5.143 Another respondent was aware of a complaint relating to reflected light from a nearby wind turbine, and agreed that acknowledgement of reflected light issues would be helpful.

10 rotor diameter distance

5.144 Both the development planner and Environmental Health Officer (EHO) for one case study suggested the guidance could remove the reference to ten rotor diameters, because they were aware of examples of shadow flicker at greater distance. It was suggested it would be appropriate to have more of an evidence based assessment with a focus on factors which influence shadow flicker such as topography and wind direction.

5.145 A development planner felt that references to this distance should reflect what is proportionate and effective.

5.146 An EHO was used to working with the ten rotor diameter distance as a limit and agreed it would be useful to have clarity on this in the guidance.

5.147 One of the respondents identified a case study example[47] of shadow flicker being reported and confirmed beyond ten rotor diameters distance from a development.

Case Study example of shadow flicker beyond ten rotor diameters

Full planning permission was granted for the erection of a small wind farm comprising turbines of 80m rotor diameter.

For the original turbines the closest was 1540m from the property experiencing shadow flicker. The resident of this property stated that they experienced shadow flicker on a significant number of occasions.

Several extensions to the wind farm were approved subsequent to the original application resulting in a development of twice the number of turbines in the original planning application. The extensions comprise turbines with the same hub height, tip height and rotor diameter as the original planning application.

The extensions brought three turbines to within 1km of the complainant. One turbine is located 790m from the complainant – 10m within the 10 times rotor diameter.

Shadow flicker monitoring was undertaken by the operator at the affected property for the period between the months of October and February.

This recorded a large number of shadow flicker events – on a small number of days up to three shadow flicker events were recorded, therefore shadow flicker was being caused by more than one turbine.

The total recorded shadow flicker in the recording period was less than twenty hours. The duration of the individual shadow flicker events are all less than 30 minutes.

Reference to the degrees either side of north affected by shadow throw

5.148 A development planner agreed that clarity was needed on the use of this threshold but that there could be a definition of the area where impacts would not occur.

5.149 Two respondents were not aware of 130 degrees either side of north being used as a cut off.

Thresholds for exposure to shadow flicker

5.150 A development planner expressed caution over the definition of significance, which is subjective, as different individuals have different tolerance. They identified that if figures are provided then

[47] As the example is subject to an ongoing complaint the case details have been anonymised.

the reasoning behind how the significance figures are arrived at needs to be robust. They agreed guidance on thresholds of significance would be helpful when dealing with complaints, particularly at a later date. Shadow flicker can always be mitigated, and the concern would be if shadow flicker shut down was going to affect the overall productivity of the turbine (this approach is used in relation to noise, if significant periods of shutdown will negate the operation of the turbine then an application is recommended for refusal). Thresholds would need to be set out within the Scottish Government guidance.

5.151 An Environmental Health Officer (EHO) noted they would welcome clarity on what constitutes significant shadow flicker as this would improve consistency in assessment and consistency in review.

5.152 A development planner suggested that if the German guideline for thresholds of exposure has been robustly tested and is applicable in this country then this would be reasonable, and another agreed that it would be helpful to have information on significance thresholds set out in the guidance.

Financially interested properties

5.153 A development planner noted that financial interest shouldn't count in shadow flicker, because as with noise, the financial interest can change and there is often a lack of verification of a stated financial interest.

5.154 Another development planner suggested that the treatment of financially interested properties should be on a case by case basis.

'In most instances they could be provided with mitigation by the applicant as part of any agreement they had. Noise is different as this could make a dwelling uninhabitable or cause serious health issues. If shadow flicker was likely to be so bad that it would have the same impact then criteria would be needed.'

5.155 An Environmental Health Officer agreed it would be useful to have some clarification on how to define and treat financially interested properties and the overlap of this issue with noise.

Definition of different types of receptors to light and shadow related effects

5.156 A development planner noted that sensitive receptors are classed as dwellings but many people live and work in the rural area of the planning authority. There are many rural businesses and shadow flicker could impact on these. It is important to draw out the potential impacts on rural business but perhaps no need for further research into sensitive receptors.

5.157 An Environmental Health Officer agreed there needs to more clarity regarding different types of receptor and how to consider individuals who are sensitive to changes in light, epilepsy, mental health illness, etc. Also, with many people now working/employed in their own home or in a rural environment some clarity on whether these types of receptor should be considered would be helpful, and suggested possible different thresholds of significance.

5.158 An Environmental Health Officer suggested that they would treat hospital/school as same sensitivity as residential, but that more guidance on sensitivity of receptors would be helpful.

Definition of parameters when shadow flicker may occur 'Likely case' modelling

5.159 A development planner agreed that it would be useful to include a clear statement of the parameters required for the occurrence of shadow flicker and the factors then used in likely case scenario calculation.

5.160 Another development planner agreed there was a need for consistency in the presentation of likely case and worst case and that it makes it easier for development management to assess. It was noted that the severity of impacts presented in assessments can change in significance from the assessment through to the conclusion. Planning officers are aware of the issues surrounding the presentation of results and add conditions accordingly. It was specifically recommended that in calculating likely case scenarios it would be important to add topography or the elevation of the turbine above the receptor.

5.161 An EHO supported the need for very clear guidance on how a shadow flicker assessment should be done and presented. Noting that currently, unless local authorities have the proprietary modelling software, they are unable to replicate consultants shadow flicker assessments and are therefore very much constrained into accepting assessments at face value. It was highlighted that as with noise impact assessments for wind turbines, the acceptance of reports at face value is highly likely to mean acceptance of a poorly undertaken and often inaccurate assessment. They made the following suggestion to address this issue:

'I think it would help enormously if the Scottish Government could provide free to use (or subsidised) simple modelling tools to local authorities to enable consultants' assessments to be checked and properly appraised (e.g., similar to the freely available tools provided for basic air quality assessment purposes).'

5.162 An EHO noted they usually dealt with 'reasonable worst case'. The respondent agreed that clarity on the factors to take into account and how to identify likely case scenario would be helpful.

Greater reliance on distance thresholds set out in national guidance than local guidance

5.163 A development planner commented that the guidance in the planning authority dates from the middle of the last decade, and several parts of the guidance are effectively out of date as they do not refer to the current evidence base. The distance threshold used in the guidance is not referenced as to how this figure was identified. An EHO explained the greater reliance on distance thresholds in national guidance than local SPG as what would normally be held up at inquiry.

Cumulative effects

5.164 The respondents did not have any experience of complaints where there are cumulative issues, but agreed that guidance on cumulative effects should be provided to ensure consistency. It was noted that as sites become more tightly packed together (due to availability of land) that cumulative issues may become problematic.

Mitigation

5.165 One of the case studies applies a model condition to address shadow flicker (and to compensate for lack of specialist knowledge) to most large wind turbine planning consents. It was also indicated that it would be helpful to determine where the expertise should lie (i.e., with Planning staff or Environmental Health staff) and whether shadow flicker is a public health issue or solely an amenity issue.

5.166 Another respondent suggested that the planning authorities include the 'catch all' condition in relation to shadow flicker simply to cover all bases, and that as a technical issue, planners are reliant on advice from Environmental Health on shadow flicker.

Public perceptions of light and shadow effects

5.167 The second part of the Stage 2 focuses on academic and grey literature relating to public perception of light and shadow effects. Issues to considered include:

- The extent to which non-specialists understand the difference between shadow flicker, other light related effects and wider landscape and visual effects.
- A review of the way that shadow flicker and other light related wind turbine effects are addressed in the grey literature. This will include identification and review of media articles, material produced by groups opposing wind developments, material produced by wind energy developers and trade associations and materials published by 'neutral' third party organisations (e.g. British Horse Society)

5.168 The search for relevant literature sources to inform Stage 2 of the project identified some challenges in relation to finding relevant documents which refer to shadow flicker. Shadow flicker is a marginal topic area for which there is a limited recognition and reporting. In relation to impacts on the public, the other impacts arising from wind turbines are typically of greater magnitude than those for shadow flicker and receive greater levels of coverage.

5.169 The literature search for stage 1 of the study also provided coverage of the issues in relation to the way people experience, perceive and are affected by light and shadow effects (which was originally intended to form part of Stage 2).

Media articles

5.170 A small number of media articles have been identified through the Stage 2 literature review in relation to shadow flicker, these include articles referring to wind turbines and shadow flicker in general, and those referring to specific wind farms and issues experienced at those locations.

5.171 An article reported in *The Guardian*[48] in 2012 refers to guidance and the distance shadow flicker can be experienced *'Planning guidelines state that shadow flicker can impact on residents who live within a distance 10 times greater than the blade's diameter.'* The article also explores the frequency of flicker produced by large turbines and how this flicker is lower than that required to trigger seizures. It also states that *'there is limited scientific evidence of association between annoyance from prolonged shadow flicker (exceeding 30 minutes per day) and potential transitory cognitive and physical health effects'*. However this article demonstrates the repetition of duration of experience of shadow flicker (30 minutes a day) without defining whether this is worst case or likely case exposure.

5.172 An article in *The Telegraph*[49] describes shadow flicker as an occurrence through constrained openings such as windows, and notes that the scale of the problem depends on a number of factors such as wind speed and direction, the position and point of the sun, and cloudiness. It also refers to the limited occurrence of shadow flicker, and the effectiveness of mitigation, in particular turbine shut down systems. This illustrates recognition of the factors influencing the occurrence of shadow flicker and the effectiveness of mitigation if correctly applied.

5.173 A related article[50] also in *The Telegraph* sets out the different impacts of wind turbines covering noise, flicker, blade glint and radiation. It explains that shadow flicker has not been found to have health effects, but that it can cause 'significant nuisance'. In relation to blade glint it reiterates that this is no longer an issue due to paint finishes used by manufacturers.

5.174 An article relating to one experience of shadow flicker in Ireland[51] reported in *The Journal* does not mention any other light related effects, but reports on the shadow flicker within a household located within a reported 330m of a wind turbine. The article reports the respondents as saying they were not warned about the shadow flicker from the wind farm, and that they experience significant negative effects from the shadow flicker. It is reported that the whole house is affected during a shadow flicker occurrence, and that blinds provide insufficient mitigation. They also note that complaints to the wind farm operator have not resolved the shadow flicker issues. Interestingly, the same article also refers to the noise experienced from the wind farm, and indicates that noise levels are quite intrusive. This potentially supports the previously identified link between shadow flicker nuisance and noise.

5.175 An article produced by PagerPower also relates the issue of shadow flicker relating to flare stacks at Mossmorran and Little Raith wind farm in Fife[52]. This article highlights the occurrence of shadow flicker in relation to the flare stack, and that unlike shadow flicker from the sun, the light source does not move relative to the receptor. Although this is a very location specific issue, the article highlights the need to consider other sources of shadow flicker. The article makes reference to distance, but states that the affected zone of shadow flicker from a non-moving points source *'may be more or less than ten times rotor diameter.'*

[48] Wind Myths: turbines can damage your health 28th February 2012 https://www.theguardian.com/environment/2012/feb/28/wind-turbines-damage-health

[49] Shadow Flicker: rotating blades can cause headaches 17th March 2011 http://www.telegraph.co.uk/news/earth/earthnews/8386273/Shadow-flicker-rotating-blades-can-cause-headaches.html

[50] Can wind farms really make you ill? The evidence 17th March 2011 http://www.telegraph.co.uk/news/earth/earthnews/8386397/Can-wind-farms-really-make-you-ill-The-evidence.html

[51] The Journal '"It's a disaster": Family affected by windfarm's turbine flicker ' February 7th 2015 http://www.thejournal.ie/athea-wind-farm-1915304-Feb2015/

[52] Flare Stacks and Wind Turbine Shadow Flicker D Scrivener (undated) available at: http://www.pagerpower.com/news/wind-turbine-shadow-flicker-flare-stacks/

5.176 A review of the public information on Binn Eco Park Wind Farm includes a supporting document on the benefits of the proposal[53]. However there are no references to the environmental impacts of the wind farm within this document which focuses solely on the economic and climate change benefits. Associated newspaper coverage of the decision[54] did not make reference to shadow flicker, although health risk, noise nuisance and impacts on the environment were mentioned.

Wind farm opposition groups

5.177 A search of wind farm opposition group material on shadow flicker was also undertaken. *Save Straiton for Scotland* raised specific concerns about the misrepresentation of shadow flicker from Linfairn Wind farm[55]. A member of the group undertook a critical review of the shadow flicker report for the wind farm. The text raises specific concerns relating to the parameters applied in the calculation of the shadow flicker extent from Linfairn Wind Farm, which are limited to ten rotor diameters. The commentary highlights that the ten rotor diameter threshold was used as a cut off in the calculation of the extent of shadow flicker, and that particularly in the case of this wind farm located at the south end of a valley, with the majority of properties at a lower altitude than the wind turbines, the extent of shadow flicker is greater.

5.178 A wind farm action group in Wales[56] makes more generic references to light and shadow effects. Text on the website includes *'The strobe effect when sun is behind the rotating blades can, according to medical opinion, cause dizziness, headaches and trigger seizures.'* This conflicts with the current evidence which concludes that the frequency of modern larger turbines does not trigger epileptic seizures. It follows this statement with, *'Shadow flicker and reflected light from the blades can also cause problems. These light disturbances are experienced inside the home as well as outside,'* but does not provide comment on what problems are caused or the distances at which they may be experienced.

5.179 Wind Aware Ireland[57] sets out the social, economic and environmental impacts of wind turbines. In relation to shadow flicker, the website quotes the Minnesota Department of Health (2009) stating that shadow flicker can be an issue both indoors and outdoors. It misquotes that in England the recommended shadow flicker setbacks for current wind turbine designs are 10 rotational diameters. It also states examples of seizures induced by wind turbines on small wind farms in the UK, and that *'anecdotal evidence would suggest that shadow flicker causes stress and annoyance'*.

Developers and trade associations[58]

5.180 The Irish Wind Energy Association[59] website provides a summary of the environmental impacts of wind energy. In relation to shadow flicker it states, *'The assessment of potentially sensitive locations or receptors within a distance of ten rotor diameters from proposed turbine locations will normally be suitable for EIA purposes.'* This appears to support the use of ten rotor diameters as the assessment area, and not looking beyond this area. It also states *'A guideline of not more than 30 hours of shadow flicker per year is suggested for dwellings,'* without defining if this is worst case or likely case.

5.181 The Danish Wind Energy Association[60] includes information on shadow flicker, within a wider discussion of setback distances in relation to noise. *'It is recommended that the calculated average of shadow hours on neighboring houses do not exceed 10 hours per year. If the shadow*

[53] http://www.elpower.co.uk/sites/www.elpower.co.uk/files/subpage/binn_eco_park_wind_farm_-_supporting_document.pdf

[54] https://www.thecourier.co.uk/news/local/perth-kinross/251443/locals-angered-after-councillors-overrule-advice-in-approving-binn-eco-park-wind-turbines/

[55] Save Straiton for Scotland Misrepresentation of Shadow Flicker for Linfairn Wind farm J S. Nolan, supporter Save Straiton for Scotland, Feb 2015 https://savestraiton.files.wordpress.com/2015/02/appendix-vii-misrepresentation-of-shadow-flicker-for-linfairn-wind-farm.pdf

[56] Mynydd Llansadwrn Action Group http://www.turbineaction.co.uk/wind-turbine-issues/shadow-flicker-and-strobe-effect-even-indoors.html

[57] http://www.windawareireland.com/social-issues/

[58] The British Wind Energy Association Renewable UK, and the European Wind Energy Association did not yield any results for searches in relation to shadow flicker on their websites.

[59] http://www.iwea.com/index.cfm/page/environmentalimpacts?#q72

[60] http://www.windpower.org/en/policy/planning_and_regulation.html

limit is exceeded the wind turbine owner may alternatively be required to shut down the wind turbine in critical periods'.

5.182 A document on the above website titled *Technological solutions to reduce the environmental impacts of wind energy systems*[61] includes comment on the coating of wind turbine blades with a matt surface to avoid issues of light reflection. In relation to shadow flicker it states that, '*In Denmark the distance from the wind turbine to the house should be less than 2 km to qualify as shadow flicker. The guideline in Denmark is that up to 10 hours per year is tolerated. For nearshore wind farms it has no practical relevance due to the distance.'*

Other material

5.183 The British Horse Society (BHS) carried out a survey[62] in 2012 of equestrians' experiences with wind turbines in order to inform the BHS response to proposed turbine developments as well as informing BHS policies and guidance to developers. This survey informed the preparation of a Scottish Wind Farm Advice Note[63] by the BHS. The survey and advice note recognise that there are many factors relating to wind turbines which may startle or unsettle a horse, including the noise and sight of the moving blades. The survey also identified horses' reaction to shadows on the ground where a horse is required to pass, and reactions varied from taking little notice to fearful. The British Horse Society has a particular focus on safety, and in relation to distance at which shadows are experienced states within the Advice Note that '*shadows can affect ground a considerable distance from the turbine at certain times of day or year, when the sun is very low*'.

5.184 Therefore no specific mention of distance which shadows from turbines can be experienced is made. The only references to distance are for set-back distances relevant to turbine failure.

5.185 A survey carried out by the University of Ulster and Chartered Institute of Environmental Health (Ireland)[64] assessed community views on wind energy generation focusing on perceptions of environmental quality by the residents of two neighbourhoods, one situated within 3km of an operational wind farm site and the other situated within 3km of a proposed wind farm site. The respondents in Site 1 (proposed site) were asked to rate their concern about a number of issues related to wind farms on a scale of 1 to 5. 70.9% of respondents were not concerned at all about noise during construction. 60.9% were not concerned at all about Radio or TV signal interference. 67.3% were not concerned at all about shadow flicker effect. No information on shadow flicker on the operational wind farm site was recorded.

Stage 2 Conclusions

Understanding the difference between shadow flicker, other light related and wider landscape and visual effects

5.186 The literature review did not identify any confusion between shadow flicker and other light related and wider landscape and visual effects among non-specialists. The Stage 1 literature review did however identify the relationship between the experience of noise and annoyance related to wind turbines. This was also identified within another article by the Journal of the Acoustical Society of America (2016) on annoyance associated with shadow flicker and experience of wind turbine noise[65]. This article suggested that experience to one type of impact (noise) from wind turbines may also increase sensitivity to other impacts. In addition setback distances for wind turbines in relation to noise are also sometimes referred to in text which refers to shadow flicker. Therefore the interrelationship between noise and shadow flicker is related, but presents opportunities for further misinterpretation.

5.187 From the articles reviewed evidence was not found for any consistent misunderstanding in relation to shadow flicker by non-specialists. However the one of the respondents suggested there was some confusion of shadow flicker and shadow throw.

[61] Report from Hegavind (2016) Technological solutions to reduce the environmental impacts of wind energy systems

[62] www.bhs.org.uk/~/.../bhs/.../wind-turbine-experiences-bhs-2012-survey-results.ashx?...

[63] www.bhs.org.uk/~/media/bhs/files/.../wind-farms-in-scotland-bhs-advice-note.ashx?

[64] University of Ulster and Chartered Institute of Environmental Health (Ireland) (2012) Living with Wind Turbines an investigation into public perceptions and experiences of affected communities

[65] The Journal of the Acoustical Society of America, (2016). Estimating annoyance to calculated wind turbine shadow flicker is improved when variables associated with wind turbine noise exposure are considered

Presentation of shadow flicker and other light related turbine effects in the media / organisation publicity material

5.188 It is apparent that there is some innate confusion over the application of the ten rotor diameter distance, and variation in its use as a threshold (whereby the interpretation is that significant shadow flicker effects will not be experienced beyond this distance, and therefore are not assessed beyond this distance) or a guideline (the most significant shadow flicker effects will be experienced within this distance, but shadow flicker may also be experienced beyond this distance).

5.189 The minor changes to the language in various guidance documents when referring to the ten rotor diameter distance have led to its original meaning being altered in some instances, and in the propagation of this through various types of documentation.

5.190 As concluded from the Stage 1 literature review, there is a lack of evidence to support the use of ten rotor diameters as a cut off, and this is entirely down to misinterpretation of the original reference to this distance.

5.191 The case study review has added further evidence to the issues identified from the literature review surrounding the definition and approach to the assessment of light and shadow flicker in the planning process and the presentation of these effects.

5.192 No evidence was found of alternative presentation of shadow flicker issues in engagement and consultation with residents, and evidence was not found on the extent to which light and shadow effects and impacts are features in pre-application consultation with residents. The literature review in particular explored the evidence for how residents understand and perceive light and shadow effects.

5.193 The study did not identify evidence on the extent to which public perceptions of shadow flicker match predicted and actual effects.

6 Conclusions and Recommendations

Stage 1 and 2 conclusions and recommendations

6.1 This section of the report sets out the combined conclusions from Stage 1 and 2 of the study, drawing together the findings from the literature review, case study analysis and interviews and specifically exploring:

- recommendations on the content of draft planning guidance on light and shadow effects;
- the definition of light and shadow effects and significance of impacts;
- the assessment of light and shadow effects and significance of impact; and
- the communication of light and shadow effects and impacts with residents.

General conclusions

6.2 The literature review has highlighted the risks associated with government guidance documents repeating information from other sources, without full investigation of the original source documents. Guidance documents should include reference sources where appropriate, particularly to support recommendations, or guidance documents should be supported by a more detailed research report.

6.3 Accuracy of the repetition of information from source documents also needs to be ensured, as highlighted by the issues associated with the German exposure thresholds where the omission of reference to 'worst case' or 'likely case' is critical.

Recommended content of guidance on shadow flicker

Recommendation 1: Definition of Shadow Flicker

6.4 There needs to be consistency between guidance documents and planning policy on the definition of shadow flicker. The most widely used definition of shadow flicker within guidance documents is as follows:

"Under certain combinations of geographical position, time of day and time of year, the sun may pass behind the rotor and cast a shadow over neighbouring properties. When the blades rotate, the shadow flicks on and off; the ***effect or impact*** *is known as "shadow flicker".*

6.5 Based on the review of shadow flicker definitions the above definition is identified as covering the key aspects of shadow flicker, and aligned with the definition in national guidance documents, and therefore appropriate.

Recommendation 2: Definition of Shadow Throw

6.6 The literature review identified that experience of shadows outdoors is not clearly recognised within policy and guidance, and the case studies identified limited reference to this effect. The extent to which shadow throw is an issue in Scotland is potentially limited, however for clarity shadow throw (also referred to as 'passing shadows') should be defined. A definition of the outdoor effects of light and shadow related effects was not identified within the guidance, and has emerged from the literature review and review of SPG. A possible definition is *'a moving shadow across open ground'*.

6.7 As noted in the earlier conclusions for Stage 2, the definition of the impact of shadow throw in terms of impacts on safety, amenity or nuisance may influence how this effect is dealt with in the planning system.

Recommendation 3: Acknowledgement of reflected light issues

6.8 It is recognised that reflected light issues are not identified as a significant issue within the guidance documents, literature or case studies. For completeness, guidance should include acknowledgement of the issue of reflected light, which can be most apparent under wet or icy conditions. It should refer or cross reference to the use of paint colour and surface finishes which reduce this effect, as in the SNH guidance.

Recommendation 4: Night time lighting

6.9 No specific issues associated with night time lighting were identified in the study, other than the inclusion of a condition relating to this in one of the case studies, and some reference in the interviews to this being raised as a minor issue. The guidance could acknowledge impacts of night time lighting through cross reference to Scottish Natural Heritage guidance[66]. With increasing turbine size in new and repowered wind farms, it is more likely that schemes will trigger requirement for lighting under CAA or MOD rules. This requirement may be satisfied by infrared lighting but in some cases visible red flashing or constant lighting may be required. It is recommended that guidance should clarify the likely requirement for visible lighting, and how potential landscape and visual effects should be addressed.

Recommendation 5: Definition of parameters when shadow flicker may occur

6.10 The guidance should explicitly set out the parameters when shadow flicker may occur and which are required for likely case scenario modelling. The bullet points in the Northern Ireland Best Practice Guide to PPS18 identify some of these parameters, the parameters are also identified by Pager Power (see Appendix 1), and the case study review identified some additional parameters. These are identified as follows.

6.11 Parameters affecting the occurrence of shadow flicker:

- The direction of the residence relative to the turbine(s).
- The distance from the turbine(s).
- The turbine hub-height and rotor diameter.
- Blade width.
- The time of year.
- The proportion of day-light hours in which the turbine operates.
- The frequency of bright sunshine and cloudless skies (particularly at low elevations above the horizon).
- The prevailing wind direction.
- Window sizes and orientations.
- Landform and elevation differences between the turbine and receptors.
- Speed of blade rotation.

6.12 In relation to calculating likely scenario, percentage operational time (dependent on wind strength and operational maintenance factors) can be applied to the final figure of the quantification of hours / day or / year that effects could occur and is not required to be part of the model calculations.

6.13 The study found that some of the modelling software allows incorporation of factors which will generate a more realistic outcome, but others require these factors to be calculated and applied to the modelled 'worst case' result.

6.14 There appears to be significant variation in the factors taken into account when calculating 'likely case' or 'realistic' shadow flicker, and the case study review identified a lack of clarity in presentation of findings. The guidance should explicitly set out the parameters which are required for likely case scenario modelling.

[66] Scottish Natural Heritage (2014) Siting and Designing Wind Farms in the Landscape Version 2

6.15 Use of a matrix would allow the shadow flicker assessment to note what factors have been taken into account in the calculation, whilst clearly set against a standard list. An example of the factors included in the case studies is provided in Table 7.2 below.

Table 6.1 example matrix showing factors taken into account in calculating likely case scenario based on case study examples.

Factors influencing occurrence of shadow flicker likely case scenario calculation	Sources of data in case study examples
Average sunlight hours for the location	EU funded Satel-Light European Database of Daylight and solar radiation Met office data for nearest location Figures cited in the shadow flicker assessments are in the region of 35% of daylight hours being sunshine hours
Average % of time the turbine is operational	Cited in examples as 90% and also 85%. It is unclear if this reflects maintenance downtime only.
Yaw angle	This can be location specific based on wind direction data (which would give a different likely case factor for different receptors, depending on their location), or an assumed factor based on random yawing (taken from Danish wind energy website as 63%)

Recommendation 6: Reference to the degrees either side of north affected by shadow throw

6.16 Although the Scottish guidance does not refer to the parameter of 130 degrees either side of north, some of the case study examples referenced this figure, in line with other UK guidance. However, it was unclear how or if it was applied to the case studies. The review of the computer models identified that latitude is an integral element of the calculation, and therefore so long as no steps are taken to exclude properties which fall outside of this, the modelling will allow for any factors relating to latitude.

6.17 Scottish guidance should not include reference to the occurrence of shadow throw 'within 130 degrees either side of north'. In line with the recommendation that shadow flicker assessment should be based on significance thresholds, guidance should avoid reference to limiting the area of assessment. It may be appropriate to include explanation that the pattern of shadow effect varies with latitude and modelling will clarify the area of shadow effect from a wind turbine.

Recommendation 7: Exclusion of reference to the 10 rotor diameter distance

6.18 Although a number of other factors may contribute to the significance of shadow flicker potentially being greatest closer to the wind turbines, the ten rotor diameter distance threshold does not appear to have robust evidence within the literature examined.

6.19 Secondly, there is frequent misapplication of the ten rotor diameter distance as a limit within which shadow flicker modelling is applied. Although it is recognised that shadow flicker effects may be greatest within the ten rotor diameter distance, assessment of cumulative effects needs to consider properties beyond this distance.

6.20 There was some variation in the distance thresholds applied in guidance documents relevant to the case studies (two sets of supplementary guidance use distances greater than ten rotor diameters), but a general use of ten rotor diameters to limit the assessment of shadow flicker

within environmental statements (with one exception which used a zone of theoretical influence to identify potential receptors, but the distance the shadow was calculated for appears to be 2km). This illustrates a reversion to national guidance over local guidance documents and therefore it is not possible to ascertain if shadow flicker effects beyond ten rotor diameters are occurring for the case studies.

6.21 Scottish guidance should not include reference to the ten rotor blade diameter distance in relation to shadow flicker due to the misapplication of this figure even when presented in current guidance as the area where impacts are most likely to occur. It appears more appropriate to identify the factors which influence when shadow flicker is more likely to occur and when it is less likely to occur, based on local conditions. The guidance should focus on avoidance of harm and nuisance, which should be established by exposure thresholds, and not on limiting the area of assessment.

Recommendation 8: Thresholds for exposure to shadow flicker and use of worst case and likely case scenarios

6.22 The German guidelines are clear on the exposure thresholds for both worst case and likely case scenarios of 30 hours per year or 30 minutes a day worst case and eight hours a year likely case. These thresholds are most widely quoted, although some countries have set their own limits. It would be potentially useful to engage in more detailed discussions with officials in Belgium and Netherlands to understand the origins of the thresholds they use. Discussions with German officials may allow identification of the origin for the 20% coverage of the sun threshold quoted.

6.23 There appears to be a lack of clarity within existing guidance and literature on when worst case and likely case predictions are referred to, and this was reflected in the case studies. Guidance documents referring to exposure thresholds for shadow flicker must be explicit in their reference to limits relating to worst case and likely case scenarios. The German approach is based on setting significance thresholds based on exposure thresholds, and not on a generic distance threshold.

6.24 The origins of the German thresholds for significance of exposure are based on findings from a laboratory study which measured the stress response of adults exposed to shadow flicker. However the scale of this study was limited in extent, and the study was noted in another literature source as not having been published in a peer reviewed journal.

6.25 Furthermore, using exposure thresholds relies on accurate prediction of shadow flicker by the computer models, and ensuring the modelling is not unnecessarily limited.

6.26 Of the three computer models which are widely used in relation to shadow flicker, only WindPRO was identified as allowing for likely case scenario modelling. Therefore any requirements within guidance for likely case scenario modelling would have a significant impact on the use of the different models.

6.27 The case study review has identified inconsistency in the definition and application of 'significance' in relation to predicted shadow flicker both worst case and likely case. This is reflected both in the presentation of shadow flicker results and in their interpretation by planners. Due to the lack of guidance on significance, the case study review found that planners are in a difficult position when reviewing shadow flicker assessment findings, even when the findings are presented clearly.

6.28 In the majority of the case study examples the planning authority compensates for any flaws in the assessment process through the use of a precautionary condition which allows for mitigation of any shadow flicker, even when the assessment suggests no significant impacts. In one example there is greater reliance on the ES findings and the proposed mitigation within this.

6.29 The interviews identified support for guidance on assessing the significance of shadow flicker effects. Guidance on significance would need to be used to support the required mitigation. If turbine shutdown is required this may need to be combined with any shut down required in relation to noise to identify potential impacts on the overall productivity of the turbine.

Recommendation 9: Definition of different types of receptors to light and shadow related effects

6.30 The case study review identified that there needs to be clarity on the different approaches to assessing significance of levels of effect at financially involved properties. This is an established difference in noise assessment, however it is unclear how appropriate this is in relation to shadow flicker, particularly in light of the lack of clarity in assessments on 'significance'.

6.31 The study review was inconclusive in relation to the definition of different types of receptor based on other variables and their sensitivity to light and shadow related effects. There was some reference to residential and business use, and the interviews highlighted the need to consider impacts on rural businesses.

6.32 There is a need to include guidance on different factors which may affect the sensitivity of different types of receptor to light and shadow related effects.

Recommendation 10: Approach to assessing cumulative effects

6.33 The study found limited reference to the identification and assessment of cumulative effects, however it was identified as an issue covered in the case studies and an area where there was a lack of clarity or consistency in approach. The guidance should set out the need to consider cumulative shadow flicker and further guidance on how this should be approached.

Summary of recommendations

- The guidance should define shadow flicker.
- The guidance should define shadow throw.
- The guidance should refer to reflected light issues and night time lighting, with reference to SNH guidance.
- The guidance should set out the parameters when shadow flicker will occur and factors to be taken into account in calculating likely case scenario.
- The guidance should not include reference to 10 rotor diameter distance, reflecting that this has been misinterpreted.
- The guidance should not include reference to 130 degrees either side of north, as it potentially limits the assessment area, although this effect is unlikely to be significant.
- The guidance should outline significance thresholds to apply to shadow flicker assessment results.
- The guidance should advise against the use of factors which may limit the area of assessment, prior to identifying potential significance, and ensure the consideration of site specific factors such as topography.
- The guidance should provide clarity on the approach to financially involved properties, however this may be an issue best addressed primarily in relation to noise impacts from wind turbines.
- The guidance should provide structure for undertaking shadow flicker assessments to assist planners and environmental health officers in the review and interpretation of these findings.
- The guidance should provide a recommended approach to identifying receptors and the different types of receptor which may be affected by shadow flicker.
- The guidance should outline an approach to assessing cumulative shadow flicker.

Role of plans and Supplementary Planning Guidance

6.34 The case study review identified very limited reference to shadow flicker within the local plans examined, with only one of the local plans making passing reference to the issue.

6.35 The supplementary planning guidance and other local authority guidance relevant to renewable energy demonstrated variation in the detail and coverage of issues relevant to shadow flicker. For example the definitions of shadow flicker were not all consistent with those used in the national planning guidance documents.

6.36 In relation to the issues surrounding separation distances and the use of the ten rotor diameter distance, the majority of the SPG demonstrate the correct terminology without changing the original intended use of the distance as a guideline, not a cut-off. Two of the SPG also included text relating to the variability of separation distances and specific reference to topography. This is an important point of detail as issues relating to the influence of topography on increasing the distance at which shadow flicker may be experienced have been raised as a potential issue.

6.37 None of the SPG explored significance thresholds in relation to shadow flicker, which highlights a key gap in the interpretation of shadow flicker effects. In relation to the definition of receptors, some of the SPG attempted to define sensitive locations, but provided limited detail.

6.38 The SPG did not explore issues around the parameters when shadow flicker may occur, worst case and likely case scenarios, issues associated with latitude and cumulative effects, beyond only cursory references.

6.39 Three of the SPG provide specific text on mitigation which demonstrates a hierarchy of locating turbines to avoid shadow flicker, mitigation through restricted operation of the turbine during conditions when shadow flicker may occur, and other mitigation measures such as screening or blinds.

6.40 In summary, local plans provide almost no coverage of shadow flicker issues. Supplementary planning guidance and other local authority guidance relevant to renewable energy provide coverage of some issues, and reflect national guidance in relation to the ten rotor diameter distance but lack detail on key issues such as significance of effects. Furthermore the case study review identified a clear reversion in the Environmental Statements to national level guidance and documents in relation to shadow flicker with very limited reference to supplementary planning guidance. This reliance on national level guidance and documents further underlines the importance of clear national guidance or standards for shadow flicker.

Decision making and conditions

6.41 The case studies present a clear picture of the way in which shadow flicker is addressed in the decision making process and in the associated conditions. Four of the case studies demonstrated a precautionary approach to shadow flicker through the conditions attached to the decision. This was irrespective of the level of effects identified in the shadow flicker report. This supports the finding from the case study review of lack of clarity and accessibility of the shadow flicker reports, and the challenges of gaining a clear understanding of the extent and significance of shadow flicker. One of the case studies referred to the proposed mitigation within the Environmental Statement, with more limited scope, illustrating a less precautionary approach than applied in the other examples.

Presentation and communication of Shadow Flicker to non-specialists

6.42 A number of issues have been identified in relation to the clarity of presentation and communication of shadow flicker at the technical level. Shadow flicker reports are by their nature technical, but also include confusion of issues around terminology, significance and distance thresholds. It appears that some of these issues are transferred into other literature presented to non-specialists. For example the issue of shadow flicker triggering photo sensitive epilepsy is not associated with the blade frequency of the modern larger turbines, but is referred to within media articles. Reference to shadow flicker by the wind industry tends to focus on the limited area likely to be affected, and that effects can be mitigated.

6.43 The study also identified the issue of combined environmental effects from wind farms, and the potential effects of increased sensitivity to shadow flicker when noise impacts were also occurring.

6.44 More generally, and supported by the interviews, there is some confusion over the definition of the impact of shadow flicker. For planning and environmental health this is how it relates to defining the impact of light and shadow effects from wind turbines in terms of amenity or nuisance, and also public understanding of issues such as shadow throw.

Areas for future research

6.45 The project has identified a number of questions which could be addressed through modelling to provide robust findings to support the study conclusions, particularly in relation to the ten rotor diameter distance. These are:

6.46 **Thresholds of exposure**: Modelling exposure thresholds as distance thresholds based on worst case scenario in terms of wind direction, cloud cover and window orientation. This would allow the definition of an area on a map of where exposure exceeds the threshold set out in the German guidance. This would allow identification of where it is possible to experience more than 30 minutes a day shadow flicker, the distances at which these occur and if these are beyond ten rotor diameters. A sophisticated model would be required to account for these parameters, and the most appropriate model identified to date is WindPRO, although other models may be developed or improved going forward.

6.47 **20% obscuration of the sun**: Modelling how different turbine dimensions affect what distance from the wind turbine the threshold of 20% obscuration of the sun is reached. This would allow an understanding of whether the ten rotor diameter distance threshold potentially relates to the figure of 20% obscuration of the sun. Again, at this point in time the only model which allows the input of this variant is identified as WindPRO, although other models may be developed or improved going forward.

6.48 **130 degrees of north**: Modelling of the same dimension turbine at different latitudes to identify what area is affected by shadow flicker.

6.49 **Modelling shadow flicker extent in relation to receptors at significantly lower elevation than the wind turbines:** This would allow evidence to be provided on the effects of topography on the extent and duration of shadow flicker.

References

Shadow Flicker Assessments

Arcus Renewable Energy Consulting Ltd. (October 2012). *Gorpley Wind Farm Environmental Statement: Chapter 14 – Shadow Flicker*. Available at: http://www.rossendale.gov.uk/planx_downloads/Gorpley_14_ShadowFlicker_Final.pdf. [Accessed 11 May 2016].

Broadview Energy Limited. (April 2013). *Bicton Wind Farm: Environmental Statement Appendix 1: Shadow Flicker*. Available at: http://broadviewenergy.com/download_file/3c3c66bfd4c39c831fcc4b498a48aee1. [Accessed 11 May 2016].

Farmwind Limited. (August 2012). *Oulton Wind Turbine: Shadow Flicker Assessment*. Available at: http://www.broadland.gov.uk/MVM.DMS/Planning%20Application/648000/648378/20130177%20Documentation%20&%20Environmental%20Report%20Appendix%209a_Shadow%20Flicker%20Assessment%20RECEIVED%20250213.pdf. [Accessed 11 May 2016].

Gauld, R. on behalf of Skeabrae Renewable Ltd. (Feb 2014). *Skeabrae Wind Energy Project: Environmental Health Studies: Noise and Shadow Flicker Assessment*. Available at: http://www.orkneywind.co.uk/explore/Skea%20Brae/OSE3526%20Chapter%206%20Revision%203.pdf. [Accessed 13 May 2016].

Lancaster University. (n/a). *Wind Turbine Project: Shadow Flicker and Light Reflection*. Available at:http://www.lancaster.ac.uk/windturbine/Documents/Single%20Turbine/Chapter%208%20Shadow%20Flicker.pdf. [Accessed 13 May 2016].

Land Use Consultants, on behalf of RWE npower renewables. (Nov 2010). *Brechfa Forest East Wind Farm Assessment: Environmental Statement.* Available at: https://www.rwe.com/web/cms/mediablob/en/1801790/data/1800804/1/rwe-innogy/sites/wind-onshore/united-kingdom/in-development/supplementary-environmental-information/Chapter-1-Introduction.pdf. [Accessed 10 May 2016].

Neo Environmental. (June 2015). *Higher Mount Pleasant Farm: Shadow Flicker Assessment.* Available at: http://www.rossendale.gov.uk/planx_downloads/100799_-_Shadow_Flicker_Assessment.pdf. [Accessed 10 May 2016].

TNEI Services Ltd. on behalf of Partnerships for Renewables (Dec 2010). *HMP Standford Hill Wind Energy Development Environmental Statement: Chapter 14 – Shadow Flicker*. Available at: http://www.pfr.co.uk/documents/Environmental%20Statement%20vol%201.pdf. [Accessed 10 May 2016].

TNEI Services Ltd., on behalf of 2020 Renewables. (December 2014). *Whitelaw Brae Wind Farm Environmental Statement: Chapter 18 – Other Effects.* Available at: http://www.2020renewables.com/media/1151/ch18_other-effects_final-r1.pdf. [Accessed 10 May 2016].

Vattenfall. (August 2013). *South Kyle Wind Farm Environmental Statement: Chapter 18 – Shadow Flicker*. Available at: https://corporate.vattenfall.co.uk/globalassets/uk/projects/south-kyle/18-shadow-flicker-130806-a4.pdf. [Accessed 10 May 2016].

Local Plans and Supplementary Planning Guidance

Aberdeenshire Council (2012) *Aberdeenshire Local Development Plan 2012.* Available at: https://www.aberdeenshire.gov.uk/planning/plans-and-policies/The-Local-Development-Plan-2012/ . [Accessed 29th October 2016]

Aberdeen City Council. (April 2013). *Supplementary Guidance: Wind Turbine Development in Aberdeen City.* Available at: http://www.aberdeencity.gov.uk/nmsruntime/saveasdialog.asp?lID=49836&sID=14394. [Accessed 16 May 2016].

Aberdeenshire Council. (Aug 2005). *Use of Wind Energy in Aberdeenshire: Part 2 – Guidance for Assessing Wind Energy Developments.* Available at: https://www.aberdeenshire.gov.uk/media/8107/2005_2windassessing06.pdf . [Accessed 17 May 2016].

Angus Council (2009) *Angus Local Plan Review 2009*. Available at: https://archive.angus.gov.uk/localplan/review.htm [Accessed 29th October 2016]

Angus Council (2012) *Angus Local Plan Review (2009) SPG: Implementation Guide For Renewable Energy Proposals.* Available at: www.angus.gov.uk/.../angus_council_renewable_energy_implementation_guide.pdf [Accessed 29th October 2016]

Ceredigion County Council. (July 2014). *Ceredigion Local Development Plan 2007 – 2002: Draft Supplementary Planning Guidance – Renewable Energy.* Available at: https://www.ceredigion.gov.uk/utilities/action/act_download.cfm?mediaid=51744&langtoken=eng . [Accessed 18 May 2016].

Comhairle nan Eilean Siar. (August 2015). *Outer Hebrides Local Development Plan: Supplementary Guidance for Wind Energy Development (Consultation Draft 2015).* Available at: http://www.cne-siar.gov.uk/planningservice/documents/ldp/consultation/Consultation%20Draft%20Supplementary%20Guidance%20for%20Wind%20Energy%20Development.pdf. [Accessed 17 May 2016].

Community Places. (January 2015). *Guide: Wind Turbines and Wind Farms – Guide to Planning Policies.* Available at: http://www.communityplaces.info/sites/default/files/Wind%20Turbines%20and%20Wind%20Farms,%20Guide%20to%20Planning%20Policies,%20Jan%2015.pdf. [Accessed 18 May 2016].

Conwy County Borough Council. (January 2015). *Conwy Local Development Plan 2007 – 2022: Supplementary Planning Guidance – LDP17: Onshore Wind Turbine Development.* Available at: http://www.conwy.gov.uk/upload/public/attachments/630/LDP17_Onshore_Wind_Turbine_Development_Jan_15.pdf. [Accessed 18 May 2016].

Cornwall Council. (November 2011). *Renewable Energy Planning Guidance Note 3: The Development of Onshore Wind Turbines.* Available at: http://www.cornwall.gov.uk/media/5830885/Onshore-Wind-V3-February-2014.pdf. [Accessed 18 May 2016].

East Ayrshire Council. (March 2015). *East Ayrshire Local Development Plan: Proposed Plan - Planning for Wind Energy (Draft Supplementary Guidance).* Available at: https://www.east-ayrshire.gov.uk/Resources/PDF/L/LDP-Wind-Energy.pdf. [Accessed 17 May 2016].

Falkirk Council. (July 2015). *Spatial Framework and Guidance for Wind Energy Development: Supplementary Guidance SG14.* Available at: https://www.falkirk.gov.uk/services/planning-building/planning-policy/supplementary-guidance/docs/supplementary-guidance/adopted-documents/14%20SG14%20Spatial%20Framework%20and%20Guidance%20for%20Wind%20Energy%20Development.pdf?v=201512071400. [Accessed 17 May 2016].

Fife Council (2012) *Adopted Mid Fife Local Plan*. Available at: https://www.fifedirect.org.uk/topics/index.cfm?fuseaction=page.display&p2sid=C1B1AE31-1CC4-

E06A-52867243662458B4&themeid=2B482E89-1CC4-E06A-52FBA69F838F4D24 [Accessed 29th October 2016]

Fife Council (2014) *Fife Local Development Plan Proposed Plan October 2014*. Available at: https://www.fifedirect.org.uk/topics/index.cfm?fuseaction=page.display&p2sid=8E4FDA75-DE92-7F88-58587D1BB5658375&themeid=2B482E89-1CC4-E06A-52FBA69F838F4D24 [Accessed 29th October 2016]

Fife Council (2013) *Wind Energy Planning Supplementary Guidance*. Available at: http://publications.fifedirect.org.uk/c64_WindenergySPG.pdf [Accessed 29th October 2016]

Gwynedd Council. (June 2014). *Supplementary Planning Guidance: Onshore Wind Energy.* Available at: https://www.gwynedd.llyw.cymru/en/Council/Documents---Council/Strategies-and-policies/Environment-and-planning/Planning-policy/Unitary-Development-Plan/SPG-Onshore-Wind-Energy-June-2014.pdf. [Accessed 16 May 2016].

Land Use Consultants. (March 2009). *Alnwick Local Development Framework Planning for Renewable Energy Supplementary Planning Document (Consultation Draft).* Available at: http://www.northumberland.gov.uk/WAMDocuments/1C093ACC-4757-45FB-AC6A-F1D12379ECE6_1_0.pdf?nccredirect=1. [Accessed 18 May 2016].

North Lanarkshire Council. (March 2012). *Assessing Planning Applications for Wind Turbine Developments: Supplementary Planning Guidance Note Ref SPG.12 NLLP Policy EDI.3(A)2.* Available at: http://www.northlanarkshire.gov.uk/CHttpHandler.ashx?id=7542&p=0. [Accessed 18 May 2016].

North Lanarkshire Council (2012). *North Lanarkshire Local Plan*. Available at: http://www.northlanarkshire.gov.uk/index.aspx?articleid=16016 [Accessed 29th October 2016]

North Somerset Council. (July 2014). *Renewable and Low Carbon Energy Generation in North Somerset: Wind Turbines (Supplementary Planning Document).* Available at: https://www.n-somerset.gov.uk/wp-content/uploads/2015/11/wind-turbines-supplementary-planning-document.pdf. [Accessed 17 May 2016].

Perth and Kinross Council. (2014). *Perth and Kinross Local Development Plan*. Available at: http://www.pkc.gov.uk/developmentplan [Accessed 29th October 2016].

Perth and Kinross Council. (2005). *Supplementary Planning Guidance for Wind Energy Proposals in Perth and Kinross*. Available at: http://www.pkc.gov.uk/article/15070/Supplementary-guidance-Wind-energy [accessed 29th October 2016].

Rushcliffe Borough Council. (June 2015). *Wind Energy Supplementary Planning Document.* Available at: http://www.rushcliffe.gov.uk/media/rushcliffe/media/documents/pdf/planningandbuilding/planningpolicy/spds/Wind%20Energy%20SPD%20Final%20Version%20June%202015.pdf. [Accessed 17 May 2016].

Rutland County Council. (May 2012). *Supplementary Planning Document: Wind Turbine Developments (Consultation Draft).* Available at: http://www.rutland.gov.uk/pdf/Draft%20Wind%20Turbine%20Developments%20Supplementary%20Planning%20Document.pdf. [Accessed 16 May 2016].

South Ribble Borough Council. (May 2014). *Renewable and Low Carbon Energy Supplementary Planning Document.* Available at: http://www.southribble.gov.uk/sites/default/files/RENEWABLE%20LOW%20CARBON%20ENERGY%20SPD%20ADOPTED_0.pdf. [Accessed 18 May 2016].

Stirling Council. (March 2011). *Stirling Council Supplementary Planning Guidance: Interim Locational Policy & Guidance for Renewable Energy Developments (Wind Turbines).* Available at:

http://www.stirling.gov.uk/__documents/planning/future-development/development-advice/adopted-policies-_and_-guidance.pdf. [Accessed 17 May 2016].

Guidance and Literature Sources

Aberdeenshire Council. (2005). *Supplementary Planning Guidance Use of Wind Energy in Aberdeenshire Part Two - Guidance for Assessing Wind Energy Development*. Available at: https://www.aberdeenshire.gov.uk/media/8107/2005_2windassessing06.pdf. [Accessed n/a].

Boverket. (2012). *Planering och Provning av Vindkraftverk på land och i kustnära vattenområden*. (Wind Energy Handbook, Planning and testing of wind turbines on land and in coastal waters). Available at: http://www.boverket.se/globalassets/publikationer/dokument/2013/vindkraftshandboken.pdf. [Accessed n/a].

Clarke A.D. (1991). *A Case of Shadow Flicker/Flashing: Assessment and Solution*. Open University: Milton Keynes.

Department for Communities & Local Government. (Updates 2014 – 2015). *National Planning Policy Framework Planning Practice Guidance: Renewable and Low Carbon Energy – Particular Planning Conditions for Hydropower, Active Solar Technology, Solar Farms and Wind Turbines.* Available at: http://planningguidance.communities.gov.uk/blog/guidance/renewable-and-low-carbon-energy/particular-planning-considerations-for-hydropower-active-solar-technology-solar-farms-and-wind-turbines/. [Accessed 19 May 2016].

Department for Communities & Local Government. (2013, withdrawn March 2014). *Planning Practice Guidance for Renewable and Low Carbon Energy*. Available at: https://www.planningportal.co.uk/directory_record/719/planning_for_renewable_energy_a_companion_guide_to_pps22. [Accessed 19 May 2016].

Department of the Environment. (August 2009). *Planning and Environmental Policy Group: Best Practice Guidance to Planning Policy Statement 18 'Renewable Energy'*. Available at: http://www.planningni.gov.uk/index/policy/planning_statements/planning_policy_statement_18_renewable_energy__best_practice_guidance.pdf. [Accessed n/a].

Environment, Community and Local Government. (December 2013). *Proposed Revisions to Wind Energy Development Guidelines 2006: Targeted Review in Relation to Noise, Proximity and Shadow Flicker – December 11th 2013.* Available at: http://www.environ.ie/sites/default/files/migrated-files/en/Publications/DevelopmentandHousing/Planning/FileDownLoad%2C34769%2Cen.pdf. [Accessed n/a].

Fehily Timoney & Company on behalf of Element Power Ireland Ltd. (March 2015). Environmental Impact Statement for the Proposed Maighne Wind Farm in County Kildare and County Meath: Chapter 12 – Shadow Flicker. Available at: http://maighnewindfarm.ie/environmental/environmental-impact-study/volume-2-main-eis. [Accessed n/a].

Freund, H.D. (2002). Hans-Dieter Freund,. *Einflusse der Lufttrubung, der Sonnenausdehnung och der Flugelform auf dem Schattenwruft von Windergieanlagen*. DEWI magazin nr 20/2002 (Influences of the opaqueness of the atmosphere, the extension of the sun and the rotor blade profile on the shadow impact of wind turbines). FH Kiel/University of applied sciences.

Haugen KMB. (2011). *International Review of Policies and Recommendations for Wind Turbine Setbacks from Residences: Setbacks, Noise, Shadow Flicker, and Other Concerns*. St. Paul, MN: Minnesota.

Osten, T., & Pahlke, T. (1998). *Schattenwurf von windenergieanlagen: wird die gebraeuschabstrahlung der MW-Anlagen in den Schatten gestellt?* (Shadows of wind turbines : Will the greater use of large turbines be put in the shade?). DEWI Magazine, Nr. 13, 6-12. Available at: http://www.dewi.de/dewi/fileadmin/pdf/publications/Magazin_13/02.pdf. [Accessed n/a].

Parsons Brinckerhoff. (2011). *Update of UK Shadow Flicker Evidence Base*. Department for Energy and Climate Change.

Planning Portal. (2016). *Policy and Legislation: Planning for Renewable Energy – A Companion Guide to PPS22*. Available at: https://www.planningportal.co.uk/directory_record/719/planning_for_renewable_energy_a_companion_guide_to_pps22. [Accessed 20 May 2016].

Pohl, J., Faul, F. & Mausfeld, R. (May 2000). *Belästigung durch periodischen Schattenwurf von Windenergieanlagen, Laborpilotstudie.* Institut für Psychologie der ChristianAlbrechts-Universität, Available at: http://cvi.se/uploads/pdf/Kunskapsdatabas%20miljo/Ljud%20och%20Skuggor/Skuggor/Utredningar/Laborstudie%20Schattenwurf.pdf. [Accessed n/a].

Predac. (undated). *Spatial Planning of Wind Turbines Guidelines and Comparison of European experiences*. This publication is part of the PREDAC project with support from EU Commission, 5th RTD Framework Programme, 2002-2004. Available at: http://www.cler.org/IMG/pdf/WP8_ANG_guide.pdf. [Accessed n/a].

Scottish Government. (May 2014). *Onshore Wind Turbines*. Available at: http://www.gov.scot/Resource/0045/00451413.pdf. [Accessed 19 May 2016].

Scottish Government. (June 2014). *Scottish Planning Policy*. Available at: http://www.gov.scot/Resource/0045/00453827.pdf. [Accessed 19 May 2016].

Scottish Natural Heritage. (2014). *Siting and Designing Wind Farms in the Landscape Version 2.* Available at: http://www.snh.org.uk/pdfs/strategy/renewables/Guidance_Siting_Designing_wind_farms.pdf. [Accessed n/a].

SLR, Hoare Lea Acoustics. (2015). *Wind Farm Impacts Study Review of the Visual, Shadow Flicker and Noise Impacts of Onshore Wind Farms*. ClimateXChange.

Smedley, Andrew R. D., Webb, Ann R., Wilkins, Arnold J. (2010). Potential of Wind Turbines to Elicit Seizures Under Various Meteorological Conditions. *Epilepsia*, 51 (7), 1146- 1151.

Superna Energy L.L.C. (2006). *Lempster Wind Project Shadow Impact Assessment*. Lempster Wind, LLC and Community Energy. Available at: www.nhsec.nh.gov/projects/200601/documents/28_shadow_flicker_assessment.pdf. [Accessed n/a].

Twardella, D. (undated). *Bedeutung des Ausbaus der Windergie fur die menschliche Gesundheit* (Consequences of wind energy for Health). Bayerisches Landesamt fur Gesundheit and Lebensmittelsicherheit [Bavarian State Office for Health and Food Safety].

Verkuijlen E. & Westra, C.A. (October 1984). *Shadow Hindrance by Wind Turbines*. Proceedings of European Wind Energy Conference: European Wind Energy Association.

Von Hunerbein, S,. Moorhouse, A., Fiumicelli, D. & Baguley D. (2013) *Report on Health Impacts of Wind Turbines, Report for Scottish Government*. Available at: http://usir.salford.ac.uk/29183/1/HealthEffects_Final_IQ1-2013_20130410.pdf. [Accessed n/a].

Welsh Assembly Government. (February 2011). *Practice Guidance: Planning Implications of Renewable and Low Carbon Energy.* Available at: http://gov.wales/docs/desh/publications/110228planimplicationsen.pdf. [Accessed 21 May 2016].

Widing, A., Britse G., Wizelius T., (2004). *Centrum för Vindkraftsinformation Institutionen för naturvetenskap och teknik.* Gotland University: Sweden. [English translation of abstract] Available at: http://cvi.se/uploads/pdf/Kunskapsdatabas%20miljo/Ljud%20och%20Skuggor/Ljud/sammanfattning/Fallstudie%20sammanfattn050630.pdf. [Accessed n/a].

(n/a) (2002). *Hinweise zur Ermittlung und Beurteilung der optischen Immissionen von Windenergieanlagen.* Available at: https://www.umwelt.sachsen.de/umwelt/download/laerm_licht_mobilfunk/WEA-Schattenwurf-Hinweise_LAI.pdf. [Accessed n/a].

Appendix 1 Review of tools and methods: Comparison of Shadow Flicker Models by Pager Power

As part of this study, Pager Power carried out a comprehensive review intended to compare and contrast the technical tools for the assessment of shadow flicker that are currently available to developers. This Appendix presents the contents of Pager Power's report.

Glossary

Term	Meaning
Angular size	This is a term that relates to the apparent size of an object based on how much of an observer's field of view is taken up by the object. For example, if lines were drawn from a point on the Earth to either side of the sun, the angle between those lines would be half a degree. This means the angular size of the sun is 0.5° from Earth. Another way of saying this would be that the sun subtends an angle of half a degree to an observer on Earth.
Azimuth angle	This angle describes the direction that something is facing. The angle is measured clockwise from north. A window that faces directly east has an azimuth angle of 90 degrees. A window that faces directly south has an azimuth angle of 180 degrees.
Interpolation algorithm	Terrain or surface data typically comprises known height values at regular intervals across a region. OS Panorama data, for example, provides terrain height above mean sea level every 50 metres throughout the United Kingdom. Very often, locations of interest are positions in between the points with known heights. This means that a calculation is required to determine the height based on the surrounding points. There are various approaches to doing this, known as 'interpolation algorithms.
DSM	Digital Surface Model. This is a set of data that provides height information, relative to sea level, of a surface. DSM data therefore includes obstructions such as buildings and forestry, which can be relevant for visual screening purposes.
DTM	Digital Terrain Model. This is a set of data that provides height information, relative to sea level, of the terrain. This relates to the 'bare Earth' case, without reference to obstructions such as buildings and forestry. If a building with a height of 20 metres is located on terrain that is 10 metres above sea level, the DTM data would give a value of 10 metres. DSM data for the same location would give a value of 30 metres.
Vertical tilt angle	This angle relates to windows in the case of shadow flicker modelling. It describes whether the window is vertical or whether it is angled backwards or forwards. A 'normal' window that is angled at 90 degrees to the ground would have a vertical tilt of 0 degrees.
ZVI	Zone of Visual Influence.

Introduction

Assessment overview

In order to gain planning consent, wind farm developments in Scotland must demonstrate that there will not be unacceptable levels of impact in a variety of areas – including shadow flicker and related effects.

However, the guidance around how to assess shadow flicker and how to define an 'acceptable' impact is lacking.

The purpose of this report has been to:

- Investigate the parameters that contribute to shadow flicker impacts.
- Identify the most popular models that are available for assessing shadow flicker.
- Compare the available models to each other and consider whether they capture the important technical parameters pertaining to shadow flicker.

Definitions of shadow flicker

Table 1: Definitions of shadow flicker from three relevant sources.

Source	Definition
#1 Update of UK Shadow Flicker Evidence Base Parsons Brinckerhoff March 2011	*The term "shadow flicker" refers to the flickering effect caused when rotating wind turbine blades periodically cast shadows over neighbouring properties as they turn, through constrained openings such as windows.*
#2 National Policy Statement for Renewable Energy Infrastructure (EN-3) Department of Energy and Climate Change July 2011	*Shadow flicker is the effect caused when an operating turbine is located between the sun and a receptor, such as a dwelling or place of work. The effect occurs when the shadow of the rotating blades falls over the dwelling causing the light intensity within specific affected rooms of the occupied building to fluctuate.*
#3 Planning for Renewable Energy, A Companion Guide to PPS22[67] Office of the Deputy Prime Minister July 2013	*Under certain combinations of geographical position and time of day, the sun may pass behind the rotors of a wind turbine and cast a shadow over neighbouring properties. When the blades rotate, the shadow flicks on and off; the effect is known as 'shadow flicker'. It only occurs inside buildings where the flicker appears through a narrow window opening.*

[67] Note that this guidance has officially been withdrawn as of March 2014 - however the technical content pertaining to Shadow Flicker is still relevant for the purpose of this report.

Note that neither the National Planning Framework (NPF-3) for Scotland nor Scotland's National Marine Plan provides a definition of shadow flicker.

It can be seen that the precise wording of the definitions varies between various sources. Two of the three sources (#1 and #3) in Table 1 (on the previous page) explicitly state that effects are observed only when sunlight illuminates a room through a constrained opening (in #3 specified as a narrow window). To an extent, the remaining source (#2) implies this same scenario by referring to the light intensity 'within specific affected rooms' but does not elaborate further.

This report is an investigation of modelling tools for shadow flicker and related effects – specifically any effects related to changing light intensities due to the spinning blades obstructing sunlight.

Therefore, the investigation has considered the ability of the modelling tools to evaluate reliably the effect of rotating turbine blades on light intensity at surrounding locations.

How shadow flicker is caused

Overview

In order to model potential shadow flicker effects accurately, it is important to understand the physical parameters that cause the issue.

The key considerations are set out in the following sub-sections.

Angular Size of the Sun

When viewed from earth, the sun subtends an angle of just over half a degree. This means that if lines were drawn from earth to either side of the sun, the angle between the lines would be 0.5 degrees. Figure 1 below illustrates this.

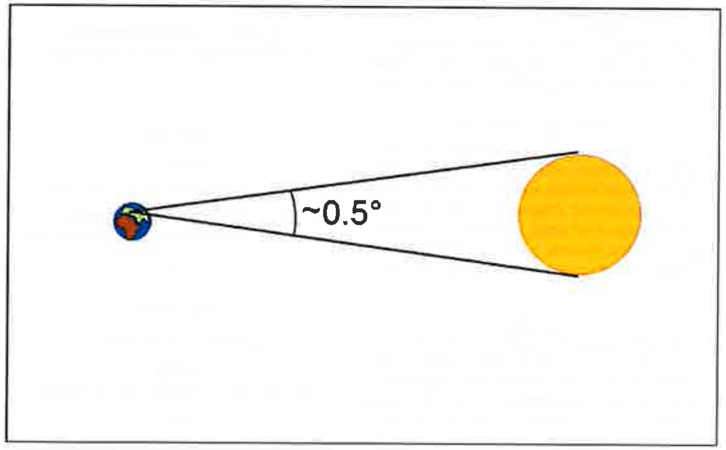


Figure 1: Angular size of the sun

This means that something with an angular size of up to half a degree will partially obscure the sun. An object with an angular size of over half a degree will entirely obscure the sun.

To put this in context, a person's field of vision is typically about 200° horizontally and 135° vertically[68].

If an object intermittently obscures the sun, the observed light intensity will fluctuate. This will be the case for partial or full obscuration. The greater the extent of the obscuration, the more noticeable the effect.

Wind Turbines Obscuring the Sun

There are two ways that a wind turbine rotor can be said to obscure the sun:

1. The turbine rotor, seen as a disc, having an angular size of at least half a degree. This would lead to partial obscuration of the sun.
2. The turbine blade having an angular size of at least half a degree (vertically). This would lead to total intermittent obscuration of the sun.

[68] Guidance on Signal Positioning and Visibility Issue One, December 2003. Railway Guidance Group Note

These scenarios are illustrated in figures 2 and 3, which are below and on the following page respectively.

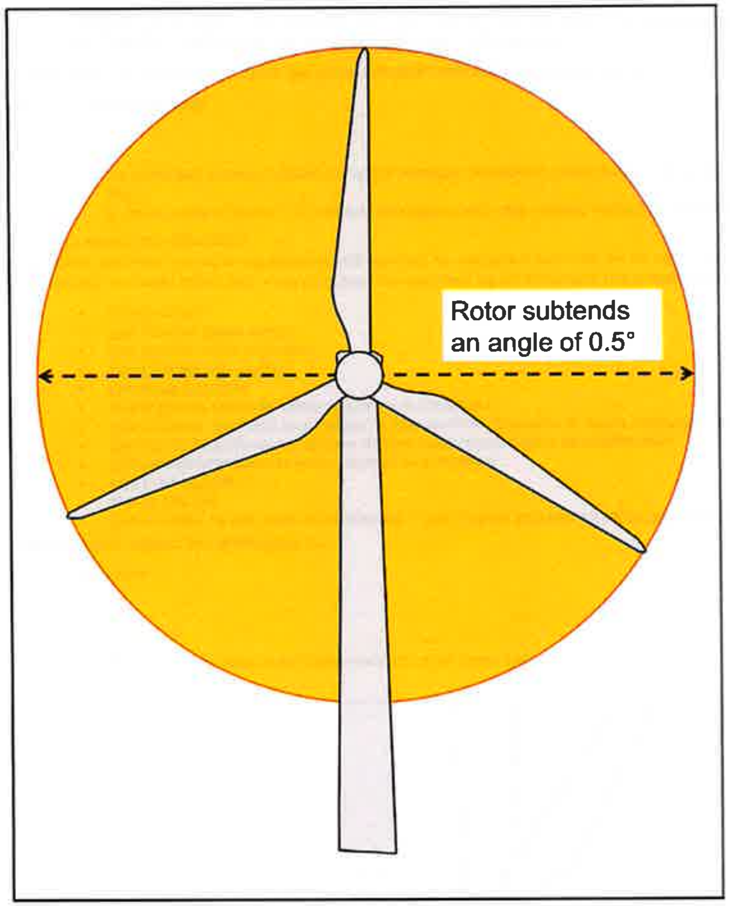


Figure 2: Rotor diameter with the same angular size as the sun

The scenario illustrated in Figure 2, above, would be unlikely to cause significant shadow flicker effects. In this scenario the turbine blades would only obscure part of the sun from view. Furthermore, the total amount of obscuration would remain constant as the blade rotates, such that changes in observed intensity would be relatively subtle.

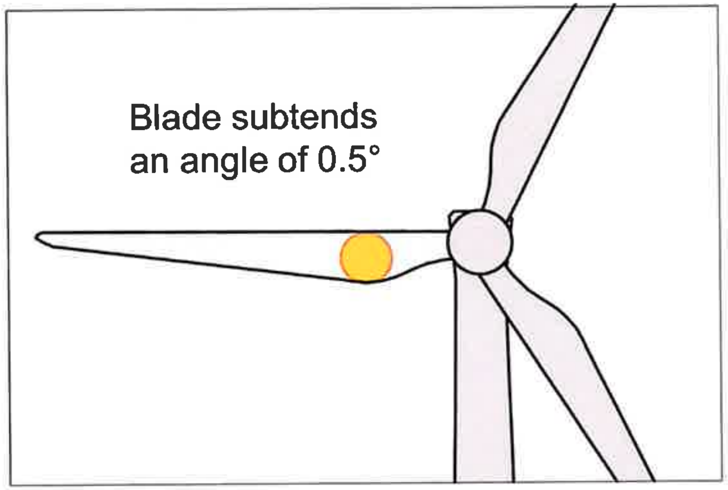


Figure 3: Turbine blade with the same angular size as the sun

The scenario illustrated in Figure 3 above is likely to cause significant shadow flicker.

This is because:

- The sun would be entirely obscured intermittently as the rotor spins.
- Paragraph 75 of the withdrawn companion guide to PPS22 supported the view that obscuration of the sun by the widest portion of the blade was the principle mechanism for shadow flicker [69].
- A popular rule of thumb for shadow flicker effects is to consider receptors within 10 rotor diameters. While the precise derivation of this buffer is unclear, it is more in keeping with the scenario in Figure 3 than the scenario in Figure 2.

The situation shown in Figure 3 is the worst-case scenario because the turbine is facing the observer with the widest portion of the blade obstructing the view of the sun. It also shows a case where the sun is entirely obscured by the blade.

The actual geometry is variable, based on the relative location and height of the observer and the turbine. The intervening terrain, sun position and orientation of the turbine will also affect the geometric relationship.

Cases where there is partial obscuration of the sun would also result in shadow flicker – because the light intensity at an observer's location would fluctuate. Figure 4, on the next page, illustrates such a case.

[69] *"At distance, the blades do not cover the sun but only partly mask it, substantially weakening the shadow. This effect occurs first with the shadow from the blade tip, the tips being thinner in section than the rest of the blade. The shadows from the tips extend the furthest and so only a very weak effect is observed at distance from the turbines."* – Planning for Renewable Energy, A Companion Guide to PPS22, Office of the Deputy Prime Minister, July 2013

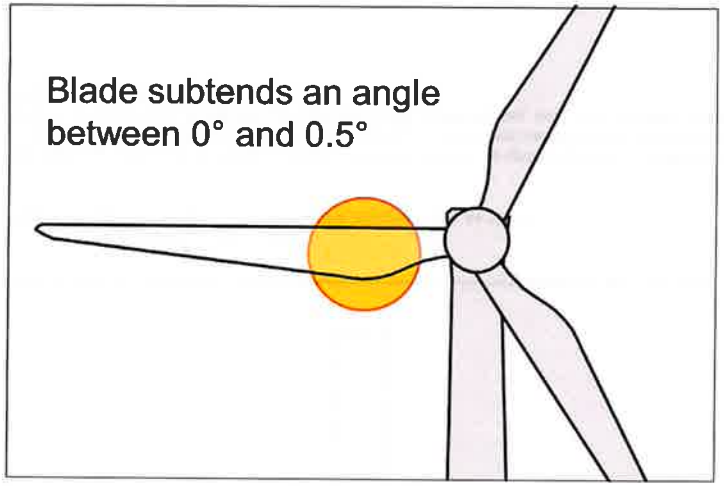


Figure 4: Turbine blade with a smaller angular size than the sun

Key parameters

Shadow flicker effects are dependent on:

- The location of the wind development – the turbine latitude dictates the observed path of the sun in the sky.
- The time of year.
- The terrain elevation at each turbine and observer.
- The effect of intervening terrain and/or obstructions such as hedgerows.
- The location, size and orientation of the receptor (window or other restricted opening).
- The distance between each turbine and receptor.
- The wind direction.
- The turbine hub height.
- The turbine rotor diameter.
- The turbine blade width.
- Cloud cover.

Factors such as cloud cover and wind direction are relevant when assessing the overall expected impact throughout the year. In terms of determining whether or not there will ever be an effect, an ideal approach would consider both:

- A worst-case scenario i.e. sunny conditions with the widest aspect of the blade facing the sun.
- An expected scenario based on likely weather conditions (wind and cloud cover) in the area.

Further considerations

From a technical perspective, there are three possible outcomes for a given receptor:

1. No shadow flicker effects are possible under any circumstances.
2. Shadow flicker effects are possible and the sun will be intermittently obscured entirely by the rotating blades.
3. Shadow flicker effects are possible and the sun will be intermittently obscured partially by the rotating blades.

Comprehensive formal guidance on shadow flicker effects is likely to define:

- Requirements for an assessment process.
- A quantified definition of an 'acceptable' impact.

The definition of an acceptable impact may be related to one or more of the following:

- Number of hours per day.
- Number of hours per year.
- Severity of impact.

In order to evaluate the number of hours within a given time period that effects could be experienced, the model must be able to assess worst-case scenarios based on the geometric locations of the sun, the turbines and the receptors.

In order to evaluate the severity of the impact, the change in observed intensity must be quantified in some way. A reasonable approach would be to define this in terms of percentage of sun obscuration e.g. if the widest part of the blade obscures less than 50% of the sun under worst-case conditions, the impact is considered negligible[70].

[70] The value of 50% is for explanation purposes only, there is no recommendation within this report with regard to acceptable limits

Available tools

Overview

There are various commercial software packages that allow developers to model the potential shadow flicker. This review has sought to identify the most popular and most technically advanced models.

Identification of Models

Potential models were identified based on:

- A review of the literature referenced in Table 1 on page 9 of this report.
- A review of planning applications for the following large Scottish wind farms:
    - Clyde (extension).
    - Black Law (extension).
    - Fallago Rig.
    - Whitelee.
- A web search for other options – this was primarily a cross-check to support the above.

The assessed models are listed below. These are the software packages referenced in *Update of UK Shadow Flicker Evidence Base, Parsons Brinckerhoff, March 2011*. No other modelling options were identified[71] for assessment:

- WindFarm.
- Gerrard Hassan (GH) WindFarmer.
- WindPRO.

[71] Where specific reference was made to modelling software, it was one of the options that has been listed. In many cases there was no mention of the specific modelling details, or the need for modelling was dismissed altogether based on separation distances and/or turbine visibility.

Comparison of tools

Process

The available information for each modelling software package was reviewed. This was largely based on information from the companies directly, supported by external reviews within the previously cited literature.

It is understood that each tool takes as inputs the coordinates of the turbines and receptors. It is also understood that the path of the sun through the sky is accounted for in each of the models.

The following questions were investigated for each tool:

- Which of the following technical parameters are entered for the turbine:
    - Hub height.
    - Rotor diameter.
    - Blade thickness.
- Which of the following technical parameters are entered for the receptor:
    - Dimensions – effects for a window that is 2 metres by 1 metre could be different than for a window that is 0.5 metres by 0.5 metres.
    - Azimuth angle – a window that directly faces a turbine could be affected differently than a window that is directed towards one side of a turbine.
    - Vertical tilt angle – most windows are at 90 degrees to the ground, however some windows can be set at an angle and this could affect the results.
- Which of the following is accounted for within the terrain model:
    - Earth curvature.
    - Elevation above mean sea level (i.e. DTM[72]).
    - Obstructions above ground level (DSM[73]).
    - Intervening terrain and/or screening that would obstruct the turbines from a receptors' view[74].
    - The effect of terrain and/or screening on the horizon?
    - Interpolation algorithm – terrain data is typically comprised of a database of known land heights at regularly spaced points. Ordnance Survey Panorama data, for example, provides terrain heights above mean sea level every 50 metres. If a turbine or a receptor is located at some arbitrary location between these defined points, the terrain height must be extrapolated based on the known heights surrounding the location. There are various ways of doing this, with different levels of accuracy and conservatism.
- Can the effect of the prevailing wind direction be accounted for in any way?
- Can the effect of cloud cover be accounted for in any way?
- Are the precise days and times for predicted effects given?
- Are sunrise and sunset times incorporated (i.e. could the model erroneously predict effects at time when the sun would not be up)?

Assessment – Wind Farm

Table 2 below summarises the assessment of the shadow flicker capabilities within WindFarm by ReSoft. Note that WindFarm is a software package designed to aid in multiple areas of wind development. At the time of writing, version 4 of the software was available and version 5 was available on pre-release. The data was sourced from:

- The ReSoft website – which gives an overview of their Shadow Flicker Software.
- Update of UK Shadow Flicker Evidence Base, Parsons Brinckerhoff, March 2011.
- Direct enquiries to ReSoft (via email – See Appendix 2).

[72] Digital Terrain Model

[73] Digital Surface Model

[74] Note that a model could incorporate terrain data to calculate the relative heights of turbines and receptors, but not account for terrain that intercepts an observer's view of the turbines. This is why a separate category is listed for intervening terrain specifically.

Table 2: WindFarm review

Category	Question	Answer	Remarks
Turbine Data	Is hub height incorporated?	Yes	-
	Is rotor diameter incorporated?	Yes	-
	Is blade thickness incorporated?	No	The average chord width can be used to limit the assessment distance but nothing else.
Receptor Data	Are dimensions incorporated?	Yes	-
	Is azimuth angle incorporated?	Yes	-
	Is vertical tilt angle incorporated?	Yes	-
Terrain Model	Is earth curvature incorporated?	Yes	-
	Is elevation above mean sea level incorporated?	Yes	Terrain data can be imported.
	Are structures above ground incorporated?	No	The terrain data could be modified to account for known obstructions.
	Is intervening terrain / screening accounted for?	Potentially	It is understood that intervening terrain can be incorporated as part of the ZVI assessment within WindFarm. It may be possible to include this data as part of the shadow flicker assessment.
Terrain Model	Is the effect of terrain / screening on the horizon accounted for?	Yes	A minimum elevation angle for the sun can be entered.
	What interpolation algorithm is used?	Bilinear interpolation	-
Wind Direction	Can the prevailing wind direction be incorporated in any way?	No	-

Category	Question	Answer	Remarks
Cloud Cover	Can the likely cloud cover be incorporated in any way?	No	Results could be exported and manipulated further thereafter.
Sunrise / Sunset	Are the sunrise and sunset times incorporated?	Yes	This may be restricted to setting a minimum angle for the model to consider.
Model Output	Are the hours per day and hours per year that effects can occur quantified?	Yes	-

Assessment – GH WindFarmer

Table 3 below summarises the assessment of the shadow flicker module of GH WindFarmer. The data was sourced from:

- The Garrad Hassan website, which provides an overview of the module.
- Update of UK Shadow Flicker Evidence Base, Parsons Brinckerhoff, March 2011.
- Direct contact with Gerrard Hassan (via email, see Appendix 2).

Table 3: GH WindFarmer review

Category	Question	Answer	Remarks
Turbine Data	Is hub height incorporated?	Yes	-
	Is rotor diameter incorporated?	Yes	-
	Is blade thickness incorporated?	No	-
Receptor Data	Are dimensions incorporated?	No	Receptors are modelled as a single point.
	Is azimuth angle incorporated?	Yes	-
Terrain Model	Is vertical tilt angle incorporated?	Yes	-
	Is earth curvature incorporated?	Yes	-
	Is elevation above mean sea level incorporated?	Yes	-
	Are structures above ground incorporated?	No	
	Is intervening terrain / screening accounted for?	No	The terrain data could be modified to account for known obstructions.
Terrain Model	Is the effect of terrain / screening on the horizon accounted for?	Yes	There are three options: Assuming that turbines and the sun are always visible - reduces calculation time for sites in flat terrain Checking if turbine visibility is obstructed by terrain Checking if turbine and sun visibility is obstructed by terrain

Category	Question	Answer	Remarks
	What interpolation algorithm is used?	Bilinear interpolation	-
Wind Direction	Can the prevailing wind direction be incorporated in any way?	Yes	There are different rotor models in WindFarmer: rotor modelled as a sphere, rotor modelled as a plane following the sun's azimuth or with a fixed orientation. This could go some way to incorporating the prevailing wind direction, although some further data interpretation would most likely be required[75].
Cloud Cover	Can the likely cloud cover be incorporated in any way?	No	-
Sunrise / Sunset	Are the sunrise and sunset times incorporated?	Yes	This is restricted to setting a minimum angle for the model to consider.
Model Output	Are the hours per day and hours per year that effects can occur quantified?	Yes	-

[75] Because assuming a fixed orientation is not entirely realistic, the prevailing wind direction will not occur 100% of the time

Assessment – WindPRO

Table 4 below summarises the assessment of GH WindFarmer. The data was sourced from:

- The WindPRO website, which provides an overview of the module and an example output report.
- Update of UK Shadow Flicker Evidence Base, Parsons Brinckerhoff, March 2011.
- Direct contact with Gerrard Hassan (via email, see Appendix 2).

Table 4: WindPRO review

Category	Question	Answer	Remarks
Turbine Data	Is hub height incorporated?	Yes	-
	Is rotor diameter incorporated?	Yes	-
	Is blade thickness incorporated?	Yes	The example report made available by WindPRO shows that calculations are only made when more than 20% of the sun is covered by the blade.
Receptor Data	Are dimensions incorporated?	Yes	-
	Is azimuth angle incorporated?	Yes	-
	Is vertical tilt angle incorporated?	Yes	-
Terrain Model	Is earth curvature incorporated?	Yes	-
	Is elevation above mean sea level incorporated?	Yes	-
	Are structures above ground incorporated?	Yes	-
	Is intervening terrain / screening accounted for?	Yes	-
	Is the effect of terrain / screening on the horizon accounted for?	Yes	-

Category	Question	Answer	Remarks
Terrain Model	What interpolation algorithm is used?	Triangular Irregular Network	-
Wind Direction	Can the prevailing wind direction be incorporated in any way?	Yes	Real expected values can be produced based on wind direction.
Cloud Cover	Can the likely cloud cover be incorporated in any way?	Yes	Real expected values can be produced based on assumptions regarding solar statistics.
Sunrise / Sunset	Are the sunrise and sunset times incorporated?	Yes	-
Model Output	Are the hours per day and hours per year that effects can occur quantified?	Yes	-

Comparison of models

It can be seen that there are some differences between the models – these are summarised in Table 5 below. Note that there are different ways of defining a realistic 'worst case scenario' and a 'likely scenario'. The judgement has been made based on first principles and the author's professional opinion.

Table 5: Model comparison

Category	Feature	WindFarm (ReSoft)	GH WindFarmer	WindPRO	Input required for worst case scenario?	Input required for likely scenario?
Turbine Data	Incorporation of hub height	✓	✓	✓	✓	✓
	Incorporation of rotor diameter	✓	✓	✓	✓	✓
	Incorporation of blade thickness	✗	✗	✓	✗	✓
Receptor Data	Incorporation of window dimensions	✓	✗	✓	✓	✓
	Incorporation of azimuth angle	✓	✓	✓	✗	✓
	Incorporation of vertical tilt angle	✓	✓	✓	✗	✓
Terrain Model	Incorporation of earth curvature	✓	✓	✓	✗	✓
	Incorporation of a terrain model	✓	✓	✓	✗	✓
	Incorporation of structures above ground	✗	✗	✓	✗	✓

Category	Feature	WindFarm (ReSoft)	GH WindFarmer	WindPRO	Input required for worst case scenario?	Input required for likely scenario?
	Incorporation of intervening terrain	*Possibly*	✗	✓	✗	✓
Terrain Model	Incorporation of terrain / screening on the horizon	✓	✓	✓	✗	✓
	Sophisticated terrain data interpolation algorithm	✓	✓	✓	✗	✓
Wind Direction	Incorporation of wind direction	✗	✓	✓	✗	✓
Cloud Cover	Incorporation of likely cloud cover	✗	✗	✓	✗	✓
Sunrise / Sunset	Incorporation of sunrise and sunset times	✓	✓	✓	✗	✓
Model Output	Quantification of hours per day / per year that effects could occur	✓	✓	✓	✓	✓

Differences

It can be seen that there are some differences between the available modelling tools. The potential implications of these differences are presented below.

Blade Width

Incorporation of blade width is required to maximise the accuracy of the assessment. This is because obscuration of the sun by the blade is the primary mechanism that leads to the shadow flicker effects – see Section 2 of this report.

If blade width is not incorporated, the modelling would determine that any obscuration of the sun results in shadow flicker effects[76]. Whilst this is not the most accurate approach, it is the most conservative.

Window Dimensions

Modelling the window as a point rather than considering its true dimensions is an approximation that limits the accuracy of the assessment. It could also make the assessment less conservative in a scenario where the shadow partially covers a window. This is illustrated in Figure 5 below.

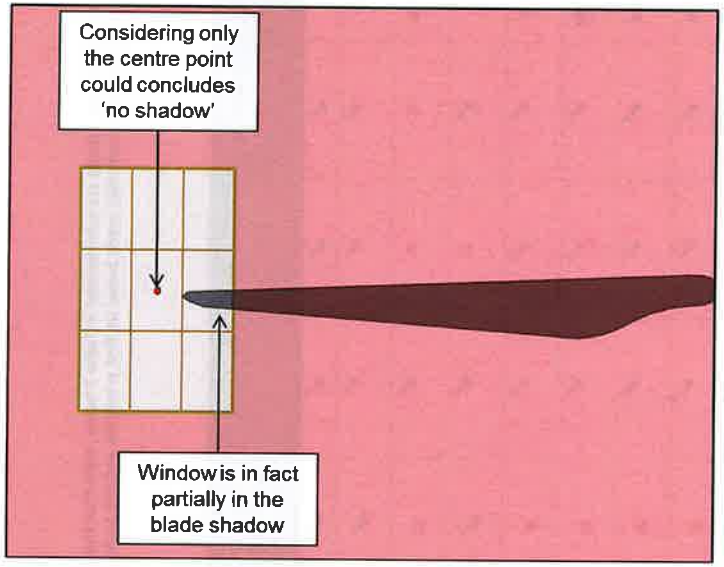


Figure 5: Importance of window dimensions

[76] In reality, partial obscuration of the sun may not result in significant effects

Incorporation of structures above ground and/or intervening terrain

Structures or terrain that obstructs the path between a receptor and a turbine could reduce potential effects. If a hedgerow removes a turbine rotor from view, there can be no shadow flicker effects.

Assuming that the path between a receptor and a turbine is clear presents a worst-case scenario, which ensures a conservative assessment. However, it is not the most accurate approach and could potentially identify impacts that would not materialise in practice.

Incorporation of wind direction and/or cloud cover

Wind direction affects the orientation of the turbine rotor. This has implications for the likely extent of shadow flicker effects. Modelling the prevailing wind direction, and the associated 'profile' of the turbine rotor, would facilitate the most accurate results.

The same is true for cloud cover – if the intensity of the sunlight is low due to obscuration by clouds, the magnitude of the shadow flicker effects could reduce.

Assuming the rotor is always 'facing' a receptor and that there is no cloud cover presents a worst-case scenario. However, the real-world effects could be less than predicted.

Prevailing wind direction and predicted could cover are particularly relevant in the context of shadow flicker hours per year – because the likely effect over a protracted period of time is more reliable than for any given day in isolation.

Appendix 2 Consultation Responses to the review of tools and methods

WindFarm

From: support <support@resoft.co.uk>
Sent: 26 May 2016 12:05
To: Kai Frolic
Subject: Shadow Flicker

Follow Up Flag: Flag for follow up
Flag Status: Completed

Hi Kai

Please use support@... for support questions - info for licences and upgrades.

Please read the ShadowFlicker.pdf tutorial for info.

1 average chord width can be used for limit distance but nothing else
2 bilinear interpolation
3 no
4 no - you need to export the results and manipulate them in a spreadsheet
5 yes - see the tutorial

Regards
Alan Harris

Hi there,

I have a couple of questions a or the Shadow Flicker modelling capabilities within WindFarm which are not in the FAQs.

Could you please advise me regarding the below:

- Is the blade width incorporated in the shadow flicker modelling?

- How is the terrain data interpolated at specific points (e.g nearest neighbour, weighted average, other)?

- Can the prevailing wind direction be accounted for within the shadow flicker calculation?

- Can cloud cover be accounted for within the shadow flicker calculation - and if so how is this estimated?

- Are sunrise and sunset times accounted for within the shadow flicker calculation (i.e to avoid predicting effects before the sun is up)?

Many thanks in advance,

Kai Frolic

Pager Power
New Mill
Bakers Court
Great Cornard
Sudbury
Suffolk

1

GH WindFarmer

From: GH - WindFarmer <windfarmer@dnvgl.com>
Sent: 26 May 2016 08:38
To: Kai Frolic
Subject: RE: GL WindFarmer Shadow Flicker Module

Follow Up Flag: Flag for follow up
Flag Status: Flagged

Dear Kai

Please find the answers below:

- Does the model incorporate hub height, rotor diameter and blade thickness?

The model uses turbine hub height and rotor diameter and optionally the offset between the rotor and the tower.
Blade thickness is not considered but this can be covered by a maximum distance where flicker can occur set by the user.

- Does the model incorporate the dimensions and of the window?

Receptor locations are modelled as a single point so for modelling larger windows you would need to use multiple receptors.

- Does the model incorporate the azimuth and vertical tilt of the window?

Yes, receptors have settings for bearing and tilt so you can model windows or greenhouse cases where flicker can be seen from all directions.

- Does the model include Earth Curvature?

Yes (optional).

- Can screening obstructions be incorporated into the analysis?

Screening uses the digital terrain model as input so if the data include obstacles they are considered.
It is not possible to define obstructions like walls, hedges or trees on top of the digital terrain data.

- Is the effect of intervening terrain on visibility and the horizon accounted for within the results?

Yes, there are 3 options:
- assuming that turbines and the sun are always visible - reduces calculation time for sites in flat terrain
- checking if turbine visibility is obstructed by terrain
- checking if turbine and sun visibility is obstructed by terrain

- How are terrain data values at particular locations interpolated (e.g. Nearest neighbour, weighted average etc)

Terrain height at turbines and receptors uses a bilinear interpolation of the gridded terrain data.

1

- Are the prevailing wind direction and cloud cover accounted for within the model - if so how are these determined?

There are different rotor models in WindFarmer: rotor modelled as a sphere, rotor modelled as a plane following the sun's azimuth or with a fixed orientation.
The option with fixed orientation can be used to model shadow flicker for the prevailing wind direction.
Cloud cover is not considered (worst case calculation only).

- Are the sunrise and sunset times considered (e.g to avoid predicting effects when the sun isn't up)?

Yes, there is no flicker if the sun's elevation is less than a minimum elevation angle set by the user.
To consider sunrise and sunset this can be set to 0 deg.
However, this minimum angle is often set to 3 deg to encounter for low light intensity when the sun is close to the horizon and obstructions by nearby obstacles.

Please don't hesitate to contact us again if you have any further questions.

Regards,

Anja Neubert

Best regards
for GL GH Deutschland GmbH

Dipl.-Met. Anja Neubert
Senior WindFarmer Specialist, Software Tools and Products Renewables Advisory DNV GL - Energy

For WindFarmer technical support write to windfarmer@dnvgl.com Marie-Curie-Str. 1, 26129 Oldenburg, Germany www.dnvgl.com

DNV and GL have merged to form DNV GL - Read more here: www.dnvgl.com/merger

-----Original Message-----
From: Kai Frolic [mailto:kai@pagerpower.co.uk]
Sent: 25 May 2016 15:49
To: GH - WindFarmer
Subject: GL WindFarmer Shadow Flicker Module

****************-Important message from DNV GL - GSS IT-****************
- PLEASE NOTE! This Message has been sent to your Legacy domain address which will soon be OBSOLETE! You need to notify the sender to use your DNVGL.COM address for the future.
As announced, the legacy domain address will be REMOVED after 01.01.2015, thus such messages as this will NOT reach you anymore. More information will be found here:
<http://inside.dnv.com/intra/news/matters/2014/gss/termination_of_legacy_email_domains_per_01012015.asp>
****

Good afternoon,

2

I am looking into the capabilities of the Shadow Flicker module within GL WindFarmer.

I have some technical questions, listed below, I hope that someone can advise me on these queries.

- Does the model incorporate hub height, rotor diameter and blade thickness?

- Does the model incorporate the dimensions and of the window?

- Does the model incorporate the azimuth and vertical tilt of the window?

- Does the model include Earth Curvature?

- Can screening obstructions be incorporated into the analysis?

- Is the effect of intervening terrain on visibility and the horizon accounted for within the results?

- How are terrain data values at particular locations interpolated (e.g. Nearest neighbour, weighted average etc)

- Are the prevailing wind direction and cloud cover accounted for within the model - if so how are these determined?

- Are the sunrise and sunset times considered (e.g to avoid predicting effects when the sun isn't up)?

Thank you in advance,

Kai Frolic

Pager Power
New Mill
Bakers Court
Great Cornard
Sudbury
Suffolk
CO10 0GG

01787 319001

3

WindPRO

From: EMD International A/S <support@emd.dk>
Sent: 25 May 2016 15:59
To: Kai Frolic
Subject: Re: [Ticket#1010575] Shadow Flicker Modelling In WindPRO

Follow Up Flag: Follow up
Flag Status: Completed

Hello Kai,
- Does the model include Earth Curvature?
Yes. However, since the calculation runs only for distances of max 2,5 km, Earth curvature is irrelevant.
- How are terrain heights at particular points interpolated (e.g Nearest neighbour, weighted average, other)?
We use the Triangular Irregular Network method.

Cheers

Maurizio
WindPRO Support Team

Maurizio Motta

--
EMD International A/S
Niels Jernes Vej 10
9220 Aalborg Ø
Tel: +45 96 35 44 44
Email: support@emd.dk - Web: http://www.emd.dk/
--

25/05/2016 16:50 - Kai Frolic wrote:

Good afternoon,

I am looking into the capabilities of the Shadow Flicker module within WindPRO

The website and the example report answered most of my questions. I just have two points I'd like to clarify

I have some technical questions, listed below, I hope that someone can advise me on these queries.

- Does the model include Earth Curvature?

- How are terrain heights at particular points interpolated (e.g. Nearest neighbour, weighted average, other)?

Thank you in advance,

Kai Frolic

Pager Power
New Mill
Bakers Court
Great Cornard
Sudbury
Suffolk
CO10 0GG

01787 319001

Kai Frolic

Pager Power
New Mill
Bakers Court
Great Cornard
Sudbury

1

Annex 2

SHADOW IMPACTS

Executive Summary

The evidence presented in this paper demonstrates that there is no scientific basis to the statements within PPS 18 and it's Best Practice Guide (BPG), that only dwellings within 10 rotor diameters need to be considered likely to suffer shadow flicker. We contend that the statement is technically inadequate or erroneous since it is contrary to the recommendations of its ultimate source, which itself contains significant additional errors.

Similarly, the statements within the BPG that, shadow flicker only occurs inside buildings where the flicker appears through a narrow window opening, has no evidential basis.

Finally, research with patients vulnerable to photo-sensitive epilepsy showed that seizure risk does not decrease significantly until the distance from the flickering turbine exceeds 100 times the hub height."

A proper application of the findings themselves and other documented research and experiences and included video evidence demonstrate that a minimum distance of 10 rotor diameters, will not resolve the problem of shadow flicker, and that the zone in which this occurs is much greater than that represented in PPS 18. A slavish attachment to the demonstrably erroneous statements within PPS 18 therefore leaves residents vulnerable to the inadequately assessed adverse impacts of shadow flicker and shadow casting and is consequently a failure in the duty of care required of all public servants.

HEALTH AND SAFETY WARNING TO SENSITIVE INDIVIDUALS

For your own safety, before viewing any of the video clips on the attached DVD, I would strongly urge you to note both of the statements made below from one of those exposed.

"Flicker is hard to capture properly on amateur video, on the spur of the moment, so some of the clips may appear not particularly dramatic and indeed some may need careful viewing to appreciate any effect at all (but I can assure you that the real experience was both dramatic - and unpleasant.

Because this is a small high speed turbine, the flicker frequency is quite high and, as I understand it, falls within the danger zone for people with photo-sensitive epilepsy - as such I believe it could trigger a fit in a sensitive individual; whilst neither myself nor my wife suffer from this condition, we did feel distinctly unwell after being exposed to a single episode of intense flicker within the house, leaving us both with headaches that persisted for several days. We now find that intent viewing of these video clips causes a minor recurrence of this effect, in a less severe form. So please be careful when viewing these clips - even though the flicker may appear minor and confined to a small portion of the image, I recommend glancing away from the screen regularly, several times during each clip."

Introduction

Developers will sometimes assert that, as PPS 18 is government policy, its statements may not be questioned. However, as Mr. Justice Matting stated with respect to the noise standard applied in a judicial review brought by the Renewable Energy Foundation (CO/9686/2007): "It will always be open to any objector to an application for permission to develop a site as a windfarm, to contend that the statement is technically inadequate or erroneous."

It is exactly these shortcomings in the BPG it is hoped to demonstrate, as well as the absence of evidence to support the belief that a separation distance of 10 rotor diameters will remove the possibility of serious shadow-flicker for neighbours of wind turbines.

What PPS 18 and the Best Practice Guide require

It is worth bringing together the main requirements concerning shadow impacts within the policy guidance.

Firstly, in PPS 18 under Policy RE 1, the promotive nature of the document has two distinct constraints applied, one to all renewable technologies and an additional one specifically to wind energy:

"Development...will be permitted provided the proposal...will not result in an unacceptable adverse impact on:

public safety, human health, or residential amenity;
visual amenity and landscape character;"

Applications for wind energy development will also be required to demonstrate all of the following:

(i) that the development will not have an unacceptable impact on visual amenity or landscape character through: the number, scale, size and siting of turbines;

that the development will not cause significant harm to the safety or amenity of any sensitive receptors1 (including future occupants of committed developments) arising from noise; shadow flicker; ice throw; and reflected light;..."

Some further guidance is given in the Best Practice Guide (BPG):

"1.3.76 Problems caused by shadow flicker are rare. At distances greater than 10 rotor diameters from a turbine, the potential for shadow flicker is very low...

1.3.77 …It is recommended that shadow flicker at neighbouring offices and dwellings within 500m should not exceed 30 hours per year or 30 minutes per day[3]. 3 The shadow flicker recommendations are based on research by Predac, a European Union sponsored organisation promoting best practice in energy use and supply which draws on experience from Belgium, Denmark, France, the Netherlands and Germany."

In summary, therefore, the proposal must satisfy four fundamental criteria to be permitted to proceed:

It must not result in an unacceptable adverse impact;

It will be required to demonstrate that it will not have an unacceptable impact and will not cause significant harm;

Shadow flicker should not exceed 30 hours per year;

Shadow flicker should not exceed 30 minutes per day.

We will return to the erroneous belief that beyond a separation distance of 10 times the rotor diameter, the 'potential for shadow flicker is very low', later in this response.

Shortcomings in the shadow flicker assessment

The approach to shadow flicker in many applications seems to rely on The belief that if nearby residences are beyond ten times the rotor diameter from the proposed turbines, shadow flicker impact cannot occur and need not be assessed. This position is not fully supported even by PPS 18.

The result is not an assessment of shadow flicker impacts at all, but an artificial estimation of the results of applying input assumptions to a prescribed area. This is a classic example of 'you don't find what you don't look for'!

Three aspects should be kept in mind at all times when considering such measurements.

Firstly, there is no adequate guidance in the BPG on the conversion of an astronomical worst case scenario to a realistic scenario including meteorological parameters. As will be seen below, such guidance does exist to convert from clear to cloudy skies, with appropriate reductions in shadow flicker hours permitted, but is ignored;

Secondly, Parsons Brinckerhoff in their 'Update of UK Shadow Flicker Evidence Base, 2011' for the Department of Energy and Climate Change (DECC), noted that 'The majority of respondents to the industry questionnaire expressed concerns that quantifying acceptable levels of shadow flicker duration would be problematic…'. In other words, shadow flicker impacts are difficult to measure accurately, even for the industry;

Finally, the shadow flicker recommendations in the BPG are not based on best practice and research by Predac, as asserted. If they were, the assessment process would be much simpler and significantly more realistic. This will be discussed further, below.

Does 10 times rotor diameter prevent shadow flicker at a home?

It is vital that this question is answered since applicants appear to rely on the claim in the BPG that, "At distances greater than 10 rotor diameters from a turbine, the potential for shadow flicker is very low", to set the boundary within which shadow flicker impacts will occur.

It is, however, necessary to remove the obscurity which permitted the erroneous assertions about the location, extent and direction of shadow flicker to remain unchallenged for so long.

Was PREDAC the authority for 10 rotor diameters?

Although it is inferred in the BPG to PPS 18 (1.3.77 shown above) that the section on shadow-flicker is based on a survey by PREDAC, a European Union sponsored organisation promoting best practice at energy use and supply, it is in fact a direct lift from the policy in the Irish Republic, which itself misquotes PREDAC. It would appear that no attempt has been made in the intervening five years to check that the Irish version was correct before placing it within PPS 18.

The Irish guidelines from the Department of Environment, Heritage and Local Government (Undated), include the following statements:

It is recommended that shadow flicker at neighbouring offices and dwellings within 500m should not exceed 30 hours per year or 30 minutes per day [Predac*]" (Page 33)
"At distances greater than 10 rotor diameters from a turbine, the potential for shadow flicker is very low.

*The shadow flicker recommendations are based on the survey by Predac, a European Union sponsored organisation promoting best practice at energy use and supply which draws on experience from Belgium, Denmark, France, the Netherlands and Germany."

These statements are placed directly into PPS 18 without alteration.

What PREDAC actually says:

A copy of the shadow flicker section of the PREDAC document is attached as Appendix 1, but the following quotations are relevant:

"It is recommended at neighbouring dwellings and offices that flickering shadows are not exceeding 30 hours /year or 30 min. per day with normal variation in wind directions and with clear sky. (This follows the German norm of 30 hours a year at clear sky)." (Page 21)

The Irish guidelines imply that Predac is the source of the 'within 500 m.' and 'At distances greater than 10 rotor diameters' , when in fact Predac makes no mention of either. PREDAC considered practice in Belgium, Denmark, France and the Netherlands, as well as some information from Germany and Ireland. None of the nations surveyed adopted the PREDAC model.

Indeed, PPS 18 has also disingenuously misrepresented the German model recommended by Predac. For example, the BPG states that 'Shadow flicker only occurs inside buildings where the flicker appears through a narrow window opening' (1.3.72). German guidance, however, recognises shadow flicker both internally and externally, and sets strict limits on the levels of acceptable shadow flicker effect, using two methods:

An astronomical worst case scenario limited to a maximum of 30 hours per year or 30 minutes on the worst affected day;
and a realistic scenario including meteorological parameters limited to a maximum of 8 hours per year.

In determining exact times, the type of receptor (e.g. window) should be considered. When indoors, the reference height should be set at the centre of the window. When outdoors, the reference height is set at 2m above ground level. Sunshine duration data should cover a period of at least a year, and the data should be available by a competent authority on request [Notes on the Identification and Evaluation of the Optical Emissions of Wind Turbines, States Committee for Pollution Control – Nordrhein-Westfalen (2002)]. See Appendix 2 on Germany and Shadow Flicker.

It should be noted that the German guidance on which the BPG is clearly based, also states that "Shadow flicker should be limited to a maximum of 30 minutes per day... When this benchmark is exceeded for at least three days, appropriate measures need to be implemented to reduce the impact to guarantee a maximum duration of shading of 30 minutes" (Appendix 2).

This confusion is commented on in recommendations made to the Scottish Government in 2017 on the content of future guidance on shadow flicker in the following terms:

> **Recommendation 8: Thresholds for exposure to shadow flicker and use of worst case and likely case scenarios**
>
> The German guidelines are clear on the exposure thresholds for both worst case and likely case scenarios of 30 hours per year or 30 minutes a day worst case and eight hours a year likely case. These thresholds are most widely quoted, although some countries have set their own limits.
>
> The case study review has identified inconsistency in the definition and application of 'significance' in relation to predicted shadow flicker both worst case and likely case, and the application of a precautionary approach in the

decision making process. There is a need for guidance on the thresholds of exposure to shadow flicker in Scotland.
(Appendix 6)

The true origins of 10 times the rotor diameter

The source of the assertion of a 10 rotor diameter limit on the extent of the flicker-affected zone and the paucity of research into the adverse impacts of shadow-flicker and reflected light are both revealed by a Parliamentary Question by Llew Smith, the former labour MP for Blaenau Gwent. A Written Answer was provided as follows:

House of Commons Hansard Written Answers for 23 Feb 2004, Column 74W

Llew Smith: To ask the Secretary of State for Trade and Industry what research has been undertaken by (a) her Department, (b) the Energy Technology Support Unit on behalf of her Department and (c) consultants for her Department on (i) shadow flicker and (ii) noise from wind farms. [155024]
Mr. Timms: ..No research has been carried out into shadow flicker from wind turbines under the DTI's New and Renewable Energy Programme. However, others have conducted research in this area and references [2] to those studies are provided as follows.

[2] Clarke, A. D. (1991), A Case of Shadow Flicker/Flashing: Assessment and Solution, Open University, Milton Keynes
Clarke, A. D. October (1995). Assessment of Proposed Wind Energy Project at Meenacahan, Donegal, Ireland, for Shadow Flicker. Report for B9 Energy Services Ltd.

The reference Clarke (1995) is apparently not in the public domain, but it should be noted that the MEENACAHAN application was refused on 20 December 1995 and a subsequent appeal was also refused on 18 July 1996. Since, therefore, the turbines were never built, there was no opportunity to test the veracity of any hypothesis in the second report and, as will be seen below, even the DECC do not refer to it.

The remaining reference to Clarke (1991) has been established through the Open University Library as:
Clarke, A. D. (1991), A Case of Shadow Flicker/Flashing: Assessment and Solution, 'Wind Energy Conversion' (1991) pp 93-97, Eds DC Quarton & VC Fenton, Proceedings of the 13th British Wind Energy Association Conference, 'Wind Energy and the Environment', Swansea 10-12 April 1991.

That this has remained the sole source for the assertion that 10 times the rotor diameter forms the limit beyond which shadow flicker is supposed to have little effect, was confirmed in 2010 and 2011 in correspondence between the Renewable Energy Foundation (REF) and the Department of Energy and Climate Change (DECC). Note, however, that Clarke's paper itself does not make the ten rotor diameter claim attributed to it. In fact its recommendation is 'that turbines should be sited at least ten diameters distance from habitations, and more if sited to the East/Southeast or West/Southwest, and the shadow path identified' (emphasis added). The following statements are relevant:

Renewable Energy Foundation Response to:
DECC Consultation on the National Policy Statement EN-3 Renewable Energy Infrastructure 22 February 2010

41. Shadow Flicker.
42. (2.7.73) The claim that 'flicker effects have been proven to occur only within ten rotor diameters of a turbine' cannot be substantiated. In correspondence with DECC, we requested the source from which this statement was derived and were informed that it was a paper by A.D. Clarke 1991 for Open University entitled "A Case of Shadow Flicker/Flashing: Assessment and Solution". However, this paper does not prove the ten rotor diameter claim. In fact its recommendation is 'that turbines should be sited at least ten diameters distance from habitations, and more if sited to the East/Southeast or West/Southwest, and the shadow path identified' (emphasis added). The evidence indicates that the EN-3 recommendation that only dwellings within 10 rotor diameters need to be considered likely to suffer shadow flicker is not correct and needs to be amended.

RENEWABLE ENERGY FOUNDATION RESPONSE To DECC Consultation on the Revised Draft National Policy Statement EN-3 Renewable Energy Infrastructure and related documents 24 January 2011

27. Shadow Flicker. (2.7.73) Yet again, the draft EN-3 repeats the unsubstantiated claim that shadow flicker only occurs within ten rotor diameters of a turbine. In correspondence with DECC before the last consultation closed, we requested the source from which this statement was derived and were informed that it was a paper by A.D. Clarke 1991 for Open University entitled "A Case of Shadow Flicker/Flashing: Assessment and Solution". However, on examination we found that this paper does not prove the ten rotor diameter claim. In fact its recommendation is 'that turbines should be sited at least ten diameters distance from habitations, and more if sited to the East/Southeast or West/Southwest, and the shadow path identified' (emphasis added).
33. EN-3 at para 2.7.65 refers to 'research and computer modelling' has demonstrated this 10-rotor-diameter rule, but there is no reference to substantiate this claim. The given reference is still an indirect reference to the 1991 A. D. Clarke paper. If there was any basis for the assumption that shadow flicker is solely dependent on rotor diameter (and thus not dependent on total turbine height, for example), then experienced and reputable developers would not carry out the substantial assessments of shadow flicker over significantly greater distances.

This conclusion has been again confirmed in 2017 in research for the Scottish government, as follows:

Recommendation 7: Exclusion of reference to the 10 rotor diameter distance

Although a number of other factors may contribute to the significance of shadow flicker potentially
being greatest closer to the wind turbines, the ten rotor diameter distance threshold does not appear to have robust evidence within the literature examined.

Secondly, there is frequent misapplication of the ten rotor diameter distance as a limit within which shadow flicker modelling is applied.
(Appendix 6)

It is clearly worth considering the statements actually made by A. D. Clarke, since this sole source is the origin of all claims that 10 times the rotor diameter will resolve the vast majority of shadow flicker problems. The quotations are from the 'Update of UK Shadow Flicker Evidence Base' 2011, prepared by Parsons Brinckerhoff for the Department of Energy and Climate Change, including their synopsis:

A Case of Shadow Flicker / Flashing: Assessment and Solution, Clarke A.D. (1991)

Synopsis

This paper makes reference to a complaint submitted to a Local Planning Authority (LPA) relating to disturbance from shadow flicker and reflected sunlight from a wind turbine – the details of the complaint and the LPA that it was submitted to were not included in the paper.

Relevant text extracts

"A recommendation was made that turbines should be sited at least ten diameters distance from habitations, and more if sited to the East / Southeast or West / Southwest, and the shadow path identified." (Page 93)

"The effect can be pronounced in rooms in buildings facing the turbine, especially if the window is the sole source of light for a room." (Page 93)

"It has been found that the frequencies of flicker that produce disturbance are between 2.5 Hz and 40 Hz." (Page 93)

"Most medium and large wind turbines have a rotation rate of between 30 r/min [rotations per minute] and 60 r/min, and smaller turbines often have a faster rotation. Most turbines in use today are two or three bladed, constant speed types, producing shadow flicker rates in the range of 1-3 Hz. Variable speed turbines may produce a 2-6 Hz flicker rate. Therefore the shadow flicker from turbines has frequencies that could in the right conditions produce light flicker effects to susceptible persons." (Page 93)

"The shadow will be most pronounced when the blades of the turbine face the building and present the largest shadow area." (Page 94)

"Residents of a neighbouring house claimed that shadow flicker and reflected sunlight from the turbine blades were causing disturbance to them. After complaints were made to the local Planning Authority, a study was carried out to investigate the problem." (Page 94).

"The turbine's dimensions and data were obtained:

Turbine rating: 200 kW
blade diameter: 25m
tower height: 30m
swept area: 491m square
rotation rate: 44 r/min & 33 r/min in light winds number of blades: 3
flicker frequency: 2.2 Hz & 1.65 Hz." (Page 94)

"Wind turbines close to habitations, e.g. ten diameters distance should not be sited to the East or South East, or West or South West of habitations, unless the shadow path has been identified and does not fall on windows of habitations or occupied buildings." (Page 95)

"The minimum separation distance for wind turbines from habitations should be approximately 10 blade diameters. This is emerging from experience and research as a standard guideline, in order to reduce problems of visual impact, noise, shadow disturbance, and safety". (Page 95)

It is also instructive to include two paragraphs of A. D. Clarke's research unaccountably omitted by Parsons Brinckerhoff from their 'review':

1. " short study was carried out investigating a reported problem of shadow flicker and flashing from the blades of a turbine. The incidence of this phenomenon was confirmed and the duration and frequency of occurrence assessed. The shadow flicker period would be short and only occur at certain times, but could cause irritation. A device to stop the turbine when shadow flicker occurred was recommended and is described. A recommendation was made that turbines should be sited at least ten diameters distance from habitations, and more if sited to the East/ Southeast or West/ Southwest, and the shadow path identified" (our emphasis)
2. "Clearly it is best to avoid the problem in the first place by attention to careful siting. Wind turbines close to habitations, e.g. ten diameters distance should not be sited to the East or South East, or West or South West of habitations, unless the shadow path has been identified and does not fall on windows of habitations or occupied buildings. Two other alternatives are that the turbine is stopped by a device such as the one described, or that it is sited well beyond the normal separation distance of ten diameters, as the shadow will then no longer be in sharp focus. This distance has not yet been identified." (our emphasis)

The statement from the GPG to PPS 18 (1.3.76) that, "Problems caused by shadow flicker are rare. At distances greater than 10 rotor diameters from a turbine, the potential for shadow flicker is very low.", is thus contrary to the recommendations of its ultimate source and is open to serious challenge. The actual overall recommendation to be inferred from Clarke (1991) is that to avoid the problem of shadow flicker, wind turbines to the east/southeast, or west/southwest of habitations should be sited well beyond 10 rotor diameters, at a distance not yet identified.

Careful study reveals Clarke's research to have been seriously misrepresented in all guidance which has been based upon it, usually without attribution. Similarly, the statements within the BPG to PPS 18 (1.3.72) that, "...'shadow flicker'...only occurs inside buildings where the flicker appears through a narrow window opening. A single window in a single building is likely to be affected for a few minutes at certain times of the day during short periods of the year", has no support from Clarke's work. Neither are such statements made in the Predac document referred to in a footnote.

<u>Problems with A D Clarke's research</u>

As can be seen from the 2004 parliamentary written answer, the later correspondence between REF and the DECC, and the 2017 Scottish research, Mr. Clarke's 1991 paper is the solitary foundation on which the supposed 'solution' to shadow flicker is constructed. This is despite his paper not supporting the ten rotor diameter claim asserted for it and indeed recommending a greater separation distance, with significant but uncalculated increases for certain compass directions. This remains the position even following the Parsons Brinckerhoff report of 2011 for the DECC.

However, to this misinterpretation of Clarke's results must be added a series of problems with the research itself:

a. The research was never designed to form the basis for a generally applicable rule, being related to a specific case. This would have restricted its application, even in the absence of errors;

b. Clarke's research is not verifiable or repeatable since the identity and location of the turbine and affected property are not stated;

c. Further, his work took place before any wind farms had been constructed in the UK, the first being erected after his paper was written. His work related only to a small domestic turbine in unknown circumstances;

d. No comment is made on the local topography and elevations of the respective dwellings to each other, or the environment in which they were situated, which might have affected the degree of flicker from the turbine;

e. The flicker calculations are flawed, as they only take into account blade area and not the total turbine tip height, which can increase the occurrences. Since many turbines can be purchased with different tower heights for the same blade diameter, this can increase the period of time when the light source will be viewed through the moving blades;

f. Similarly, no account has been taken of the effect of turbine base elevation in differentially increasing turbine height. Two turbines of identical hub height and blade diameter but with bases at different elevations, will differ in the period of time when the light source will be behind the moving blades;

g. Since it was based on a single turbine investigation, Clarke's research could not reveal the existence of flicker reflection between multiple turbines and other external shadow flicker phenomena, such as reflection from bodies of water and urban glow. He therefore took no account of cumulative flicker impacts;

h. Finally, by the research being restricted to a single domestic turbine, there was no requirement to take account of shadow propagation problems. Turbines on elevated ridgelines will cast very long shadows into the adjacent valleys because the sun will rise much higher in the sky than for turbines located amongst domestic or farming buildings.

Other challenges to the proposed solution to shadow flicker

The 10 rotor diameter assumption has also been decisively challenged by two other pieces of research. Delft University of Technology in the Netherlands, after conducting research on the flicker effect, concluded that "there is no rule-of-thumb regarding the distance from a turbine where shadow flicker may be an issue."
Similarly, a comprehensive Swedish study by Gotland University suggested that the geometrical model for shadow impact calculation is not accurate when there are several turbines at large distances from a building.

These studies are corroborated by local experience with the Wolf Bog wind farm in Co. Antrim (see Appendix 3). In the 'Supporting information for an application to vary condition 10 of planning approval G/2004/9597/F…' dated 26th May 2006, the developer of the Wolf Bog site, (Appendix 3, pp.1 & 2.of their document) identifies shadow flicker effects at distances of up to 22 times the rotor diameter of 80 m. The worst affected property was at 15 times the rotor diameter (table on page 1 of report compared with page 2). The Wolf Bog developer used current industry software to reveal much greater shadow impact distances. This is further borne out by the Parsons Brinckerhoff 2011 report for DECC mentioned above. Section 4.4 demonstrates that shadow flicker from a single turbine using various proprietary software packages in a field trial, is cast approximately 31 times the rotor diameter in an easterly direction and 29 times in a north easterly direction.

In 2010 and 2011, Stroud District Council in Gloucestershire, accepted that evidence provided to them during consideration of a wind farm application (Proposed Wind Farm Development at Standle Farm Stinchcombe Dursley S10/1638/FUL), clearly demonstrated the existence of serious shadow flicker from an operating wind turbine. These impacts occurred within a home at a distance of 21 rotor diameters and in the gardens and neighbouring properties, out to a distance of 31 rotor diameters. This caused the appearance of trees and shrubs to 'flicker' dramatically to the naked eye (see Stroud videos on attached DVD, but note health warning at start of this document). Occurrence of such effects out of doors and at such large distances, refutes the statements within the BPG to PPS 18. Both house and garden were due west of the turbine, underwriting the recommendation of Clarke noted earlier, that to avoid the problem of shadow flicker, wind turbines to the east/southeast, or west/southwest of habitations should be sited well beyond 10 rotor diameters, at a distance not yet identified.

Another local example is the Slieve Divena wind farm at Garvaghy, which casts shadow flicker well over 20 times the rotor diameter. Video clips of this impact are also included on the attached DVD.

In an application for a single turbine for which information is readily available (T/2013/0009/F), and which failed at planning appeal, it was calculated that when the turbine blades just covered the sun, they would have occupy an angle of 11 mrad. The 3-blade diameter for the turbine was almost 30m. Therefore the distance the observer would be for the sun to just cover 30 m. is 30m./11 mrad = 2,727m., or over one and a half miles. Most software packages do not fully evaluate the effect of this great propagation distance in their calculations.

Confirmation that this large propagation distance does not significantly reduce the impact of the shadow flicker on receptors comes from a 2008 paper by Professor Graham Harding and his team from the universities of Aston and Essex, entitled, 'Wind turbines, flicker, and photosensitive epilepsy: Characterizing the flashing that may precipitate seizures and optimizing guidelines to prevent them'. Surprisingly, this paper is not included in the review by Parsons Brinckerhoff since it clearly contradicts a number of their findings. However, part of the abstract reads as follows (see Appendix 4):

"Wind turbines are known to produce shadow flicker by interruption of sunlight by the turbine blades. Known parameters of the seizure provoking effect of flicker, i.e., contrast, frequency, mark-space ratio, retinal area stimulated and percentage of visual cortex involved were applied to wind turbine features. The proportion of patients affected by viewing wind turbines expressed as distance in multiples of the hub height of the turbine showed that <u>seizure risk does not decrease significantly until the distance exceeds 100 times the hub height</u>." (emphasis added).

This has been borne out by a number of local cases of fits and other adverse health impacts brought on by turbine flicker, the most recent near Cookstown in May 2015. In each case the turbine was located at distances well beyond ten times the rotor diameter.

There are many other examples that could be quoted, but suffice to say that against the assertions made on behalf of a single piece of research, which that research does not sustain, a proper application of the findings themselves and other documented research and experiences demonstrate that a minimum distance of 10 rotor diameters, will not resolve the problem of shadow flicker, and that the zone in which this occurs is much greater than that represented in PPS 18.

This is confirmed by the following 'Key points in relation to origins of the ten rotor diameter distance' from the 2017 Scottish study (Appendix 6):

> The original references to ten rotor blade diameter distance separation between wind turbines and habitations by Clarke (1991) is presented as an approximate or minimum distance to avoid disturbance, and should not be interpreted as a limit at which disturbance from shadow flicker can occur.
> Within the text of the original article by Clarke (1991) there is blurring of the impacts of visual impact, noise, shadow disturbance and safety in relation to the ten rotor diameter separation distance.
> Clarke (1991) does not make reference to distance and the effect of wind turbines and epileptic convulsions commenting only on the frequency of flicker and speed of blade rotation.

Results of exposure to shadow flicker

Can we identify the effects of exposure to shadow flicker on a regular basis? Clarke himself, in the section of his research omitted by Parsons Brinckerhoff but reproduced above, notes that even short periods of shadow flicker '...could cause irritation.'

The extent of the impact that shadow flicker causes is given in a psychology study (Pohl, 1999). This study concludes that the shadow flicker effect did not constitute a significant harassment. However, under specific conditions the increased demands on mental and physical energy, indicated that cumulative long-term effects might meet the criteria of a significant nuisance. This demonstrates the need to reduce the impact where possible. This is further confirmed in the German standard, which states that, " Scientific research has demonstrated experience that optical emissions in the form of periodic shadows can result in considerable harassment effects", and, "The laboratory study by the University of Kiel (Pohl et al 2000) noted that even a one-off exposure to 60 minute duration of shadows can cause stress reactions." [Notes on the Identification and Evaluation of the Optical Emissions of Wind Turbines, States Committee for Pollution Control – Nordrhein-Westfalen (2002)]. (Parsons Brinckerhoff translations).

The following additional research is helpful in this regard:

Wind Power Environmental Impact – Case Study of Wind Turbines Living Environment,
Widing et al. (2005)

Synopsis

This paper prepared by the Centre for Wind Power Information at Gotland University presents case study information from residents living near the wind turbines in När, Klintehamn and Näsudden in Sweden. The paper also indicates that it is more important on which day and in which season shadows occur, than how long the calculated/expected shadow time lasts.
In addition, a report by the Swedish Federal Housing Association (the Boverkets handbook 2003) suggests that shadow flicker duration should be assessed both on the plot of land around a house (the curtilage) as well as the façade (windows) of the property. The report states that there is a statistically significant correlation between shadow minutes per day on the façade of a property and the specified disturbance, whereas shadow minutes per day on the plot of land and disturbance are not related.

Relevant text extracts

One possible explanation why so many people are disturbed by the shadows in Klintehamn may be that the majority of the respondents live east-south-east of the power plant which, according to the calculations, results in the majority (approximately 90 % of respondents) having shadows in the evenings from April to September.
In Näsudden about half of the respondents get shadows in the evenings while the other half get the shadows in the morning or at midday. For those respondents who do not get disrupted even though the expected shadow time is long, shadows appear mainly in the morning or in winter. For those respondents who are disturbed despite the short estimated shadow time shadows occurring in the evenings. In När no respondent got shadows during summer evenings. This may indicate that it is more important on which day and in which season shadows occur, than how long the calculated/expected shadow time lasts.
In Näsudden there is no relationship whatsoever between the estimated shadow time and the specified disturbance. There is however a moderate-strong connection between the distance to the closest turbine and annoyance from shadows. Since according to the Boverkets handbook (the handbook of the "Federal Housing Agency") (Boverket 2003) a new guideline has been introduced, due to which the shadow time is calculated on the plot of land instead of on the windows, the shadow time in Klintehamn was calculated partly on land and partly on the facade. There is a statistically significant moderate correlation between shadow minutes / days on the facade and the specified disturbance. Whereas shadow minutes / days on the plot and disturbance are not related.

Application to and problems with an actual application (T/2013/0009/F)

Clarke's research recommends that turbines should be sited at least ten rotor diameters distance from habitations. However, if sited to the East/Southeast or West/Southwest, this distance will apparently require to be increased significantly, based on the shadow path being accurately identified and not being permitted to fall on windows of habitations or occupied buildings. It will also increase the area under consideration to at least 135 degrees either side of north.

The applicants in this case did not attempt to address this adverse impact. It is therefore important to note the following shortcomings in the approach to shadow flicker, shadow propagation and reflected light:

1. No assessment has been made, as recommended by Clarke's research, on dwellings sited to the East/Southeast or West/Southwest. The shadow path has not been accurately identified and not prevented from falling on windows of habitations or occupied buildings. Further, as also noted in the Parsons Brinckerhoff report for DECC (3.2.1), "...wind turbines are often sited southwest of built-up areas. These locations, however, are most likely to suffer shadow hindrance." (Shadow Hindrance by Wind Turbines, Verkuijlen E. & Westra C.A., 1984, Page 358). As the Swedish study indicated earlier, this is a situation of vulnerability in which many can be disturbed by shadow flicker;

2. Accurate separation distances are fundamental to noise estimation, shadow casting and shadow flicker analysis and visual impact. However, these have been found to be generally inaccurate due to OSNI co-ordinate and GPS discrepancies, error tolerance levels and turbine micro-siting allowances. This level of inaccuracy is considerably worsened in this application by significant discrepancies in grid co-ordinates. Accurate impact estimation is not possible with such a degree of error;

3. Software is only as good as its assumptions, should it be appealed to as a solution. Despite claims by the wind industry that their estimation of shadow flicker effects is a 'worst case scenario', it is actually the reverse since they would not normally consider any impacts beyond ten times the rotor diameter – in this case approximately 300 metres. Given the comments about measurement discrepancies in 2. above, it is also worthy of note that Parsons Brinckerhoff in their 'Update of UK Shadow Flicker Evidence Base, 2011' for the DECC, noted that 'The majority of respondents to the industry questionnaire expressed concerns that quantifying acceptable levels of shadow flicker duration would be problematic…';

4. Shadow effects occur on the whole facade of the residence and over the amenity areas within the curtilage, as noted in the Swedish research, above, and illustrated in several of the video clips on the attached DVD. Any 'filtering' by the applicants to reduce this to a 'windows only' internal assessment, would be contrary to both the PREDAC and German approaches on which the BPG is supposedly based;

5. Length of Shadow Casting or Propagation. To eliminate the shadow being cast, it is necessary to remove either the light source or the object casting the shadow. This cannot be achieved by software, as some have claimed. As noted when discussing Clarke's research earlier, turbines on elevated sites will cast very long shadows onto the surrounding lower ground because the sun will rise much higher in the sky. A 45 m. high turbine on level ground, will cast a shadow for the following distances as the sun rises and sets. Sun

angles less than 3 degrees above the horizon are disregarded (due to possible vegetation and building screening):

Calculated turbine shadow casting

45 metre Turbine on level ground

Sun angle (Degrees above horizon)	Shadow distance in metres
10	255.21
5	514.35
3	858.65

There is, however, a significant elevation to the base of the proposed turbine above the surrounding properties, and The shadow will potentially be cast over two and a half kilometres, with the worst affected properties being impacted for up to an hour a day.

7. Width of Shadow Casting or Propagation. At angles larger than, for example, an outstretched hand (120 mrad) one would expect the shadows on the landscape to be easily distinct. This corresponds geometrically to a viewshed distance around the observer of 30m. /120mrad = 250m. Thus a resident would be exposed to shadow flicker from this turbine for 250 m. in each compass direction from his home as this is well within a rural scenic viewscape not restricted to property lines;

8. The shadow and the flicker will be observed well above any vegetative screening, because of the unavoidable human attraction to motion. This was clearly demonstrated to be the case with two incidents that caused ill health at 33 rotor diameters from the Wolf Bog wind farm in Co. Antrim. However, the proposed turbine is completely exposed on the crest of Drumadarragh Hill;

9. It is untrue that a shadow will not be cast when the sun is obscured by clouds. Northern Ireland has many bright cloudy days when substantial shadows can be cast. An examination of the output from solar panels will quickly demonstrate that more output is produced on bright cloudy days than cloudless ones;

10. It is also untrue that a shadow will not be cast when the turbine is not operating. As discussed above, although the flicker effect may be absent, a shadow will always be cast when the sun passes behind a turbine. Further, stationary blades continue to cause problems of reflection;

11. Flicker effects also occur at night from a rising or setting moon. Rural residents are particularly affected since they experience very dark skies;

12. Visual disturbance and wide-angle disruption can result when wide horizon expansive sunsets occur. Brightly lit from behind, though not casting shadows, the flickering blade movement of a turbine on the horizon will

disrupt the viewscape. The proposed turbine location is a particularly extreme instance of this;

No competence, no policing

We have already quoted Parsons Brinckerhoff's comment that 'The majority of respondents to the industry questionnaire expressed concerns that quantifying acceptable levels of shadow flicker duration would be problematic…';. They go on to note that, 'Conversely to the developers' response, LPAs [local planning authorities] were generally in favour of adopting quantitative guidelines, although concerns were raised about the practicalities of implementation, in particular the need to characterize the sensitivity of receptors in order to determine appropriate levels of shadow flicker. It is thought that LPAs favour a quantitative solution as it is straightforward to assess when developments are taken through the planning process.'

It may indeed be convenient for planners to assess applications on the basis of quantified shadow flicker impacts, but this only has meaning if the expertise exists to understand the causes and solutions to shadow and flicker problems, and to clearly separate developer assertion from realistic prediction. This ability does not presently reside within planning. This was clearly revealed in an application for a single turbine (U/2014/0065/F)

The German guidance on which the Best Practice Guide to PPS 18 is clearly based, also states that:

> "Shadow flicker should be limited to a maximum of 30 minutes per day… When this benchmark is exceeded for at least three days, appropriate measures need to be implemented to reduce the impact to guarantee a maximum duration of shading of 30 minutes".

In this example, the applicant's own shadow flicker report revealed an exceedance of the 30 minutes per day maximum every day for the following continuous periods:

House 1 29 January to 13 February(inclusive) and 27 October to 13 November (inclusive);

House 2 17 January to 4 February (inclusive) and 7 to 26 November (inclusive);

House 3 11 to 20 February (inclusive) and 22 to 31 October (inclusive);

House 4 14 to 21 May (inclusive) and 21 to 28 July (inclusive).

The reason given for accepting this level of shadow flicker was that the calculations were a worst case and that this did not reflect the weather conditions in the area. This was accepted by the planners.

However, the 2017 Scottish research found:

> 3.26 Of the documents reviewed, only the Northern Ireland Best Practice Guide to PPS18 refers to a threshold for duration of effect, 'It is recommended that shadow flicker at neighbouring offices and dwellings within 500m should not exceed 30 hours per year or 30 minutes per day.'... However it is noted by Haugen (2011) that the German guidance is often misquoted, as it refers to 30 hours / year worst case, and 8 hours / year likely case. PPS18 appears to reflect this observation, omitting reference to worst case or likely case in relation to the threshold.

Further, it should be highlighted that light nuisance powers held by councils within Northern Ireland under the Clean Neighbourhoods and Environment Act (NI) 2011 only relate to 'artificial light' produced by a luminaire (a light fixture or source) and hence cannot be used to address complaints of shadow or light flicker caused by a wind turbine. As a consequence, issues regarding shadow or light flicker associated with wind turbines would fall outside council's sphere of expertise.

No competent authority therefore exists to scrutinize the often minimalist claims made by developers, in clear contravention of the EIA Directive 85/337EC, which requires an assessment independent of a developer's submission, 'That obligation does not correspond to the broader one, imposed by Article 3 of Directive 85/337 on the competent environmental authority, to carry out itself an environmental impact assessment in the light of the factors set out in that provision. (C-50/09, Commission v. Ireland, paragraph 44)' – from, EIA of Projects, Rulings of the Court of Justice, p.25/6).

In a situation were a major adverse impact is neither being adequately assessed or policed, decisions on the merits of applications are being made in ignorance. The protection of the public's health must, therefore, be paramount and a precautionary approach to the infliction of uncontrolled shadow casting and flicker must be adopted.

Conclusion

Evidence has been provided supporting serious concerns about the accuracy of the shadow flicker assessments procedures and the assumptions on which it is based. Examples have been given of use of the industry-standard software which demonstrate significantly greater shadow impact zones beyond the 10 times the rotor diameter applied, and this is fully supported by video recordings of actual occurrences accompanying this document.

The evidence presented in this paper also indicates that there is no scientific basis to the statement that only dwellings within 10 rotor diameters need to be considered likely to suffer shadow flicker, and that it is a serious environmental pollutant that can have significant harmful effects on the welfare of persons subjected to it. Further, confusion in PPS 18 in it's reference to worst case or likely case in relation to thresholds for exposure, ensures that nearby residents are more exposed to shadow flicker incidents.

It is therefore contended that many more properties, over a much wider area than has been considered until now, will be vulnerable to an unacceptable adverse impact for longer periods of time.

In view of the absence of effective assessment and policing of such environmental impacts, it is recommended that the Council should urgently review this part of PPS 18 and the Best Practice Guide, with a view to introducing a more adequate method of protection for the public residing around wind energy installations.

DRK 12 September 2019

ANNEX 3

The Chief Environmental Health Officers Group (CEHOG) response on the draft of PPS 18, 11 March 2008

Protection of amenity

The document advises that the planning policy aims to prevent unacceptable detrimental effects upon the locality and amenity. Page 36, paragraph A37 states, "The planning system exists to regulate the development and use of land in the public interest. The material question is whether the proposal would have an unacceptable detrimental effect on the locality generally, and on amenities that ought, in the public interest, to be protected."

However the level of protection afforded by the current ETSU-R-97 standard referenced on page 45 would be considered to provide a lower level of protection against "unacceptable detrimental effects on the locality generally, and on amenities…". Page 45, paragraph A79 states,

"The report, 'The Assessment and Rating of Noise from Wind Farms' (ETSU-R-97), describes a framework for the measurement of wind farm noise and gives indicative noise levels calculated to offer a reasonable degree of protection to wind farm neighbours, without placing unreasonable restrictions on wind farm development."

The Department should give careful consideration to the possible interpretation of such terminology and references and should ensure that the final wording of the Statement will ensure that local amenities are adequately protected. Accordingly, the Department may wish to align the wording of paragraph A37 with that used within paragraph A79.

Noise levels generated by wind turbines

Page 45, Table 1, 'Noise generated by wind turbines compared with other everyday activities', presents a number of typical noise sources and their approximate noise levels. With regard to wind farms it states, "Wind Farm at 350m , 35–45 dB".

The above information could be construed as suggesting that wind farms positioned at 350m are acceptable. As a rule of thumb, 500 metres between wind farm developments and sensitive receptors is normally considered sufficient distance, however, even distances in excess of 500 metres may be inadequate in specific circumstances. With regard to separation distances, ETSU page 46, paragraph 7 states,

"The difference in noise emissions between different types of machine, the increase in scale of turbines and wind farms seen today and topographical effects described below all dictate that separation distances of 350 – 400 metres cannot be relied upon to give adequate protection to neighbours of wind farms."

EH suggests that the above reference be added to paragraph A76 and that the separation distance as presented within Table 1 be increased to 500 metres.

Appendix 4 ETSU-R-97

Minimum separation distance

Paragraph 47 of the annex to PPG 22 refers to experience from mainland Europe which has shown that there is unlikely to be a significant noise problem for a residential property situated further than distances of 350-400 metres from a wind turbine. The PPG also suggests that:

> *"Lesser separation distances may be acceptable depending on the turbines used and the specific conditions at a site."*

This was true for the flat, open sites typical of Northern Europe and for the size and number of turbines used in wind farms at the time of writing PPG 22. We believe the guidance in **PPG** 22 was intended to give the reader an appreciation of the magnitude of the separation distances that would be required to protect local amenity. Indeed, wind farms have been constructed with this order of separation distance which have not resulted in complaints over noise. There are however a number of further considerations relevant today.

The emitted sound power level (SWL) from different wind turbines may vary by several dB for the same wind speed condition at hub height depending upon the size and design features of the turbine. Assuming hemi-spherical propagation with atmospheric absorption of 0.005dB/m this means that a quiet wind turbine with a SWL = 95dB(A) positioned at 245m from a dwelling would have the same acoustic impact as a turbine with a SWL = 101dB(A) positioned at 437m from a dwelling. (Note: this would result in an incident noise level at a dwelling of 38dB(A) from a single wind turbine.)

For small and medium-sized wind farms, say less than 10 to 20 turbines, incident noise levels at a residence are usually only influenced by those turbines closest to the residence. However, the advent of the larger wind farms being proposed and built today means that the cumulative effect of many turbines at some distance from the residence may also increase the noise levels around a property. Greater separation distances will therefore be required to achieve the same noise levels as a smaller wind farm using the same type of turbines.

The difference in noise emissions between different types of machine, the increase in scale of turbines and wind farms seen today and topographical effects described below all dictate that separation distances of 350-400 metres cannot be relied upon to give adequate protection to neighbours of wind farms.

Annex 3

Appendix 2

Relevant statements in PPS 18, the Best Practice Guide (BPG) and the Supplementary Planning Guidance (SPG). The most relevant statements have been underlined.

> PPS 18, 4.23. "Micro-generation is widely accepted to be the production of heat (less than 45 kW capacity) and/or electricity (less than 50kW capacity) from low or zero carbon energy sources…"

BPG, 1.1.1 "This section describes the technology of wind turbines in relation to current turbine sizes (600kW-3MW) that are expected to comprise the bulk of the UK's onshore wind generated electricity provision. In most respects this information will be equally valid for both smaller wind turbines, more suited to locations with higher population densities, and the larger machines that will be developed in the coming years…"

BPG, 1.2.5 The blades are usually of a glass-fibre reinforced plastic construction. Other materials used include wood-epoxy laminates and carbon fibres. These may both become more prevalent as current wind turbine designs are scaled up. They are generally the largest single item that is transported to a wind farm during construction. Smaller turbines (less than 50kW) may use blades made of a variety of other materials such as plastics, metal or wood.

BPG, 1.2.8 "The nacelle is mounted on the tower, which for large grid-connected turbines is normally of a tubular steel construction. Smaller turbines (less than 50kW) may be mounted on similarly designed towers, but may equally use lattice or guyed towers. Turbines designed specifically for micro-generation may be mounted directly onto existing structures, such as roofs."

BPG, 1.2.12 "Wind turbines can be deployed singly, in small clusters, or in larger groups known as wind farms…"

BPG, 1.3.1 "While the Department is reviewing permitted development for small scale renewable energy development for both domestic and non-domestic premises, all development involving wind turbines currently requires planning permission under the Planning (Northern Ireland) (Order) 1991."

BPG, 1.3.25 "Turbines in wind farms will normally be tall, frequently located in open land, and therefore will often be highly visible. Domestic turbines will be smaller (generally less than 15m)…"

BPG, 1.3.52 For wind farm developments the best practice separation distance of 10 times rotor diameter to occupied property should comfortably satisfy safety requirements. For a smaller individual wind turbine, for example on a farm enterprise, the fall over distance (i.e. the height of the turbine to the tip of the blade) plus 10% is often used as a safe separation distance.

BPG, 1.3.76 Problems caused by shadow flicker are rare. At distances greater than 10 rotor diameters from a turbine, the potential for shadow flicker is very low…

BPG, 1.4.4 "Wind turbines fall within descriptions of development listed under Schedule 2, category 3(j) to the EIA Regulations. The Department of the Environment is required to screen applications for the need for EIA where the development involves the installation of more than 2 turbines or the hub height of any turbine or height of any other structure exceeds 15 metres."

SPG, 'Functional relationships between single turbines and their landscape settings should be reflected in turbine siting. Ideally turbines should be closely associated with, and in scale with, the farms, settlements or industrial plant that they serve.'

Annex 3

Single Turbine Policy Considerations relating to Separation Distances

Under Policy RE 1 of Planning Policy Statement 18 'Renewable Energy' (PPS 18), a minimum separation distance is prescribed:

> *"For wind farm development a separation distance of 10 times rotor diameter to occupied property, with a minimum distance not less than 500m, will generally apply."*

This is repeated word for word in SPPS 6.227 and is the authority to which planners appeal for the exclusion of single wind turbines from its application.

Whilst not accepting the adequacy of this separation distance, we show that:

1. PPS 18 and the supporting Best Practice Guidance use the terms "wind farm" and "wind farm development" to refer to all wind energy developments, with the exception of smaller single turbines. The terms are also used pragmatically where the context requires, as a designation for a group of turbines.

   It follows from the general usage throughout the PPS18 Suite that the minimum separation distance in Policy RE1 applies to all wind energy developments, including smaller single turbines initially considered for Permitted Development.

   There is no legal basis to alter the meaning of the clause in Policy RE1 that sets out the minimum separation distance requirement without due process (which has not occurred).

2. In legislation contained within the EIA Regulations 1999, 2012 and 2017, 'Installations for the harnessing of wind power for energy production', including single turbines where the hub height exceeds 15 metres, are given the specific title "wind farms". A legislative definition such as this, particularly as applying to environmental impacts, always takes precedence over departmental guidance and ministerial statements on the same subject.

3. The DoE's commentary on the consultation responses to the draft PPS18 and written post-publication clarification from the DoE of separation distances for individual turbines in PPS18 confirm the policy was written to encapsulate a general separation distance on amenity grounds and that the recommended minimum separation distance should be applied as a general rule to applications for wind energy development and not only to wind farms.

4. The minimum separation distance to be applied to all turbines is based on calculations for a single turbine as the exemplar. That the derived separation distance should then be held not to apply to the exemplar itself is untenable.

5. The specific definition for smaller single turbines helps to define what constitutes a wind farm development.

6. The 'fall-over plus 10%' safety margin does not apply to any turbines larger than 15 metres in height and was not the product of practical research or experimental fieldwork.

7. PPS 18 and its associated documents do not specifically state that the 500 metre minimum separation distance does not apply to single turbines.

8. It is a logical fallacy to claim that a wind farm created incrementally in a series of steps is not subject to the minimum separation distance, even though it may be identical in every way to another created in one step. Any claim that when turbines with individual planning applications accumulate, this is not a wind farm at all, but instead 'for operational reasons' a new phenomenon – a grouping of single turbines - cannot be substantiated. Otherwise the policy is intended to promote evasion of its own guidance by permitting 'Wind farms by stealth'.

This leads to the inescapable conclusion that for any wind turbine (including those under 50Kw and under 15m in height), PPS 18 and the SPPS generally require a minimum separation distance to occupied property of not less than 500metres, or 10 times the rotor diameter, whichever is the greater.

1. **It follows from the general usage throughout the PPS18 Suite that the minimum separation distance in Policy RE1 applies to all wind energy developments. Whilst it was originally intended to exclude smaller single turbines from this policy, the proposal to introduce Permitted Development for this group was dropped after consultation.[1]**

Policy RE1 and the SPPS

PPS 18 and its supporting guidance including ETSU-R-97 (the "PPS18 Suite") use the words "wind farm" and "wind farm development" as general terms referring to all wind energy developments, with the exception of smaller single turbines[2]. The terms are also used [pragmatically] where the context requires, as a designation for a group of turbines. However, the wider meaning that includes single turbines must be taken to apply generally throughout the PPS18 Suite since otherwise it is silent on many important issues in respect of single turbines where it has been applied up until now.

Consequently, as the context of the separation distance requirement in Policy RE1 does not require the term 'wind farm development' to refer to a group of turbines, it follows from the general usage throughout the PPS18 Suite that the minimum separation distance applies to all wind energy developments, including smaller single turbines[3] originally proposed for permitted development.

[1] Smaller single turbines defined as not exceeding 50kW and 15m height.
[2] Smaller single turbines defined as not exceeding 50kW and 15m height.
[3] Smaller single turbines defined as not exceeding 50kW and 15m height.

The minimum separation requirement in SPPS 6.227 is a simple reproduction of the requirement in Policy RE1 of PPS18. The SPPS introduces a definition of a wind farm as *"development comprising more than 2 turbines"* in a footnote to 6.222. However, to take "wind farm development" in SPPS 6.227 as also equivalent to the development of a 'wind farm' as defined in the SPPS footnote (i.e. *"development comprising more than 2 turbines")* would be to alter the meaning of the clause in Policy RE1 that sets out the minimum separation distance requirement. There is no legal basis for any such alteration without due process, including a proper consultation procedure and an assessment of the impact of the original policy. None of this has occurred, nor could any subsequent change be applied retrospectively before September 2015. Further, as will be seen in 2. Below, there is no legislative authority for the change.

Thus the SPPS does not say that its definition of a wind farm carries through to the PPS18 Suite and nor does it define "wind farm development". To seek to apply the SPPS definition generally in the PPS18 suite would render it materially deficient as above.

Most issues in the PPS18 Suite are equally applicable to single turbines
The Best Practice Guide (BPG) repeatedly makes reference to the minimum separation distance apparently to reassure the reader or justify a conclusion (Noise 1.3.43; Safety 1.3.52; Shadow Flicker 1.3.76). These issues apply equally to single turbines and to turbines located in groups. Noise, reflection, flicker etc. and flying debris and ice from a turbine will not avoid becoming a dangerous nuisance to nearby residents simply because a turbine stands alone. Indeed, the single turbine could be very significantly larger than, and by virtue of being alone, very significantly closer to, a home than a turbine in a wind farm.

Therefore, since a turbine is not made any less safe by virtue of being part of a group, the minimum separation distance as stated above must be applicable irrespective of turbine numbers.

The PPS18 Suite and the SPPS must be the sole determinants of minimum separation distances
Planners often claim the freedom to categorise certain wind energy applications in such a manner as will result in their being removed from the protection of a minimum separation distance.

Where does such authority come from? In order to find out, a Freedom of Information request was made to the Department of the Environment (NI) on 25 June 2014 asking for, '...all information, including directives, instructions, interpretations, operational guidance and training materials, on the applicability of the minimum separation distance of 500 metres to wind farms and single wind turbines'.

In its reply dated 3 July 2014, the Department stated that:

> *"At this time, the Department has no further material to provide you. Policy, legislation and directives are available to the general public electronically at the planning portal, available at http://www.planningni.gov.uk/."*

If this link is followed, it reveals that all policies relating to the applicability of the minimum separation distance of 500 metres to wind farms and single wind turbines are the PPS 18 suite of three documents – PPS 18 itself, it's Best Practice Guide (BPG) and the Supplementary Planning Guidance (SPG), also known as the Landscape Character Assessment. The SPPS must also now be taken into account.

The Information Commissioner stated that should any further documentation emerge later, this would form the basis of legal action against the Department. Therefore the basis for determining when this minimum distance of 500 metres should be applied must rest on the three documents identified plus the SPPS. We will see, however, that several others available to the Department, will aid this process.

It is a common practice amongst planners to treat the guidance in PPS 18 and its associated documents, as somehow optional. However, the Planning function, whether undertaken by central or local government, falls under the jurisdiction of the Office of the Northern Ireland Ombudsman and it is therefore bound by the Parliamentary Ombudsman's Principles of Good Administration.

It is a concern that the PPS 18 suite of guidance is frequently treated in a cavalier fashion and that by simply using a non-defined term such as 'operational purposes', the planning guidance on separation distances has been regularly set aside without a reasonable or adequate explanation or evidence of an improved decision, as required in the Ombudsman's Principles of Good Administration.

2. The legislative definition of a wind farm

BPG 1.4.4 states that wind turbines fall within descriptions of development listed under Schedule 2, category 3(j) to the EIA Regulations. The Department of the Environment is required to screen applications for the need for EIA where the development involves the installation of more than 2 turbines or the hub height of any turbine or height of any other structure exceeds 15 metres

Although this description in the BPG 1.4.4 of the legislation is an accurate transcription of part of the legislative text, it is also incomplete in such a manner as to alter the overall meaning of that text. It fails to acknowledge that the legislation is defining a wind farm and is not merely stating a specific requirement.

The 1999, 2012 and more recent 2017 legislation all give the following definition in Schedule 2, 3 (j):

Installations for the harnessing of wind power for energy production (wind farms).

(i) *the development involves the installation of more than 2 turbines; or*

(ii) *The hub height of any turbine or height of any other structure exceeds 15 metres.*

Thus *'Installations for the harnessing of wind power for energy production'*, including single turbines where the hub height exceeds 15 metres, are given a specific title: (wind farms). The inclusion of parentheses shows that the added remark provides an explanation or extra information that is separate from the main part of the sentence.

Once again we see a reference to a height of 15 metres as being somehow different from taller turbines. It is to these smaller turbines that consideration was being given for permitted development rights.

A legislative definition such as this, particularly as applying to environmental impacts, creates the framework within which departmental guidance and ministerial statements must operate and is superior to both. It must be applied in its entirety in the appropriate circumstances, which in this case is the obvious relationship between separation distances and environmental impacts. It is noteworthy that this definition has governed unchanged since before the introduction of PPS 18 in 2009, has continued through the introduction of the SPPS in 2015 and remains in force today. There is therefore no legislative authority for the introduction of the footnote to 6.222. In the SPPS attempting to redefine a wind farm as being solely *"development comprising more than 2 turbines". The result* would be to alter the meaning of the clause in Policy RE1 that sets out the minimum separation distance requirement.

3. Commentary on consultation responses to draft PPS18 and post-publication clarification of separation distance for individual turbines.

In the 'SUMMARY OF CONSULTATION RESPONSES' to the draft version of PPS 18, it is stated as follows, noting particularly the department's response:

> "30 Some respondents felt it would be desirable for a minimum separation distance between wind energy development and dwellings. It was considered that this would provide assistance to renewable energy developers in identifying potentially suitable sites for wind energy development proposals as well as providing more certainty to the public."
>
> "Response:
> In response to points raised through the public consultation, the Department has decided to amend the policy text to include reference to a recommended separation distance that should be applied as a general rule to applications for wind energy development. The distance is expressed as 10 times the rotor diameter or a minimum distance of 500 metres to occupied property."

Note in particular that this minimum is to be applied '…as a general rule to applications for wind energy development', and not only to wind farms.

Dr Dan Kane met with Edwin Poots, then minister of the Environment on 26 October 2009. At that meeting the minister undertook to provide the evidence underpinning the statements in PPS 18 that a separation distance of either 500 metres or 10 times the rotor diameter, would resolve all problems of noise, shadow-flicker and safety relating to wind turbine construction and operation.

As a result the e-mail below was received from Stephen Hamilton, one of the authors of PPS 18. It is reproduced below in its entirety and without correction:

14 May 2010

"Dear Mr. Kane

Following on from your email below, I would like to clarify the position on the introduction of a minimum of 500m separation distance that was not expressed in policy terms in the consultation draft.

The success or not of any renewable energy development depends on a number of factors. In general as stated in previous correspondence, such development will be permitted provided the proposal will not result in an unacceptable adverse impact on public safety, human heath, or residential amenity; specific to wind energy developments, this advice is further amplified that the development will not cause significant harm to the safety of amenity of any sensitive receptors arising from noise, shadow flicker, ice throw or reflected light.

I would like to draw your attention to the complementary Best Practice Guidance to PPS18. This guide was initially published as Annex 1 to draft PPS18 and provides guidance for other amenity considerations outside of the established ETSU noise standards applied across the whole of the UK. Paragraphs 1.3.76 and 77 of the Guidance (paragraphs A107/8 in the consultation draft) provides a separation distance to mitigate against the potential for shadow flicker. While this document is referenced in the text of policy RE1, only limited weight can be applied to this in setting a minimum standard in the protection of public safety, human health or residential amenity. Taking the comments received to the public consultation exercise from the Chief Environmental Health Officers Group (CEHOG) proposing a minimum distance of 500m on the issue of noise, the policy wording requiring a separation distance of 10 times rotor diameter separation distance not less than 500m was written to encapsulate a general separation distance on amenity grounds.

As requested, for your information I have attached an electronic copy of the CEHOG public consultation response to draft PPS18. This response was one of 90 detailed consultation responses received from a variety of organisations and personal interests, each raising issues from that organisations'/individuals' perspective. The introduction of a 10 times rotor diameter general amenity separation distance not less than 500m should only be read in the context of other policy requirements/considerations (set out above) and not by itself.

Stephen

Note particularly that '...the policy wording requiring a separation distance of 10 times rotor diameter separation distance not less than 500m was written to encapsulate a general separation distance on amenity grounds'; there is no indication of any thought of restricting the scope of the requirement.

This understanding is further confirmed in correspondence dated 18 June 2010 with Anne Lockwood, Deputy Director of the Planning and Natural Resources Division.

In her reply, Ms. Lockwood states:

'In your email, you stated "You have not revealed the origin of the "10 diameters is sufficient to prevent noise impacts". The department FEELS that this is right. Have they conducted research? Have they sought expert advice? Or is it just in their bones? Perhaps you would advise us of the basis for this intriguing assertion".

In response, I would like to refer you back to Mr Hamilton's email dated 14 May 2010. Taking on board the CEHOG comments to the PPS 18 public consultation, a minimum separation distance of 500m has been introduced to accommodate the differences in noise emissions between different types of turbine. Generally speaking, 500m is approximately the same distance as10 times rotor diameter to a turbine of 80m in height. On general amenity grounds, the 10 times rotor diameter separation distance has been introduced with particular regard to taller turbines. This increases the separation distance to sensitive receptors beyond what is required by national guidelines set out in ETSU.'

In effect, what the Chief Environmental Health Officers and Anne Lockwood are saying is that, because turbines are now bigger and noisier than those considered under the adopted noise standard of ETSU-R-97 which was written in 1996, the separation distance should be increased above the 350 to 400 m which ETSU-R-97 states is not adequate to resolve noise problems. The CEHOG recommended a minimum of 500m. Although ETSU-R-97 clearly applies also to single turbines, neither the CEHOG nor Anne Lockwood refer to any lesser distance for these. So 500 m. is the minimum separation for any turbines, either singly, in clusters or farms.

Industrial scale turbines, whether connected to the grid or not, are in nature the same as those on a wind farm, particularly in respect of the impacts visited on those living nearby. In scale they may be smaller than some turbines in a wind farm and larger than others. They do not, however, comprise a different class of industrial turbine any more than a smaller block of flats differs from a larger. A separate argument seems to have been originally anticipated for 'smaller turbines' that may be within the category considered for 'permitted development' or 'micro generation', but as will be seen below, problems identified with such turbines prevented this.

It is also clear that, irrespective of the number of turbines being considered, a minimum separation distance of 500 meters applies, and that where 10 times the rotor diameter is applied due to the size of the turbine, the separation distance cannot be less than 500 meters, but only greater than this.

4. Minimum separation distance is based on a single turbine as exemplar.

As revealed by Mr. Hamilton and Ms. Lockwood, above, the Chief Environmental Health Officers Group were the originators of the minimum separation distance of 500 metres (see Appendix 1). They in turn based their recommendation on figures found in ETSU-R-97. In this regard it is useful to record what ETSU-R-97 actually says on the matter of separation distances, and this is reproduced in full as Appendix 2.

The authors of ETSU examined the then current English standard known as PPG 22 'Renewable Energy', introduced in 1993. They noted its conclusion on experience from mainland Europe that outside distances of 350-400 metres from a wind turbine, there is unlikely to be a significant noise problem for a residential property.

However, the authors of ETSU qualified the PPG 22 finding by stating that different turbine noise emissions, increasing turbine scale and cumulative effects, and more elevated turbine locations in the UK, *'...all dictate that separation distances of 350-400 metres cannot be relied upon to give adequate protection to neighbours of wind farms.'* (ETSU-R-97, page 46)

Note that PPG 22 was published in 1993, yet by 1996 the authors of ETSU were stating that the increase in scale of turbines and wind farms 'seen today' meant that the separation distances in PPG 22 were already obsolete. Another 20 years have elapsed since the writing of ETSU-R-97, which was based on a maximum hub height of 32 meters, and it's applicability to today's turbines with hub heights of up to 140 metres is distinctly questionable.

The authors of ETSU then proceeded to use the example of a single turbine to demonstrate the ineffectiveness of the PPG 22 separation distance of 350 to 400 metres.

They calculated that what they termed a 'quiet' wind turbine with an emitted sound power level (SWL) = 95dB(A) positioned at 245m from a dwelling would have the same acoustic impact as a turbine with a SWL = 101dB(A) positioned at 437m from a dwelling.

However, it was then noted that this would '...result in an incident noise level at a dwelling of 38dB(A) from a single wind turbine.' This is important since ETSU-R-97 itself recommends when using its simplified assessment methodology, a noise limit of 35 dB(A).

How can a separation distance be based on calculations for a single turbine as the exemplar, and that separation distance then be held not to apply to the exemplar itself? Such a position is clearly untenable.

It is crucial to recognise that, based on the failure of a single turbine to meet their own minimum noise standard, the authors of ETSU concluded, '...greater separation distances will therefore be required to achieve the same noise levels as a smaller wind farm using the same type of turbines.' In other words, 437 metres was not enough to reduce the noise level to an acceptable level (in ETSU terms) even for one single turbine, and that therefore for several such turbines, an even greater separation distance would be required.

This theme continues. The Chief Environmental Health Officers Group recommended a minimum of 500 metres since turbines are now bigger and noisier than those considered under ETSU-R-97 and the 350 to 400 metres was already inadequate to resolve noise problems, even from a single turbine. Neither the CEHOG nor Mr. Hamilton or Ms. Lockwood refer to any lesser distance for single turbines. However, none of the individuals involved seem to have been aware that the authors of ETSU had already proposed an increase to 700 metres in 2004.

5. Specific definition for smaller single turbines helps to define a wind farm development;

Throughout PPS 18 and its suite of supplementary guidance, the use of terms such as microgeneration, smaller wind turbines, small clusters and larger groupings which they refer to as wind farms, should be noted. No specific definition section is included, so it is necessary to trawl through PPS 18, the Best Practice Guide (BPG) and the Supplementary Planning Guidance (SPG) for statements to aid identification. The statements considered are set out in Appendix 3 to this document.

By this method, it is possible to derive a number of useful definitions.

A. Micro-generation and 'smaller' turbines

PPS 18, 4.23, states that micro-generation is widely accepted to be the production of heat (less than 45 kW capacity) and/or electricity (less than 50kW capacity. When the BPG, 1.2.5 describes the blades of a wind turbine, it informs us that smaller turbines are those less than 50kW, and this is confirmed when describing turbine towers in 1.2.8, *"Smaller turbines (less than 50kW)".* Note, it does not say 'smaller turbines of less than 50kW. The sense of the statements is that smaller turbines are those that are less than 50kW.

B. Single turbine siting and scale

In describing wind turbines technology in relation to current turbine sizes, BPG, 1.1.1 states that the information generally had equal validity for smaller wind turbines, which are those more suited to locations with higher population densities. When discussing safety issues, BPG, 1.3.52 refers to '...a smaller individual wind turbine, for example on a farm enterprise...'. This theme is continued in BPG, 1.3.25 where, in contrast to turbines in wind farms termed 'highly visible', Domestic turbines will be smaller (generally less than 15m)..."

Finally, the SPG notes that ideally single turbines should be closely associated with, and in scale with, the farms, settlements or industrial plant that they serve.'

A two-storey building is usually between eight and nine metres to the ridgeline and an agricultural building has a maximum allowed permitted development height of 12 metres, so that even a 15 metre turbine is stretching the limits of such scaling. However, many current single turbine applications relate to turbines of up to 125 metres in height, a situation which could in no circumstances be termed '...in scale with the farm...'.

C. Clarification from proposed permitted development

It is important to understand that whilst BPG, 1.3.1 notes that, '...all development involving wind turbines currently requires planning permission', it also states at BPG, 1.3.1, that permitted development for certain sizes of wind turbines was being considered at the same time as the draft of PPS 18.

A 'Review of Permitted Development Rights for Non-domestic Small Scale Renewable Energy Development Policy Consideration', reported back in September 2009. Despite recommending that no permitted development be agreed for both Building-mounted or free standing wind turbines Until "...issues of noise, vibration, health and aircraft safety and other critical communications systems are resolved", if these could be agreed satisfactorily it was recommended that the following restrictions be applied to permitted development:

For building-mounted turbines, a maximum height to blade tip of 3 m. above the highest part of the roof. For free standing turbines, a maximum height to blade tip of 15 m.

Although permitted development rights were not introduced, we can again see the differentiation of turbines of a particular height. Taking into account the maximum agricultural building height of 12 metres, Both building-mounted or free standing turbines are restricted to no more than 15 metres in height.

D. Conclusion on 'smaller turbines'

A clear picture is emerging here of what a smaller turbine is, and this will go far to help in defining separation distances.

- Micro-generation is the production of electricity less than 50 kW capacity;
- Smaller turbines are those less than 50 kW capacity.
- Smaller turbines are those less than 15 metres to blade tip;
- Smaller turbines were considered for 'permitted development' rights.

6. The 'fall-over plus 10%' safety margin does not apply to turbines more than 15 metres in height and was not based on practical evidence;

First, it is necessary to remove one particularly prevalent misconception.

In the BPG, 1.3.52, we read as follows:

> *"For wind farm developments the best practice separation distance of 10 times rotor diameter to occupied property should comfortably satisfy safety requirements. For a smaller individual wind turbine, for example on a farm enterprise, the fall over distance (i.e. the height of the turbine to the tip of the blade) plus 10% is often used as a safe separation distance."*

The following quotation is from the review of Permitted Development Rights for Non-Domestic Small Scale Renewable Energy Development (page 81), and explains the origin of 'fall-over plus 10%' as a separation distance, frequently substituted for the minimum of 500 metres for single turbines.

> *"Although we believe that the wind industry generally has a good safety record we recognise that there will be people who will be concerned that wind turbines erected under permitted development could be dangerous for neighbours and passers by. Following consultation on domestic microgeneration, the Planning Service is considering recommending that free standing wind turbines should not be permitted where any part of the wind turbine is nearer to the neighbouring curtilage or any road than a distance equal to the total height of the turbine.*
>
> *We are in general agreement with this condition in order to protect public safety however we recommend that this should be slightly increased such that a turbine must be at least topple distance from a road or boundary, i.e. the total height of the wind turbine to the blade tip plus a 10% safety margin.*
>
> *At a stakeholder workshop, almost half of respondents agreed that permitted development rights should be limited to a topple distance (total height of turbine plus 10%). As this could prove complex to enforce if it is difficult to measure the height of a turbine to the blade tip, we recommend that the limit is given a simple numeric value that can be measured on the ground.*
>
> *If our recommendation regarding total height of 15m is accepted this would result in a turbine erected under permitted development rights being at least 16.5m from a road or boundary. For simplicity, we recommend that this minimum is rounded up to 17m."*

Therefore, if we combine the results of Section 5, above, and 'the review of Permitted Development…' in this section, we can draw the firm conclusion that the term 'smaller turbines' applies to those with less than 50kW capacity and with a height to blade tip of up to 15 meters. We can also conclude that this was the group to which the 'fall-over plus 10%' safety margin applied.

It is important to recognise that the fall-over plus 10%' does not apply to any turbines larger than 15 metres. Indeed, it is a concern that this separation distance on safety grounds was not the product of practical research or experimental fieldwork. It was arrived at, as noted in the quotation above, at a stakeholder workshop and one in which a minority of respondents agreed with the proposed separation distance.

The scale of turbine now being erected on farms and industrial premises are, in many cases, the same as, or larger, than those on some wind farms. There is no evidence that because a turbine stands either alone or in a pair that it somehow becomes safer than the identical turbine standing in a wind farm of three or more turbines. Yet significantly smaller separation distances are being applied by planners to single but larger turbines than to their smaller brethren in some wind farms.

There is no evidence to support the contention that fall over plus 10% will protect anyone from a collapsing or fragmenting turbine of any size, but particularly if it is over 15 metres in height. There has been a complete misapplication of the planning guidance in this area.

7. PPS 18 and its associated documents do not specifically state that the 500 metre minimum separation distance does not apply to single turbines.

The Department have not quoted any part of PPS 18 in support of the assertion that there is a differentiation between a single turbine and a wind farm. It resorts instead to the use of non-defined terms absent from both PPS 18 and the SPPS, such as 'operational purposes', to support differential treatment. This is an untenable position.

8. Wind farms by stealth or a logical fallacy?

As noted previously, the Department regards a planning application for more than two wind turbines to constitute a wind farm, and apply the minimum separation distance. However, by incrementally adding single turbines to an initial approval, this restriction is bypassed and a wind farm can be created within 500 metres of a dwelling. It is therefore logical to ask that when a third turbine, no matter who owns it, is added in the vicinity of two others, will all three be subject to the 500 metre minimum separation distance? If such relocation is not envisaged then one of two situations must pertain:

Either irresponsible wind farm applications will be encouraged, since a developer will be rewarded for introducing his wind farm 'incrementally' to evade the minimum separation distance.

Or the situation is not actually envisage ever to occur since the minimum separation distance was always seen as being applicable to all turbines and will prevent it.

For example, there is no guidance given on any requirement that the turbines constituting a wind farm should have only a single owner or be erected at the same time or be of the same make and model in order to fulfil that label. It is a fallacy promoted by some planners in an endeavour to evade the force of the above argument, to claim that when three or more turbines with individual planning applications accumulate, this is not a wind farm at all, but instead a new phenomena – a grouping of single turbines. These turbines could be the same model, height and distance from each other and cover the same area, as in a regular wind farm, indeed the two installations could be identical in every way. But because one is created incrementally in a series of steps, it is held that the minimum separation distance does not apply. This is both counter-intuitive and disingenuous, and an attempt to evade the implications of the planners departing from their own policy guidance.

9. Conclusion

It is a fallacy that there is a direct correlation between the rotor diameter of a wind turbine and the noise level produced, as can be demonstrated by comparing different makes of turbine with the same blade architecture. Indeed, as has been demonstrated above, the use of this metric is based on shadow flicker and not noise and this itself is based on a misreading of the original research, discussed elsewhere.

The inclusion of a minimum separation distance of 500 meters, which has been demonstrated elsewhere to be totally inadequate, is therefore even more important as a means of reducing impacts and, as stated by Mr. Hamilton above, was written to encapsulate a general separation distance on amenity grounds. By excluding single turbines from this definition, this protection, no matter how inadequate, has been removed and has placed hundreds of single turbines much closer to sensitive receptors than was ever envisaged in the original policy.

But not only have residents been exposed to significantly higher levels of impact than intended in the original document. Another effect is to frustrate any attempted recourse through either planners or Environmental Health Officers due to their continued adherence to a faulty interpretation of entitlement to protection under the minimum separation distances. It is contended that this document demonstrates that all wind turbines have an entitlement to that protection. This includes those under 15 meters in height since it was recommended that no permitted development be agreed until, "…issues of noise, vibration, health and aircraft safety and other critical communications systems are resolved", which they have never been.

Daniel Kane (Dr.)

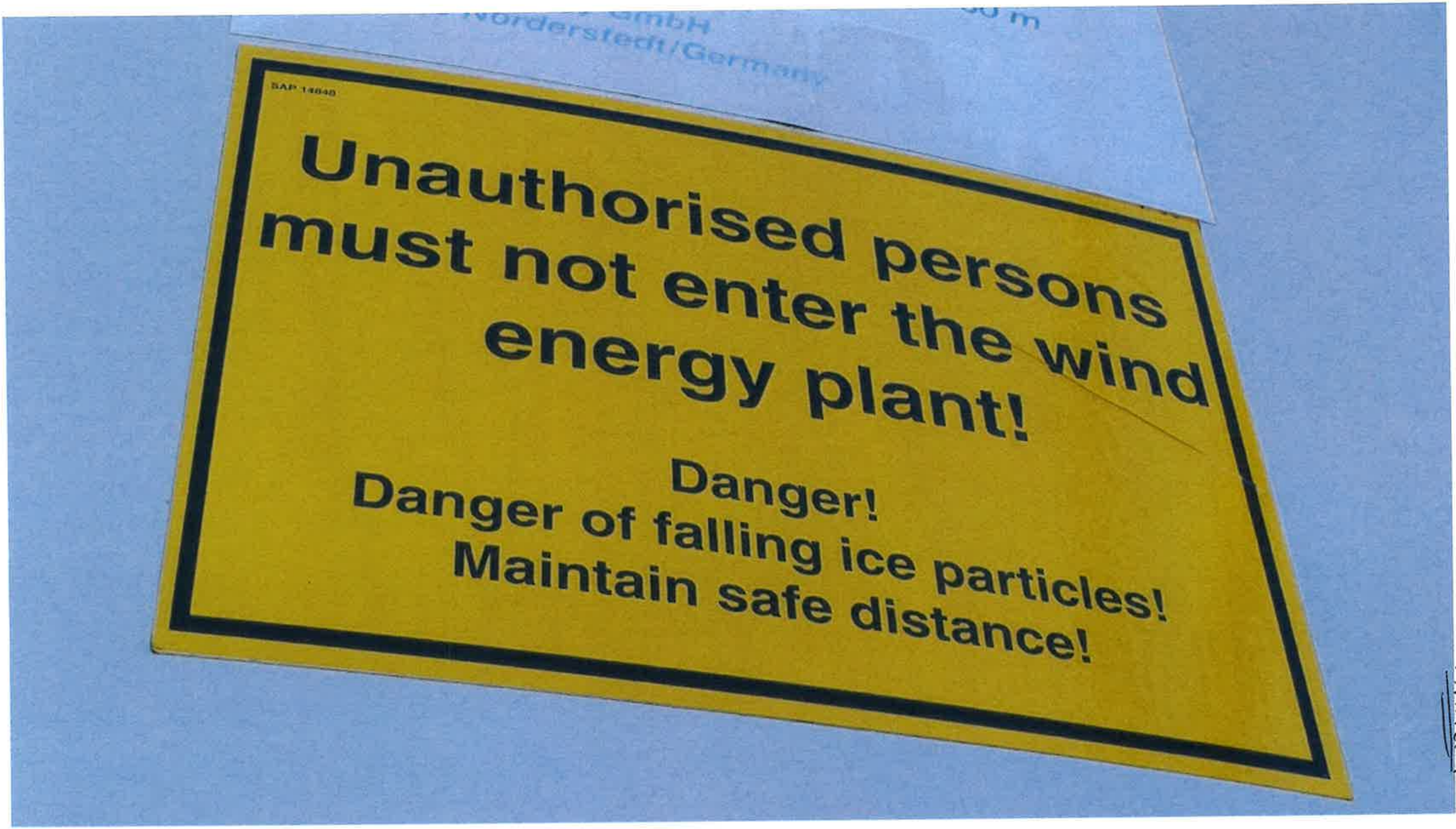
17 September 2019

ANNEX 4

Annex 4


VISITORS WEATHER WARNING
ICING
During wet and freezing conditions there is a risk that ice can form on the blades of the wind turbines.
Please DO NOT ENTER the windfarm in these conditions
LIGHTNING
Please DO NOT ENTER the windfarm during lightning conditions.
If a lightning storm starts during your visit please leave the site IMMEDIATELY
If you require assistance please call 07699 391794
THANK YOU FOR YOUR COOPERATION
19

Annex 6


Norderstedt/Germany
Unauthorised persons must not enter the wind energy plant!
Danger!
Danger of falling ice particles!
Maintain safe distance!

Annex 4

Annex

Annex 4

Telegraph.co.uk

Monday 04 June 2012

1,500 accidents and incidents on UK wind farms

The wind energy industry has admitted that 1,500 accidents and other incidents have taken place on wind farms over the past five years.

The scale of incidents is equivalent to almost one a day Photo: GETTY

By Edward Malnick and Robert Mendick

8:15AM GMT 11 Dec 2011

CommentsComments

The figures – released by RenewableUK, the industry's trade body – include four deaths and a further 300 injuries to workers.

The scale of incidents – equivalent to almost one a day – emerges following the publication of dramatic photographs showing one turbine which had crashed to the ground in a field near a road and another exploding into flames, caused by 150mph winds which buffeted Scotland and northern England last week.

Charles Anglin, RenewableUK's director of communications, stressed that last week's incidents were caused by "freak weather". The organisation said that no member of the public had ever been hurt as a result of a wind turbine accident.

A dossier of incidents, compiled by a campaign group opposed to wind farms, includes cases where blades, each weighing as much as 14 tonnes, have sheared off and crashed to the ground.

Residents living near a wind farm have reported sheltering in their homes when lumps of ice were thrown from blades from a 410-ft high turbine near Peterborough, Cambridgeshire.

Related Articles

- Wind industry's extensive lobbying to preserve subsidies and defeat local resistance to turbines

  11 Feb 2012

- Gales wreck wind turbines

  09 Dec 2011

- Storms batter Britain

08 Dec 2011

- Fierce 'weather bomb' with gale-force winds hits UK

09 Dec 2011

One manufacturer of wind turbines admitted one of its models had a defect – understood to be caused by a faulty braking system that meant the blades could fly off – that led to hundreds of turbines being ordered to be shut down in September by the Health and Safety Executive.

The company, Proven Energy Ltd, based in Scotland, went into receivership shortly after.

Blades attached to smaller domestic wind turbines have also become detached and hit buildings – in one case penetrating the roof of a cabin used as an office.

Campaigners claim that the incidents show that "some parts of the country are too windy for turbines". Most turbines automatically shut down when the wind speed rises above 56mph because at that speed they can become unsafe.

In September a blade flew off a wind turbine on the roof of a new car park at Lister hospital in Stevenage, Hertfordshire, hitting a staff member's car.

Last year a 140-turbine wind farm near Glasgow was temporarily shut down after a 14-tonne fibreglass blade broke off in windy conditions and landed at the base of its tower.

Two years ago, a 50ft turbine collapsed in the playground of a school on the Island of Raasay off the coast of Scotland, and in the same year a blade on a 190 ft wind turbine in Rotherham owned by Sheffield University broke in strong winds, prompting an investigation by its manufacturers.

The incidents were compiled by the Caithness Wind Farm Information Forum, which campaigns against turbines in Scotland and publishes accidents - backed up by media reports - on its website.

RenewableUK said the deaths had been recorded in 2009 and 2010.

One involved a maintenance worker in Scotland who had become 'tangled' with the driveshaft of a turbine while the other three deaths took place during construction of onshore and offshore wind farms.

Chris Streatfeild, RenewableUK's director of health and safety, said: "No members of the public have ever been injured or harmed in the reports we have received.

"The risk to the public is one in 100 million. You are much more likely to be injured by a lightening strike than by a wind turbine."

Mr Streatfeild said RenewableUK had recorded 1,500 incidents over the past five years, many of which were very minor. Of those, about 18 per cent - or close to 300 incidents - led to an injury, again usually very minor.

He said planning and safety rules meant turbines were always at a certain minimum distance from roads and homes, reducing further the risk to the public. He said the number of fires and structural collapse each amounted to just a 'handful'.

Mr Anglin said last week that wind farms had an "excellent health and safety record", adding: "In stressful situations any power equipment may develop faults, and that's true of gas, nuclear, oil, and is also true of wind."

The Health and Safety Executive (HSE) said last week it was "extremely difficult" to assemble a "complete picture of reported incidents at wind farms" because accidents are not recorded by industry type.

The HSE said its figures showed three fatal accidents between 2007/08 and 2009/10 and a total of 53 major or dangerous incidents in the same time frame.

An HSE spokesman said wind turbines were classed as machines rather than buildings or structures and that there was no obligation to report mechanical failures.

Angela Kelly, chairman of the Country Guardian, a national network of anti-wind farm campaigns, said: “We have been aware of accidents on wind farms for years but the new figures released by the industry’s own trade body are particularly alarming.

“Developers seem to have ignored the fact that some parts of the country are too windy for turbines.”

-

UK News

- News »
- Science »
- Earth »
- Robert Mendick »

Elsewhere

60 years of the Queen

Happy and glorious, the river Queen

In UK News

Queen's Diamond Jubilee: 60 years in 60 photographs

Annex 4

Windpower Monthly

Annual blade failures estimated at around 3,800

14 May 2015 by Shaun Campbell , 5 comments

WORLDWIDE: Wind turbine rotor blades are failing at a rate of around 3,800 a year, 0.54% of the 700,000 or so blades that are in operation worldwide.

Siemens was forced to curtail 700 turbines worldwide after a B53 failure

The figures, from research carried out by renewable energy undewriter GCube, were delivered by Andrew Bellamy, former head of Areva's 8MW blade programme, in his opening address to Windpower Monthly's blade manufacturing and composites conference in London on 12 May.

Bellamy, co-founder of renewables advisory firm Aarufield, pointed out that blade failures are the primary cause of insurance claims in the US onshore market. They account for over 40% of claims, ahead of gearboxes (35%) and generators (10%).

The wind industry also faces a struggle to secure the carbon fibre materials it needs for lighter and stronger blade designs, warned Bellamy.

"There's growing competition for these materials from the automotive and aerospace industries," he said. "And they are willing, and able, to pay more than we are."

Recent examples of blade failures include a blade from a Vestas V90 3MW turbine that snapped on a wind farm in the north of Denmark last year. At the time, Vestas said the winds were not particularly high.

In another case last year, GE was forced to replace 33 blade on its turbines at a Michigan wind farm after a blade broke on the project.

GE put the failure down to a "spar cap anomaly". It was the second such incident involving the 1.6-100 model, and was followed by a third at the 94MW Orangeville wind farm in New York State, also in November.

Possibly the biggest blade issue was faced by Siemens in 2013 when it was forced to curtail around 700 turbines worldwide. This was caused by a bonding failure in its B53 blade.

Annex 4

Annex4

Menu

REPORT LINKS WIND TURBINES TO HUMAN HEALTH PROBLEMS

FEBRUARY 19, 2018
By Bonner R. Cohen

For full study click here.

A recent report by GateHouse Media examines the health-related problems reported by residents and landowners from Oregon to Massachusetts and concludes they are caused by wind turbines.

The rapid expansion of wind power facilities in the United States, driven in large part by federal government subsidies and state renewable-energy mandates, has been accompanied by a spreading rash of health complaints from people living near the giant, spinning turbines.

A recent report *by GateHouse Media* examines reports of health-related problems by residents and landowners from Oregon to Massachusetts and concludes they are caused by the turbines.

The report, "In the Shadow of Wind Farms," is an in-depth investigation of the wind industry's effect on predominantly rural communities where turbines have been erected. During the course of the six-month investigation, the authors interviewed more than 70 families living near three-dozen proposed or current wind installations. They also spoke with 10 state and local lawmakers, examined hundreds of pages of public-service-commission records about wind-energy projects, reviewed court filings in seven wind-related lawsuits, and inspected lease agreements for at least eight wind facilities on private land.

The authors also combed public documents and media reports to identify 400 families living near industrial wind installations who have publicly complained about shadow flicker, noise, health problems, and misleading statements by wind companies soliciting agreements to place turbines on private land.

Rapidly Growing, Wealthy Industry

Citing figures from the Energy Information Administration, the report notes wind power has experienced dramatic growth in the United States over the past decade, with the number of wind facilities growing from 300 with 15,000 turbines to more than 1,000 installations in 41 states comprising some 53,000 turbines.

Although the first wind facilities were located in sparsely populated areas such as California's Mojave Desert, today thousands of turbines can be found in every region of the country, except for the Southeast, where unfavorable wind conditions and a lack of state renewable-energy mandates (save for North Carolina) have limited the growth of the industry.

In favorable locations, wind companies have offered communities various incentives to accept their projects, in addition to the tax revenues generated by these multimillion-dollar installations.

Benefits with Strings Attached

Some communities receive fixed annual payments instead of tax revenues. In one case cited in the report, Barber County, Kansas gets $500,000 a year from the Flat Ridge Wind Project, plus an additional $5,000 for every megawatt of power the project produces.

Wind-energy companies, often working with local utilities, request landowners' permission to put turbines on their land. Landowners who sign contracts with wind companies can receive as much as $14,000 a year per turbine, according to the report.

The contracts often lead to conflicts. The *GateHouse Media* investigation found companies convince landowners to sign away their property rights for generations based on the promise of potential profits with minimal potential problems from wind turbines. The contracts typically do not allow property owners to terminate the agreements, even if they are seeking relief from what they say are intolerable living conditions caused by the turbines.

Complaints About Health Effects

By far the greatest source of conflict between landowners and wind companies is complaints about the health effects the spinning turbines have on those exposed to them on a daily basis.

Complaints come from landowners with turbines on their property and from their neighbors, the investigation found. The most frequently cited problems include shadow flicker, loud noises, sleep disturbance, and low-frequency vibrations that have driven dozens of families from their homes.

In rural Mason County, Michigan, for example, Cary and Karen Shineldecker say they suffered anxiety, headaches, ear pressure, tinnitus, heart palpitations, and sleep disturbances after Lake Winds Energy began operating its 476-foot-tall turbines around their home. After unsuccessfully fighting the wind farm, they sold their property at a loss just to escape the nuisance.

A chorus of similar complaints about the Shirley Wind Farm in Brown County, Wisconsin prompted the local Board of Health to declare the turbines a health hazard. Dozens of residents of Falmouth, Massachusetts complained of nausea, dizziness, migraines, and anxiety after Notus Clean Energy erected a wind turbine in their community. In Calhan, Colorado, four families told investigators they left their homes and moved away to escape the Golden West Wind Energy Center. Hundreds of people nationwide have filed similar complaints.

Although the wind industry generally denies wind turbines harm the health of those living near them, *GateHouse Media* found wind companies have entered into six settlements with parties complaining of ailments associated with the turbines.

Variety of Complaints

Jay Lehr, Ph.D., science director for The Heartland Institute, which publishes *Environment & Climate News*, says wind farms cause health problems and raise energy costs.

"It's about time the formidable health impacts of wind turbines came to the fore," said Lehr. "In addition to the health risks, wind power is 100 percent dependent on fossil fuels for backup when the wind doesn't blow, increasing their costs.

"As a result of wind power's wider use in Europe, people there pay three times as much for electricity as do Americans," Lehr said.

Craig Rucker, executive director of the Committee for a Constructive Tomorrow, says wind farms have also been linked to wildlife deaths.

"We have long known wind turbines kill hundreds of thousands of birds and bats annually," said Rucker. "Now we have growing evidence that humans, too, are at risk from these installations, yet we continue to subsidize this nonsense."

Bonner R. Cohen, Ph.D. (**bcohen@nationalcenter.org**) *is a senior fellow at the National Center for Public Policy Research.*

INTERNET INFO

Emily Le Coz and Lucille Sherman, "In the Shadow of Wind Farms," Gate House Media, December 13, 2017: http://gatehousenews.com/windfarms/home/?skipintro=true

ARTICLE TAGS

ENERGY HEALTH CARE

SUB-TOPIC

Energy: Wind

AUTHOR

bonnerc

Bonner R. Cohen

Bonner R. Cohen is a senior fellow with the National Center for Public Policy Research, a position he has held since 2002.

Full Bio

bcohen@nationalcenter.org

CONTACT US

3939 North Wilke Road
Arlington Heights, Illinois 60004

PHONE: 312/377-4000
FAX: 312/277-4122

Harpur Hill, Buxton
Derbyshire, SK17 9JN
T: +44 (0)1298 218000
F: +44 (0)1298 218590
W: www.hsl.gov.uk

HEALTH & SAFETY LABORATORY

Numerical Modelling of Wind Turbine Blade Throw

Report Number ESS/2006/27

Project Leader: **Lynne Jones**

Author(s): **Richard Cotton**

Science Group: **Health Improvement**

DISTRIBUTION

Tim Allmark	NII, HSE (2 copies)
Andrew Curran	Health Improvement Group Director
	Mathematical Sciences Unit Library
	HSE LIS

PRIVACY MARKING:
Not to be communicated outside Government Service or BWEA without the approval of the authorising officer: Tim Allmark.

HSL report approval:	**Andrew Curran**
Date of issue:	**19th April 2007**
Job number:	**JS2005208**
Registry file:	**26441**
Electronic file name:	**Numerical Modelling of Wind Turbine Blade Throw**

Annex 4

CONTENTS

EXECUTIVE SUMMARY

Objectives

To create a simple model of blade throw from a wind turbine and apply the results to a site at [redacted].

Main Findings

Two variants of a model were created, based upon the same equations of motion and differing only in the methods used to generate wind and blade speeds.

Under Variant 1, 99th percentile throw distances were found to be between 155 and 198m for a full blade, and 312 and 1462m for a 10% blade fragment, depending upon the level of drag assumed. Variant 2 predicted similar throws of 159 to 203m for a full blade, and 329 to 1395m for a fragment.

[redacted]

Recommendations

The model contains several assumptions that may decrease its accuracy. In particular, effects of lift, gliding and bouncing are not considered. It is recommended that future research should be directed at exploring ways to incorporate these aerodynamic effects into the model. The size of the coefficient of drag was shown to have a large effect on the throw distance for blade fragments, and additional research to determine this value more precisely would be beneficial.

1 INTRODUCTION

[redacted] is seeking permission to construct nine wind generators, an anemometry mast, a sub-station, and associated infrastructure on land [redacted]. A report has been produced by [redacted], the developer, which attempts to quantify the risk posed by blade shedding onto the adjacent [redacted] sites. This report has been reviewed by NII and HSL, and was found to be lacking in a number of areas. In particular, the methodology contained in that report was not transparent enough to be replicable, did not account for the effect of drag, and contained a variety of technical errors. The work described in this report is intended to provide an independent view of the level of risks posed by the proposed wind farm.

This report compares two methodologies for the estimation of impact probabilities of a full or partial blade loss from a wind turbine based upon mathematical modelling techniques, and risk contours for the [redacted] site.

2 MODEL DEFINITIONS

Two Monte Carlo simulation model variants are defined in this section. Both variants include drag, but not lift or gliding effects, and use the same equations of motion to determine the throw distance. They differ in the way that the wind speed and blade speed at the time of detachment are defined.

The first variant uses single a 'worst-case' wind speed throughout all iterations of the simulation, and an initial blade speed drawn from a beta distribution, again with pessimistic parameter assumptions.

The second variant uses wind speeds drawn from a Weibull distribution, with parameters calculated from local wind speed data, and defines the initial blade speed as a function of the wind speed.

A complete list of the assumptions made under the model is given in Section 2.1.

Physical characteristics of the turbine are based upon those of the Vestas V90. The technical specifications for this can be found in (Vestas 2006) and ([redacted]). Note that the surface area of a blade was unavailable from Vestas, and has been approximated.

Throw distances were calculated for a complete blade, and also for a one-tenth blade tip fragment (by mass). The centre of gravity of the blade tip had been approximated.

2.1 ASSUMPTIONS

2.1.1 Assumptions common to both variants

1. The blade is approximated by a point mass, which implicitly assumes that shape-related effects, such as spinning and gliding, are negligible.
2. The blade detaches cleanly and instantaneously.
3. At the time of blade detachment, the plane of blades is vertical and perpendicular to the direction of the wind. The first part of this assumption means that no prior damage has occurred to the tower to make it tilt. The second part is justifiable since modern wind turbines are designed to rotate to face the wind. Any deviation from this direction would result in slower blade rotation, and a consequent reduction in blade detachment velocity.
4. The wind velocity is assumed to be constant throughout an iteration of the model i.e. there is no gusting and the speed does not vary with altitude. In practice, wind speed typically increases with altitude – the value at tower height is used here. (An increase of around 50% is typical from ground level to tower height under conditions like those at [redacted]. See Section 2.5 and (Justus, Hargraves et al. 1978) for further information about the generation of wind speeds and their variation with altitude.)
5. The ground at the [redacted] site is horizontal. This is a reasonable approximation to reality.
6. The wind velocity is independent of the wind direction. See Appendix 5.2 for justification of this.
7. The blade comes to rest at the point where it lands (no sliding or bouncing). While this is unlikely to be the case, a point-mass ballistics model is inappropriate to model bouncing and sliding behaviour, since it is highly dependent upon the shape of the object.

8. The coefficient of drag is constant throughout the blade flight. In practice, the speed and orientation of the blade will affect C_D. To compensate for this, a range of values has been tested. (See Section 2.2.)
9. The density of the blade is constant throughout its length, and so a 10%-mass fragment will have a cross-sectional area of 10% of the full blade. In practice, the area of a 10%-mass fragment will vary depending upon its shape, and upon whether it consists of the only the outer shell or the internal beams as well.

2.1.2 Assumptions specific to Variant 1

1. The wind speed is always $30ms^{-1}$. This value is roughly comparable to the 50-year-wind value for the local area and may be considered a worst-case value. (The 50-year-wind is the speed of a peak three second gust that a fifty percent chance of occurring once every fifty years.)
2. At the time of detachment, the blade is rotating between $\frac{3}{4}$ and 2.5 times the maximal operational RPM. (The maximal operational RPM is also known as overspeed.) This implicitly assumes that a blade will never detach under low rotations. 2.5 times overspeed is a worst-case estimate of the maximum rotational speed of the turbine.

2.1.3 Assumptions specific to Variant 2

1. The wind speeds at the [redacted] site are comparable to those at a weather station in the local area. Wind farms are typically chosen for high wind speeds, so it is possible that this provides a slight underestimate of the true wind speed distribution.
2. At the time of detachment, the blade is rotating faster than $\frac{3}{4}$ times the maximal operational RPM.

2.2 CONSTANTS

Physical constants:

Symbol	Value	Description
g	9.8	Acceleration due to the Earth's gravity, $m s^{-2}$.
ρ	1.225	Density of Earth's atmosphere at 15°C at sea level, $kg m^{-3}$.

Turbine properties:

Symbol	Value	Description
A	10–80/ 1–8	Surface area of a (full/ fragmented) blade, m^2. See below.
C_D	0.05 – 1.6	Coefficient of drag, dimensionless. See below.
h	65	Height of turbine tower, m.
m	6600/ 660	Mass of a (full/ fragmented) blade, kg.

r	11.2/ 35	Radius to the centre of gravity of a (full/ fragmented) blade, m.
r_{tip}	45	Radius to tip of a blade, m.
ω_{max}	18.4	Maximum operational RPM (overspeed).
ω_{nom}	16.1	Nominal operational RPM.
w_{max}	25	Maximum operational wind speed, ms^{-1}, corresponding to ω_{max}.
w_{nom}	15	Nominal operational wind speed, ms^{-1}, corresponding to ω_{nom}.

Beta distribution:

Symbol	Description
v_{min}, v_{mode}, v_{max}, μ, p	Used to generate parameters for the beta distribution of blade speeds in Variant 1. See Section 2.5.1.

Notes:

1. The cross-sectional area of a blade (more precisely: the area of projection from the blade onto the plane perpendicular to the relative velocity vector) is approximately $100m^2$ facing the wind, and around $10m^2$ when edge on. As mentioned in Section 2.1.1, the true cross-sectional area will vary during the flight as the blade rotates relative to the wind. The range of values of A are provided as estimates of the average cross-sectional area throughout a flight.
2. A turbine blade has a coefficient of drag of around 0.04 under normal operating conditions (DWIA 2002). After detachment, the blade's orientation relative to the wind direction (through spinning and tumbling motions) increases this value, though it is unclear by exactly how much. For simplification, rather than calculate a coefficient of drag that changes throughout the blade's flight, a sensitivity analysis has been performed, considering the product of C_D and A at 0.5, 2, 8, 32 and 128 (labelled "very low", "low", "medium", "high" and "very high" respectively). The reason that these values are fixed, rather than incorporated into the Monte Carlo simulation, is that the distribution of the coefficient of drag between throws is unclear.

2.3 VARIABLES

Symbol	Description
θ	Angle of detachment, radians.
$\mathbf{v} = (v_x, v_y, v_z)$	Velocity of centre of gravity of blade, ms^{-1}.
$\mathbf{s} = (s_x, s_y, s_z)$	Position of centre of gravity of blade, m.
t	Time since detachment, s.
$\mathbf{v}_0$	Velocity of centre of gravity of blade at time 0, ms^{-1}.
$\mathbf{s}_0$	Position of centre of gravity of blade at time 0, m.

w_{10}	Local 10-minute-average wind speed, ms^{-1}.
$\mathbf{w} = (0, w_y, 0)$	Velocity of wind, ms^{-1}.
$\mathbf{w}^* = \mathbf{w} - \mathbf{v}$	Relative velocity of wind with respect to the blade, ms^{-1}.

2.4 COORDINATE SYSTEM

At the time of detachment, the blades are in the x-z plane, with the wind travelling from the negative y direction.

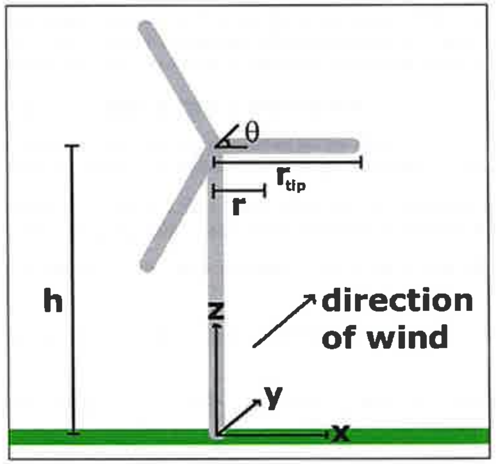


Figure 1: Schematic of coordinate system and turbine dimensions.

2.5 CALCULATION OF INITIAL POSITION AND VELOCITY

Two methods are used to generate initial wind and blade velocities.

2.5.1 Variant 1: Constant wind speed, beta distributed blade speed

Let the wind speed, w_y, be constant throughout all iterations of the Monte Carlo simulation, with a value of $30ms^{-1}$. Note that this should be considered a 'worst-case' value, since it exceeds the observed (ground level) 50-year-wind value of $23ms^{-1}$ for the local area (Mann, Larsén et al. 2004).

Let the speed of the centre of gravity of the blade be taken from a beta distribution, with parameters defined using a PERT (Program Evaluation Review Technique) method. The beta distribution replicates the choice of distribution in ([redacted]). It generates wind speeds over a finite range, with a single peak in the probability density function (i.e. it is unimodal) and a positive skewness, as expected from a real distribution of wind speeds. The precise shape does not have any underlying physical significance.

Let v_{mode} be the speed of the centre of gravity of the blade at the maximal operational RPM, ω_{max}. Now let v_{min} be $\frac{3}{4}$ of this value, and v_{max} be 2.5 times this value. The beta distribution will generate speeds between v_{min} and v_{max}, with a peak probability at v_{mode}.

$$v_{min} = 0.75 \times \frac{2\pi r \omega_{max}}{60} = 16.2;\ v_{mode} = \frac{2\pi r \omega_{max}}{60} = 21.6;\ v_{max} = 2.5 \times \frac{2\pi r \omega_{max}}{60} = 54.0.$$

Define $\mu = \frac{1}{6}(v_{min} + v_{max} + 4v_{mode}) = 26.08$, and $p = \frac{(\mu - v_{min})(2v_{mode} - v_{min} - v_{max})}{(v_{mode} - \mu)(v_{max} - v_{min})}$.

Now the initial blade speed is distributed by $u_0 \sim \beta\left(p, \frac{p(v_{max} - \mu)}{(\mu - v_{min})}\right) \equiv \beta(1.571, 4.429)$.

2.5.2 Variant 2: Truncated Weibull wind speed; related blade speed

The Weibull distribution is commonly used to describe wind speed distributions, and is widely regarded to provide a reasonable fit outside of tropical regions. Like the beta distribution described in Section 2.5.1, the distribution is unimodal and positively skewed; unlike the beta distribution, the range of speeds generated extends to infinity.

Let the local 10-minute-average wind speed, w_{10}, be taken from a Weibull distribution, with parameters calculated from Met Office data, using the "Least-squares fit to observed distribution" method described in (Justus, Hargraves *et al.* 1978), to give $w_{10} \sim \text{Weibull}(16.97, 1.796)$. Further details regarding the dataset are given in Appendix 5.1.

Assume that blade detachments only occur when the wind speed is greater than 75% of the recommended operational maximum $\frac{3}{4} \times 25 = 18.75ms^{-1}$. Now the wind speed (for the purposes of the model) is taken from a truncated Weibull distribution and converted to a 3-second-average value by multiplying by 1.365, as advised in (DNV-Risø 2001). Thus $w_y \sim (1.365 * w_{10}$ given that $w_{10} > 18.75/1.365)$.

Let the speed of the centre of gravity of the blade be a capped linear function of wind speed, $\|v_0\| = f(w_y)$, passing through the origin, and the nominal operating conditions, $(w_{nom}, v(\omega_{nom}))$. (MacQueen, Ainslie et al. 1983) suggest that blades have a theoretical maximum speed when the blade tip reaches approximately Mach 0.9 (0.9 times the speed of sound; $310ms^{-1}$). Thus the speeds are capped at $\|v_0\| = 310 * \frac{r}{r_{tip}}$, which is $77ms^{-1}$ for a full blade, and $241ms^{-1}$ for a fragment.

The blade speeds at nominal revolutions are given by $v_{nom} = 2\pi r \omega_{nom}$. For a full blade this is $18.9ms^{-1}$ and for a fragment this is $59.0\ ms^{-1}$, due to the increased radius. Then

$$f(w_y)=\begin{cases}\min(1.26w_y,77) & \text{for a full blade.}\\ \min(3.93w_y,241) & \text{for a fragment.}\end{cases}$$

2.5.3 Initial Position and Velocity

Let the angle of detachment be taken from a circular uniform distribution, $\theta \sim U(0, 2\pi)$. Then the initial position of the centre of gravity of the blade, $\mathbf{s}_0 = \begin{pmatrix} r\cos(\theta) \\ 0 \\ h + r\sin(\theta) \end{pmatrix}$, and the initial blade velocity is given by $\mathbf{v}_0 = \begin{pmatrix} -f(w_y)\sin(\theta) \\ 0 \\ f(w_y)\cos(\theta) \end{pmatrix}$.

2.6 EQUATIONS OF MOTION

The total force acting upon the blade is the sum of the effects of (Rayleigh) drag and gravity, given by $F_{total} = \frac{1}{2}C_D A\rho\left|w^*\right|^2 \hat{w}^* - mg\begin{pmatrix}0\\0\\1\end{pmatrix}$, where $\hat{w}^*$ is the unit vector in the direction of the relative velocity, and $\left|w^*\right|$ is the relative speed.

The position of the blade throughout time is the second integral of $\frac{F_{total}}{m}$, with the initial position and velocity ($\mathbf{s}_0$ and $\mathbf{v}_0$) as constants of integration. This forms a system of three second order ODEs in the x, y and z directions. See Appendix 5.3 for the equations.

Note that since A is proportional to m (by assumption 9 in Section 2.1.1), the equations of motion for a fragment and a full blade are the same.

2.7 MONTE CARLO SIMULATION

In each iteration, the system of equations was solved numerically using (Mathworks 2006) for the x and y position coordinates at ground level (z=0). 10000 blade failures were simulated for each model variant, at each of the five levels of drag mentioned in Section 2.2.

2.8 ANNUAL PROBABILITY OF FAILURE

(Larwood 2005) notes that although limited reliable data is available, blade failure statistics are typically of the order 10^{-3} to 10^{-2} per turbine per year. In both variants the probability of failure is given as 10^{-3} per turbine per year. Assuming independence of failure between turbines, the probability of failure per annum over the whole farm of nine turbines is $1-(1-0.001)^9 = 0.896\%$. Notice that since the probability of multiple blade failures (under the independence assumption) is small, this is close to the mean number of turbines failing per year, $9\times0.001 = 0.009$.

3 RESULTS

3.1 TOTAL THROW DISTANCE

The mean, 95th, 99th and 99.9th percentile and standard deviation throw distances for each model variant are presented for full blade detachment in Table 1, and for blade fragments in Table 2. (Maximum throw distances are not very meaningful for this model since they are heavily dependent upon the number of iterations, and so have not been included.) Means and 99th percentiles throws are presented as bar charts in Figures 2 and 3 respectively.

For each level of drag, (defined here as the product of the coefficient of drag and "cross-sectional area", C_D*A,) the results for the mean, 95th, 99th and 99.9th percentile throw distances were very similar under Variant 1 and Variant 2. For example, under medium drag (C_D*A = 8), the mean throw distance was 68m under Variant 1, and 74m under Variant 2. Likewise, the 99th percentile throw distance was 183m under Variant 1, and 185m under Variant 2. This suggests that assumptions for wind speed and blade speed are comparable between variants over the top end of the distributions.

For full blade detachments, the level of drag had very little effect upon the mean, though there was a slight increase under very high drag (C_D*A = 128) in Variant 1 (mean = 86m, compared to 67m to 70m under other drag levels).

For fragment detachments, the mean throw distances decreased with increasing drag (mean = 326m at C_D*A = 0.5, mean = 152m at C_D*A = 128 under Variant 1; mean = 365m at C_D*A = 0.5, mean = 139m at C_D*A = 128 under Variant 2). 99th percentile throw distances showed the same effect, dropping from 1462m to 312m as drag increased from 0.5 to 128 under Variant 1, and from 1395m to 329m under Variant 2.

Drag Level	C_D*A	Variant 1: Full blade Mean	95^{th}	99^{th}	99.9^{th}	Std dev	Variant 2: Full blade Mean	95^{th}	99^{th}	99.9^{th}	Std dev
V. Low	0.5	70	156	198	255	46	77	158	203	269	49
Low	2	70	153	196	251	45	77	156	200	260	48
Medium	8	68	145	183	231	42	74	148	185	240	45
High	32	67	129	155	187	35	70	129	159	202	38
V. High	128	86	139	158	175	35	73	128	165	218	34

Table 1: Means and 95^{th}, 99^{th} percentile throws under each variant, by level of drag, for full blade detachments.

Drag Level	C_D*A	Variant 1: Fragment Mean	95^{th}	99^{th}	99.9^{th}	Std dev	Variant 2: Fragment Mean	95^{th}	99^{th}	99.9^{th}	Std dev
V. Low	0.5	326	984	1462	1919	331	365	994	1395	1892	348
Low	2	305	897	1276	1652	296	341	900	1229	1613	313
Medium	8	257	681	886	1080	220	283	682	861	1093	233
High	32	193	416	490	554	133	199	410	488	582	138
V. High	128	152	284	312	331	91	139	259	329	403	82

Table 2: Means and 95^{th}, 99^{th} percentile throws under each variant, by level of drag, for blade fragment detachments.

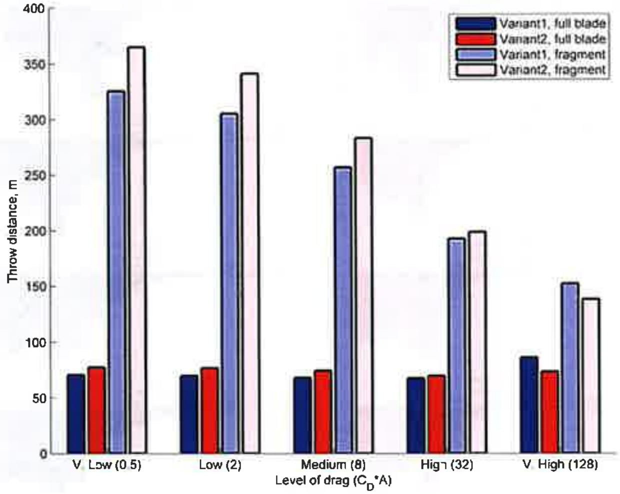


Figure 2: Mean throw distances for each variant by level of drag.

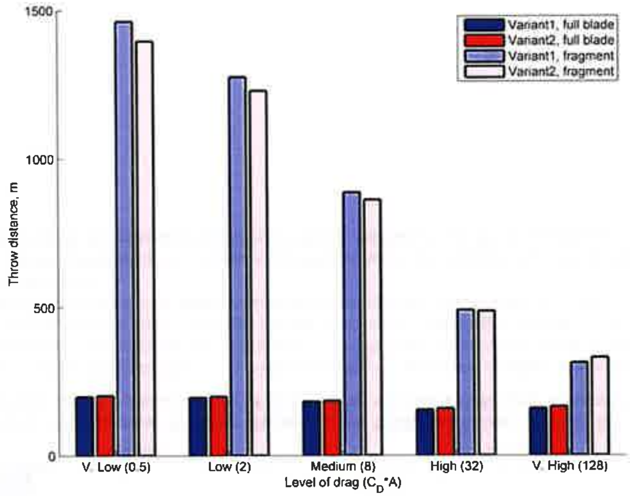


Figure 3: 99^{th} percentile throw distances for each variant by level of drag.

Histograms of the throw distances are presented for each variant, for full and partial blades (Figures 3–6). Under small levels of drag, the distribution of throw distances was strongly right skewed, with the size of the skew decreasing as drag increased. For full blade throw, both variants predicted a single throw distance frequency maximum close to the mean throw distance. For partial blade throw, both variants typically predict a frequency peak close to zero, and another close to the throw maximum.

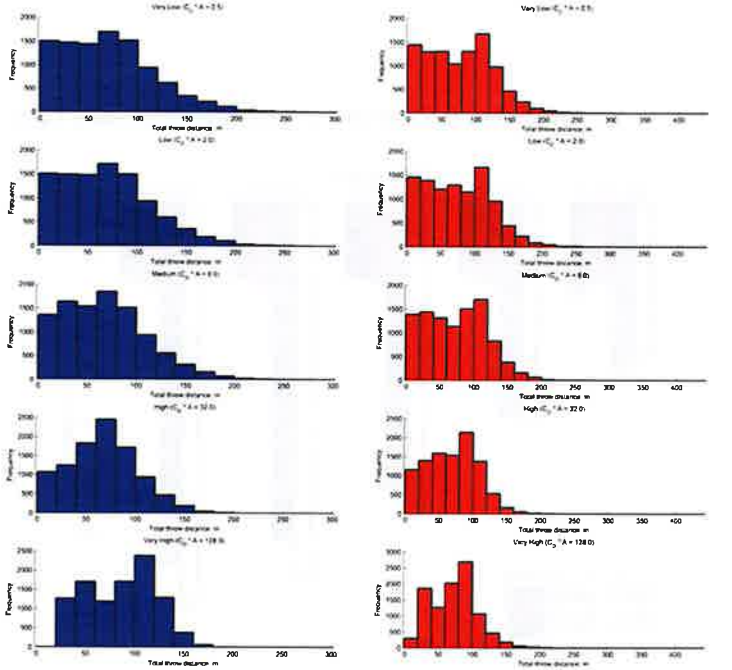


Figure 4: Histograms of throw distances for 10000 simulated throws for a full blade, under various levels of drag, using Variant 1 (left) and Variant 2 (right).

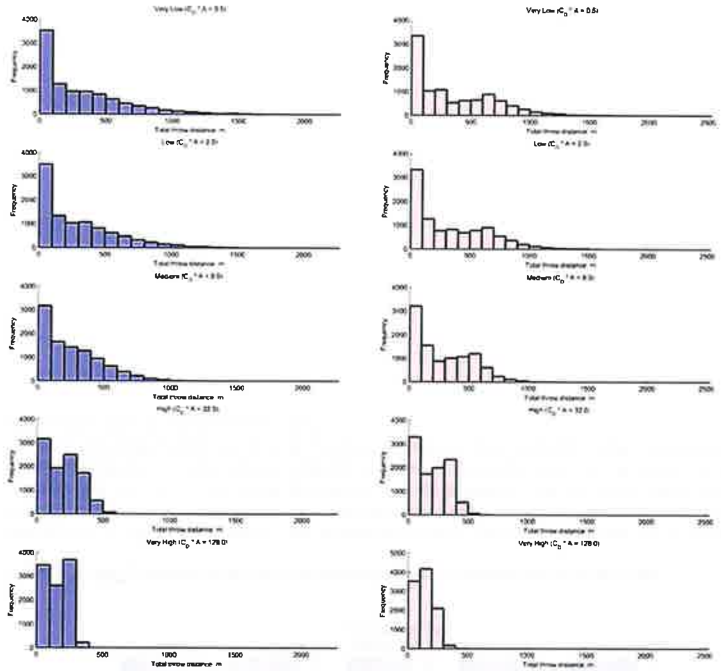


Figure 5: Histograms of throw distances for 10000 simulated throws for a blade fragment, under various levels of drag, using Variant 1 (left) and Variant 2 (right).

Figure 6 shows the probability of a blade travelling at least some distance, **given that it has been thrown**. For example, the probability of a 10% blade fragment travelling at least 760m (the shortest distance from a planned turbine location to a building) is around 0.1 under very low drag assumptions, 0.04 under medium drag assumptions and less than 10^{-4} under very high drag assumptions.

The annual probability of a blade travelling at least this distance can be calculated by multiplying by the annual probability of failure, estimated as 0.001 in Section 2.8.

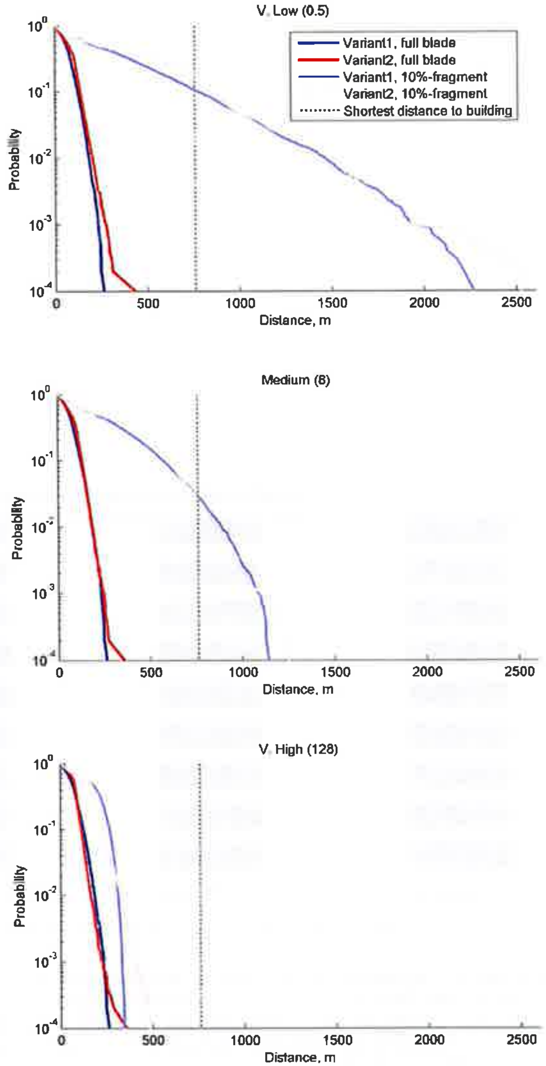


Figure 6: Probabilities of a blade (fragment) travelling at least some distance, given that it has been thrown, by level of drag.

3.2 CROSS THROW VERSUS LONG THROW

Table 3 shows the mean angle of deviation of the landing position from the x-axis for each variant under different levels of drag. (See Figure 7 for a description of this angle.) With no drag the deviation is necessarily zero, and the deviation increases with the level of drag. Long throw (x-direction) – cross throw (y-direction) equivalence occurs between high and very high drag (C_D*A = 32 and C_D*A = 128) for full blades and fragments.

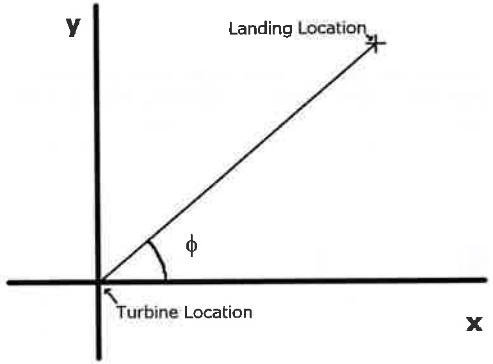


Figure 7: Plan of the angle of deviation of the landing position from the x-axis, ϕ.

Drag Level	C_D*A	Mean angle of deviation from x-axis, degrees — Full blade: Variant 1	Full blade: Variant 2	10% Fragment: Variant 1	10% Fragment: Variant 2
V. Low	0.5	1	1	1	1
Low	2	4	3	3	3
Medium	8	11	8	9	7
High	32	30	21	21	17
V. High	128	61	50	44	36

Table 3: Mean angle of deviation of the landing position from the x-axis, in degrees, by level of drag, and by variant.

3.3 RISK CONTOURS

Risk contours are presented for a single turbine in Figures 8 and 9, and for the nine proposed turbines at their expected locations in Figures 10 and 11. In each graph, the area is divided up into 25m by 25m regions, coloured according to the probability of a blade landing in that region, given that a blade has been thrown. Again, the annual probability of a blade landing in a particular region can be calculated by multiplying by the annual probability of failure. Note that the ragged appearance of boundaries between colours is an artefact of the numerical technique used to create the graphs.

The locations of the nine turbines are given in Table 4, as described in ([redacted]). The yellow region on each graph represents the approximate location of the [redacted] site boundary, and the red region represents the approximate location of the buildings on this site. The method for calculating the direction of the wind for each throw is discussed in Appendix 5.4.

As with the total throw distances, there was little difference between the risk contours for Variant 1 and Variant 2. For full blades, in all cases, the probability of a blade landing in a region on the power station site was less than 10^{-6} (10^{-9} per annum). For fragments, this was true under very high drag assumptions (C_D*A = 128), but under medium and very low drag (C_D*A = 32, 8) the probability approached 10^{-4} (10^{-7} per annum) for some regions on the site.

Turbine Number	Easting	Northing
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

Table 4: Proposed locations for each turbine.

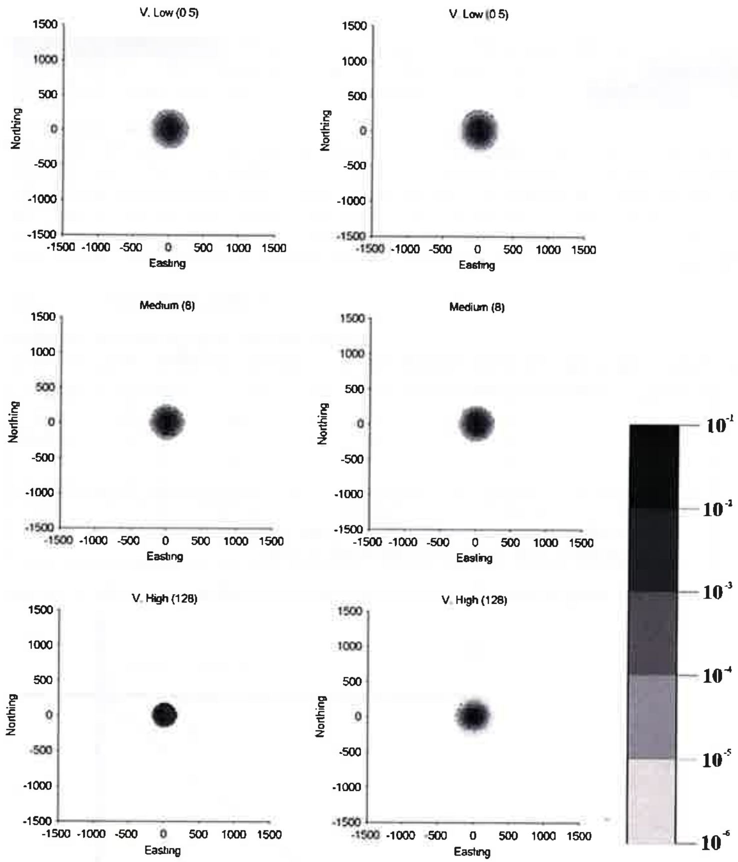


Figure 8: Risk contours for a single turbine and a full blade at very low, medium and very high drag, using Variant 1 (left) and Variant 2 (right).

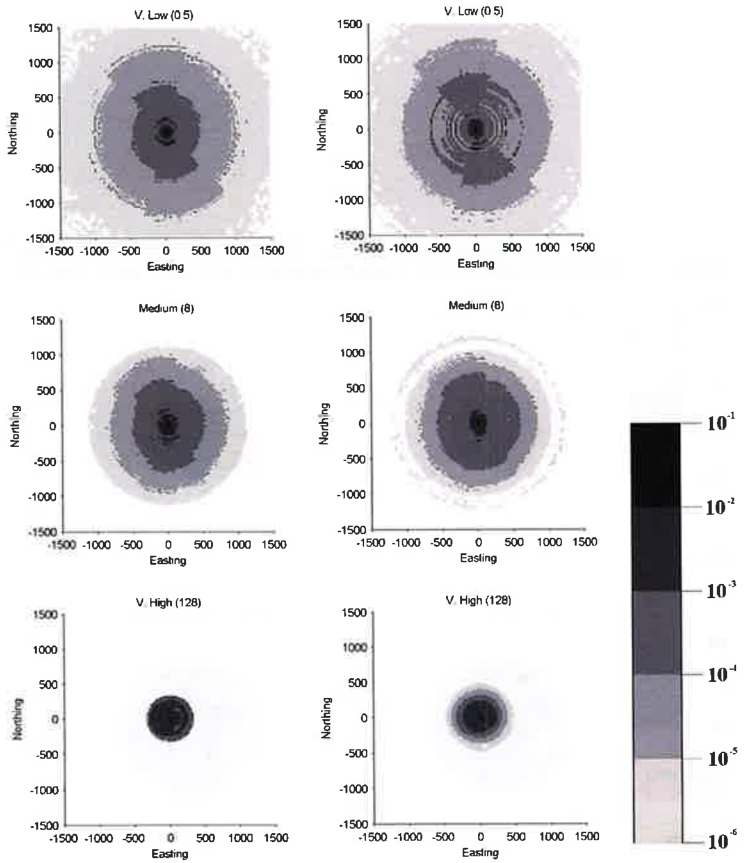


Figure 9: Risk contours for a single turbine and a fragment at very low, medium and very high drag, using Variant 1 (left) and Variant 2 (right).

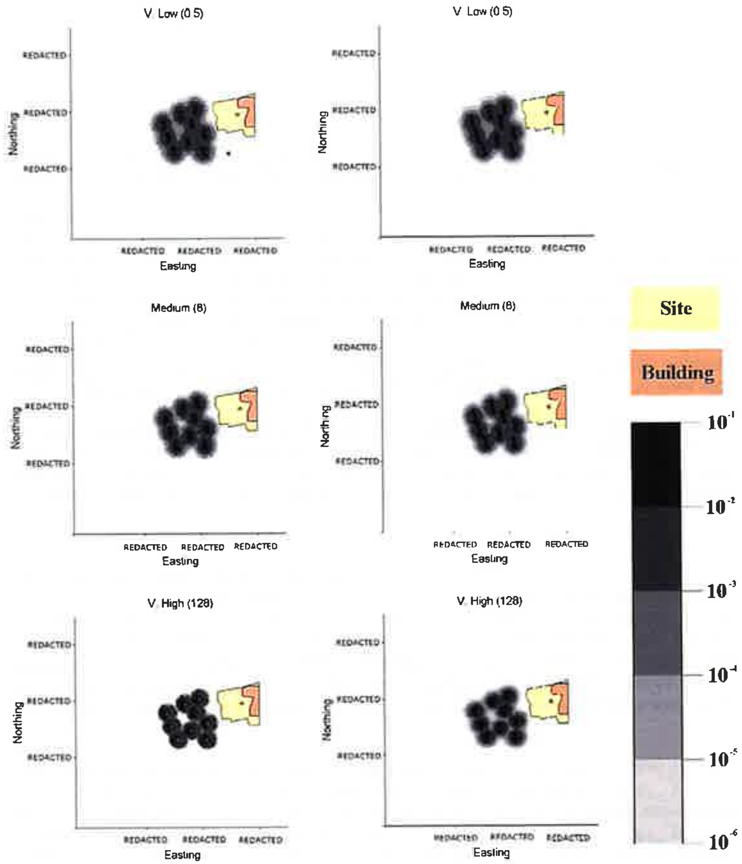


Figure 10: Risk contours for all nine turbines and a full blade at very low, medium and very high drag, using Variant 1 (left) and Variant (right).

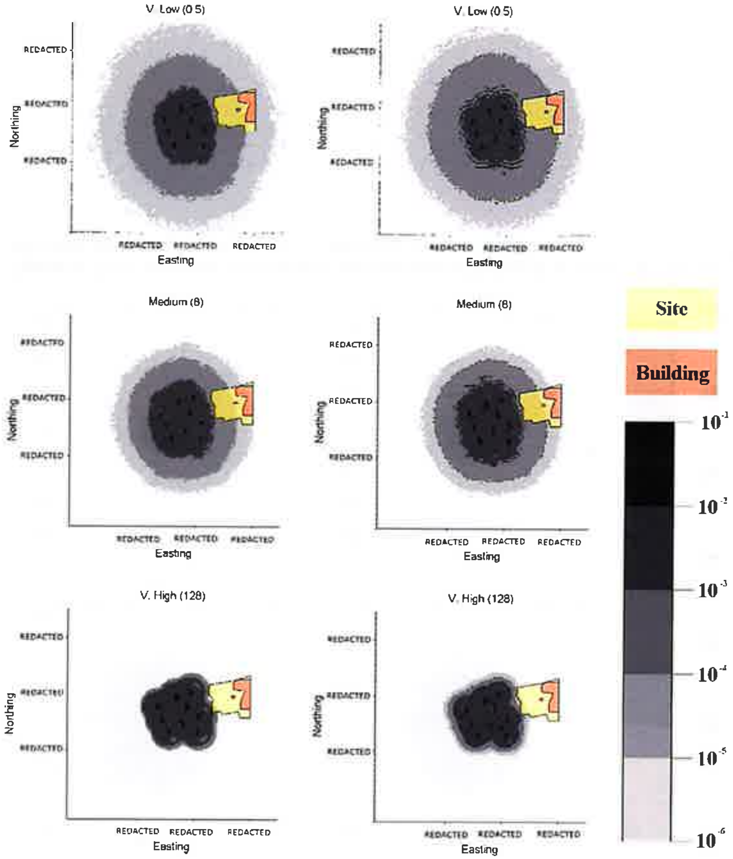


Figure 11: Risk contours for all nine turbines and a fragment at very low, medium and very high drag, using Variant 1 (left) and Variant (right).

4 DISCUSSION

4.1 SUMMARY

The model in this report was defined as a response to deficiencies in representations of wind and blade speeds used in a previous report by ([redacted]). Both of the variants were based upon the same equations of motion and differed only in the methods used to generate wind and blade speeds. Under Variant 1, 99th percentile throw distances were found to be between 155 and 198m for a full blade and 312 and 1462m for a 10% blade fragment, depending upon the coefficient of drag. Variant 2 predicted similar throws of 159 to 203m for a full blade and 289 to 1365m for a fragment.

Under Variant 2, the mean wind speed was 22.8ms^{-1} and the 95th percentile speed was 30.2ms^{-1}, compared to 30ms^{-1} for all iterations in Variant 1. Likewise, the mean and 95th percentile detachment blade speeds were 26.1ms^{-1} and 37.9ms^{-1} respectively for full blades under Variant 1 and 28.8ms^{-1} and 38.2ms^{-1} under Variant 2. For fragments, the mean and 95th percentile detachment speeds were 81.5ms^{-1} and 118.9ms^{-1} under Variant 1 and 89.7ms^{-1} and 117.5ms^{-1} under Variant 2.

It is the remarkable similarity between the wind speed and blade speed estimates that explain the similarity in throw predictions. The motivations behind the two variants of the model were different. The beta distribution in Variant 1 considers a worst-case initial blade velocity based upon the overspeed value of the turbine, whereas the Weibull distribution in Variant 2 derived the initial blade velocity from the local wind speed and nominal operating conditions of the turbine. The fact that these values so closely match is coincidence – in an area of higher or lower winds, the model variants would diverge.

4.2 MODEL CRITIQUE

The model defined here includes a substantial number of assumptions, some more reasonable than others. The areas of the model that are weakest are the point-mass approximation, which means that lift, spinning, gliding and bouncing effects cannot be accounted for, and the unknown relationship between the wind speed and the blade speed at detachment.

(MacQueen, Ainslie et al. 1983) showed that a gliding blade could travel two to three times further than a tumbling blade, so such aerodynamic considerations are potentially important. MacQueen did however conclude that a stable gliding position was unlikely. It is possible that the uneven distribution of mass throughout the length of the blade could result in different aerodynamic motions for a full blade or a fragment. For example, a full blade has its centre of gravity close to the base, so a dart-like throw is conceivable. In contrast, a tip fragment has its centre of gravity nearer its middle; so spinning motions are more plausible. This model cannot consider such rotations, and so further research is required to establish any possible aerodynamic motions.

There is a lack of data regarding the relationship between wind speed and blade speed under normal conditions or detachment conditions.

4.3 EXISTING DATA ON BLADE THROW

There is no comprehensive database containing details of real life occurrences of blade throw that include accurate measurement of throw distance, fragment size and turbine model. (CWIF 2006) provides a list of wind turbine related accidents, including 37 instances of blade throw where the distance was recorded. The Caithness Windfarm Information Forum data is often based upon estimates from eyewitness testimony or unvalidated reports, rather than accurate measurement of distances. Throws are often not distinguished between full blade throw and fragments, and fragment sizes are typically not given. Consequently, the dataset cannot be considered reliable or in any way definitive. However, it can provide validation to an order-of-magnitude accuracy for the model.

Nineteen of the throws were reported as 100m or less, including six cases where the blade dropped to the ground close to the turbine shaft. In all but one of the remaining cases, the throw distance was reported as 600m or less. A single incident at Burgos in Spain was reported as resulting in blade fragment throw of "almost 1000m".

These incidents broadly compare with the model's results, suggesting that the model provides correct throw distances to an order-of-magnitude. The model underrepresents very short throws and 'drops' – see Section 4.5 for further discussion of this.

4.4 COEFFICIENT OF DRAG

For the [redacted] site, knowledge of the level of drag is crucial to determining whether the blade can be thrown as far as the power station. Under very low to medium drag levels the 99th percentile throw distances for fragments exceeded the distance of 760m from the nearest turbine to the power station buildings.

It should be noted that the apparent difference in the effect of drag between full blades and fragments is entirely due to the higher initial velocity of the fragments. Since the area and mass have opposing effects and are scaled down proportionally, the equations of motion are identical between the two cases.

For full blades the initial blade velocities are close to the wind velocities, meaning that the relative velocity (difference between the wind and blade velocities) is very small. Since the size of the drag force is proportional to the square of the relative velocity, the drag had very little effect regardless of the coefficient of drag.

By comparison, the initial blade speed for fragments is much higher, giving a relative velocity that isn't trivially small. This means that under higher levels of drag, the drag force quickly reduces the blade speed, and so the fragment behaves similarly to the full blade. Under lower levels of drag, the drag force is too small to have much effect and so the fragment retains its high speed and travels further.

In general, smaller fragments will be thrown further, and there is a fairly smooth progression of throw distances from a full blade to a 10%-fragment. A 10% fragment was considered close to the worst-case: smaller fragments will travel slightly further, but have a reduced capacity for causing damage.

4.5 RISK CONTOURS

Under the highest level of drag ($C_D*A = 128$) the probabilities of a full blade landing immediately adjacent to the turbine are low, as demonstrated by white regions at the turbine locations on the risk contours (particularly visible under Variant 1, Figure 9). There have been

several instances of very short throws recorded, see Section 4.3, which leads to two possible conclusions. Firstly, $C_D*A = 128$ is inappropriately high; or secondly, the model breaks down at short throw distances. In practise, both of these conclusions are likely to be true. The range of levels of drag chosen were considered to span beyond the likely "real-life" range, so $C_D*A = 128$ is almost certainly an overestimate. The first two assumptions of the model, given in Section 2.1 (point mass approximation and clean detachment), break down at very short throw distances. For a throw of less than 100m, the length of the blade becomes nontrivial; similarly, a non-clean detachment is likely to increase the chance of the blade dropping, rather than being thrown.

5 APPENDICES

5.1 WIND SPEED DATA

The wind speed data is taken from a site at [redacted] ([redacted]) and is averaged over the period 1990-1999. Cumulative frequencies are given in Table 4. The height of the anemometer for this data is assumed to be 13m, and wind speeds are calculated at the height of the tower, h = 65m.

Wind speed, knots	Cumulative frequency
1	0.0220
3	0.0779
6	0.2165
10	0.4760
16	0.7902

Table 5: Cumulative wind speed data for [redacted] (1990-1999).

5.2 INDEPENDENCE OF WIND DIRECTION AND WIND SPEED

Directional wind speed data from the same source in Appendix 5.1 was used to calculate Weibull distributions, using the method outlined in Section 2.5.2, for the wind speeds over 30° sectors. The mean wind speeds for each sector are given in Table 5 below.

Sector	341-10	11-40	41-70	71-100	101-130	131-160
Mean Speed	11.93	10.22	9.95	11.36	15.40	14.19

Sector	161-190	191-220	221-250	251-280	281-310	311-340
Mean Speed	13.72	16.92	19.32	15.99	15.60	13.95

Table 6: Calculated mean wind speed by wind direction sector for [redacted] (1990-1999).

The difference in mean wind speeds by sector is at most 19.32/9.95 = 2.05.

The site at [redacted] is approximately flat, and there is no reason to suspect a strong bias in wind speed from a particular direction – the wind speeds are likely to show a similar but not identical variation as the [redacted] site. Given the lack of availability of reliable directional wind speed data for the [redacted] site, and that there are much larger uncertainties within the model than this, using a uniform wind speed across all directions is appropriate.

5.3 ODES OF BLADE MOTION

The equations of motion resulting from the force acting upon the blade can be decomposed into a system of six first order ODEs, with initial conditions $\mathbf{v}_0$ and $\mathbf{s}_0$.

$$\frac{ds_x}{dt} = v_x$$

$$\frac{ds_y}{dt} = v_y$$

$$\frac{ds_z}{dt} = v_z$$

$$\frac{\partial v_x}{\partial t} = \frac{1}{2m} C_D A \rho \left| w^* \right| \hat{w}_x^*$$

$$\frac{\partial v_y}{\partial t} = \frac{1}{2m} C_D A \rho \left| w^* \right| \hat{w}_y^*$$

$$\frac{\partial v_z}{\partial t} = \frac{1}{2m} C_D A \rho \left| w^* \right| \hat{w}_z^* - \begin{pmatrix} 0 \\ 0 \\ g \end{pmatrix}$$

5.4 GENERATING WIND DIRECTIONS FOR RISK CONTOURS

Table 6 displays a wind rosette for the [redacted] site taken from ([redacted]). Each risk contour plot contains the 10 repetitions of the 10000 simulated throws, each rotated independently by an angle taken from the piecewise uniform distribution formed from the wind rosette.

For example, the probability density function for the wind direction being between 135° and 165° is constant and equal to 0.0417.

Angle (°)	345-15	15-45	45-75	75-105	105-135	135-165
Probability	0.0609	0.0723	0.1025	0.2368	0.1706	0.0417

Angle (°)	165-195	195-225	225-255	255-285	285-315	315-345
Probability	0.044	0.0538	0.0502	0.0287	0.0695	0.0691

Table 7: Wind rosette for the [redacted] site.

6 REFERENCES

CWIF (2006). Wind Turbine Accident Compilation, Caithness Windfarm Information Forum.

DNV-Risø (2001). Guidelines for Design of Wind Turbines, Det Norske Veritas and Risø National Laboratory.

DWIA. (2002). "Aerodynamics of Wind Turbines: Drag." from http://www.windpower.org/en/tour/wtrb/drag.htm.

[redacted].

Justus, C. G., W. R. Hargraves, et al. (1978). "Methods for Estimating Wind Speed Frequency Distributions." Journal of Applied Meteorology **17**(3): 350-353.

Larwood, S. (2005). Permitting Setbacks for Wind Turbines in California and the Blade Throw Hazard, California Wind Energy Collaborative, University of California, Davis.

MacQueen, J. F., J. F. Ainslie, et al. (1983). "Risks associated with wind-turbine blade failures." IEE Proceedings, Part A - Physical Science, Measurement and Instrumentation, Management and Education, Reviews **130**(9): 574-586.

Mann, J., X. G. Larsén, et al. (2004). Regional Extreme Wind Climates And Local Winds. Extreme Winds and Developments in Modelling of Wind Storms, Cranfield University.

Mathworks, T. (2006). MATLAB.

Vestas (2006) "V90-3.0MW An efficient way to more power." , DOI:

This post was contributed by a community member. The views expressed here are the author's own.

Neighbor Posts (Https://Patch.Com/Massachusetts/Falmouth/Posts)

Vestas Confidential Health and Safety Instruction manual for a Falmouth MA wind farm

Evidenced by the Vestas Confidential Health and Safety Instruction manual for a Falmouth MA wind farm. Page 10 no one allowed 1640 feet

By Frank Haggerty, Patch Contributor (https://patch.com/users/frank-haggertye0dbc553242f63bb0b4c3acd2f8df71d82de8d597c3d2d03e2929a2b2178abbf)
Jan 9, 2016 6:31 am ET

(https://patch.com/massachusetts/falmouth/amp/26100777/vestas-confidential-health-and-safety-instruction-manual-for-a-falmouth-ma-wind-farm) Reply

ww.facebook.com/sharer/sharer.php?
3A//patch.com/massachusetts/falmouth/vestas-
ial-

1-

itter.com/intent/tweet?
as%20Confidential%20Health%20and%20Safety%20Instruction%20manual%20for%20a%20Falmouth%20MA%20wind%20farm&url=https%3A//patch.com/massachusetts/falmou
ial-

1-

w.reddit.com/submit?
%3A//patch.com/massachusetts/falmouth/vestas-
ial-

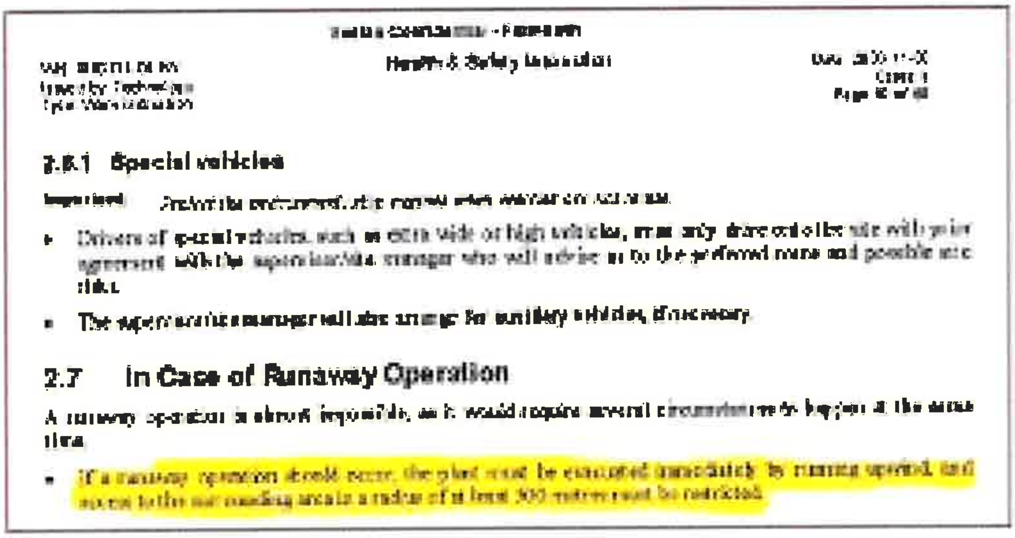
1-

estas%20Confidential%20Health%20and%20Safety%20Instruction%20manual%20for%20a%20Falmouth%20MA%20wind%20farm)

'estas%20Confidential%20Health%20and%20Safety%20Instruction%20manual%20for%20a%20Falmouth%20MA%20wind%20farm&body=Vestas%20Confidential%20Health%2
ial-

1-

Exhibit 2


Health & Safety Instruction

2.6.1 Special vehicles

2.7 In Case of Runaway Operation

Vestas advises to *"evacuate by running upwind ...access to the surrounding area in a radius of at least 500 meters [1640 ft.] must be restricted."*

Vestas Confidential- Falmouth Health and Safety Instructions

Vestas Confidential Health and Safety Instruction manual for a Falmouth MA wind farm 2006-11-06

"it is indefensible, from a safety perspective alone, to specify in a wind ordinance designed to protect the public health, safety and welfare a setback that is less than 1640 feet. "

WIND TURBINE SAFETY CONSIDERATIONS

2013/07/vestas -nordex.pdf

Vestas is one of the leading wind turbine manufacturers, with approximately 70% market share worldwide.

Based on its prominence in the world market, the Vestas Safety
Manual (32 pages) is a credible source of safety information. Nordex is another well know manufacturer of wind turbines. Its Safety Manual (130 pages) likewise is considered a credible source of information on the subject of safety.

Vestas Confidential- Falmouth Health and Safety Instructions Date 2006-11-06

Vestas advises to "evacuate by running upwind ...access to the surrounding area in a radius of at least 500 meters [1640 ft.] must be restricted."

On page 3 of the Vestas Safety Regulations for Operators and Technicians Manual, point

2. – Stay and Traffic by the Turbine, Vestas personnel are instructed to stay away from a turbine by 400 m (1312 ft) unless it is necessary.

Taken in context, this distance would apply to normal operating conditions. (See Exhibit 1)

Under abnormal operating conditions, Vestas expands this distance in consideration of the safety of its employees.

This is evidenced by the Vestas Confidential Health and Safety Instruction manual for a Falmouth MA wind farm. Page 10 of this manual addresses the situation of a free spinning "runaway turbine".

In that manual, instructions are for no one to be allowed within a 1640 feet (500 m) radius. (See Exhibit 2)

DANGER FALLING TURBINE PARTS

In case of a fire in the nacelle or on the rotor, parts may fall off the wind turbine. In case of a fire, nobody is permitted within a radius of 500 m from the turbine.

(See Exhibit 3) Given that these standards apply to employees who are familiar with the safety implications of wind turbines and are equipped to deal with abnormal conditions, it is indefensible, from a safety perspective alone, to specify in a wind ordinance designed to protect the public health, safety and welfare a setback that is less than 1640 feet.

Click on the link below to see *Exhibit 2, Vestas-Falmouth Confidential Health and Safety Instruction Date* 2006-11-06

http://northeastwindmills.com/wp-content/uploads/2013/07/vestas-nordex.pdf (http://northeastwindmills.com/wp-content/uploads/2013/07/vestas-nordex.pdf)

Note # MTC, Massachusetts Technology Collaborative, took delivery of the V82 turbines in September, 2006 and warehoused them in Houston, TX at storage fees as high as $3,000 a month. They eventually found a 'home' — in Falmouth, MA

The MTC, Massachusetts Technology Collaborative today is called the MassCEC, Massachusetts Clean Energy Center (https://patch.com/massachusetts/falmouth/falmouth-man-arrested-straight-pride-parade) **Falmouth Man Arrested At Straight Pride Parade (https://patch.com/massachusetts/falmouth/falmouth-man-arrested-straight-pride-parade)**

1d

(/massachusetts/falmouth/s/gtzm5/pack-smarter-eliminate-clutter-these-compression-cubes) **Pack Smarter and Eliminate Clutter With These Compression Cubes (https://patch.com/massachusetts/falmouth/s/gtzm5/pack-smarter-eliminate-clutter-these-compression-cubes)**

6h

Read more local news from (https://patch.com/massachusetts/falmouth) **Falmouth**

Featured Events (/#what-is-featured-event)

(https://patch.com/massachusetts/falmouth/calendar/event/20190909/628879/ussr-russia-myths-mysteries-and-spying) **Sep 9**
USSR/RUSSIA - Myths, Mysteries and Spying (https://patch.com/massachusetts/falmouth/calendar/event/20190909/628879/ussr-russia-myths-mysteries-and-spying)

(https://patch.com/massachusetts/falmouth/calendar/event/20190910/625031/job-fair-hiring-event-sept-10-nursing-rn-lpn-cna-servers) **Sep 10**
Job Fair/Hiring Event – Sept. 10 - Nursing (RN/LPN/CNA), Servers (https://patch.com/massachusetts/falmouth/calendar/event/20190910/625031/job-fair-hiring-event-sept-10-nursing-rn-lpn-cna-servers)

+ Add your event

SEP 5 **See More Events Near You > (https://patch.com/massachusetts/falmouth/calendar)**

Featured Classifieds (/#what-is-featured-classified)

+ Add your classified

Latest News Nearby

1. Foxborough, MA News (https://patch.com/massachusetts/foxborough)
   Patriots Vs. Steelers Week 1: 5 Things To Know (https://patch.com/massachusetts/falmouth/s/gtzvy/new-england-patriots-vs-pittsburgh-steelers-2019-nfl-week-1)
2. Barnstable-Hyannis, MA News (https://patch.com/massachusetts/barnstable-hyannis)
   Cape Cod Man Killed In Route 6 Crash (https://patch.com/massachusetts/falmouth/s/gtzob/cape-cod-man-killed-route-6-crash)
3. Boston, MA News (https://patch.com/massachusetts/boston)
   Hurricane Dorian To Hit MA With 60 MPH Wind, Rain (https://patch.com/massachusetts/falmouth/s/gtznr/tropical-storm-watch-hurricane-dorian-inches-closer-ma)
4. Boston, MA News (https://patch.com/massachusetts/boston)
   How MA Ranks Nationally In Strictness Of DUI Laws (https://patch.com/massachusetts/falmouth/s/gtz8r/here-s-how-ma-ranks-nationally-strictness-dui-laws)
5. Falmouth, MA News (https://patch.com/massachusetts/falmouth)
   Check Out These 5 Open Houses Near You (https://patch.com/massachusetts/falmouth/falmouth-dont-miss-these-5-open-houses-nodx-20190904)

Get Tickets Nearby

Jinjer & The Browning (https://patch.com/massachusetts/falmouth/tickets/event/4040153)

Friday, Oct 04 at 6:30pm

Get Tickets Near You (https://patch.com/massachusetts/falmouth/tickets/)

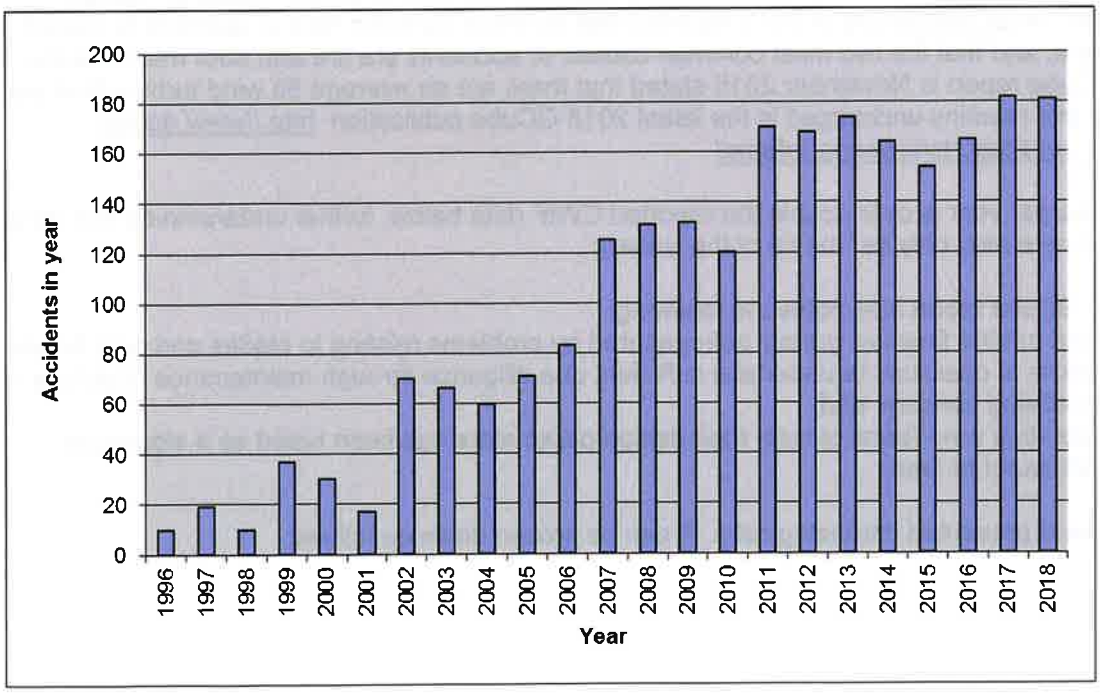
Summary of Wind Turbine Accident data to 30 June 2019

The detailed table includes all documented cases of wind turbine related accidents and incidents which could be found and confirmed through press reports or official information releases up to 30 June 2019. CWIF believe that this compendium of accident information may be the most comprehensive available anywhere.

Data in the detailed table is by no means fully comprehensive – CWIF believe that it may only be the "tip of the iceberg" in terms of numbers of accidents and their frequency. Indeed on 11 December 2011 the Daily Telegraph reported that RenewableUK confirmed that there had been 1500 wind turbine accidents and incidents in the UK alone in the previous 5 years. In July 2019 EnergyVoice and the Press and Journal reported a total of 81 cases where workers had been injured on the UK's windfarms since 2014. The CWIF data has only 15 of these (<19%).

Additional evidence that CWIF data only represents the "tip of the iceberg" can be found in the 13 August 2018 publication by Power Technology https://www.power-technology.com/features/golden-hour-paramedics-saving-lives-offshore-windfarms/ The article reports 737 incidents were reported from UK offshore windfarms during 2016 alone, with the majority occurring during operations rather than development. 44% of medical emergencies were turbine related. In comparison, only 4 UK offshore incidents are listed in the CWIF data - equivalent to 0.5%.

The CWIF data does however give an excellent cross-section of the types of accidents which can and do occur, and their consequences. With few exceptions, before about 1997 only data on fatal accidents has been found.



The trend is as expected – as more turbines are built, more accidents occur. Numbers of recorded accidents reflect this, with an average of 44 accidents per year from 1999-2003 inclusive; 95 accidents per year from 2004-2008 inclusive; 156 accidents per year from 2009-2013 inclusive, and 174 accidents per year from 2014-2018 inclusive.

This general trend upward in accident numbers is predicted to continue to escalate unless HSE make some significant changes – in particular to protect the public by declaring a minimum safe distance between new turbine developments and occupied housing and buildings.

In the UK, the HSE do not currently have a database of wind turbine failures on which they can base judgements on the reliability and risk assessments for wind turbines. Please refer to http://www.hse.gov.uk/research/rrpdf/rr968.pdf.

This is because the wind industry "guarantees confidentiality" of incidents reported. No other energy industry works with such secrecy regarding incidents. The wind industry should be no different, and the sooner RenewableUK makes its database available to the HSE and public, the better. The truth is out there, however RenewableUK don't like to admit it.

Some countries are finally accepting that industrial wind turbines can pose a significant public health and safety risk. In June 2014, the report of the Finnish Ministry of Health called for a minimum distance of 2 km from houses by concluding*: "The actors of development of wind energy should understand that no economic or political objective must not prevail over the well being and health of individuals."* In 2016 Bavaria passed legislation requiring a minimum 2km distance between wind turbines and homes, and Ireland are considering a similar measure.

The Scottish government has proposed increasing the separation distance between wind farms and local communities from 2km to 2.5km (http://www.bbc.co.uk/news/uk-scotland-scotland-politics-26579733) though in reality the current 2km separation distance is often shamefully ignored during the planning process.

Our data clearly shows that blade failure is the most common accident with wind turbines, closely followed by fire. This is in agreement with GCube, the largest provider of insurance to renewable energy schemes. In June 2015, the wind industry's own publication "WindPower Monthly" published an article confirming that "Annual blade failures estimated at around 3,800", based on GCube information. A GCube survey in 2013 reported that the most common type of accident is indeed blade failure, and that the two most common causes of accidents are fire and poor maintenance. A further GCube report in November 2015 stated that there are an average 50 wind turbine fires per year, and this remains unchanged in the latest 2018 GCube publication http://www.gcube-insurance.com/reports/towering-inferno/

The 50 fires per year is over double the reported CWIF data below, further underpinning that data presented here may only be "the tip of the iceberg".

The 2018 GCube report also notes the following:

- Wind turbine fires are greatly outnumbered by problems relating to blades and gear boxes;
- Failure of operators to undertake sufficient due diligence through maintenance checks is of increasing concern, and;
- Operating wind farms outwith their design parameters has been noted as a significant contributor to fires.

Data below is presented chronologically. It can be broken down as follows:

Number of accidents

Total number of accidents: 2500

By year:

Year	Before 2000	2000-2004	05	06	07	08	09	10	11	12	13	14	15	16	17	18	*19
No.	109	244	72	83	125	135	132	124	171	174	181	167	160	166	185	193	79

** to 30 June 2019*

Fatal accidents

Number of fatal accidents: 146

By year:

Year	Before 2000	2000-2004	05	06	07	08	09	10	11	12	13	14	15	16	17	18	*19
No.	24	12	4	5	5	11	8	8	15	17	5	3	8	6	9	3	3

** to 30 June 2019*

Please note: **There are more fatalities than accidents as some accidents have caused multiple fatalities.**

Of the 193 fatalities:

- 121 were wind industry and direct support workers (divers, construction, maintenance, engineers, etc), or small turbine owner /operators.
- 72 were public fatalities, including workers not directly dependent on the wind industry (e.g. transport workers). 17 bus passengers were killed in one single incident in Brazil in March 2012; 4 members of the public were killed in an aircraft crash in May 2014 and a further three members of the public killed in a transport accident in September 2014. This includes several suicides from those living close to wind turbines.

Human injury

173 accidents regarding human injury are documented.

By year:

Year	Before 2000	2000-2004	05	06	07	08	09	10	11	12	13	14	15	16	17	18	*19
No.	5	11	6	10	16	18	9	14	12	15	9	9	9	10	13	4	3

** to 30 June 2019*

Please note: **There are more injuries than accidents as some accidents have caused multiple injuries.**

During the 173 accidents, 205 wind industry or construction/maintenance workers were injured, and a further 76 members of the public or workers not directly dependent on the wind industry (e.g. fire fighters, transport workers) were also injured. Eight of these injuries to members of the public were in the UK.

Human health

Since 2012, 153 incidents of wind turbines impacting upon human health are recorded.

By year:

Year	12	13	14	15	16	17	18	*19
No.	6	27	19	13	17	36	28	7

** to 30 June 2019*

Since 2012, human health incidents and adverse impact upon human health have been included. These were previously filed under "miscellaneous" but CWIF believe that they deserve a category of their own. Incidents include reports of ill-heath and effects due to turbine noise, shadow flicker, etc. Such reports are predicted to increase significantly as turbines are increasingly approved and built in unsuitable locations, close to people's homes.

Blade failure

By far the biggest number of incidents found was due to blade failure. "Blade failure" can arise from a number of possible sources, and results in either whole blades or pieces of blade being thrown from the turbine. A total of 423 separate incidences were found:

By year:

Year	Before 2000	2000-2004	05	06	07	08	09	10	11	12	13	14	15	16	17	18	*19
No.	35	53	12	17	23	20	26	20	20	29	36	32	22	21	18	26	13

** to 30 June 2019*

Pieces of blade are documented as travelling up to one mile. In Germany, blade pieces have gone through the roofs and walls of nearby buildings. This is why CWIF believe that there should be a minimum distance of at least 2km between turbines and occupied housing, in order to adequately address public safety and other issues including noise and shadow flicker.

Fire

Fire is the second most common accident cause in incidents found. Fire can arise from a number of sources – and some turbine types seem more prone to fire than others. A total of 375 fire incidents were found:

By year:

Year	Before 2000	2000-2004	05	06	07	08	09	10	11	12	13	14	15	16	17	18	*19
No.	7	63	14	12	21	17	18	16	22	23	26	19	21	28	25	27	16

** to 30 June 2019*

The biggest problem with turbine fires is that, because of the turbine height, the fire brigade can do little but watch it burn itself out. While this may be acceptable in reasonably still conditions, in a storm it means burning debris being scattered over a wide area, with obvious consequences. In dry weather there is obviously a wider-area fire risk, especially for those constructed in or close to forest areas and/or close to housing. Five fire accidents have badly burned wind industry workers.

Structural failure

From the data obtained, this is the third most common accident cause, with 209 instances found. "Structural failure" is assumed to be major component failure under conditions which components should be designed to withstand. This mainly concerns storm damage to turbines and tower collapse. However, poor quality control, lack of maintenance and component failure can also be responsible.

By year:

Year	Before 2000	2000-2004	05	06	07	08	09	10	11	12	13	14	15	16	17	18	*19
No.	15	32	7	9	13	9	16	9	13	10	15	13	12	11	14	9	2

** to 30 June 2019*

While structural failure is far more damaging (and more expensive) than blade failure, the accident consequences and risks to human health are most likely lower, as risks are confined to within a relatively short distance from the turbine. However, as smaller turbines are now being placed on and around buildings including schools, the accident frequency is expected to rise.

Ice throw

43 reports of ice throw were found. Some are multiple incidents. These are listed here unless they have caused human injury, in which case they are included under "human injury" above.

By year:

Year	Before 2000	2000-2004	05	06	07	08	09	10	11	12	13	14	15	16	17	18	*19
No.	9	8	4	3	0	3	4	1	1	1	0	1	1	3	1	2	1

** to 30 June 2019*

Ice throw has been reported to 140m. Some Canadian turbine sites have warning signs posted asking people to stay at least 305m from turbines during icy conditions.

These are indeed only a very small fraction of actual incidences – a report* published in 2003 reported 880 icing events between 1990 and 2003 in Germany alone. 33% of these were in the lowlands and on the coastline.
** ("A Statistical Evaluation of Icing Failures in Germany's '250 MW Wind' Programme – Update 2003, M Durstwitz, BOREAS VI 9-11 April 2003 Pyhätunturi, Finland.)*

Additionally one report listed for 2005 includes 94 separate incidences of ice throw and two reports from 2006 include a further 27 such incidences. The 2014 entry refers to multiple YouTube videos and confirmation that ice sensors do not work.

Transport

There have been 216 reported accidents – including a 45m turbine section ramming through a house while being transported, a transporter knocking a utility pole through a restaurant, and various turbine parts falling off and blocking major highways. Transport fatalities and human injuries are included separately. Most accidents involve turbine sections falling from transporters, though turbine sections have also been lost at sea, along with a £50M barge. Transport is the single biggest cause of public fatalities and injuries.

By year:

Year	Before 2000	2000-2004	05	06	07	08	09	10	11	12	13	14	15	16	17	18	*19
No.		7	6	6	19	12	11	11	24	17	14	17	14	16	19	14	9

** to 30 June 2019*

Environmental damage (including bird deaths)

250 cases of environmental damage have been reported – the majority since 2007. This is perhaps due to a change in legislation or new reporting requirement. All involved damage to the site itself, or reported damage to or death of wildlife. 80 instances reported here include confirmed deaths of protected species of bird. Deaths, however, are known to be far higher. At the Altamont Pass windfarm alone, 2400 protected golden eagles have been killed in 20 years, and about 10,000 protected raptors (Dr Smallwood, 2004). In Germany, 32 protected white tailed eagles were found dead, killed by wind turbines (Brandenburg State records). In Australia, 22 critically endangered Tasmanian eagles were killed by a single windfarm (Woolnorth). Further detailed information can be found at: www.iberica2000.org/Es/Articulo.asp?Id=3071

600,000 bats were estimated to be killed by US wind turbines in 2012 alone. 1.4 million bird fatalities per annum are estimated if the US reaches it's 20% target for wind generation.

1,500 birds are estimated to be killed per year by the MacArthur wind farm in Australia, 500 of which are raptors.

By year:

Year	Before 2000	2000-2004	05	06	07	08	09	10	11	12	13	14	15	16	17	18	*19
No.	1	11	7	5	10	21	13	20	20	20	16	21	18	22	16	24	5

** to 30 June 2019*

Other (miscellaneous)

512 miscellaneous accidents are also present in the data. Component or mechanical failure has been reported here if there has been no consequential structural damage. Also included are lack of maintenance, electrical failure (not led to fire or electrocution), etc. Construction and construction support accidents are also included, also lightning strikes when a strike has not resulted in blade damage or fire. A separate 1996 report** quotes 393 reports of lightning strikes from 1992 to 1995 in Germany alone, 124 of those direct to the turbine, the rest are to electrical distribution network.

*** (Data from WMEP database: taken from report "External Conditions for Wind Turbine Operation – Results from the German '250 MW Wind' Programme", M Durstewitz, et al, European Union Wind Energy Conference, Goeteborg, May 20-24, 1996)*

By year:

Year	Before 2000	2000-2004	05	06	07	08	09	10	11	12	13	14	15	16	17	18	*19
No.	13	47	12	16	18	24	27	25	43	36	33	33	42	32	34	56	20

** to 30 June 2019*

Caithness Windfarm Information Forum
30 June 2019

Wind turbine keels over in County Down

2 February 2017 Northern Ireland

They are used to generate electricity but this wind turbine at Ballynahinch, County Down, sparked interest from a sharp-eyed snapper after appearing to keel over.

The cause of the damage to the turbine near Begny Hill Road is still to be established.

But the eagle-eyed photographer was at the scene to capture what happened.

It is understood the turbine had only been installed in the last few days, but was not in operation.

The **NIdirect government website** says it is best to position a turbine "high on a mast or tower, as wind speed increases with height".

It adds that the "ideal site is a hill with a flat, clear exposure, free from strong turbulence and obstructions like large trees, houses or other buildings".

Share this story About sharing

Top Stories

Trump vows to restore travel ban
The US president accuses the judge who suspended his travel ban of undermining law enforcement.
4 February 2017

Trump beheading cover sparks criticism
4 February 2017

Labour promises cap on energy price rises
4 February 2017

Features

Nature's majesty
Winning photos of great gardens and parkland

10 things
Johnny Depp's alleged wine bill, and more news nuggets

'This is the end'
Black Sabbath call time on 50-year career

My missing mum
How a man's search for his birth mother uncovered her death

Flip-flopping shoppers
Retailers 'left behind' as buying habits change

Five of the worst
Sharknado and other 'bad' movies that audiences love

Super Bowl surprises
Seven eye-boggling moments from previous half-time shows

BBC News Services

On your mobile

On your connected tv

ANNEX 5

cehog
Chief Environmental Health Officers Group N.I.

11th March 2008

Mr Stephen Hamilton
PPS 18 Renewable Energy Consultation
Planning and Environmental Policy Group
Department of the Environment
12th Floor River House
48 High Street
BELFAST BT1 2AW

Dear Mr Hamilton

DRAFT PLANNING POLICY STATEMENT 18 – RENEWABLE ENERGY: CONSULTATION PAPER

The Chief Environmental Health Officers Group (CEHOG) are grateful for the opportunity to comment on the above.

I attach a response on this consultation prepared on behalf of CEHOG by the NI Pollution sub-group.

Yours sincerely

Barny Heywood

Chairman:
Nigel McMahon
Chief EHO
DHSSPSNI
Castle Buildings, Stormont
BELFAST BT4 3SQ
Tel: (028) 9052 0552

Secretary:
Barny Heywood
Western Group Environmental Health Service
Lisnamallard House, Old Mountfield Road
OMAGH, Co. Tyrone, BT79 7EG
Tel: (028) 8224 5321 / Fax: (028) 8224 5526

CEHOG Northern Ireland Pollution Sub-Group response to:
Draft Planning Policy Statement 18 - Renewable Energy: Consultation Paper
February 2008

The following response has been prepared by the CEHOG Pollution Sub-Group.

Introduction

The Government's energy policy aims to put the UK on a path to cut its carbon dioxide emissions by some 60% by 2050, with real progress by 2020, and to maintain reliable and competitive energy supplies. The development of renewable energy will make a vital contribution to these aims.

The Environmental Health profession welcome Planning Policy Statement 18 - Renewable Energy: Consultation Paper and endorse the Governments stance on reducing greenhouse gases and thereby reducing the potential for the environment to be affected by climate change.

Through the development control process, environmental health departments within their consultation responses endeavour to ensure that loss to residential amenity is minimised or object to such developments were detriment to residential amenity cannot be avoided. Current planning policy and guidance shapes environmental health department's consultation responses. It is with this perspective that the following comments are made:

Stakeholder Group

The environmental health profession actively contribute to the planning process, by providing Planning Service with expert opinion regarding the environmental impact from proposed developments e.g. noise, dust, odour impacts etc. The environmental health profession is therefore disappointed that it was not given an opportunity to provide advice and assistance within the stakeholder group.

The environmental health profession would welcome the opportunity to sit on any future planning policy stakeholders group, which addresses policy on development with the potential to impact on the environment and amenity.

Policy RE 1 - Wind Energy Development

Page 15, paragraph (vi) states,

"... the development will not cause significant harm to the safety or amenity of the users of any regularly occupied building arising from noise; shadow flicker; ice throw; and reflected light"

It is noted that, *"regularly occupied building"* is not defined within the consultation paper. Using the examples of, a residential property located in close proximity to a proposed wind farm which has not been occupied for some time but would still be in a habitable condition or a holiday home only occupied on an ad-hoc basis, a developer may use the argument that he is not required to assess the impact on such properties as they are unlikely to fall under the wording of *"regularly occupied building"*. Such circumstances could lead to loss to residential amenity for residents/future residents of these properties where the nature of the occupancy could change to fall within the "regularly occupied" term. Environmental Health (EH) recommend that impact assessments should be conducted for all sensitive receptors in the vicinity of wind farms, not just *"any regularly occupied building"*, as this would prevent any future sensitive receptors being subjected to reduced amenity.

EH recommend that the above wording be changed to:

"... the development will not cause significant harm to the safety or amenity of any sensitive receptors (including future occupants of committed developments) arising from noise; shadow flicker; ice throw; and reflected light"

Planning Service may wish to define sensitive receptors within the final policy document e.g. habitable residential accommodation (not necessarily occupied), hospitals, schools, churches etc.

Microgeneration – Provision of information
Page 20, paragraph 4.25 states,

"...For most micro-generation schemes a short report will normally suffice..."

As highlighted within a previous consultation response from the Chief Environmental Health Officer's Group regarding proposed permitted development rights for micro-generation; micro-generation schemes can result in loss to residential amenity by reason of noise disturbance if they are inappropriately located or specified.

EH departments regularly request manufacturers noise source data for micro-generation schemes proposed in close proximity to noise sensitive receptors. Therefore, it is suggested that the above statement be amended to take into consideration the need for such data, therefore removing the need to request such data at the consultation stage and expediting the planning decision process.

Limiting factors of wind farm size
Page 31, paragraph A14 states,

"Wind turbines can be deployed singly, in small clusters, or in larger groups known as wind farms. Factors that may influence the size of a development include the physical nature of the site, the capacity of the local electricity distribution network and the organisation undertaking the development..."

It is the experience of EH departments that noise impact on local residents has also been a major influence on the size of wind farm developments. As rural locations have become more populated over the past decade, it has been increasingly difficult for developers to locate suitable sites which allow sufficient separation distances between the wind turbines and local residents, to prevent detriment to amenity by reason of noise. EH suggest that the above wording be changed to:

"Factors that may influence the size of a development include the physical nature of the site, the capacity of the local electricity distribution network, the organisation undertaking the development and the noise impact on sensitive receptors... "

Separation distance
Page 32, paragraph A17 states,

"Bearing in mind the requirements for optimal performance, a distance of not less than two rotor diameters from adjoining property boundaries will generally be expected, unless there is written agreement of adjoining landowners to a lesser distance. "

A separation distance of approximately two rotor diameters between a large wind turbine and neighbouring sensitive receptors is unlikely to be sufficient to reduce the noise impact from the wind turbine to within acceptable levels. It is noted that the above paragraph refers to '*adjoining property boundaries*'. It is suggested that further definition of this statement, which makes it clear that the separation distance of two rotor diameters refers to separation from adjoining property boundaries such as agricultural land where no sensitive receptors are present at that point, may be helpful.

Cumulative noise effects
Page 35, paragraph A35 states,

"Information on any cumulative effects due to other projects, including effects on natural heritage and visual effects... "

EH suggest that noise impact should also be included within the above paragraph. The DTI publication, 'The assessment and rating of noise from wind farms, ETSU-R-97' with regard to cumulative noise impacts states,

"The Noise Working Group is of the opinion that absolute noise limits and margins above background should relate to the cumulative effect of all wind turbines in the area which contribute to the noise received at the properties in question... "

Protection of amenity
The document advises that the planning policy aims to prevent unacceptable detrimental effects upon the locality and amenity. Page 36, paragraph A37 states,

"The planning system exists to regulate the development and use of land in the public interest. The material question is whether the proposal would have an unacceptable detrimental effect on the locality generally, and on amenities that ought, in the public interest, to be protected. "

However the level of protection afforded by the current ETSU-R-97 standard referenced on page 45 would be considered to provide a lower level of protection against "unacceptable detrimental effects on the locality generally, and on amenities…". Page 45, paragraph A79 states,

"The report, 'The Assessment and Rating of Noise from Wind Farms' (ETSU-R-97), describes a framework for the measurement of wind farm noise and gives indicative

noise levels calculated to offer a reasonable degree of protection to wind farm neighbours, without placing unreasonable restrictions on wind farm development."

The Department should give careful consideration to the possible interpretation of such terminology and references and should ensure that the final wording of the Statement will ensure that local amenities are adequately protected. Accordingly, the Department may wish to align the wording of paragraph A37 with that used within paragraph A79.

Noise levels generated by wind turbines
Page 45, Table 1, '*Noise generated by wind turbines compared with other everyday activities'*, presents a number of typical noise sources and their approximate noise levels. With regard to wind farms it states, "*Wind Farm at 350m , 35–45 dB*".

The above information could be construed as suggesting that wind farms positioned at 350m are acceptable. As a rule of thumb, 500 metres between wind farm developments and sensitive receptors is normally considered sufficient distance, however, even distances in excess of 500 metres may be inadequate in specific circumstances. With regard to separation distances, ETSU page 46, paragraph 7 states,

"The difference in noise emissions between different types of machine, the increase in scale of turbines and wind farms seen today and topographical effects described below all dictate that separation distances of 350 – 400 metres cannot be relied upon to give adequate protection to neighbours of wind farms."

EH suggests that the above reference be added to paragraph A76 and that the separation distance as presented within Table 1 be increased to 500 metres.

Exceedence of background noise level
Page 45, paragraph A78 states,

"Wind-generated background noise increases with wind speed, and at a faster rate than the wind turbine noise increases. The difference between the noise of the wind farm and the background noise is therefore liable to be greatest at low wind speeds..."

It has been the experience of EH departments in reviewing noise impact assessments for wind farm developments, that the difference between noise from wind farms and the background noise level is likely to be greatest at wind speeds of 6 – 8 m/s. This is due to noise from wind turbines increasing significantly at these wind speeds prior to plateauing. Whether wind speeds of 6 – 8 m/s could be described as 'low' wind speeds is a matter of opinion. EH suggest that the above wording be changed to:

"...The difference between the noise of the wind farm and the background noise is likely to be greatest at wind speeds in the range of 6 to 8 m/s..."

Low frequency noise
It is noted that reference to the 2006 DTi document entitled, *"The measurement of low frequency noise at three UK Wind Farms, W/45/00656/00/00"* is absent within

the low frequency noise section on page 48 of the consultation paper. The DTi's documents principle findings were, *"infrasound associated with modern wind turbines is not a source which will result in noise levels which may be injurious to the health of a wind farm neighbour... low frequency noise was measurable on a few occasions, but below the existing permitted Night Time Noise Criterion... data collected showed that the internal noise levels were insufficient to wake up residents at these three sites..."*

Planning Service may wish to make reference to the DTi document within the low frequency noise section.

Biomass Plant.

Page 65, paragraph B29 advises regarding the regulation of emissions and waste products from biomass energy plant. The Department should be aware that the emissions from such plant may impact upon district council's Local Air Quality Management duties under the Environment (NI) Order 2002 as well as the enforcement of the requirements of the Clean Air (NI) Order 1981.

Therefore the Planning Service should include consultation with district council environmental health within paragraph B29.

As road traffic is the main source of air pollution, the potential emissions from traffic associated with larger biomass power facilities would be a concern in relation to local air quality management. Environmental Health would suggest that page68, paragraph B45 be amended to read, *"traffic to and from the site in order to transport biomass fuel and subsequent by-products. Traffic volumes, and the associated noise and local air pollution impacts may increase with the introduction of a larger biomass facility..."*

References to Pollution Prevention and Control Regulations (NI) 2003

Page 65, paragraph B27 makes reference to the '*pollution protection control regime*'. EH suggest that the reference is changed to '*pollution prevention and control regime*' in line with the current title of this regulatory regime.

Paragraph B30 makes references to airborne emissions from biomass power plants and discusses stack heights. It would be useful at this point to remind readers that depending on the capacity and fuel of the biomass plant, airborne emissions may be controlled via a permit issued under the Pollution Prevention and Control Regulations (PPC Regulations). Within the permit, conditions require the operator to manage the biomass plant in an appropriate manner, including achievement of emission limits. The enforcing authority for the PPC regulations is dependent on the size of the biomass plant, being either the District Council or the Environment and Heritage Service (EHSNI).

Waste Management Licensing

Page 69, Paragraph B48 makes reference to the various authorisations/permits that may also be required in addition to the seeking of planning permission for a biomass plant. It is noted that reference to Waste Management Licensing is absent. The EHSNI are the enforcing authority for the Waste Management Licensing Regulations

(NI) 2003. EH suggest that reference is made to the seeking of a waste management licence or licence exemption if waste is to be processed within the biomass plant.

Anaerobic Digesters

Page 80, paragraph C54 notes a number of items which could usefully be included with a planning application for an anaerobic digester. EH suggest that if the anaerobic digester was to be located in close proximity to neighbouring sensitive receptors that both noise and odour impact reports should also be included with any planning application.

Energy from waste

Page 87, paragraph D27 states,

"A plant that complies with license requirements for air pollution might still give rise to odours. For large projects such as MSW incinerators odour is covered under the IPPC authorisation, and for smaller projects it is covered under the local authority authorisation."

Changes in the legislation from the Industrial Pollution Control (NI) Order 1997 (IPC) to the Pollution Prevention and Control Regulations (NI) 2003 (PPC) have progressively removed authorisations and replaced them with permits. Under the PPC Regs, district councils are the enforcing authority for Part C prescribed processes. Therefore, EH suggest that the wording of the above paragraph be changed to:

"For large projects such as MSW incinerators odour is covered under the EHSNI PPC permit, and for smaller projects it is covered under the district council PPC permit."

The emissions from of certain types of Energy from Waste Plant has the potential to adversely affect district council's Local Air Quality Management duties under the Environment (NI) Order 2002 as well as the enforcement of the requirements of the Clean Air (NI) Order 1981.

Therefore EH would suggest that page 87, paragraph D27 is amended to include the following sentence:

"Emissions from Energy from Waste Plants, and traffic movements associated with larger plant, have the potential to adversely affect district council's Local Air Quality Management Plans".

It is also noted that 'Information to Accompany a Planning Application' within paragraph D30 does not make specific reference to odour impacts. EH suggests that an additional line be added, *"details of odour emissions and an assessment of their impacts."*

Hydroelectric Schemes

Page 94, paragraph E27 states,

"The noise emitted from a turbine will generally be well contained by the turbine house and not be heard more than a few metres away. If necessary, limits can be set

on noise emissions if the site is close to residential properties, by way of a planning condition."

EH welcome the use of planning conditions to limit noise emissions from hydroelectric schemes. It is suggested that the use of noise conditions should not just be limited to hydroelectric schemes but should also be employed to control noise from all types of renewable energy projects, when applicable.

Ground, Water and Air Source Heat Pumps

It is noted that reference to noise impacts is absent, within the section on heat pumps. It would appear from researching material on air source heat pumps, that they are similar in size, appearance and noise level (59 dB(A) at 1m) to commercial air handling/ refrigeration units. Councils across Northern Ireland receive numerous noise complaints every year regarding the inappropriate selection and location of such units.

EH suggest that reference is made to the fact that noise from heat pumps may cause loss to residential amenity if they are inappropriately selected or located. In providing a consultation response to Planning Service, EH departments may request noise level data for heat pumps, where they are located in close proximity to neighbouring sensitive receptors.

Dick Bowdler
Acoustic Consultant

01383 882 644
077 8535 2534
dick@dickbowdler.co.uk

ETSU-R-97

Why it is Wrong

Dick Bowdler

V2 – February 2006

The Haven, Low Causeway, Culross, Fife. KY12 8HN

ETSU-R-97

Why it is Wrong

1 INTRODUCTION

1.1 ETSU-R-97 is used throughout the UK to assess wind farm noise in planning applications. It has been incorporated into PAN45 in Scotland and PPS22 in England. Nevertheless it is a thoroughly flawed document and does not deserve the prominence it has been given.

1.2 The conclusions of ETSU-R-97 are so badly argued as to be laughable in parts (the daytime standard is based on the principle that it does not matter if people cannot get to sleep on their patio so long as they can get to sleep in their bedrooms). It is the only standard where the permissible night time level is higher than the permissible day time level.

1.3 ETSU-R-97 bears no resemblance to standards used for other industrial developments. Other renewable energy developments have to meet stricter standards. At several points the Noise Working Group that drew up the document decided that a particular standard was appropriate and then, without putting forward any evidence said that such a standard would restrict development of wind farms and so relaxed it further.

2 ASSESSMENT OF THE IMPACT OF ENVIRONMENTAL NOISE

2.1 It seems common sense that the impact of a new noise on existing residences is related in some way to the background noise. For example if the background noise level at present is 45dBA then a level of 35dB from a new industrial source would probably be inaudible. If the background noise level at present is 20dB then an industrial noise of 35dB will clearly be heard and would be very likely to produce complaints.

2.2 Indeed it is normal to set a noise limit relative to the pre-existing background noise when a new industrial noise is to be introduced into a residential area. Typical planning conditions imposed by rural local authorities (and sometimes urban ones) require that the new noise be no more than 5dB above the pre-existing background. This is based on the procedure set out in British Standard 4142.

2.3 In fact BS4142 does not purport to be a method of assessing nuisance or amenity. It was first published in 1967 and has since been revised twice though the general principles remain the same. It is simply a method of assessing the likelihood of complaints. Its origin is obscure and it has been the subject of endless criticism for a whole variety of reasons. But the fact is that it works. It has been and is still regularly used to assess noise impact and I do not know of one case where it has been suggested that BS4142 gave an anomalous result. Furthermore it was endorsed by DEFRA in September 1998, the department of government concerned with the environment at that time. They submitted their Noise and Nuisance Policy under Health Effect Based Noise Assessment Methods to the EU. This said that *BS4142:1997 provides a technical means of assessing whether or not 'complaints are likely'. The result of an assessment carried out to BS4142 would normally be relevant to the deliberations of any court considering whether or not a nuisance exists.*

2.4 BS4142 is not normally used to assess wind farms. This is done using the document ETSU-R-97 "The Assessment and Rating of Noise from Wind Farms".

2.5 ETSU-R-97 was written by a Noise Working Group (NWG) of developers, noise consultants, environmental health officers and others set up in 1995 by the Department of Trade and Industry through ETSU (the Energy Technology Support Unit). The DTI's mission is *prosperity for all by working to create the best environment for business success in the UK*. It has no brief for the protection of the environment or for the protection of the citizen from nuisance or loss of amenity. ETSU was the UK Government executive agency for energy technologies.

2.6 The status of ETSU-R-97 is perfectly clear. The preface says *The aim of the Working Group was to provide information and advice to developers and planners on the environmental assessment of noise from wind turbines. While the DTI facilitated the establishment of this Noise Working Group this report is not a report of Government and should not be thought of in any way as replacing the advice contained within relevant Government guidance. The report represents the consensus view of the group of experts listed below who between them have a breadth and depth of experience in assessing and controlling the environmental impact of noise from wind farms. This consensus view has been arrived at through negotiation and compromise and in recognition of the value of achieving a common approach to the assessment of noise from wind turbines.*

2.7 The first paragraph of the executive summary says *This document describes a framework for the measurement of wind farm noise and gives indicative noise levels thought to offer a reasonable degree of protection to wind farm neighbours, without placing unreasonable restrictions on wind farm development or adding unduly to the costs and administrative burdens on wind farm developers or local authorities.*

2.8 It is thus, by its own admission, not a method of assessing impact. What is more, the compromise reached by the NWG is so lacking in basis, so full of unfounded assertions and so badly thought out and argued that it comes up with standards for wind farm noise that are quite unlike any other noise standards. I need to explain in some detail why this is the case so that my point can be fully understood.

3 The NWG argument in ETSU

3.1 I have explained why the assessment method in ETSU-R-97 is not a measure of impact. I need to describe how the assessment method was developed by the NWG in order to explain how it relates to normal methods of measuring impact. The NWG starts by pointing out that the planning advice relating to noise says that the likelihood of complaints can be assessed, where the Standard is appropriate, using guidance in BS 4142: 1990. In examining whether BS4142 is appropriate for assessing wind turbine noise the NWG suggests that there are three reasons why it might not be. These are:

> *Wind farms are likely to be developed in largely rural areas and not in the areas to which the standard is principally addressed, namely mixed residential and industrial areas;*
>
> *the scope of BS 4142 specifically precludes situations where background noise levels are below 30dB(A);*
>
> *BS 4142 recommends that noise measurements should not be taken in extreme weather conditions such as high wind speed greater than 5 metres per second average* ".

3.2 In answer to the first point they say *Although the standard is intended for use in mixed residential and industrial areas as suggested by its title, there are no obvious reasons which prevent its application in more rural areas and indeed Members of the Noise Working Group have used it in such areas.* So BS4142 is not rejected for this reason.

3.3 To the second point they say, after some debate, *The question that arises is: if one intends to apply the principles of BS 4142 to the protection of external amenity, and the instrumentation is available to accurately measure noise levels below 30dB(A), should a margin above background approach be pursued in low noise environments or can an absolute level be justified in such circumstances?* They leave the question to be dealt with later. I should point out that since ETSU-R-97 was published BS4142 has been revised so that low noise levels are only excluded when both the background is less than 30dB and the turbine noise is less than 35dB.

3.4 Whatever the NWGs answer to the third reason, and it is not very clear what that answer is, it is obvious that they accept that there is no reason to reject the use of BS4142 at higher wind speeds because ETSU itself says that background noise should be measured at all wind speeds up to 12m/s.

3.5 In summary, thus far the NWG seem to find no good reason to reject BS4142 except that it leaves open the possibility of whether to adopt a limiting absolute level to be dealt with later.

3.6 At this point it is necessary for me to explain L_{A90} and L_{Aeq}. Noise levels can be stated in different ways. For example if a noise is fluctuating we could talk about the minimum or the maximum or the average. BS4142, in accordance with international practice, uses the measure L_{Aeq} to describe the specific noise – that is the noise to be assessed. This is effectively an average. It is actually a logarithmic average but that is of no real significance here. Again in accordance with common practice BS4142 uses L_{A90} to define background noise. This is the level exceeded for 90% of the time, so in a ten minute period the noise level is more than the L_{A90} for an aggregate of 9 minutes. So the L_{A90} is usually close to the minimum noise level.

3.7 On the question of turbine noise the NWG put forward the suggestion that L_{A90} should be used to measure turbine noise. This is because the measure will eliminate other extraneous noise. For example, if a site is affected by an occasional passing car, the L_{Aeq} may be determined by the car whilst the L_{A90} may not. I have no objection to the principle of measuring turbine noise by the use of L_{A90}. This is a method I often use where the difference between the L_{Aeq} and the L_{A90} is known and constant. However, it would be much better to measure as L_{A90} and then add back 2dB (the difference between the two) to get the L_{Aeq} value so that the units remain consistent with BS4142 and other normal practice. ETSU-R-97 carries on describing turbine noise as an L_{A90} which simply leads to confusion. BS7445 (Also ISO1996) *Description and Measurement of Environmental Noise* makes it clear that environmental noise is to be described as L_{Aeq}.

3.8 On Page 59 ETSU-R-97 says *It is proposed that the background noise levels upon which limits are based, and the noise limits themselves, are based upon typical rather than extreme values at any given wind speed. An approach based upon extreme values would be difficult to implement as the difference in measurements between turbine noise and background would depend upon the length of time one is prepared to take data. A more sensible approach is to base limits upon typical or average levels, but to appreciate that both turbine and background noise levels can vary over several dB for the same nominal conditions.* What they are saying is that, having measured background noise levels over a period of several weeks we should take the background noise level at each wind speed as the average of all the background noise levels at that wind speed. This is completely inconsistent with normal practice and suggesting it is "sensible" is merely an unfounded assertion. In using BS4142 in the field we are generally required by local authorities to measure at the quietest part of the period in question. It is not acceptable, where traffic noise predominates, to take an average of the L_{A90} values over, for example, a whole night time period. The local authority will require the background noise in the middle of the night when it is quietest. For example

> A letter from Renfrew Council in 2004 in connection with a planning application says that the impact of noise on nearby dwellings should be assessed by BS4142 and that *the background noise level for the most sensitive period that the source could operate should be used for this assessment.*
>
> At the Portree Co-Op development it was agreed that *In accordance with BS4142 the background noise should be measured as L_{A90} and the noise from the development as L_{Aeq}. Measurements of L_{A90} over any specific period should be carried out in wind speeds less than 5m/s and during a representative part of the period including the quietest part of the period. The measurements should be made in intervals of between 5 and 15 minutes. The average and standard deviation of all the measurements should be calculated and the background noise taken as the average less one standard deviation.* So the level required is more or less the quietest part of a quiet night.

3.9 In the case of background noise dominated by wind it has been my practice to take the average and the standard deviation of a group of 10 minute measurements and to define the period L_{A90} as the average less one standard deviation. Typically this is about 4dB less than the average. Statistically 15% of the time the background noise is below this level. Unless there is a large variation between day and night time background noise I will normally use the whole 24 hour data rather than separate day and night.

3.10 Returning to ETSU-R-97 on page 60, continuing discussion on background noise the NWG say, *Noise from the wind farm will be limited to 5dB(A) above background for both day- and night-time. When comparing the proposed margin with the complaints criteria suggested by BS 4142 it is important to bear in mind that the LA90 descriptor is also being proposed for the turbine noise. The Leq levels can be expected to be about 1.5-2.5dB greater. An addition of 1.5-2.5dB places the margin at the upper end of the range which can be considered to be of marginal significance ie around 5dB.* What they appear to be saying is that, because turbine noise is measured as L_{A90}, the margin above background noise that is proposed is actually 7dB in normal BS4142 terms rather than the 5dB normally adopted by local authorities. There is nothing in BS4142 that suggests that 7dB is *at the upper end of the range which can be considered to be of marginal significance.* This phrase is simply an invention of the NWG.

3.11 Further down page 60 it says that *On balance it is considered that a margin of 5dB(A)* (by which it means 7dB in BS4142 terms) *will offer a reasonable degree of protection to both the internal and external environment without unduly restricting the development of wind energy which itself has other environmental benefits.* There is no foundation whatsoever for this assertion. No evidence is brought forward or referred to.

3.12 So the position in the argument so far is this. The NWG has decided, without any foundation, that the 5dB "marginal significance" in BS4142 could be 7dB. It has decided, against all normal practice, that the background noise level for assessment purposes ought to be the average of background levels in any particular condition rather than the lowest level. In wind controlled background noise the average is likely to be at least 4dB more than a realistic background level. So the NWG consider that 11dB over background is appropriate for wind farms as against normal practice for industrial noise of 5dB over background noise. Of course I have to bear in mind that ETSU-R-97 does not purport to offer a method of assessment of impact. So the NWG is proposing that, for wind farms, a level of noise that is likely to give rise to complaints is appropriate because of the particular public benefits of wind farms. I cannot agree with this. As I exemplify elsewhere other projects of public benefit have to meet the stricter standard of 5dB above background.

3.13 Not content with establishing a margin above background noise far greater than normal, the NWG, at the bottom of page 60, continues *Applying the margin above background approach to some of the very quiet areas in the UK would imply setting noise limits down to say 25-30dB(A) based upon background levels perhaps as low as 20-25dB(A).* This is true in principle but in practice turbines generate less noise at low wind speeds and, at cut in, turbine noise might have to be limited in some areas to as little as 25dB. By the time wind speed was up to 6m/s the background noise level would be at least 25dB probably more like 30dB and so this would require turbine noise to be restricted to less than 30-35dB rather than 25-30dB. *Limits of this level would prove very restrictive on the development of wind energy.* This is simply a broad assertion. No evidence whatsoever has been adduced to demonstrate this.

3.14 Some measure of loss of amenity needs to be applied in low background noise levels and it is normal practice in rural Scotland (and sometimes in towns) to use BS4142 even in low background noise levels. For example:

> Co-Op Retail Store, Portree in 2002. *Noise of plant from the development should not exceed the background noise level by more than 5dBA or, if the noise is tonal, should not exceed the background noise at all at any noise sensitive property.* The background noise at Home Farm Road was measured at 28dB on a calm night and this was agreed as the background noise.
>
> New factory for Vestas at Machrihanish in 2001. At this new factory (ironically the factory that makes wind turbines) Argyll and Bute Council require that: *The rated noise level from the development shall not exceed the predetermined ambient noise level (the L90(A)) at the nearest noise sensitive properties at the former RAF housing, by more than 5dB(A). All measurements are to be taken in accordance with BS4142: 1997 with the measurement periods being 1 hour for the period 0800-2200 hours and 5 minutes for the period 2200-0800 hours.* The night time background noise was agreed at 27dB which was the lowest hourly level reached

during a windless night. Earlier measurements when there was sea noise and the background was 32dB were not accepted by the council.

In 2004, SEPA, at Roslin in Midlothian, asked for a BS4142 assessment for a landfill gas generator even though the background noise level was only 27dB.

3.15 On page 61 the NWG say *During the night one can reasonably expect most people to be indoors and it will not be necessary to control noise to levels below those required to ensure that the restorative process of sleep is not disturbed. A night-time absolute lower limit is therefore appropriate based upon sleep disturbance criteria.* What this says is that a turbine noise level inside peoples houses of just less than the World Health Organisation say is necessary to get back to sleep if you wake up in the night is satisfactory. It seems to me this must be the very upper limit of acceptability, not one that is well balanced. Since then, the WHO has revised its guidance 5dB lower. So the ETSU night standard is now higher than WHO say you need to get back to sleep.

3.16 When they come to day time, on Page 62 of ETSU-R-97, it says *It is also the opinion of the Noise Working Group that there is no need to restrict noise levels below a lower absolute limit of LA90,10min = 33dB(A); if an environment is quiet enough so as not to disturb the process of falling asleep or sleep itself then it ought to be quiet enough for the peaceful enjoyment of one's patio or garden.* This is a bizarre statement. It seems that the 33dBA is the 35dB sleep restoration level set out by the World Health Organisation for inside bedrooms at night. They seem to be saying that there is no need for noise levels during the day to be any lower than is necessary to allow you to go to sleep on your patio on a sunny afternoon.

3.17 Having suggested that 33dB would be satisfactory because people could get to sleep on their patio – they now say that *This level would however be a damaging constraint on the development of wind power in the UK as the large separation distances required to achieve such low noise levels would rule out most potential wind farm sites.* There is absolutely no evidence brought forward to justify this. A margin of 2km would normally easily achieve this even with the noisier modern turbines. They argue that *Wind farms have global environmental benefits which have to be weighed carefully against the local environmental impact.* So do many other things. They argue that *Wind farms do not operate on still days when the more inactive pastimes (eg sunbathing) are likely to take place.* The suggestion seems to be that the protection of people's amenity does not include protecting them whilst sunbathing in their gardens on a slightly windy day or sleeping on the patio.

3.18 Then, on page 63 there is another leap of credibility: *There is no evidence for or against the assertion that wind farm noise with no audible tones is acceptable up to and including LA90,10min levels of 40dB(A) even when background noise levels are 30dB or less.* This is just nonsense. There most certainly is evidence against this assertion. The 40dB is actually 42dB in

BS4142 units. This is at least 12dB above background noise level of "30dB or less" and BS4142 says there are likely to be complaints at turbine levels of plus 10dB. Furthermore there is no argument that BS4142 is not applicable. Even BS 4142:1990 (which was current when ETSU-R-97 was written) might easily be applicable here. If the wind speed is 5m/s, the background noise 30dB and the turbine noise 42dB(LAeq) then there is no reason not to use BS4142, it does not exclude itself in these circumstances. This noise level is also 12dB more than (twice as loud as) the WHO considers necessary for you to be able to get to sleep.

3.19 They summarise this *For periods during the day the Noise Working Group has adopted the approach that external noise limits should lie somewhere between that required to avoid sleep disturbance even if the occupant is outside of the property and the higher level that would still prevent sleep disturbance inside the property.* In other words the lowest turbine noise level that they would adopt, during the day, would be high enough to prevent you getting to sleep on your patio. The highest level they adopt during the day would not quite stop you getting back to sleep in your bedroom. Presumably the principle is that, if it is too noisy to sleep outside on your patio you can be assured you will be able to get to sleep indoors.

4 Conclusion

4.1 ETSU-R-97 is so poor technically that its conclusions have to be queried. It is put together through a series of unfounded assertions and there has been no research drawn on to justify them.

4.2 Even if one were minded to accept the suggestion that there ought to be a background noise level below which it would be appropriate to use an absolute noise level, the absolute levels proposed by the NWG are not acceptable. The night time level is 45dB(L_{Aeq}) and the day time level is 37 to 42dB(L_{Aeq}). Most wind farm sites are in rural areas where background noise levels can easily be 20 to 25dBA when turbines are operating and so the margin above background could be as much as 20dBA – a quadrupling of loudness.

inter.noise
HAMBURG 2016

A quantitative and qualitative review of amplitude modulation noise from wind energy development.

Sarah LARGE[1]

[1] MAS Environmental

ABSTRACT

The adverse impact of amplitude modulation (AM) has been acknowledged in research, papers, and anecdotal evidence since at least 2002. Only in 2013, in the UK, did wind industry acousticians finally acknowledge the common impact of AM and the need for control. Some still deny the need for control at public inquiries. Despite two independent bodies, the Institute of Acoustics (IoA) and the Independent Noise Working Group (INWG), announcing a review of AM from a planning perspective in 2014 and the UK Government's DECC commissioning further review of AM in 2015 the UK is still, at the time of writing, without any unanimous and/or accepted guidance for assessing and conditioning AM at the planning stage. This paper reviews a range of metrics and methods that have been proposed and their ability to work with real world data. This paper questions whether a "one size fits all", purely quantitative approach reflects subjective AM impact and provides initial findings of a preliminary study testing whether different manifestations of AM can be considered equal.

1. INTRODUCTION

The rhythmic variation of wind turbine noise, occurring at blade pass frequency, is generally termed amplitude modulation (AM). This aspect of wind turbine noise is commonly generated by wind turbines (1). There is still no consensus amongst those researching and assessing the occurrence of AM in the far field as to how to describe (qualitatively and quantitatively) this aspect of the noise, to what degree it is a problem, how often it occurs, what causes it and on a more basic level what term should be used to describe it. In the UK AM that occurs in the far field and is outwith the definition provided in ETSU-R-97 has been referred to as "excess" or "enhanced" amplitude modulation (EAM). Others have referred to it as "greater than expected amplitude modulation" (GTEAM) whereas a research project published in 2013 provided definitions for "normal" AM (NAM) and "other" AM (OAM) (2). This lack of clarity in the acoustics community is equally reflected by those who experience AM in and around their homes and provide a range of descriptors and comparators when describing impact (3).

Whilst wind farm noise and specifically AM are a significant source of complaints, relying on complaints alone cannot fully describe the extent of the problem (4). The WHO estimate that only 15-25% of people identified as highly annoyed by noise will complain (5). The character of AM within wind farm noise adds to its annoyance (6). In the UK most of those working for and with the wind industry appear to have recognised the issue of AM and accept it is in need of control, but how is still a matter of debate.

2. METHODS FOR MEASURING AND ASSESSING AM

2.1 Noise conditions

A minority of wind farms in the UK have been approved with a planning condition to control AM. In 2009 the Den Brook Wind Farm was approved with a condition that considered the regular occurrence of AM in excess of 3dB (as a peak to trough value in the A weighted time series) in the far field as unreasonable. This has since been added to by the developer to include a scheme for the identification of GTEAM (Den Brook Wind Farm, "condition 21") and involves finding the energy within a critical band centred on the blade passing frequency, looking for values greater than 2.5.

A draft planning condition was appended to the Renewable UK research published in December

[1] sarah@masenv.co.uk

2013 (2) and this has been adopted in some cases. This uses a similar methodology to that of the condition 21 referenced above. It finds the energy at blade passing frequency and uses this as the AM value for that period. These values are averaged over a 10 minute period followed by a further averaging of the 10 minute values for each wind speed (using a best fit line). A penalty (maximum of 5dB) is applied to the wind farm noise level depending on the AM value for each wind speed. Significant flaws with this approach and the developer modified Den Brook condition (condition 21) have been identified (7) through testing with an extensive database of EAM obtained from the Cotton Farm Wind Farm where a permanent monitoring station has been established.

Outside of the UK, draft planning guidelines for wind farms in New South Wales set a variation of 4dB(A) at the blade passing frequency as excessive amplitude modulation. This results in a 5dB(A) penalty applied to the measured wind farm noise level. Previous research by the author has shown that application of a 5dB penalty to the UK wind farm noise limits would fail to prevent adverse impact in the majority of cases tested (8).

2.2 Methods of identifying AM

Whilst there are relatively few criteria for judging the acceptability of AM there are a number of methods for identifying and quantifying AM. These have been categorised in to time domain, frequency domain and hybrid methods (9). Examples include the (original) Den Brook condition, which identifies AM by interrogating the temporal A weighted noise trace. The D_{AM} index is another time series based method described by Fukushima et al (10). The most commonly reported and tested method referenced in papers analysing AM uses fast Fourier transform (FFT) to find the energy at blade passing frequency. Other methods have included reconstructing the time series of the AM based on FFT analysis (11). Different methods for identifying AM are well described elsewhere and have not been detailed further in this paper (7,9).

2.3 Modifiers of AM perception

In the UK there appears to be a strong industry preference for an automated AM assessment method that outputs a single numerical value of AM for a defined time period. This value is based either on the energy found at blade passing frequency or with an estimate of the typical difference between the peak and trough of the AM. Annoyance from wind farm noise has also been related to the overall A weighted sound pressure level (L_{Aeq}) (2).

No method presented to date takes account of cumulative factors such as spectral content, impulsivity (though it is noted that others have investigated use of impulsivity for quantifying AM(12)) or other features that may contribute to the perception of AM. Pedersen and Waye identified descriptions of swishing, whistling, pulsating / throbbing and resounding as the most common sources of annoyance (13). Annoyance has also been identified as a function of modulation depth, modulation rise time, modulation frequency (including harmonics), the average level of the noise and psychological responses (9). The unpredictability of AM and better audibility at night, due to lower masking noise and greater transmission, have also been highlighted as factors contributing to annoyance (14).

Thus, whilst a multitude of factors have been identified as influencing AM perception, assessment methods tend to reduce this to interrogation of a single feature of AM, relating annoyance to a numerical value based only on this one feature of the AM.

3. TESTING RESPONSES TO AM

3.1 Individual differences

It is evident from personal music preferences that there is great diversity in listener's perception and discrimination of sound versus noise. Research has found that wind farm noise is more annoying at lower levels than other sources of environmental noise (12, 15). Although certain features of wind farm noise, including AM, have been highlighted as causing annoyance there is a lack of research further identifying specific character features of AM that cause an increase in annoyance. Research by the University of Salford found that annoyance rating of AM was not significantly affected by frequency content or shape of the AM waveform but was significantly affected by the frequency rate of the modulation, the overall loudness of the test sound and modulation depth (2). Despite these initial findings the overall conclusions of the research noted that annoyance was mainly related to overall level (L_{Aeq}).

Whilst the findings of the University of Salford research indicate that a single numerical value for AM, potentially related simply to the overall average decibel level, could sufficiently describe annoyance there still remains uncertainty, for example from the factors highlighted by research discussed in Section 2.3 above. The Salford research used an artificially generated AM signal which may not include many of the characteristics, including random fluctuations, found in real world AM. The use of a single numerical descriptor for assessing noise, whilst convenient, has long been acknowledged as limited (16). There is uncertainty as to how a value for AM is to be derived and whether a judgement of acceptability based on this value would adequately address the annoying features associated with AM as described in other research and in lay evidence.

3.2 How do people hear wind turbine AM?

It could be argued that approaching wind turbine noise assessment pre-armed with a knowledge of psychoacoustics and wind turbine noise manifestation is subject to experimental bias. An acoustician is familiar with formal definitions of 'hum, 'whine', 'low frequency', 'modulating', 'irregular' and whilst amongst the acoustics community these definitions hold some clarity, to the lay person the same sound could be described in a manner of different ways.

When attempting to define an assessment tool for AM, and indeed setting a level of acceptability, a number of elementary questions require consideration.

→ Does all AM sound or impact the same?

Can listeners actually perceive a difference in AM samples? For example, is there a noticeable difference between AM that is low frequency or mid frequency dominated? Is there a noticeable difference between AM that modulates by 7-8dB or by 3-4dB. Can a listener discern whether a short extract of AM, used comparatively, has intermittent AM or constant AM and even if they can, does this alter their overall judgement of the sound over a time period? Is it simply categorised at a more basic level of 'noisy' or 'not noisy'?

→ Is there a consensus amongst the population as to what is "good" and "bad" sounding AM?

If AM doesn't sound the same and there are noticeable differences, do listeners generally agree as to what can be considered positive and negative attributes of AM? A repetitive rhythm to one listener may be soothing but to another may be considered relentless and intolerable.

→ Do existing AM metrics reflect different characteristics of AM?

If listeners do perceive differences in AM samples, do metrics for AM reflect these judgements? Does a single number rating for AM adequately, albeit potentially indirectly[2], penalize samples that are rated as most intrusive and permit samples that are considered acceptable?

3.3 MAS Environmental Wind Farm Noise Annoyance Study

In the absence of any substantial research asking or investigating the above questions it is of some concern that UK guidance on rating and assessing wind turbine AM could be imminently approved. As a result, and with limited funds and time, a basic online study was developed to begin investigating these questions. The survey is accessible online at: http://www.masenv.co.uk/survey/.

Six samples considered to have varying attributes of AM were taken from data measured by the external permanent monitoring station at Cotton Farm Wind Farm, Cambridgeshire UK.[3] All samples had the same L_{A90}, a narrow range of L_{Aeq}'s and lasted for approximately 50 seconds.[4] As the main purpose of the study was to investigate discrimination of character features and annoyance between samples of AM, no reference non-modulating wind farm noise was included in the study. Only the audio of the sample was presented on the website to prevent any visual clues for annoyance rating. The

---

[2] An AM control might simply state that all AM above a modulation depth of 3dB(A) is unacceptable. If adverse character and impact do not occur when there is AM with a modulation depth below 3dB(A) then the control prevents adverse impact from noise character without specifically identifying these features or focusing on preventing their occurrence.

[3] For more information and for real time information logging noise levels from the wind farm visit: http://www.masenv.co.uk/~remote_data/. The noise monitor is located in a free field location at the boundary of residential property just under 650m from the nearest turbine.

[4] The LA90 metric is used to measure wind farm noise in the UK and is therefore used as the overall decibel level of the wind farm noise assessed. In this study all samples had an LA90 of 39dB.

samples were anonymised and the order randomised each time the page was visited.[5] Participants were asked to listen to the six clips and rate them on a scale of 0-10 for perceived annoyance. Participants were then asked a few brief questions to gain some basic information including their age and the character of the area they lived in. In order to maximise participation the study was designed to be quick and easy to complete, fairly basic and anonymous. At the end of the survey participants could leave any additional feedback or information on the study / study samples in a comments box.

3.4 Limitations

As with any online study there are limitations and factors that cannot be controlled. One of the main limitations is a lack of control over the playback used by participants to listen to samples. This would vary across headphone and laptop / computer speakers both in terms of frequency output and volume. Some responses indicated that the volume was not loud enough as samples could not be heard and other comments indicated that samples were played at too high a volume. Whilst this will have some effect on the study results it is not considered to undermine the main purpose of this study, which was to investigate whether differences between AM samples could be heard and whether samples would be perceived as more or less annoying *than each other*. Assuming that participants did not change the volume between samples, these comparisons could still be fairly made. The study format also lacked control over the range of participants completing the study. Whilst a range of ages completed the study there was a lack of participants under 30 and few living in urban areas completing the study. Whilst the lack of control over participants could be considered a limitation, the number of responses that the online survey allowed is an advantage of this approach.

3.5 AM samples

The six samples used in the study are shown graphically below. These have been labeled A-F for ease of reference in this paper and should not be confused with the randomised letters A-F that appear on the study website. Plotted on to the graphs is the 100ms L_{Aeq} (black trace, read off left hand x-axis) and the AM values for each 10 second period derived using the UK Institute of Acoustics (IoA) Amplitude Modulation Working Group (AMWG) Consultation Software.[6] Also labeled on the graphs is an approximate peak to trough value of the A weighted time series trace. This allows comparison of four different methods for quantifying AM. Method 1 (pale blue trace, read values off right hand y-axis) is a time series method for quantifying AM based on the methods used in Fukushima et al (9,10). Method 2 follows an FFT approach for quantifying AM using the frequency domain (pale green trace, read values off right hand y-axis) (9). Method 3 is a hybrid approach using a reconstructed time series founded on an FFT analysis of the original data (lilac trace, read values off right hand y-axis) (9). The 10 minute AM value for each sample period, Methods 1-3, is given in boxes in the top left hand corner of the graph. This 10 minute value is the LA10 of all the individual AM values calculated within a 10 minute period (9). The individual peak to trough values can be used for comparison against the criterion set in the original Den Brook condition. For ease of comparison all graphs use the same axis scaling. A summary of the study samples' period L_{A90} and L_{Aeq} is given in Table 1 below.

Table 1: Summary of study sample's period L_{A90} and L_{Aeq}

	Sample A 31/12/2013	Sample B 22/06/2014	Sample C 08/10/2014	Sample D 17/05/2015	Sample E 02/08/2015	Sample F 02/12/2015
L_{A90} (dB)	39	39	39	39	39	39
L_{Aeq} (dB)	42	44	42	42	42	41

5 The order of the samples always appears A-F but the sample attributed as A-F changed each time.
6 For more information see: http://www.ioa.org.uk/publications/wind-turbine-noise and particularly the AMWG Discussion Document available online:
http://www.ioa.org.uk/sites/default/files/AMWG%20Discussion%20Document.pdf

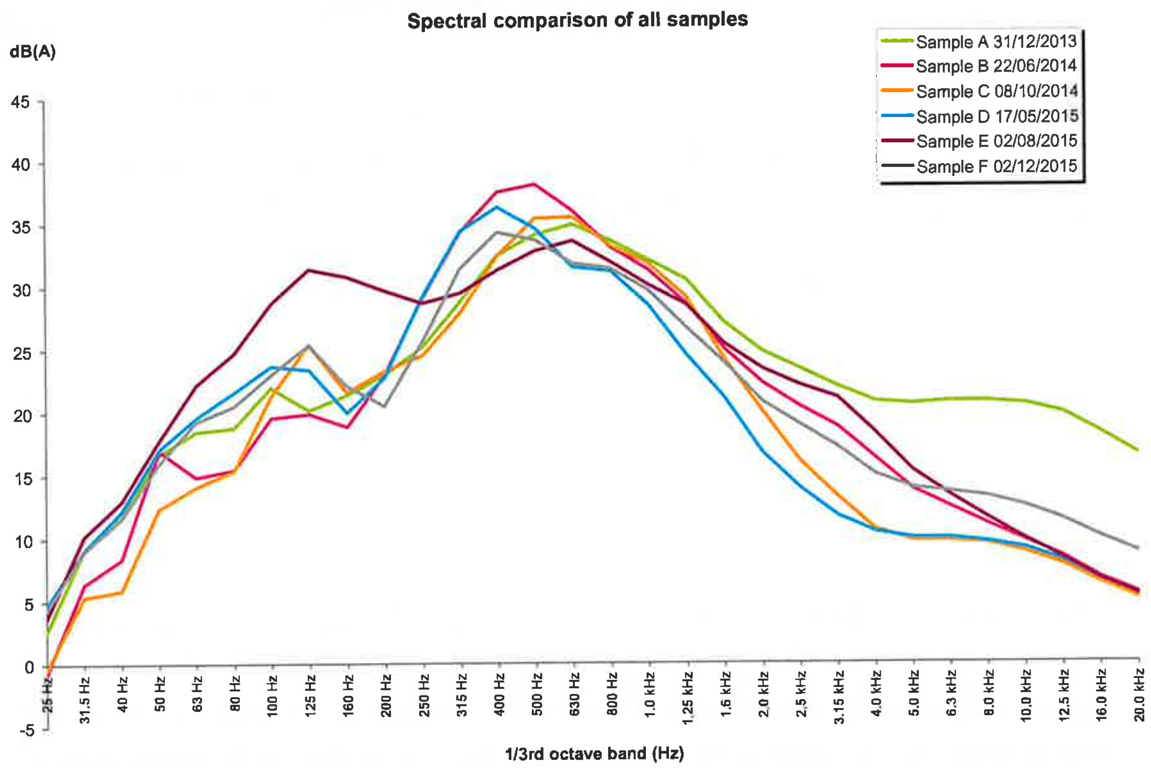


Figure 1: Spectral comparison (A weighted) of study samples.

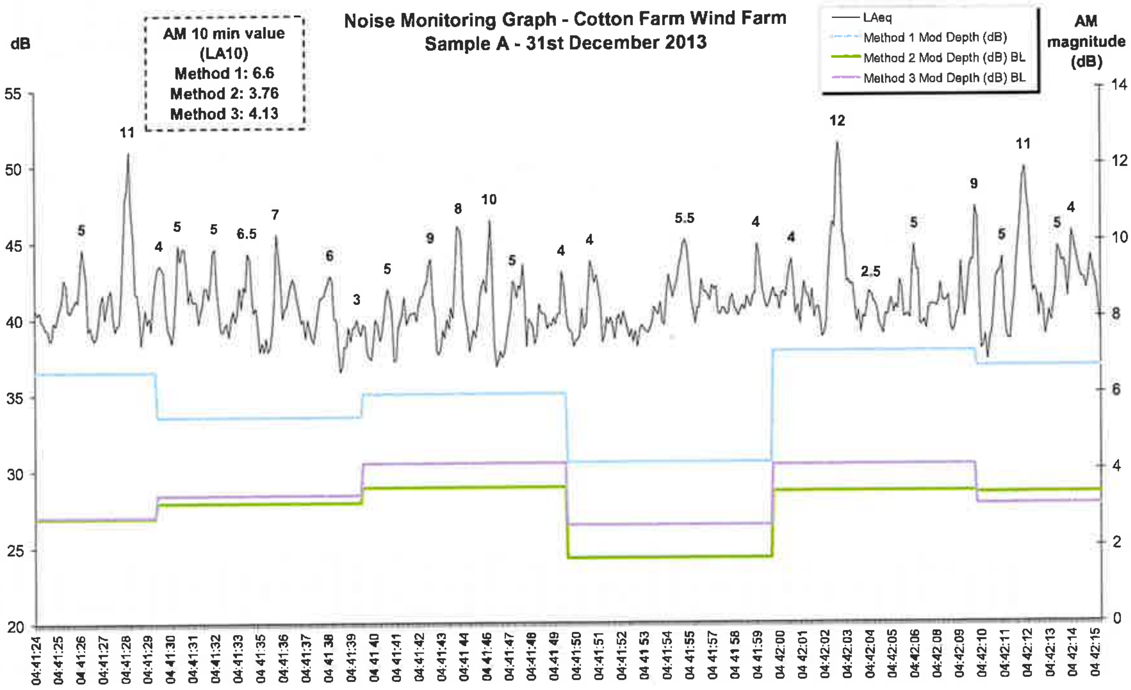


Figure 2: Study sample A - data measured on 31/12/2013. The sample on this occasion was chosen as it exhibited intermittent AM with a variable peak to trough.

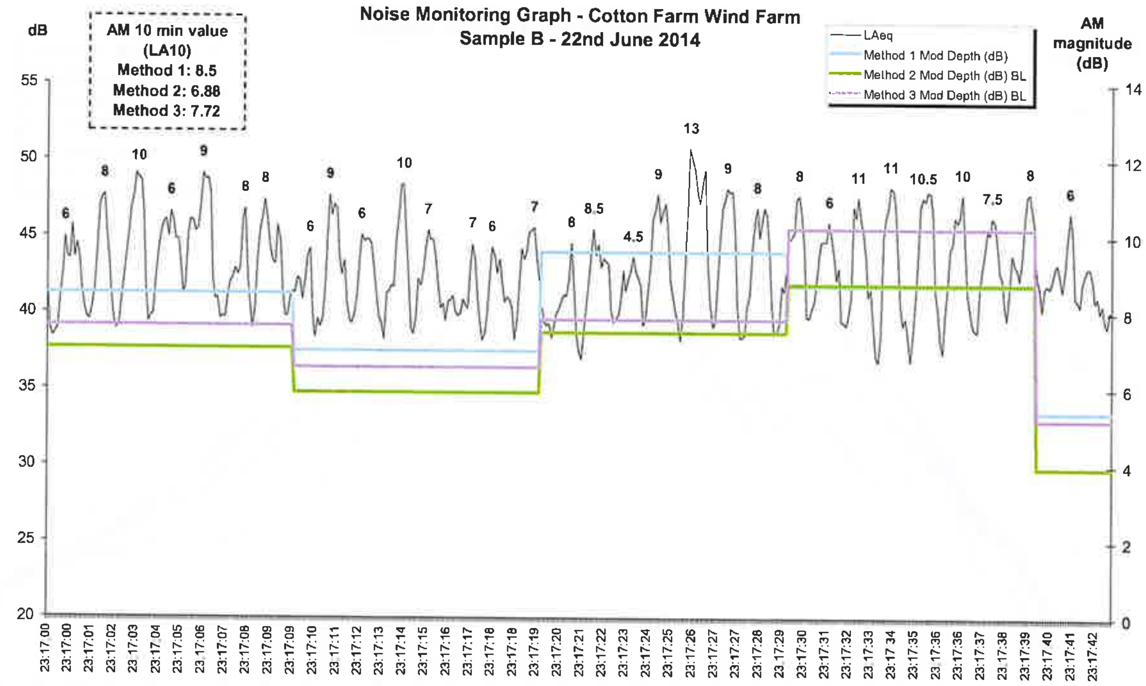


Figure 3: Study sample B - data measured on 22/06/2014. This sample was chosen as the AM was fairly consistent and constant throughout the period whilst also having a significant peak to trough variation.

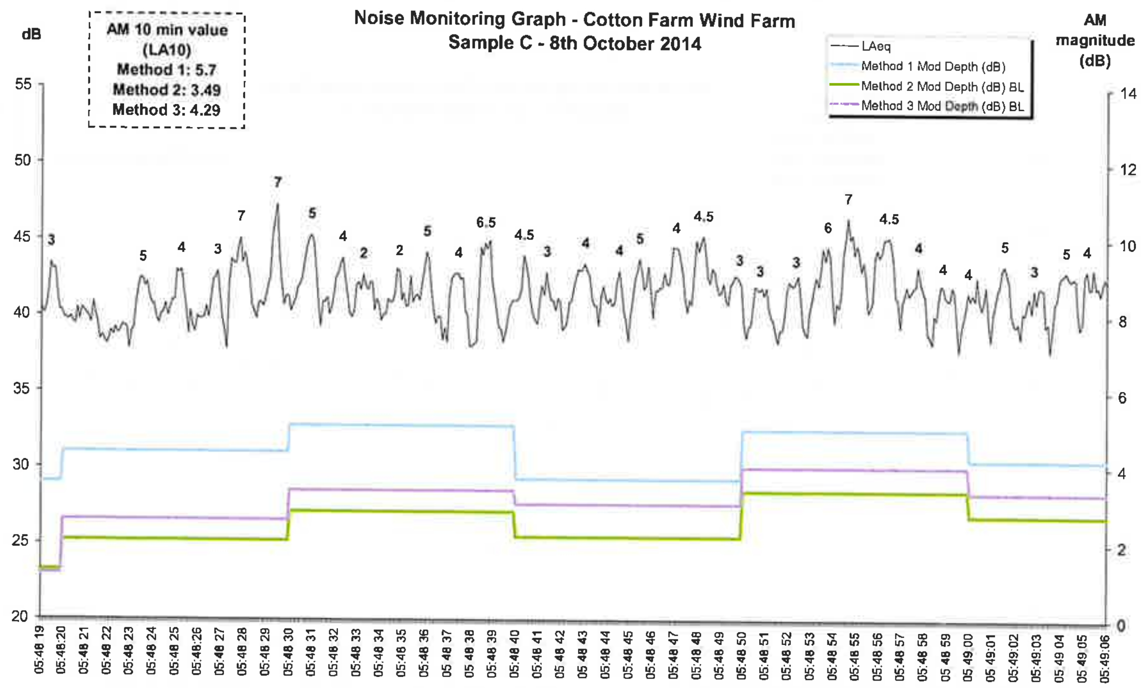


Figure 4: Study sample C - date measured on 08/10/2014. This sample is considered to show a period of AM that is not constant or consistent, with sounds of mid - high frequency i.e. "swish" rather than "whoomph" and has variable peak to trough differences.

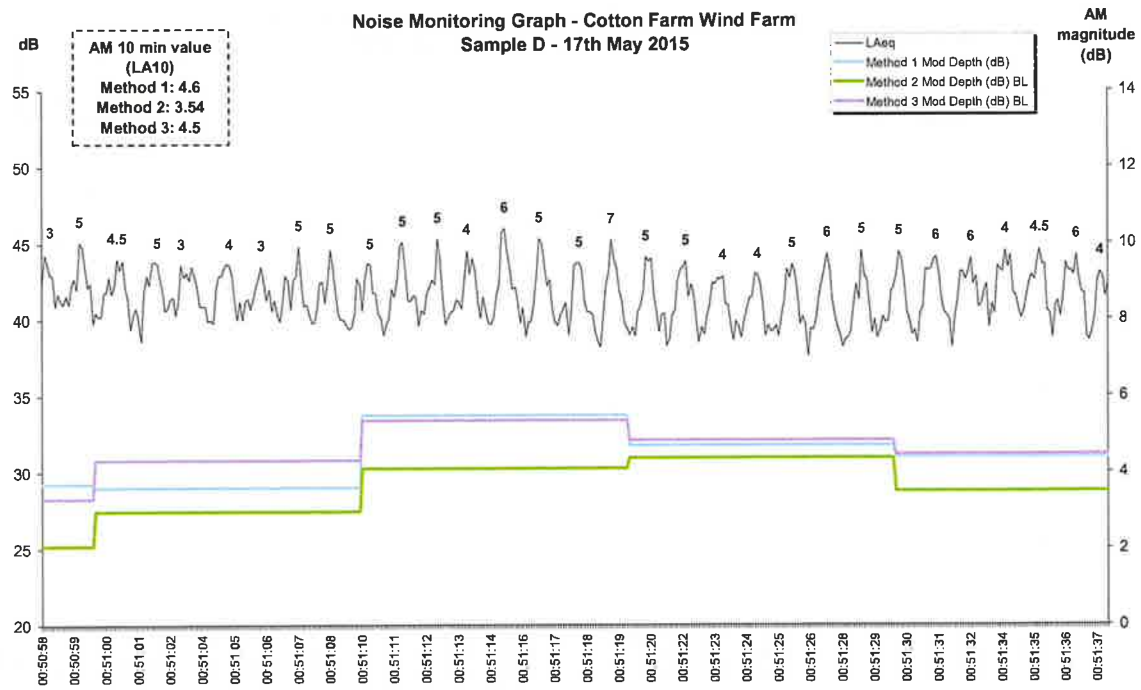


Figure 5: Study sample D - data measured on 17/05/2015. The sample on 17/05/2015 shows a period of consistent, regular and constant AM but with a lower typical peak to trough difference to that shown in the data on 22/06/2014.

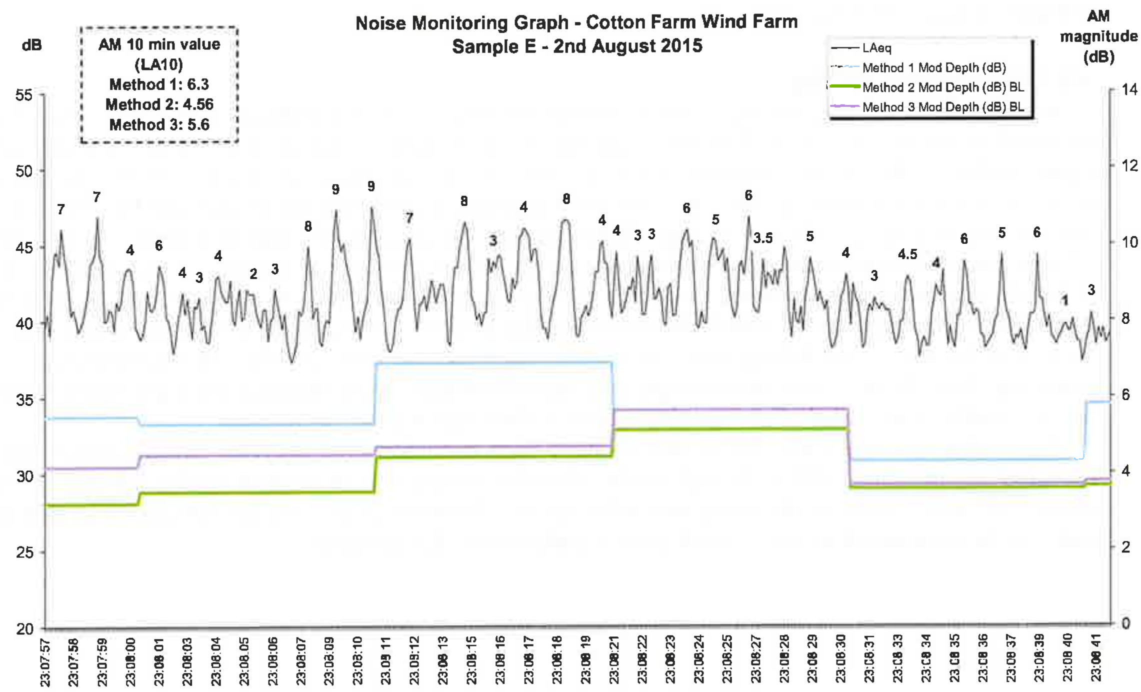


Figure 6: Study sample E - data measured on 02/08/2015. This sample was used as the AM had an intermittent and variable peak to trough difference, did not always vary significantly but had a low frequency quality to the sound, e.g. "whoomph" rather than "swish".

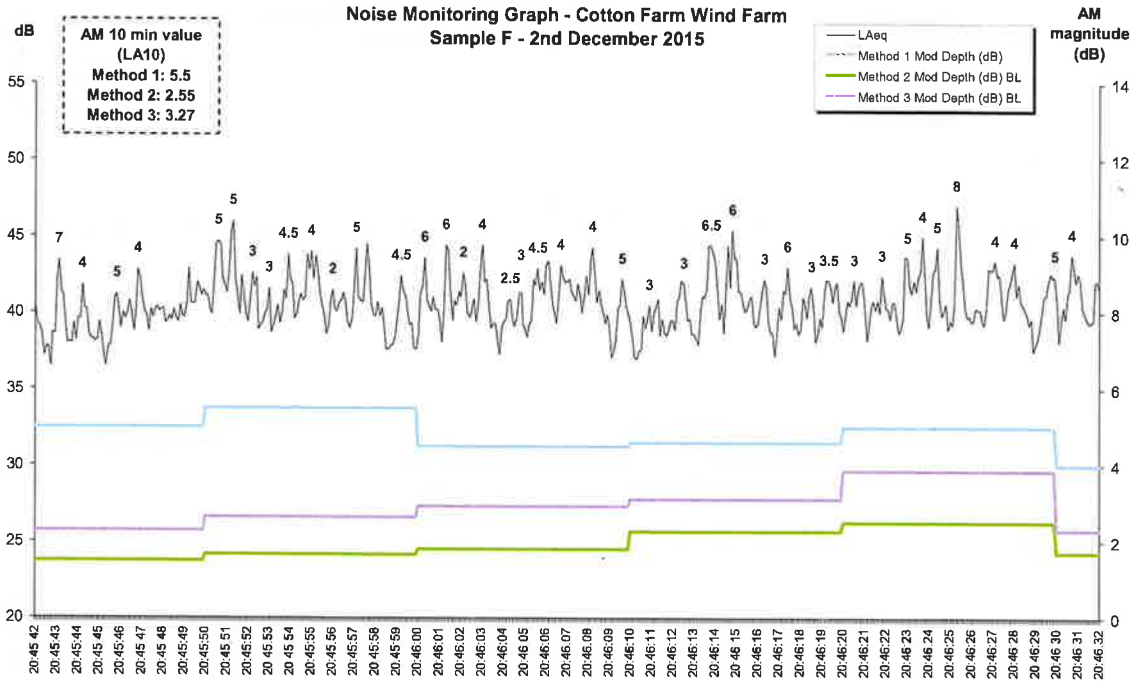


Figure 7: Study sample F - data measured on 02/12/2015. This sample was chosen as a period of lower peak to trough variation AM and also that had a mid - higher frequency sound character, e.g. "swish".

The study samples exhibit a range of differences in the modulation depth, how modulation depth depth varies with time, the character, frequency content and clarity of individual peaks and troughs and how these features vary with time. The samples represent many common features of AM including complex changes in noise character.

3.5.1 Preliminary results

At the time of writing the study had received 336 responses. A summary of the participant data is provided in Table 2 below. Preliminary analysis of the results is presented in Figures 8 and 9 below. Figure 8 shows the average annoyance ratings for all participants across each sample (see left hand axis for annoyance rating). Also plotted on the graph is the AM value derived by Methods 1-3 discussed in Section 3.5 above (see right hand axis for AM magnitude). Figure 9 shows the percentage of responses for annoyance ratings provided by participants between 0 and 10 for each sample. A line of best fit has been added for each sample to show an approximate trend in how each sample was rated. A number of participants provided additional feedback on the AM samples in the comments section at the end of the survey, including what the samples sounded like and / or why some samples were more annoying than others. Common descriptors in these responses were identified and are listed in table 3 below. A tally is provided of the number of times these descriptors were used.

No results from the initial 336 responses have been excluded from analysis. Initial analysis has not revealed any obvious outliers though further detailed analysis of individual results has not yet taken place. Full description of the study methodology and limiting factors are not discussed in this paper and will be considered in more detail post completion of full analysis.

Table 2: Summary of participant information

Age	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-99
Count	0	13	23	50	93	111	45	1	0

Area type	Rural	Very quiet suburban	Suburban	Residential urban	Urban near some industry	Area of heavy industry
Count	251	27	25	24	8	1

Area description	Free from intrusive noise	Impacted by some annoying noise sources on occasions	Generally noisy from transport sources	Generally noisy due to a mix of different types of noise such as industrial noise	Very noisy
Count	203	92	23	13	5

Live near wind farm?	No	Yes
Count	251	85

If "yes" to live near wind farm, do you hear wind farm noise?	Regularly	Sometimes	Never
Count	55	17	9

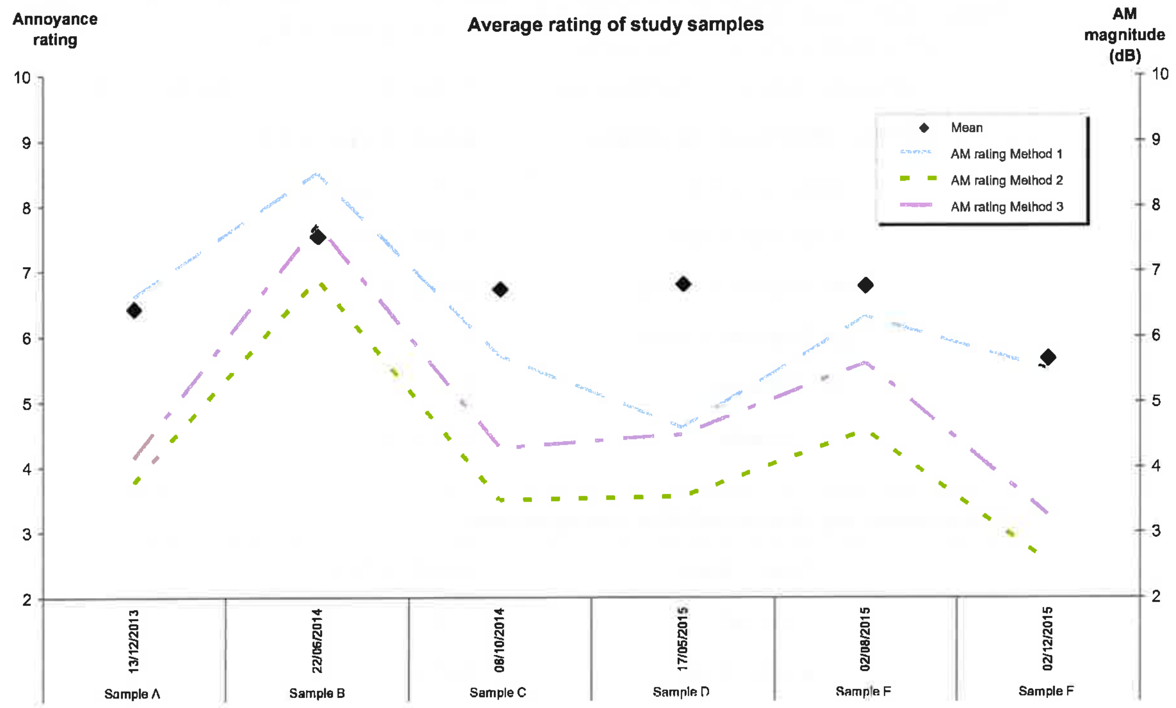


Figure 8: Average annoyance rating of study samples compared with average 10 minute AM rating for Methods 1-3.

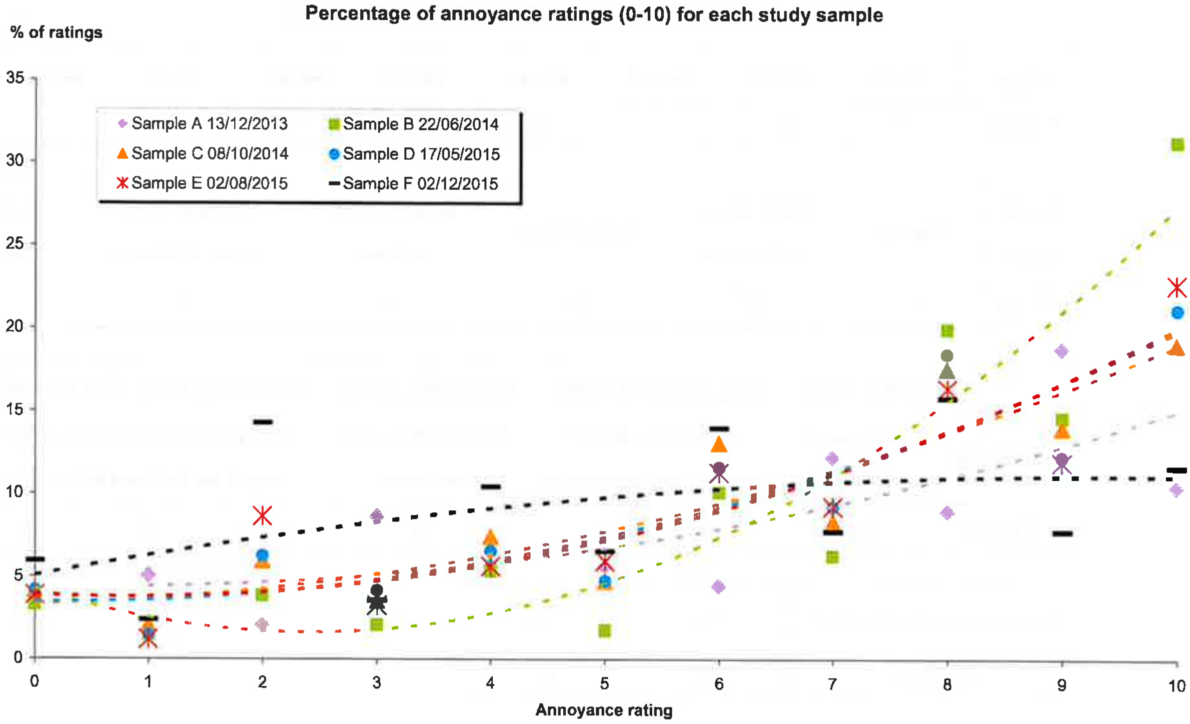


Figure 9: Percentage of responses for each study sample rated 0-10 and corresponding best fit line.

Table 3: Summary of comments relating to character descriptions of study samples.

Character feature	More annoying	Less annoying
Annoying because of the change in the noise, anticipating the noise, irregular	~~IIII~~ ~~IIII~~ III	
Continuous, regular, constant noise	~~IIII~~ I	~~IIII~~ III
Pulsing / throbbing / modulating	~~IIII~~ ~~IIII~~ III	
Repetitive noise	~~IIII~~ ~~IIII~~ II	
Rhythmic noise	~~IIII~~ III	I
Low frequency noise	~~IIII~~ II	
High frequency noise	II	
Sharper	II	
Louder	~~IIII~~ III	
Other annoying characteristics / comparisons		
Drone / hum	~~IIII~~ IIII	
Aircraft	III	
Tumble dryer	~~IIII~~	
Wind in trees	II	

4. DISCUSSION

4.1 Did participants hear differences in the samples?

The primary aim of the study was to ascertain if participants judged samples of AM with the same decibel level, as determined in accordance with UK guidance, as equally annoying.[7] The majority of participants rated the samples differently, only 46/336 participants (14%) rated the samples equally. This indicates that listeners do respond differently to samples of AM that have different characteristics and that some types of AM are more or less annoying than others.

The range of annoyance ratings given by participants was fairly small, on average ratings ranged by 3. This suggests that whilst participants judged the samples to be more or less annoying than each other, they were not judged to be significantly better or worse. This is reflected in the average scores given for each sample.

The highest annoyance rating was given to Sample B. This sample has the highest L_{Aeq} (by 2-3dB) of all the samples and has the most consistent, highest peak to trough variation of all samples. Samples D, E and C were on average all rated similarly at 6.8, 6.8 and 6.7 respectively. These samples all have the same L_{Aeq} and L_{A90} but have differing characteristics. Of particular note, Sample E has significantly more low frequency content than all other samples. Sample D consistently varies by approximately 5dB peak to trough whereas Sample E is more intermittent with peak to trough values ranging unpredictably from 2-3dB to 7-9dB. Only rated as slightly less annoying, with an average of 6.4, was Sample A. This sample is similar to Sample E but is more intermittent and has more extreme peak to trough variation, ranging from AM with 2-3dB up to 11-12dB peak to trough variation. The lowest rating of 5.7 was given to the AM in Sample F. This has a slightly lower L_{Aeq} (41dB) than the other samples and has intermittent AM with typically lower peak to trough variation. These results suggest that participants generally considered AM with consistently lower peak to trough variation to be least intrusive and AM with consistently higher peak to trough variation to be the most intrusive. However, samples that are intermittent and have a greater variation in peak to trough levels were considered to be similarly annoying compared to samples with lower peak to trough levels but which are constant and consistent throughout the period.

Figure 9 provides more information regarding how each sample was rated. It again confirms that Sample B was clearly rated as the most annoying, receiving significantly more annoyance ratings of 10 than the other samples. All samples with the exception of Sample F display a trend of increasing annoyance ratings, i.e. relatively few ratings of 0-3 and an increasing number of ratings from 4 up to 10. Sample F had a similar number of responses rating it as '2 – noticeable' as it did '6 – annoying'. This sample does not have significant peak to trough variation compared to other samples and does not have any specific characteristics such as low frequency content or unpredictable high AM peaks (for example up to 9-11dB peak to trough variation). The lack of additional character, other than the AM alone, could perhaps explain the different overall response to this sample and more uncertainty amongst participants as to how it should be rated.

Whilst the average rating of Samples C, D, and E was more or less the same, Figure 9 does show some differences in how the samples were rated. Sample E received marginally more annoyance ratings of '10' than Samples D and C. This could be taken as support that AM with more low frequency noise (Sample E) is more annoying than samples with intermittent but much higher peak to trough variation (Samples D and C). Notwithstanding that Samples B, C, D and E have significantly more ratings of '10', Sample A has a significant number of ratings of '9'. Sample A has the most intermittent and unpredictable AM with significant peak to trough variation of up to 11-12dB. Thus, whilst Sample A is ranked fourth out of six samples for annoyance, it still has attributes that cause participants to rate it highly for annoyance.

4.2 AM rating methods

Figure 8 plots the average annoyance rating produced by participants of the survey for each AM sample and the AM rating for each sample using Methods 1-3 discussed in Section 3.5 above and based on the 10 minute period from which the sample was taken.[8] The AM rating methods give an 'AM magnitude' in decibels and although it is not clear whether this magnitude is expected to reflect the typical peak to trough variation of the AM or if the value is to be used as a penalty, it is reasonable to

---

[7] Annoying in this discussion refers to a lay definition, in a broad sense of noisiness / unacceptability.

[8] The AM in the 10 minute periods from which samples were taken continued in a similar manner.

assume that the values may be used in this way, i.e. to rate modulation depth. As such the AM magnitude has been compared to the annoyance ratings of participants. The AM rating methods generally followed the shape of the annoyance ratings and clearly identified Sample B as the most annoying giving it an AM rating of between 7 and 9. These values tend to reflect the peak to trough values within that sample period.

Whilst the AM rating methods appear, to some extent, to reflect subjective response, the range of the 10 minute AM values attributed to the samples by Methods 1-3 is much greater than the range of annoyance ratings attributed by participants. The range of annoyance ratings given by participants across the samples is 5.7 – 7.5, indicating that whilst samples were perceived differently they were not significantly better or worse than each other. The range of 10 minute AM values for Methods 1, 2 and 3 across the samples is 4.6-8.5, 2.6 – 6.9, and 3.3 – 7.7 respectively, making some samples of AM appear significantly better or worse than others. This wider fluctuation in the empirical methods (Methods 1-3) indicates that they do not fully reflect aspects of AM that participants judge as relevant contributors to annoyance.

The lowest AM ratings were derived by Methods 2 and 3 and were given to Sample F and A. With reference to Figures 2-6, these are the AM samples showing the least well defined and least regular AM peak to trough variation. Methods 2 and 3 rely on a clearly and regularly defined periodic variation in the measured data to detect and rate AM. Where this does not arise lower values of AM are attributed. This disagrees with participant's responses. For example, Sample A was given an annoyance rating of 6.4. It contains AM that is intermittent but has AM with peak to trough variation up to 10-12dB.[9] Methods 2 and 3 give this sample an AM value of 3.8 and 4.1 respectively. Thus, AM methods 2 and 3 do not appear to reflect subjective ratings of the samples' annoyance well where the AM is not clearly defined and regular.

4.3 Comments

Much of the value in this study came from the comments that participants provided detailing why some samples of AM were perceived as more or less annoying than other samples and the descriptions of the samples. Table 10 provides a summary of the main descriptors that participants used to describe the samples and an approximate tally of how many times these descriptors were mentioned.

Of interest is the apparent conflict between participants stating that the samples were annoying both due to regularity / constancy and irregularity of the samples. As the comments were optional, clarity as to the meaning of these descriptions could not be sought and lay views may contradict without clear definition. However, it could suggest that both these features cause annoyance equally in participants. It could also be subject to definition, for example whether constant / regular referred to the regularity and constancy of the AM on a second by second basis or that AM occurring in this manner lasting for hours / days at a time would cause annoyance. The rhythmic and repetitive nature of the samples was listed several times as a key annoyance factor and lower frequency sounding AM was generally considered to be more annoying than the higher frequency sounding AM.

A noticeable finding from the comments was that several participants judged some samples to be louder than others. The samples were chosen because they all had the same L_{A90} value and as such should in general terms be judged to be of similar 'loudness' by UK wind farm noise guidance.[10] In reality this may not be the case. Whilst the samples did have slightly different L_{Aeq}'s (see table 1), the levels were not significantly different and varied by a maximum of 3dB, which is generally considered to be a just-perceptible change.[11] This supports an argument that wind farm noise that also contains AM is poorly described using the L_{A90} index and suggests the need for an assessment method for AM that is detached from ETSU-R-97 and its associated L_{A90} values. It is unclear from the results whether the small changes in L_{Aeq} or variation in AM character is driving the perception of different loudness between the samples.

AM was likened to aircraft noise and tumble dryer noise, which is a common likeness identified in earlier research (3). The description of the AM samples having a 'drone' and 'hum' quality was also noted by several participants. This is interesting as such terms are usually associated in acoustics with steady noise sources and those with constant tonal content as sometimes caused by motors. Such

[9] This type of AM has been found to be a common feature at most sites where AM has been observed.

[10] Loudness here refers to a lay term and not a formal acoustic definition of loudness, which has not been calculated for these samples.

[11] When in the field rather than in a laboratory environment.

descriptions were responsible for early complaints from wind farms being attributed to low frequency noise rather than AM (17). This description perhaps warrants further investigation alone as to whether participants hear both AM and low frequency noise, whether the combination / interaction of these factors causes complaints or whether it is a miscommunication between those listening to and those assessing wind farm noise.

5. CONCLUSIONS

Numerous methods have been proposed to quantify AM but there are few methods or planning conditions that set a level of acceptability. Limited work has been done investigating whether methods for quantifying and controlling AM reflect subjective judgements of AM. At the outset this paper asked three questions:

→ Does all AM sound the same?

→ Is there a consensus amongst the population as to what is "good" and "bad" sounding AM?

→ Do AM metrics reflect different characteristics of AM?

The MAS online study found that participants do clearly hear differences between samples of AM and that some samples were considered as more or less annoying than other samples. The difference between samples strongly appears a result of character difference rather than differences in energy levels (L_{Aeq} or L_{A90}) as differences in energy levels between samples were small. This has clear implications for methods of rating AM and for those responsible for determining what is or is not acceptable AM.

There was a general consensus that one sample in the study was the most annoying and one sample was the least annoying. Other samples were rated similarly to each other. Whilst there was a consensus over the most / least annoying sample the difference between the annoyance rating of the samples was small. This could suggest either that as soon as AM is present it is generally considered to be annoying and / or that there are multiple characteristics of AM rendering it annoying for different reasons. With regard to comments provided by participants there was some disagreement between features of "good" and "bad" AM. This disagreement mainly focused around features of regularity, irregularity, constancy and repetitiveness. Rhythmic features, low frequency sounds and drones / hums were all listed as contributing to annoyance in accordance with the findings of other research.

Whilst in general the AM rating methods investigated tended to reflect the general trend in annoyance reflected by participants, identifying which samples were more or less annoying, there were limitations to the methods. In particular methods for rating AM significantly underestimated the annoyance response of samples that did not have a regular, clearly defined periodic variation in the measured data. This indicates that caution must be exercised if such an approach is to be taken forward for rating AM as whilst the methods may work well in some circumstances and for some periods of AM they may dismiss many other periods or cases where there is a real AM problem that manifests differently to the 'ideal' and regular peak to trough form tested by others.

This paper indicates that all types of AM cannot be treated equally and shows that participants can and do identify the different characteristics in samples of AM. It shows that changes in character other than peak to trough depth affect perception of AM. Although samples of AM were rated differently, the range between ratings was not great suggesting that the mere presence of AM triggers a significant annoyance reaction. Whilst no non modulating wind farm noise was provided against which samples could be compared, this finding was supported by comments provided by participants.

Research has conclusively identified that wind farm noise is more annoying at lower levels than other sources of environmental noise and that the presence of AM is a significant contributor to this annoyance. Further work is needed to identify why AM is annoying, what features of AM contribute to annoyance and whether these factors all contribute to annoyance equally. This work should be used to inform controls for AM rather than having AM controls imposed dictating what listeners should or should not find annoying.

6. FURTHER WORK

This paper presents only the initial findings of the study and further analysis of the results will be completed and reported on at a later date. At this initial stage it is evident that differences between AM samples can be heard and specific and different characteristics are identified between samples. This warrants further investigation in more controlled conditions. Further work in this area should be undertaken and is particularly important given the imminent imposition of AM controls in the UK. Until there is further understanding of the variations in commonly arising AM, the value of any metric addressing one feature of AM cannot be known. Without a better understanding of how those exposed to wind farm noise perceive AM there can be little confidence that controls will adequately resolve justified complaints of adverse impact.

ACKNOWLEDGEMENTS

The author would like to thank all those who took the time to respond to the MAS Wind Farm Annoyance Study. Particular thanks go to the Cotton Farm Residents Association for their continuing support and cooperation in allowing the use and investigation of wind farm noise impact using the data measured with the community permanent monitoring station.

REFERENCES

1. S. Yokoyama, S. Sakamoto and H. Tachibana. Study on the amplitude modulation of wind turbine noise: part 2- Auditory experiments. Proc. Inter-noise 2013, (2013).
2. Renewable UK. Wind Turbine Amplitude Modulation: Research to Improve Understanding as to its Cause and Effect. Available from: http://www.renewableuk.com/download.cfm/docid/528AF1A8-9F36-41E4-8F39042D4BEB795D [Accessed 15 May 2016].
3. Stigwood, M., Large, S., & Stigwood, D. Audible amplitude modulation - results of field measurements and investigations compared to psychoacoustical assessment and theoretical research. Proc 5th International Conference on Wind Turbine Noise; 28-30 August 2013; Denver, Colorado 2014.
4. The Independent Noise Working Group. Wind Turbine Amplitude Modulation and Planning Control Study. Work Package 3.1 - Study of Noise and Amplitude Modulation Complaints Received by Local Planning Authorities in England. Available from: http://www.heatonharris.com/reports-publications [Accessed 15 May 2016].
5. World Health Organisation. Noise and Health. Copenhagen; WHO; 2000.
6. Lee S., Kyutae, K., Choi, W., & Lee, S. Annoyance caused by amplitude modulation of wind turbine noise. Noise Control Eng J. 2011; 59:38-46.
7. The Independent Noise Working Group. Wind Turbine Amplitude Modulation and Planning Control Study. Work Package 5A and 5B - Towards a draft AM condition. Available from: http://www.heatonharris.com/reports-publications [Accessed 15 May 2016].
8. Large, S., & Stigwood, M. The noise characteristics of 'compliant' wind farms that adversely affect its neighbours. Proc Inter-noise 43; 16-19 November 2014, Melbourne, Australia 2014.
9. Institute of Acoustics Amplitude Modulation Working Group. Methods for Rating Amplitude Modulation in Wind Turbine Noise. Available from: http://www.ioa.org.uk/sites/default/files/AMWG%20Discussion%20Document.pdf [Accessed 16 May 2016].
10. A. Fukushima, K. Yamamoto, H. Uchida, S. Sueoka, T. Kobayashi & H. Tachibana. Study on the amplitude modulation of wind turbine noise: part 1-Physical investigation. Proc. Inter-noise 2013, (2013)
11. Cooper, J. & T. Evans. Automated detection and analysis of amplitude modulation at a residence and wind turbine. Proc of Acoustics 2013; 17-20 November 2013; Victor Harbor, Australia 2013.
12. Di Napoli, C. Long Distance Amplitude Modulation of Wind Turbine Noise. Proc Fourth International Meeting on Wind Turbine Noise; 12-14 April 2011; Rome, Italy 2011.
13. Pedersen E, & Waye KP. Perception and annoyance due to wind turbine noise - a dose response relationship. J Acoust Soc Am. 2004;116(6):3460–3470.
14. Van den Berg, F. Wind turbine noise: an overview of acoustical performance and effects on residents. Proc of Acoustics 2013; 17-20 November 2013; Victor Harbor, Australia 2013.
15. Michaud, DS., Keith, SE., Feder, K., Voicescu, SA., Marro, L., Than, J., Guay, M., Bower, T., Denning, A., Lavigne, E., Whelan, C., Janssen, SA., Leroux, T., & van den Berg, F. Personal and situational variables associated with wind turbine noise annoyance. J Acoust Soc Am. 2016;139(3):1455–1466.
16. Berglund, B. & Lindvall, T. (ed.) World Health Organisation, Karolinska Institute (Sweden). Community Noise. Archives of the Center for Sensory Research; 1995; 2(1); 1-195.
17. Hayes McKenzie Partnership Ltd. The Measurement of Low Frequency Noise at Three UK Wind Farms. UK Department of Trade and Industry (DTI). Contract number: W/45/00656/00/00. 2006.Available from: http://webarchive.nationalarchives.gov.uk/20090609003228/http://www.berr.gov.uk/files/file31270.pdf [Accessed 16th May 2016]

Journal of Sound and Vibration 455 (2019) 136–149

Contents lists available at ScienceDirect

Journal of Sound and Vibration

journal homepage: www.elsevier.com/locate/jsvi

Prevalence of wind farm amplitude modulation at long-range residential locations

Kristy L. Hansen [a,*], Phuc Nguyen [a], Branko Zajamšek [b], Peter Catcheside [b], Colin H. Hansen [c]

[a] College of Science and Engineering, Flinders University, Tonsley, 5042, Australia
[b] College of Medicine, Flinders University, Bedford Park, 5042, Australia
[c] School of Mechanical Engineering, The University of Adelaide, Adelaide, 5005, Australia

ARTICLE INFO

Article history:
Received 27 September 2018
Revised 1 May 2019
Accepted 3 May 2019
Available online 13 May 2019
Handling Editor: R.E. Musafir

Keywords:
Amplitude modulation
Wind farm noise
Low-frequency noise
Tonal noise

ABSTRACT

The presence of amplitude modulation (AM) in wind farm noise has been shown to result in increased annoyance. Therefore, it is important to determine how often this characteristic is present at residential locations near a wind farm. This study investigates the prevalence and characteristics of wind farm AM at 9 different residences located near a South Australian wind farm that has been the subject of complaints from local residents. It is shown that an audible indoor low-frequency tone was amplitude modulated at the blade-pass frequency for 20% of the time up to a distance of 2.4 km. The audible AM occurred for a similar percentage of time between wind farm percentage power capacities of 40 and 85%, indicating that it is important that AM analysis is not restricted to high power output conditions only. Although the number of AM events is shown to reduce with distance, audible indoor AM still occurred for 16% of the time at a distance of 3.5 km. At distances of 7.6 and 8.8 km, audible AM was only detected on one occasion. At night-time, audible AM occurred indoors at residences located as far as 3.5 km from the wind farm for up to 22% of the time.

1. Introduction

The rapid global expansion of wind energy has been associated with widespread complaints regarding annoyance, sleep disturbance and adverse health effects from people who have been exposed to wind turbine noise [1]. Therefore, to ensure that residents living near wind farms are not subjected to excessive noise-related disturbance, it is important to identify potentially disturbing wind farm noise components. Moreover, suitable methods for quantifying these components are required. Acceptable threshold levels also need to be defined to determine the prevalence of potential noise disturbance.

Several researchers have shown that amplitude modulation (AM) of wind farm noise contributes to annoyance [2–5]. Despite this finding, many regulations and guidelines concerning wind farm noise do not include penalties for this characteristic, possibly due to the ongoing debate as to what constitutes a reasonable penalty [6]. As discussed by Perkins et al. [7], the exposure-response to wind turbine AM noise is influenced by several factors including AM depth, noise level, duration/consistency of AM, time of occurrence and noise sensitivity of the individual.

Several methods have been developed to determine the AM depth of wind farm noise based on analysis in the time-domain, frequency-domain and a combination of both [8]. Recently the AM Working Group (AMWG), on behalf of the UK

* Corresponding author.
E-mail address: kristy.hansen@flinders.edu.au (K.L. Hansen).

https://doi.org/10.1016/j.jsv.2019.05.008
0022-460X/

Institute of Acoustics, conducted an extensive review of existing methods for AM detection and quantification [8]. Following this review and a period of consultation, the group developed a method referred to as the IOA 'reference method' [9], which incorporates concepts developed by other research groups including Fukushima et al. [10] and Renewable UK [2] into a hybrid (time- and frequency-domain based) method. The main advantages of this method are that it can be automated, allowing analysis over long time periods, and it is robust to background noise contamination, reducing the instances of false positives.

This study investigates the suitability of the IOA 'reference method' for detecting low-frequency AM of a tone that is generated by wind turbines. The motivation for this analysis is to investigate the prevalence of a low-frequency 'thumping' or 'rumbling' noise that has been mentioned in complaints from residents. In fact, during a study by the South Australian Environmental Protection Agency in 2013, at least 14 (out of 15) residents living at various distances up to 8 km complained of 'thumping' and/or 'rumbling'. Their responses were documented in noise diaries that were collected over several weeks and these were provided to our research group. Since the IOA 'reference method' has been validated using broadband noise [2,11], which is representative of wind farm noise at distances less than 1 km from a wind farm, some modifications are proposed to extend its applicability to tonal AM measured at larger distances. These include changes to the analysis bandwidth, reduction in the prominence factor representing 'valid AM', assessment of the tonal audibility and reduction in the AM depth for cases when the tonal audibility is less than 0 dB at AM 'troughs'. The modified algorithm is then applied to outdoor and indoor data measured at 9 residences over a total of approximately 64 days of continuous recording to investigate the prevalence of AM and the associated AM depth. Relationships between AM and distance from the wind farm, AM and wind farm operating conditions and AM and time of day are also explored.

2. Measurement set-up

Outdoor measurements were carried out for a total of approximately 64 days at 9 different residences located between 1 and 9 km from the nearest wind turbine of a South Australian wind farm, which at the time of measurements was made up of 37 operational turbines, each with a rated power of 3 MW. The wind farm is positioned along the top of a ridge and the wind turbine hub height relative to the residences varies between 85 and 240 m. The wind turbine and residence locations are shown in Fig. 1. Time series data were acquired both outdoors and indoors using National Instruments 9234 (at 10240 Hz sampling rate) and Bruel and Kajer LAN-XI Type 3050 (at 8192 Hz sampling rate) data acquisition systems, respectively. The outdoor microphone was a G.R.A.S type 40AZ with a 26CG preamplifier, which has a noise floor of 16 dB(A) and a flat frequency response down to 0.5 Hz. The outdoor microphone was mounted at a height of 1.5 m and protected using a spherical secondary windscreen with a diameter of 450 mm. Details of the construction of this windscreen are provided in Hansen et al. [12]. The outdoor microphone was typically positioned at least 20 m away from the residence and at least 10 m from surrounding vegetation to minimise façade reflections and wind-induced vegetation noise, respectively. A typical outdoor measurement set-up is shown in Fig. 2. The indoor microphone was a B&K type 4955, which has a noise floor of 6.5 dB(A) and a flat frequency response down to 6 Hz. The indoor microphone used in the analysis was mounted on a mini tripod and positioned approximately 100 mm from a room corner, at the intersection between two walls and the floor. Two other indoor microphones were mounted at heights of 1.5 m

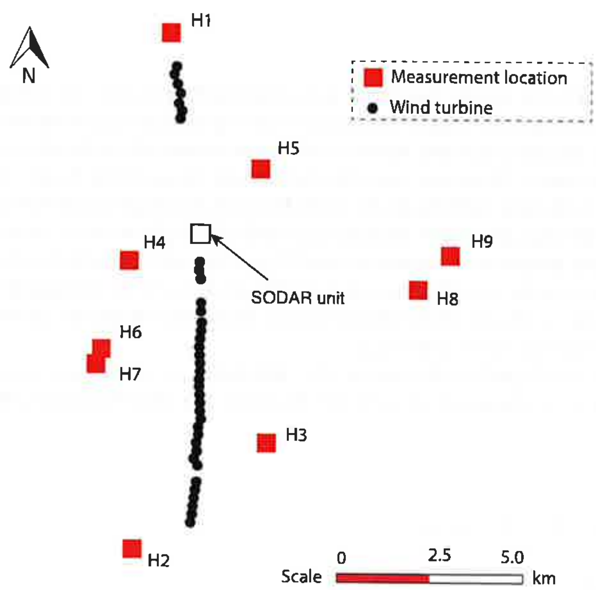


Fig. 1. Scaled diagram showing position of residences relative to the wind farm.

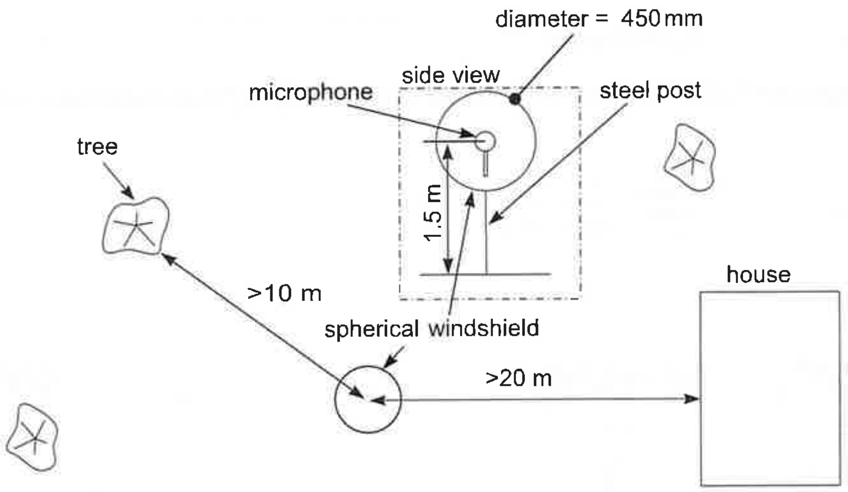


Fig. 2. Schematic showing a typical outdoor measurement set-up.

Table 1
Number of 10-min samples measured outdoors and indoors at each residence.

Residence	H1	H2	H3	H4	H5	H6	H7	H8	H9
Distance (km)	1.3	2.3	2.4	2.5	3.3	3.4	3.5	7.6	8.8
Outdoors	833	700	471	1548	1087	640	1659	999	848
Indoors	834	803	860	1561	1091	640	1344	989	850

and positioned randomly within the room. At all residences, the indoor measurements were taken in a room that faced as closely as possible towards the wind farm and the windows were closed. A total of 8716 and 8972 10-min samples of outdoor and indoor data, respectively, were analysed in this study. The number of 10-min samples taken outdoors and indoors at each residence is shown in Table 1.

Hub-height wind speed data for the nearest wind turbine to each residence were available from the wind farm operator for all residences except H5, for which the hub height data were measured using a Fulcrum 3D SODAR. The SODAR was located on the same ridge-top as the wind turbines, as shown in Fig. 1. The resolution of this device is ± 0.01 m/s, according to the manufacturer. Power output data for the wind farm were obtained from the Australian Energy Market Operator website [13] in 5-min averages. These data pertain to the entire wind farm and data for each individual wind turbine were not available.

3. Analysis techniques

3.1. AM detection and quantification method

Several methods have been developed for detecting and quantifying AM and they can be divided into 3 categories: time-domain [10], frequency-domain [4] and 'hybrid' methods [9], the latter of which involves analysis in both the time and frequency domains. A comprehensive review of these methods can be found in Refs. [8,14]. In this study, the IOA 'reference method' [9], a hybrid method, has been used for detecting and quantifying AM. However, to ensure reliable detection of the low-frequency tonal AM that is characteristic of the wind farm noise analysed in this study, several modifications were required, which are as follows:

1. The bandwidth of analysis was limited to a single 1/3-octave band containing AM with the highest associated AM depth.
2. The prominence factor described in the IOA 'reference method' was reduced to 3. This means that the spectral peak at the BPF did not need to be as high above the noise floor of the power spectrum to be considered as wind farm AM.
3. The audibility of the tone was assessed based on the sound pressure level (SPL) in the 50 Hz 1/3-octave band and masking noise in the first critical band (20–120 Hz).
   (a) The normal hearing threshold curve specified in ISO 389-7 [15] was used to determine if the SPL in the 50 Hz 1/3-octave band was sufficiently high to be potentially audible.
   (b) For cases identified in (a), the tonal audibility was assessed using the method outlined in the IEC 61400-11 standard [16]. Note that this standard does not explicitly state that the tone should be above the hearing threshold. However, this is an important consideration for low level tones, and thus audibility was also evaluated using ISO 389-7 [15].

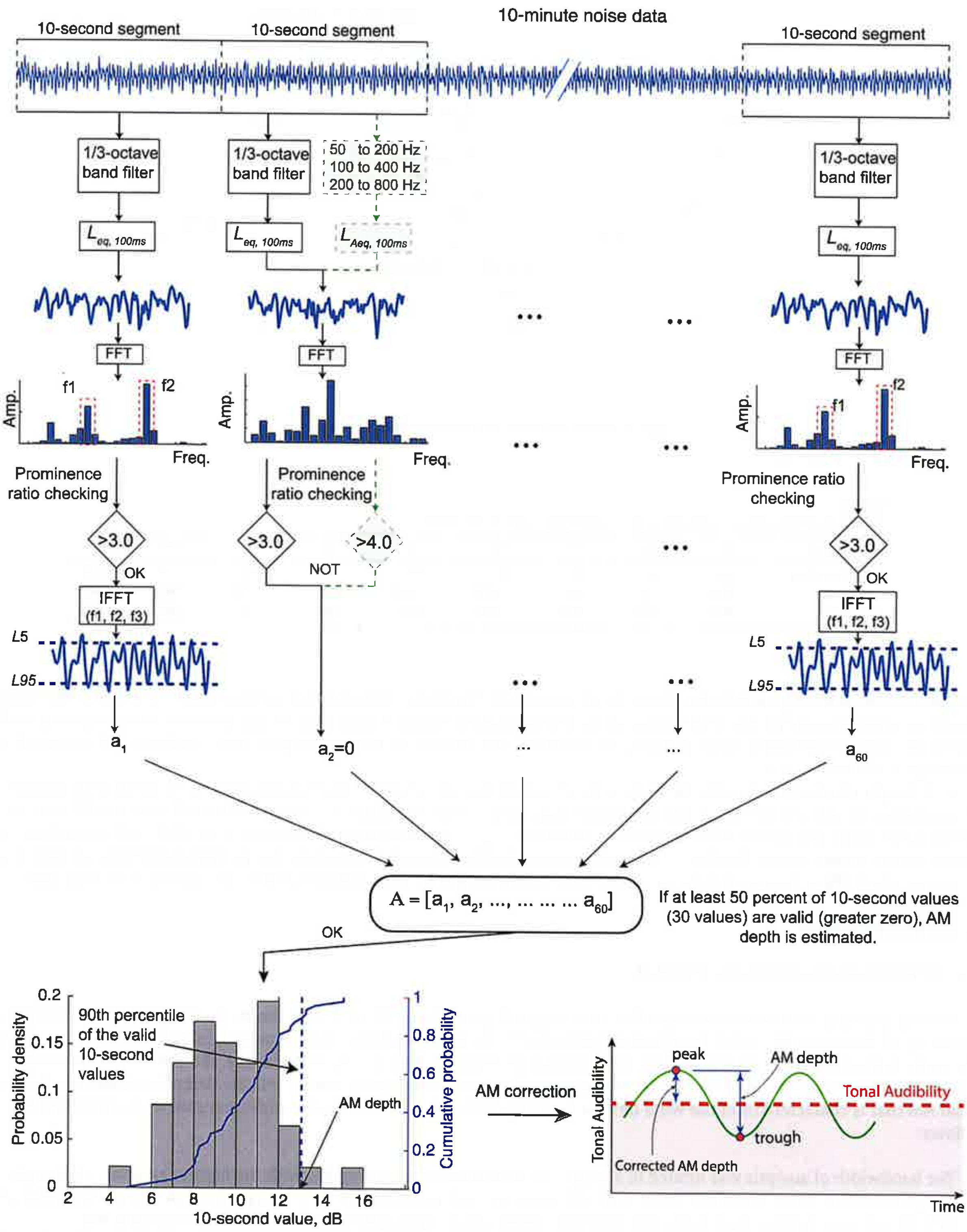


Fig. 3. A summary of the steps for determining and quantifying AM based on the IOA 'reference method' that has been modified to suit analysis of AM of a low-frequency tone. The Inverse Fast Fourier Transform (IFFT) is calculated using the fundamental and first two harmonics. The values in the box shaded green with dashed grey outline are the original values used in the IOA 'reference method'. The modifications are applied for all 10-s segments. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

4. If the AM troughs, as pictured in the bottom-right of Fig. 3, were not expected to be audible based on the calculated tonal audibility, the AM depth was reduced. For instance, if the tonal audibility was 0 dB and the AM depth was 6 dB, the reduced AM depth would be 3 dB. This is referred to as the 'AM correction' hereafter.

For the specific wind farm and receiver distances analysed in this study, narrowband analysis revealed that the most significant AM occurs at approximately 46 Hz [17]. Therefore, due to the tonal nature of the AM, the analysis bandwidth was reduced to the 50 Hz 1/3-octave band. Although Bass et al. [9] suggest an analysis bandwidth of 50 Hz–200 Hz, it is highlighted that this bandwidth precludes the audible tone and that even if the lower bound were extended to 40 Hz, the AM depth would be much lower. This is expected for the tonal AM analysed in this study but the approach may not be valid for broadband AM such as 'swish'. In fact, it is recommended that before deciding on the analysis bandwidth, it is important to identify the frequency range in which AM occurs. To ensure that the AM depth is not underestimated, it is important to choose a bandwidth that results in the highest AM depth. In this analysis, a narrow bandwidth of 2 Hz, centred on the tone, was also investigated but it was found that the AM depth was close to that obtained using 1/3-octave bands. Moreover, use of 1/3-octave bands is required by the New Zealand standard for wind farm noise measurement [18] and has been used by other researchers [19,20] for AM analysis.

The prominence ratio was reduced from 4 to 3 based on a systematic analysis, which is described in Section 3.2. Fig. 3 shows a summary of the steps for determining and quantifying AM based on the IOA 'reference method' with the modifications discussed above.

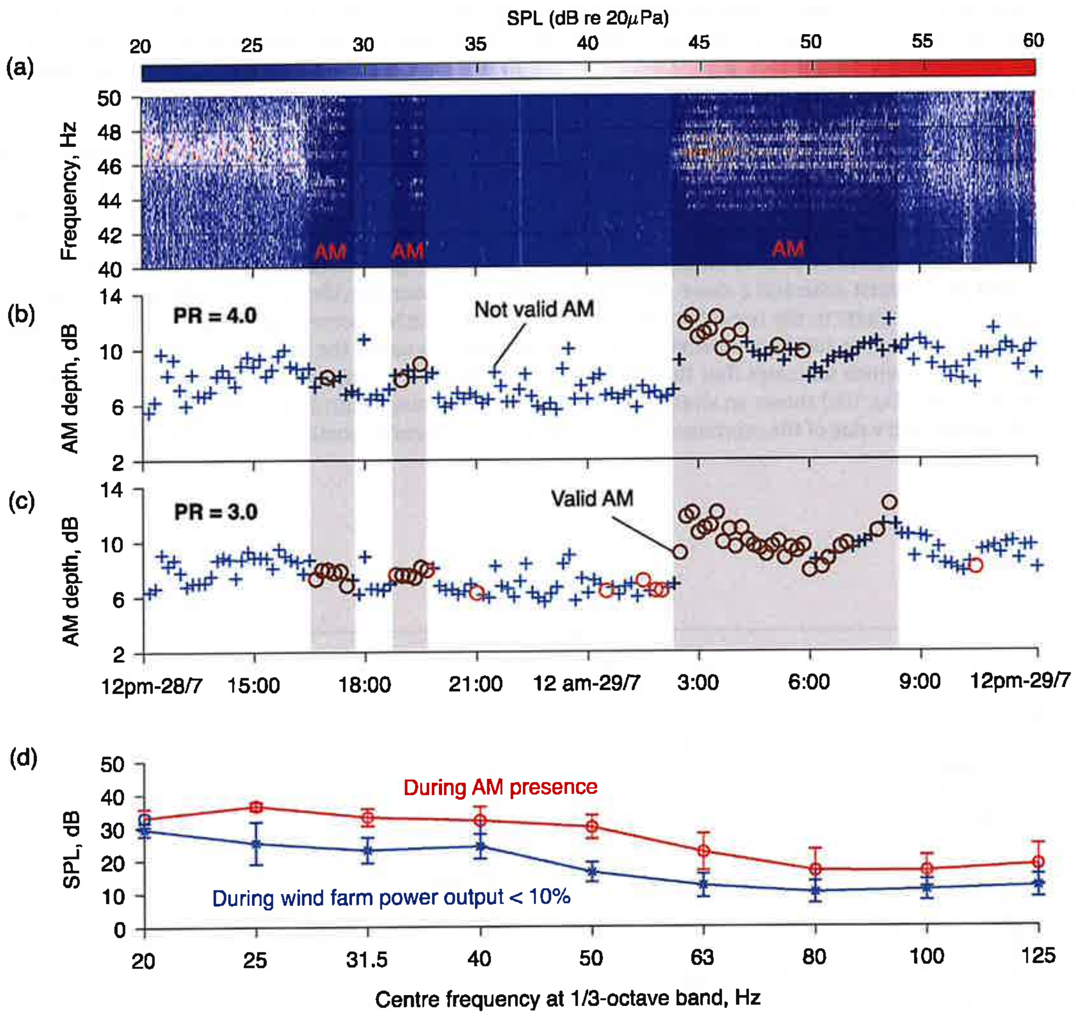


Fig. 4. The effect of prominence ratio on the result of AM detection for measurements at H5. (a) Spectrogram showing the presence of AM, as determined by a human scorer, shaded in grey. The AM is characterised by horizontal bands of relatively high SPL spaced at the BPF. (b), (c) Results of AM detection corresponding to prominence ratios of 4.0 and 3.0, respectively. The red and blue markers show AM depth for 10-min data points that are considered valid and not valid, respectively using the IOA 'reference method' [9]. (d) Mean and standard deviation of 1/3-octave spectra corresponding to data containing wind farm AM (red) as shaded in (a–c), and the period with negligible wind farm noise (blue), as indicated by the low-level signal without AM in the centre of (a–c). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

3.2. Validation of AM detection algorithm

To show a visual representation of the accuracy of the IOA 'reference method' with prominence ratios of 3 and 4, comparison is made to a spectrogram plot in Fig. 4. These data were measured at H5 over 24 h, during which there were some periods with AM present and other periods with AM absent. The plot was constructed using a Hamming window, frequency resolution of 0.1 Hz, time resolution of 5 s and 50% overlap. As shown in Fig. 4(a), use of a spectrogram plot is an effective method of identifying AM of a tone, which is visible as horizontal lines in the spectrum spaced vertically at the blade pass frequency (BPF) of 0.8 Hz. The disadvantage of this approach is that it requires significant computational resources and a human for visual data interpretation. Hence, it was used in this study as a validation tool only. The results of applying the IOA 'reference method' with modifications are shown in Fig. 4(b) and (c). Here the AM depth is plotted against time, and 10-min periods with and without AM are shown using red circles and blue plus signs, respectively. Fig. 4(d) shows that the SPL of low-frequency noise is much higher during periods containing wind farm AM compared to periods when the ambient noise is dominant.

Comparison between Fig. 4(a) and (b) indicates that the prominence ratio of 4 that is recommended by Bass et al. [9] fails to detect many occurrences of AM. On the other hand, selection of a more conservative prominence ratio of 3 results in a better correlation between the AM visible in Fig. 4(a) and the 10-min periods identified as containing AM in Fig. 4(c). The rate of detection of true and false positives for various prominence ratios is discussed in more detail below.

To further refine the selection of the prominence ratio for the entire data set, a Receiver Operating Curve (ROC) analysis was carried out using the methodology outlined by Fawcett [21]. The aim of the ROC analysis was to systematically examine true versus false positive and negative detection rates at each possible prominence ratio to find the optimal prominence ratio cut-off that simultaneously maximised both true positive (sensitivity) and true negative (specificity) detection. This is done by comparing the algorithm output to a 'gold standard' which in this case is the human-scored presence of AM. To construct the 'gold standard' data set, 96 10-min periods (equivalent to 16 h of continuous measurement) were randomly selected from each of the 9 data sets. These data were plotted in spectrograms with the same criteria used to plot Fig. 4(a). One investigator (PN) manually reviewed and classified each of the resulting 864 spectrogram segments into those containing ($N = 200$) versus not containing ($N = 664$) visually discernible AM for at least 50% of the time, as consistent with the IOA 'reference method'. The IOA 'reference method' was then employed to detect AM, using prominence ratios between 2.5 and 4.5, with steps of 0.25, and the resulting ROC curve is shown in Fig. 5(a). The standard IOA 'reference method' and prominence ratio cut-off of 4 showed high specificity (0.99) but poor sensitivity (0.09) for detecting 'gold standard' classified AM events compared to a prominence ratio of 3; which achieved a more reasonable balance of lower specificity (0.82) and higher sensitivity (0.62). A prominence ratio of 3 is closest to the top-left corner (0,1) of the ROC which represents an ideal classifier and so provides the best compromise between true and false positive rates [22]. The total area under the ROC curve (AUC) is 0.783 (95% confidence interval 0.751 to 0.815), which indicates that the IOA 'reference method' is a reasonably good discriminator of AM, but could potentially be improved. Fig. 5(b) shows an alternative method for measuring algorithm performance using the number of true and false positives for each value of the prominence ratio investigated. For each prominence ratio, the vector containing a binary

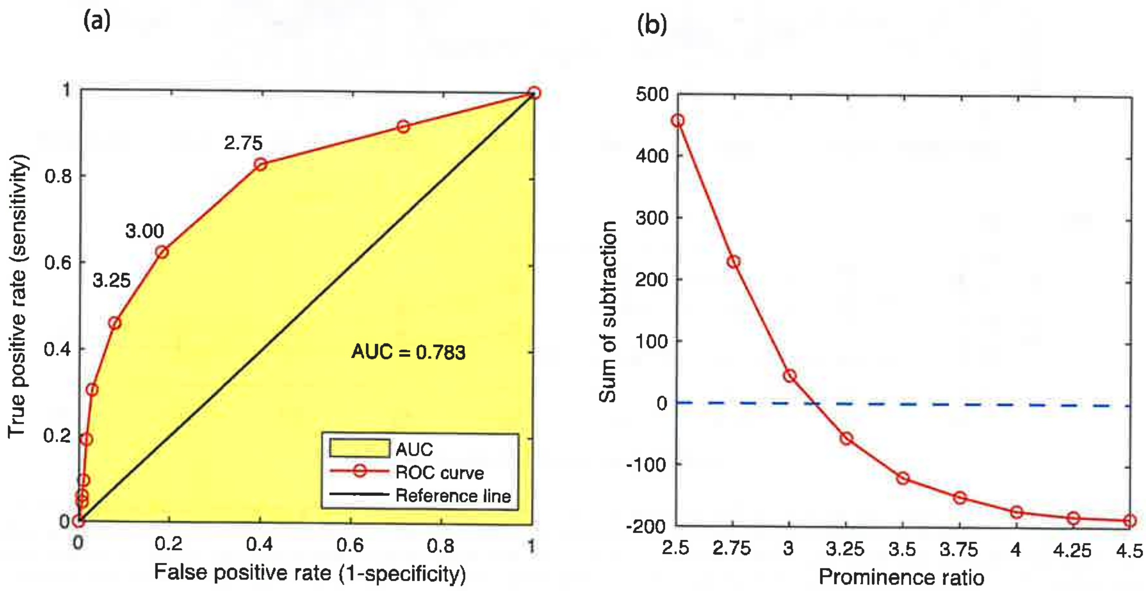


Fig. 5. Selection of the most suitable prominence ratio. (a) ROC curve analysis and (b) Sum of subtraction method.

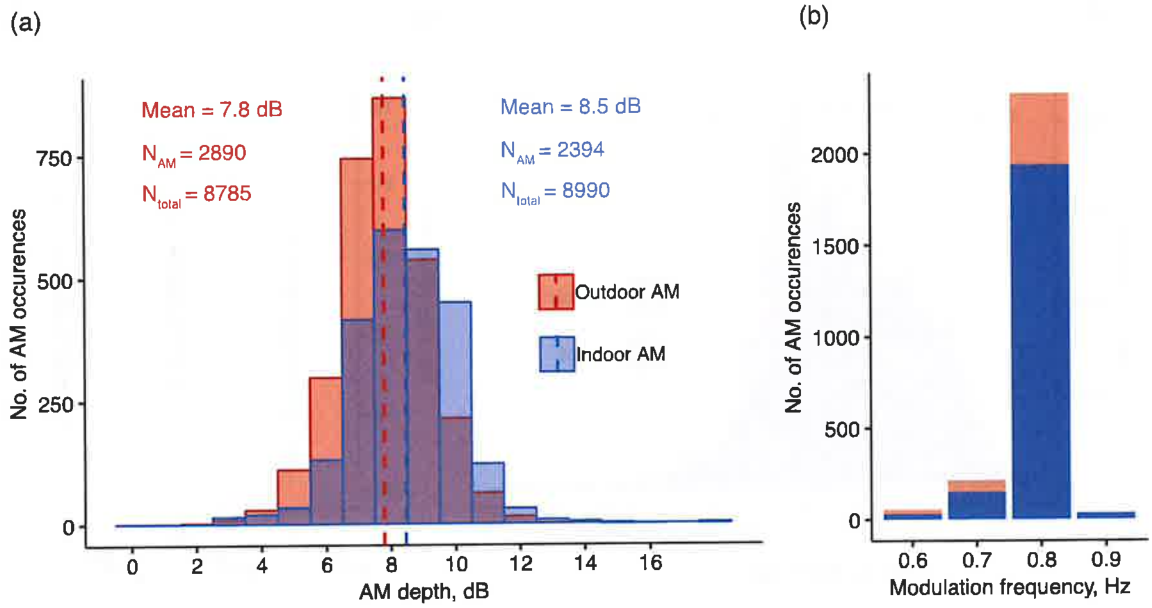


Fig. 6. AM analysis of outdoor (red) and indoor (blue) noise measured at 9 different residences located near a wind farm. The overlap between outdoor/indoor AM data is shown in purple. The 'AM correction' has not been applied. (a) Histogram of AM depth. (b) Histogram of modulation frequency. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

outcome for the presence/absence of AM from the 'gold standard' data set is subtracted from the corresponding vector obtained using the IOA 'reference method'. All elements in the resulting vector are summed and the entire process is labelled 'sum of subtraction' in Fig. 5(b). The results show that at low prominence ratios, there is a high rate of false positives whereas at high prominence ratios, there is a high rate of false negatives (i.e. non-detection of AM). The curve asymptotes near a value of −200 as this corresponds to the number of AM events in the 'gold standard' data set and thus indicates that few AM events were detected using high prominence ratios. The point closest to the blue dashed line, which reflects maximum true positives and true negatives, corresponds to a prominence ratio of 3, which is in agreement with the ROC analysis. Hence, a prominence ratio of 3 was selected for this study. Use of a higher cut-off, such as 3.5, could be used to reduce the false positive rate to more confidently 'rule-in' the presence of AM (i.e. higher specificity), but also increases the chances of missing AM (i.e. lower sensitivity). Similarly, use of a lower cut-off, such as 2.5, could be used to more confidently ensure that AM is not missed (i.e. higher sensitivity), but at the expense of falsely detecting AM in some cases (i.e. lower specificity). Ultimately AM classification methods need to both reliably detect the most annoying features of AM when AM is present, and reliably rule out AM when it is absent.

4. Results

4.1. Prevalence of AM

The results of applying the modified AM algorithm without the 'AM correction' for audibility to outdoor and indoor data measured at 9 different residences located near a wind farm are shown in Fig. 6. In Fig. 6(a), the number of AM events is plotted against the AM depth. It is evident that the mean AM depth for indoor noise was higher than that for outdoor noise. The reason for this is that the background noise in the 50 Hz 1/3-octave band was higher indoors, resulting in less AM events being detected, and thus a shift in the mean value. Given that the AM occurs in the 50 Hz 1/3-octave band, where the equal loudness contours are closer together than for mid-frequency noise, the fluctuation in loudness as a result of AM would be greater and hence potentially more annoying. On the other hand, to obtain a more realistic prediction of annoyance, the 'AM correction' should be applied, as outlined in Section 4.2. Fig. 6(b) shows that the modulation frequency was consistently 0.8 Hz, which corresponds to the expected blade-pass frequency when the wind turbines are operating at their nominal speed of 16.1 rpm [23].

4.2. Prevalence of audible AM

To determine which data points required an 'AM correction' to more accurately reflect the perception of AM depth, the tonal audibility was assessed as described in Section 3.1. Results of this assessment are shown in Fig. 7(a) and it can be seen that the tone was potentially audible both outdoors and indoors. In fact, the tone would have been audible in more cases than reflected in Fig. 7(a) since the tonal audibility assessment is based on mean values and therefore the peak audibility of an AM tone is higher.

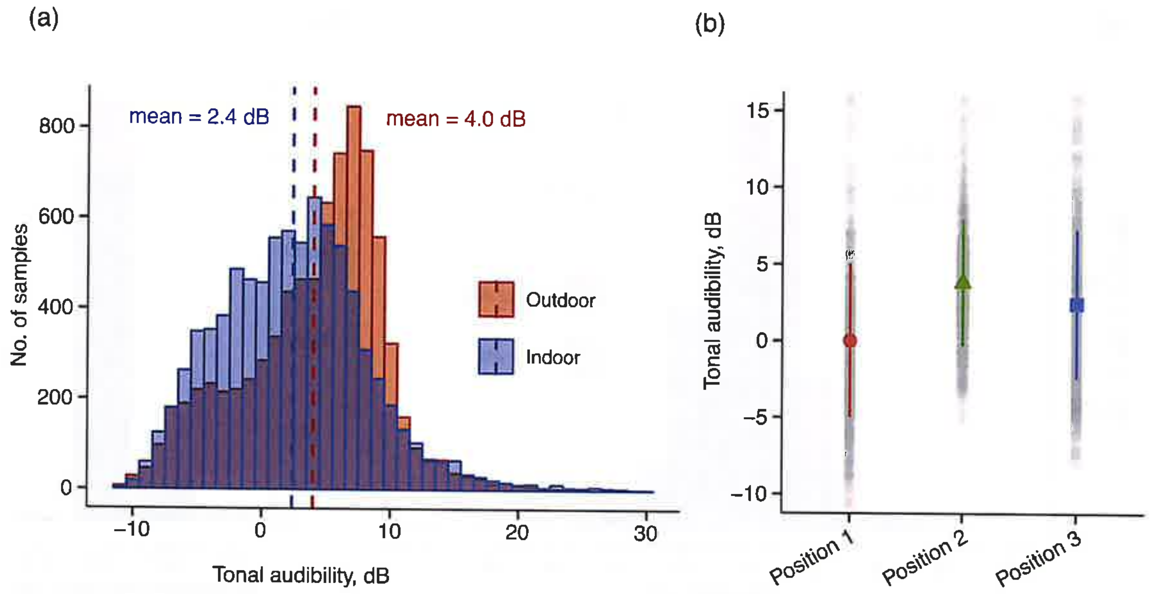


Fig. 7. (a) Histogram of tonal audibility measured outdoors (red) and indoors (blue) using the corner microphone. (b) Tonal audibility measured at 2 random locations within a room (Positions 1&2) and in the corner location (Position 3). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

The mean tonal audibility outdoors and indoors was 4 dB(A) and 2.8 dB(A), respectively. As the histogram for the outdoor data is negatively-skewed, the mode was much higher at 7 dB(A). The lower tonal audibility indoors may be the result of higher indoor masking noise.

An unexpected result was obtained when comparing the tonal audibility at various positions around the room for H5. It was found that the mean tonal audibility was highest at randomly chosen 'Position 2' in Fig. 7(b), where the microphone was mounted near the centre of the room at a height of 1.5 m. At the corner 'Position 3' in Fig. 7, the mean tonal audibility was slightly lower and therefore the results shown in Fig. 7(a) may not reflect worst case conditions. The reason that the tonal audibility is not necessarily highest in the corner is that the corner is an anti-node for all room response modes and therefore the masking noise in the critical band containing the tone would have been higher as well. At another randomly chosen location near the centre of the room at a height of 1.5 m, the mean tonal audibility was shown to be lower than the other two positions and therefore for consistency, the corner position was used in the tonal audibility assessment. However, these results indicate that it

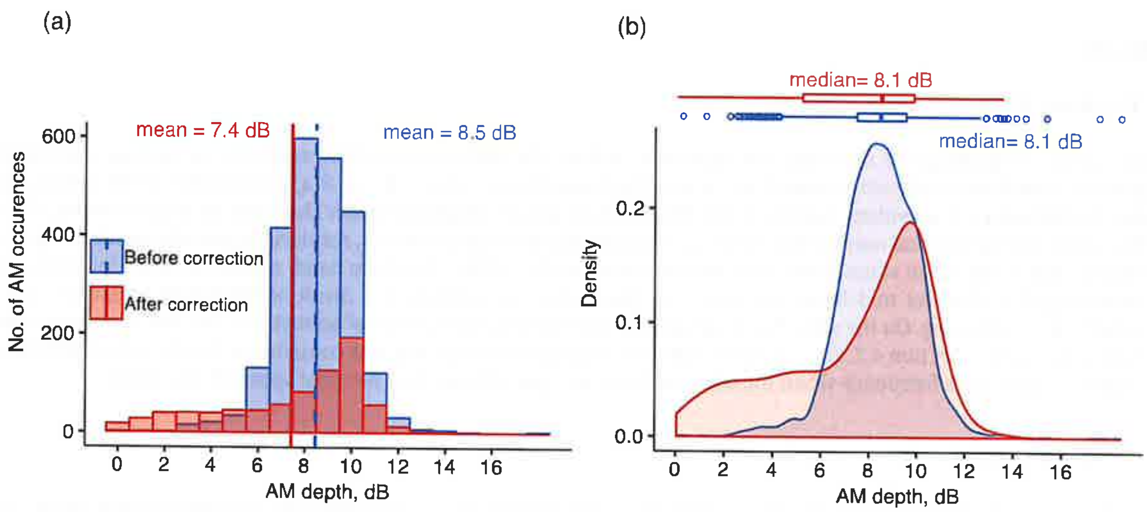


Fig. 8. Indoor noise measurements taken at 9 different locations near a wind farm before and after the 'AM correction' (blue and red, respectively). (a) Histograms of AM depth. (b) Probability Density Function of AM depth. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

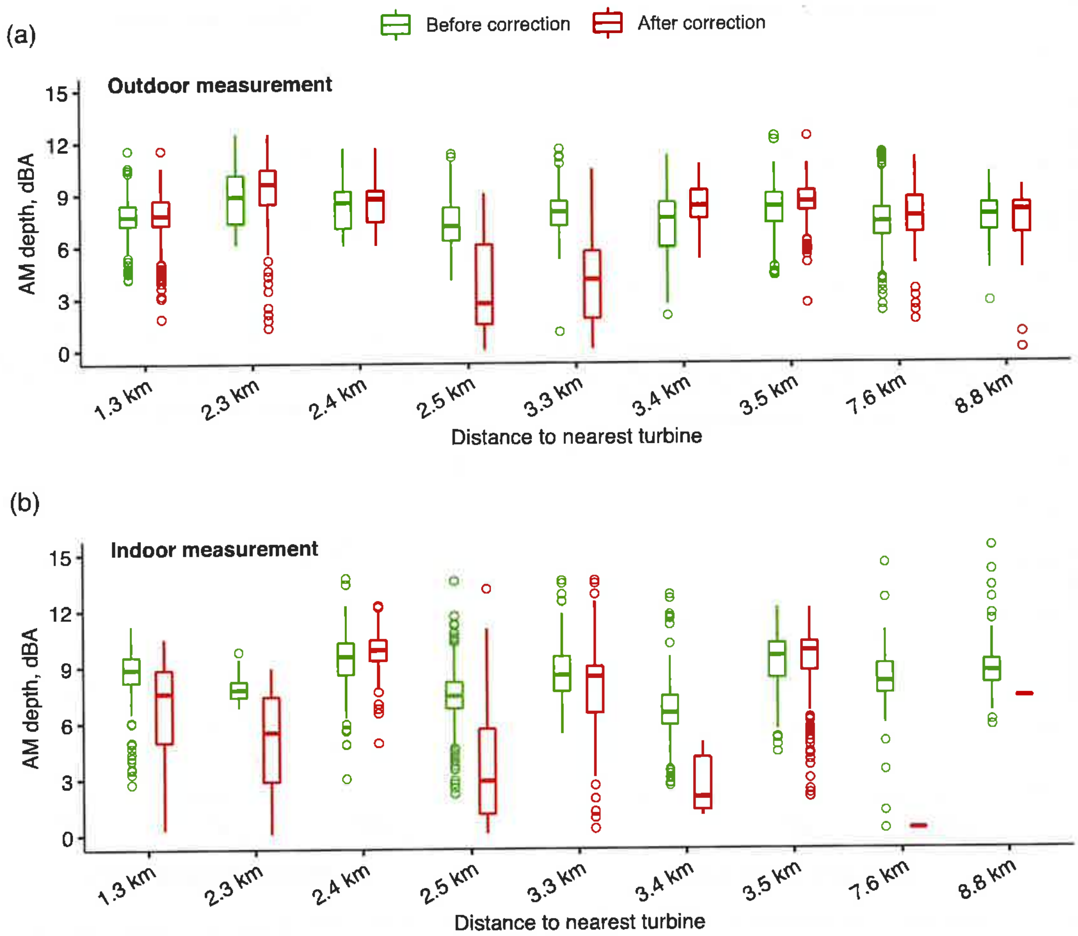


Fig. 9. Relationship between AM depth and distance from the wind farm before (green) and after 'AM correction' (red). (a) Outdoor measurement, (b) Indoor measurement. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

could be advantageous to involve the resident when selecting measurement positions when a tone is involved, since the corner position may not represent the worst case in this situation.

The results obtained after applying the 'AM correction' to the indoor data are shown in Fig. 8(a) and (b). It is evident that the 'AM correction' is necessary for a large number of data points, resulting in a reduction in the mean AM depth from 8.5 dB to 7.4 dB. This indicates that the tonal audibility at 46 Hz was often less than 0 dB, as shown in Fig. 7(a). The overall number of AM events is also much lower, indicating that a large proportion of detected AM events were entirely below the hearing threshold. Fig. 8(b) shows that the median AM depth is the same before and after correction but that the mode is higher after correction. Also, the distribution shape changes significantly and becomes negatively-skewed, which is expected as the 'AM correction' involves a subtraction only. Similar trends were observed for the outdoor data and thus the results are not presented here.

4.3. Relationship between distance from the wind farm and AM

Fig. 9(a) and (b) show uncorrected and corrected AM depth as a function of distance from the nearest wind turbine for data measured outdoors and indoors, respectively. There is no clear relationship between the AM depth and distance for both outdoor and indoor data before the 'AM correction' is applied. This is anticipated as the difference between the peak and trough SPL remains constant. Also, our previous analyses [17] have shown that the wind turbine signal is as high as 15 dB above ambient noise levels in the 50 Hz 1/3-octave band at a distance of 8.8 km from the nearest wind turbine, suggesting that masking in this frequency range may only occur during periods of low wind farm power output. In these cases, it is possible that the AM would not be detected as valid due to relatively high ambient levels. Differences in the AM depth measured at the various residences can be explained by differences in the positioning of the residences with respect to the wind farm. This affects the distance between the residence and the wind turbines other than the closest one. Also, the number of wind turbines that are orientated in a given direction with respect to the residence varies with both wind direction and residence position.

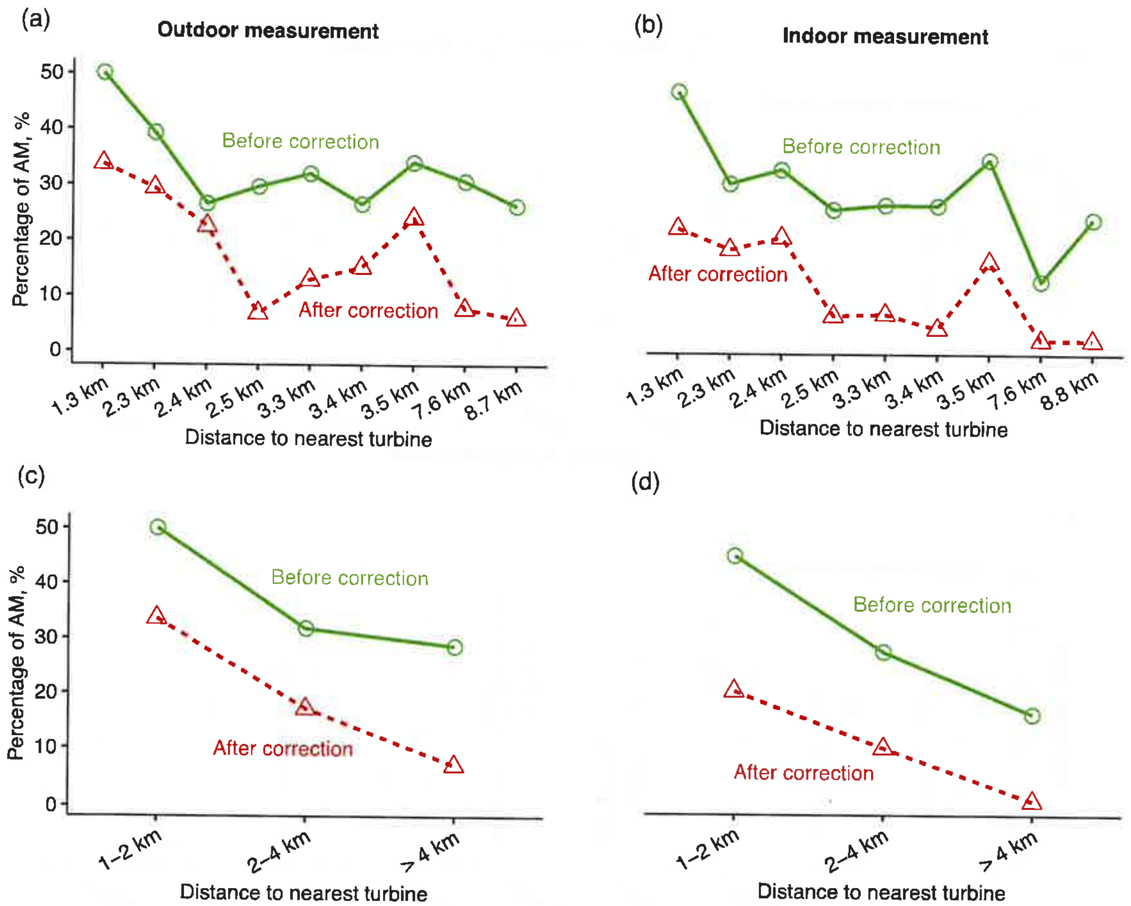


Fig. 10. Outdoor and indoor noise measurements taken at 9 different locations near a wind farm. (a, b) Relationship between the percentage of time that AM was present and the distance from the wind farm. (c, d) Relationship between percentage of time that AM was present and distance from the wind farm, where the results have been combined into three distance bins of 2 km width.

The AM depth is expected to reduce with distance when the 'AM correction' is applied, since tonal noise at 46 Hz is less likely to be audible at larger distances from the wind farm. However, this relationship is not evident in Fig. 9(a) and (b). The reason for this is that audibility of wind farm noise is dependent on the wind turbine power output and this was not the same during the measurements taken at each residence. In fact, the reduced tonal audibility and lower AM depth after 'AM correction' at 2.5 and 3.3 km in Fig. 9(a) may indicate that worst-case conditions, in terms of AM depth and audibility, were not captured at these residences. It is interesting to note that although the number of AM events is lower at 8.8 km relative to 1.3 km, the AM depth is similar outdoors both before and after the 'AM correction', as shown in 9(a). For the indoor data, there was only one instance of audible AM at 8.8 km but the associated AM depth was also similar to that measured at 1.3 km. The variation in the AM depth with distance for the indoor data after 'AM correction' shown in 9(b) can be attributed to differences in housing construction and orientation of the room relative to the wind farm. These factors affect the indoor SPL and hence audibility.

The large number of outliers, shown by the green and red open circles, in Fig. 9(a) and (b) is attributed to meteorological effects such as changes in wind direction, atmospheric stability and atmospheric turbulence. However, the number of outliers is small (10%) compared to the total number of data points, from all locations, that were used for the averages. Fewer outliers are associated with the red data points as the 'AM correction' reduces the overall number of AM events, however, the actual percentage of outliers remains the same.

Fig. 10(a) and (b) provide insight into the percentage of time that AM occurred at each residence both outdoors and indoors. These numbers should be interpreted with caution due to differences unrelated to distance such as: size of the data set, position of the residence with respect to the wind farm, worst case atmospheric conditions for wind farm AM not captured, housing construction, room orientation relative to the wind farm and room size. The latter three characteristics are only relevant when considering the results after 'AM correction'. Valid AM was detected less often indoors, which may be related to background noise, as some of the residences (but not the measurement room) were occupied during the measurement period.

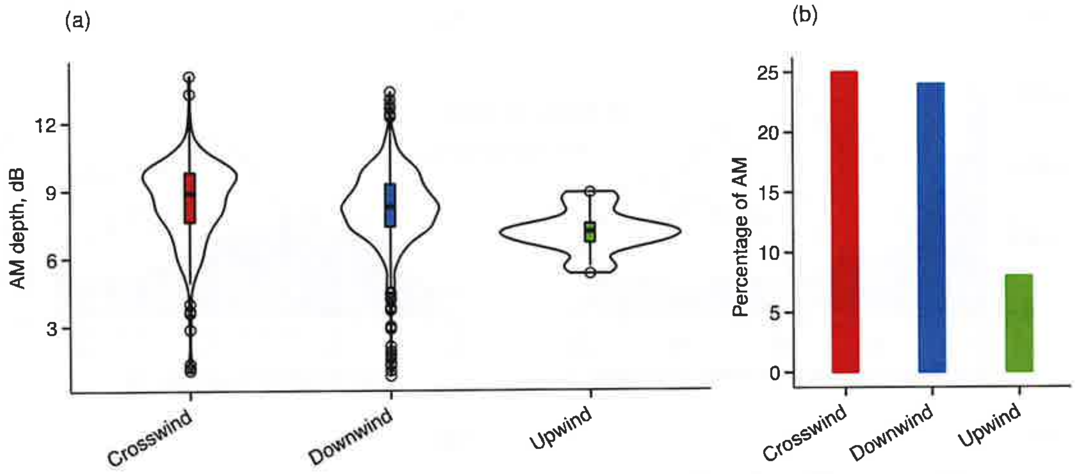


Fig. 11. Indoor noise measurements taken at 9 different locations near a wind farm. (a) Bean plot of AM depth against hub-height wind direction. (b) Percentage of time that AM was present during various hub-height wind directions.

Fig. 10(a) and (b) indicate that tonal AM was present outdoors between 25 and 50% of the time and indoors between 14 and 46% of the time. Applying the 'AM correction' results in fewer AM events, however, the tonal AM is shown to be audible outdoors and indoors up to distances of 3.5 km for as much as 24 and 16% of the time, respectively. At distances of 7.6 and 8.8 km, it is expected that the tonal AM would generally not be audible for a person with hearing in the normal range. The tonal AM could be audible at these distances for a small proportion of the population that have sensitive hearing (i.e. 2.5% of the population have a hearing threshold that is 10–12 dB less than the ISO 389-7 [15] threshold curve [14]). The results at 2.5 and 3.5 km are not considered representative for the reasons discussed in the paragraphs above. Therefore, to further investigate the relationship between percentage of AM and distance, Fig. 10(c) and (d) were plotted. To reduce the variance between measurement locations in this figure, the data have been categorised into three groups; 1–2, 2–4 and > 4 km. A clear trend of reducing AM with distance is apparent from these figures both before and after the 'AM correction'. In fact, it is shown that the occurrence of AM may be reduced by a factor of two after a distance of 2 km. A lower AM detection rate at distances greater than 2 km may be associated with a reduced signal-to-noise ratio, particularly during periods of low wind farm power output.

4.4. *Wind farm operating conditions and AM*

Fig. 11(a) provides insight into the relationship between AM depth and hub-height wind direction for the indoor data without 'AM correction'. It can be seen that the mean AM depth is similar for crosswind and downwind conditions but slightly lower for upwind conditions. Also, the distribution shapes vary such that there are more AM events with a higher AM depth under crosswind conditions. Fig. 11(b) indicates that the percentage of time that AM was present during each wind direction is similar for downwind and crosswind directions but much lower for the upwind direction. For the entire data set, crosswind, downwind and upwind conditions occurred 17%, 80% and 3% of the time, respectively. For the results shown in Fig. 11, the wind direction is defined based on the line joining the nearest wind turbine to the receiver with a margin of ±45°. This is an approximation as wind turbines adjacent to the nearest wind turbine are orientated differently for a given wind direction. On the other hand, since the wind farm layout is approximately linear in the North-South direction and most of the residences are located to the East and West of the wind turbines, the direction categories are usually applicable to the adjacent wind turbines as well.

The relationship between wind farm power output, hub-height wind speed and the presence of AM indoors is presented in Fig. 12(a) and (b). In these figures, the grey and green bars correspond to periods of no AM and valid AM, respectively. The line plot indicates the percentage of time that AM was present for the entire measurement period. As shown in Fig. 12(a), a large number of measurements were taken when the wind farm was operating at a percentage power capacity of <5% as there were several periods during which the wind speed was less than the cut-in wind speed of 3.5 m/s [23].

Fig. 12(a) and (b) indicate that the highest number of AM events is associated with a wind farm percentage power capacity and hub-height wind speed of approximately 40% and 10 m/s, respectively. After applying the 'AM correction', the peak in the percentage of time that AM was present is less distinct and it is more useful to consider a range of operating conditions. Referring to the dashed line in Fig. 12(a) and (b), it can be seen that audible tonal AM was present indoors for at least 20% of the time when the hub-height wind speed at the nearest wind turbine was between 11 and 14 m/s and the percentage power capacity was between 40 and 85%.This indicates that AM is more likely to be detected when the wind turbines are operating below their maximum rated power. It is unclear if this is a source characteristic or an environmental effect, as the background

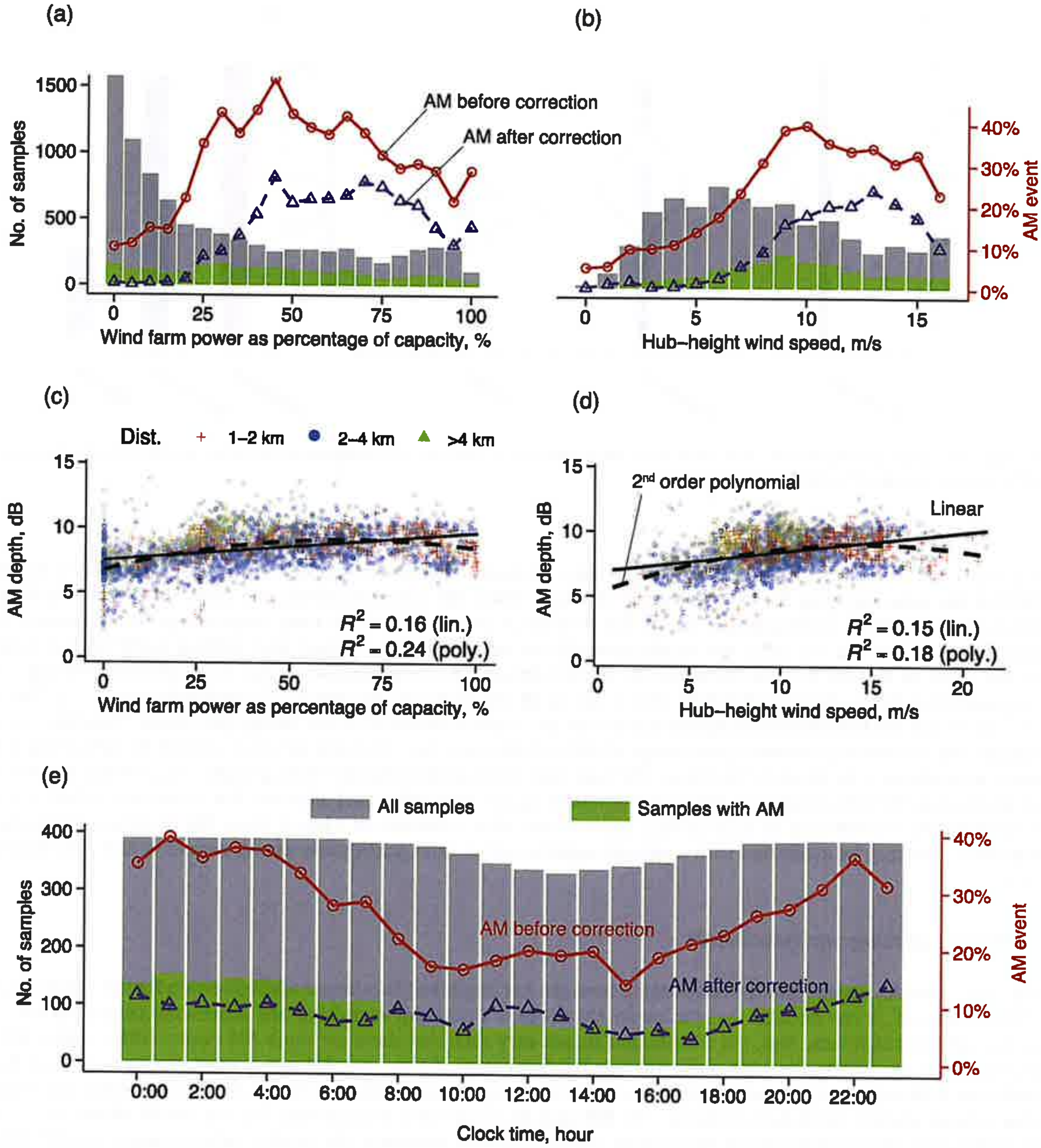


Fig. 12. Indoor noise measurements taken at 9 different locations near a wind farm. (a) Number of AM events and percentage of time that AM was present before and after 'AM correction' against wind farm percentage power capacity, (b) Number of AM events and percentage of time that AM was present before and after 'AM correction' against hub-height wind speed, (c) AM depth against wind farm percentage power capacity, where the data has been separated into 2 km-wide distance bins and the regression fits applied to all data, (d) AM depth against hub-height wind speed, where the data has been separated into 2 km-wide distance bins and the regression fits applied to all data, (e) Number and percentage of time that AM was present as a function of time of day.

noise may also be higher due to wind noise at the receiver when the wind farm is operating at higher power capacities. This could result in non-detection of AM, even though it may be present.

In Fig. 12(c) and (d), the AM depth without the correction for audibility is plotted against the percentage power capacity and wind speed at hub height, respectively. There is a poor correlation between the AM depth and percentage power capacity as well as hub-height wind speed, as indicated by the low R^2 values obtained for both linear and second order polynomial regression fits. However, according to the second order polynomial regression fit, which has a higher R^2 value, there is a general trend that the AM depth increases slightly up to a percentage power capacity and wind speed at hub height of 70% and 15 m/s, respectively, after which it decreases slightly. Limited improvement in the correlation between AM depth and percentage power capacity as well as hub-height wind speed is obtained when the data are separated into 2 km-wide distance bins. This is indicated by the large scatter in the data points for each distance bin shown in Fig. 12(c) and (d). Hence, the large variation in AM depth for the various power capacities and wind speeds at hub height is most likely attributable predominantly to meteorological effects. Detection of valid AM at a power output of 0% can be explained by the 18% false positive rate using a prominence ratio of 3, as shown in Fig. 5(a).

Fig. 12(e) shows that tonal AM occurs much more frequently during the night-time, particularly between 10pm and 5am. In fact, compared to daytime hours from 9am to 5pm, there are twice as many AM events during the night-time. This is in agreement with the findings of Van den Berg [24] and supports the idea that AM is more likely to occur during stable conditions, which occur more often at night-time. A larger proportion of AM events that occurred during the daytime were audible compared to the night-time. A possible explanation is that inaudible AM events are less likely to be detected during the daytime when the background noise level is higher. Approximately 10% of the total measurement time at night-time contained audible AM. However, at residences located up to 3.5 km from the wind farm, audible AM occurred for as much as 22% of the measurement time at night-time.

5. Conclusions

Low-frequency tonal AM with a modulation frequency consistent with the expected blade-pass frequency, has been measured between 1 and 9 km from a wind farm. The mean AM depth was 8.5 dB for noise measured indoors, slightly higher than the mean of 7.8 dB which was measured outdoors. On the other hand, when the tonal audibility was taken into account, the mean AM depth reduced to 7.4 dB for noise measured indoors and there was a similar reduction for the outdoor data.

Despite the relatively low noise levels, it was found that the tonal AM could be audible both outdoors and indoors up to distances of 3.5 km from the nearest turbine in the wind farm. The tonal audibility was higher outdoors than indoors, possibly due to higher indoor masking noise relative to the tonal noise. The indoor tonal audibility was dependent on the microphone location and the highest tonal audibility was not measured in the corner. This is because both the tonal level and masking noise are higher in the corner position since it is an anti-node for all room response modes. The relatively higher masking noise at the corner location can therefore give rise to a relatively lower tonal audibility.

There was no clear relationship between the AM depth and distance from the wind farm before the 'AM correction' for audibility was applied. This is expected, as AM depth is not affected by distance, and masking of the wind farm noise by ambient noise in the 50 Hz 1/3-octave band can be negligible, even at distances as far as 8.8 km from the nearest wind turbine. Due to differences in the power output that occurred during the measurement period at each residence, it was not possible to draw conclusions about the relationship between AM depth and distance from the wind farm after 'AM correction'. However, for the outdoor data, it was observed that the AM depth after correction was similar at the various distances. The percentage of time that AM was present was shown to reduce significantly with distance from the wind farm both before and after the 'AM correction'. This observation is consistent with noise attenuation during propagation, which results in a decrease in the wind farm noise level and hence, a reduction in tonal audibility and valid AM. Tonal AM was shown to be audible outdoors and indoors up to distances of 3.5 km for as much as 24 and 16% of the time, respectively. At distances of 7.6 and 8.8 km, the results indicate that the tonal AM would generally not be audible for a person with hearing in the normal range.

The percentage of occurrence and AM depth were both found to be higher during downwind and crosswind conditions. However, under crosswind conditions, the AM depth was higher for a larger number of AM events. The AM occurred most often when the wind farm percentage power capacity was approximately 40% both before and after the 'AM correction' was applied to account for the tonal audibility. Audible tonal AM was shown to be present indoors for at least 20% of the time for the entire data set when the hub-height wind speed at the nearest wind turbine was between 11 and 14 m/s and the percentage power capacity was between 40 and 85%.

Tonal AM occurred most often at night-time, during the hours between 10pm and 5am. Approximately 10% of the total measurement time at night-time contained audible AM. At residences located up to 3.5 km from the wind farm, audible AM occurred for as much as 22% of the time at night. This has important implications for possible sleep disruption from wind farm AM, particularly as ambient noise levels in rural South Australia can be as low as 15 and 5 dBA, outdoors and indoors, respectively. Further research is needed to determine the prevalence of AM on an annual basis. Further work is also needed to quantify the annoyance and sleep disturbance potential of this type of tonal AM.

Acknowledgements

The authors gratefully acknowledge financial support from the Australian Research Council, Projects DP120102185 and DE180100022 and fellowship FT120100510 and the National Health and Medical Research Council, Project 1113571. We also acknowledge Mahmoud Alamir's assistance in developing the AM detectison code.

References

[1] Gorica Micic, Branko Zajamsek, Leon Lack, Kristy Hansen, Con Doolan, Colin Hansen, Andrew Vakulin, Nicole Lovato, Dorothy Bruck, Ching Li Chai-Coetzer, et al., A review of the potential impacts of wind farm noise on sleep, Acoust Aust. 46 (1) (2018) 87–97.

[2] U.K. Renewable, Wind Turbine Amplitude Modulation: Research to Improve Understanding as to its Cause and Effect, Technical report, Renewable UK, 2013.

[3] B. Schffer, S.J. Schlittmeier, R. Pieren, K. Heutschi, M. Brink, R. Graf, J. Hellbrck, Short-term annoyance reactions to stationary and time-varying wind turbine and road traffic noise: a laboratory study, J. Acoust. Soc. Am. 139 (5) (2016) 2949–2963.
[4] S. Lee, K. Kim, W. Choi, S. Lee, Annoyance caused by amplitude modulation of wind turbine noise, Noise Control Eng. J. 59 (1) (2011) 38–46.
[5] C. Ioannidou, S. n Santurette, C. Jeong, Effect of modulation depth, frequency, and intermittence on wind turbine noise annoyance, J. Acoust. Soc. Am. 139 (3) (2016) 1241–1251.
[6] D. Bowdler, M. Cand, M. Hayes, G. Irvine, Wind turbine noise amplitude modulation penalty considerations, Proc. Inst. Acoust. 40 (Pt. 1) (2018) 253–261.
[7] R. Perkins, B. Berry, C. Grimwood, S. Stansfeld, A review of research into the human response to amplitude modulated wind turbine noise and development of a planning control method, in: INTER-NOISE and NOISE-CON Congress and Conference Proceedings, vol. 253, Institute of Noise Control Engineering, Hamburg, Germany, 2016, pp. 5222–5233.
[8] J. Bass, M. Cand, D. Coles, R. Davis, G. Irvine, G. Leventhall, T. Levet, S. Miller, D. Sexton, J. Shelton, Discussion Document: Methods for Rating Amplitude Modulation in Wind Turbine Noise, Technical report, IOA noise working group (wind turbine noise): amplitude modulation working group. 2015. Available at: https://www.ioa.org.uk/sites/default/files/AMWG20Discussion20Document.pdf.
[9] J. Bass, M. Cand, D. Coles, R. Davis, G. Irvine, G. Leventhall, T. Levet, S. Miller, D. Sexton, J. Shelton, Final Report: A Method for Rating Amplitude Modulation in Wind Turbine Noise. Technical report, IOA Noise Working Group (Wind Turbine Noise): Amplitude Modulation Working Group, 2016. Available at: https://www.ioa.org.uk/sites/default/files/AMWG20Final20Report-09-08-2016_1.pdf.
[10] A. Fukushima, K. Yamamoto, H. Uchida, S. Sueoka, T. Kobayashi, H. Tachibana, Study on the amplitude modulation of wind turbine noise: Part 1physical investigation, Internoise (2013) 2013.
[11] S. Yokoyama, S. Sakamoto, H. Tachibana, Perception of low frequency components contained in wind turbine noise, in: 5th International Meeting on Wind Turbine Noise, Denver, Colorado, 2013.
[12] K. Hansen, B. Zajamek, C. Hansen, Identification of low frequency wind turbine noise using secondary windscreens of various geometries, Noise Control Eng. J. 62 (2) (2014) 69–82.
[13] Australian Energy Market Operator, Wind Farm Power Output Data, 2015, http://www.nemweb.com.au/REPORTS/ARCHIVE/DispatchIS_Reports/.
[14] C.H. Hansen, C.J. Doolan, K.L. Hansen, Wind Farm Noise: Measurement, Assessment and Control, 1 edition, John Wiley & Sons Ltd, 2017.
[15] ISO389-7, Acoustics: Reference Zero for the Calibration of Audiometric Equipment Part 7: Reference Threshold of Hearing under Free-Field and Diffuse-Field Listening Conditions, 2005.
[16] IEC61400-11, Wind Turbines Part 11: Acoustic Noise Measurement Techniques, vol. 3, 2012. 0.
[17] K. Hansen, B. Zajamek, C. Hansen, Comparison of the noise levels measured in the vicinity of a wind farm for shutdown and operational conditions, in: Internoise2014, Melbourne, Australia, 2014.
[18] NZS 6808, in: Acoustics - wind farm noise, 2010.
[19] J.N. McCabe, Detection and quantification of amplitude modulation in wind turbine noise, in: Fourth International Meeting on Wind Turbine Noise, Rome, Italy, 2011.
[20] J. Cooper, T. Evans, Automated detection and analysis of amplitude modulation at a residence and wind turbine, in: Acoustics 2013, Victor Harbor, Australia, 2013.
[21] T. Fawcett, An introduction to roc analysis, Pattern Recogn. Lett. 27 (8) (2006) 861–874.
[22] N.J. Perkins, E.F. Schisterman, The inconsistency of optimal cut-points using two roc based criteria, Am. J. Epidemiol. 163 (2006) 670–675.
[23] Vestas, General Specification V90 3.0 MW VCRS, 2006. Available at: https://report.nat.gov.tw/ReportFront/PageSystem/reportFileDownload/C09503816/002.
[24] G.P. Van den Berg, The beat is getting stronger: the effect of atmospheric stability on low frequency modulated sound of wind turbines, J. Low Freq. Noise Vib. Act. Control 24 (1) (2005) 1–24.

Posted to the Irish Engineer 24 January 2018 but not reproduced by Irish Engineer website

I am surprised at some of the comments made by the professional acousticians here.

Firstly, have they forgotten already the mistakes of the past? To name just a few:

Excess Amplitude Modulation

Following the Bryn Llewelyn appeal in October 2013 Dr Jeremy Bass of RES, said:

"foolishly ... we went along the industry line that amplitude modulation is rare".

Excess AM is now shown to be neither rare nor only causing minor effects

Wake Turbulence

Turbulence, like low frequency noise, occurs naturally. But in certain conditions turbine wake turbulence can exceed it. No account of this excess noise is included in any noise regulation.

Masking Noise

The use of masking noise to justify an increase of the noise limit with wind speed was laid to rest by the pioneering work of van den Berg in 2004. The turbine can be generating power and noise while at ground level there is insufficient wind to generate masking noise.

Secondly, if low frequency noise is so benign, then why did the Danish EPA decide to add low frequency criteria to their wind turbine noise regulations, the same used for general industry. And why did they conclude that larger utility scale wind turbines shift sound energy downward and increase the potential effect of low frequency noise on people inside their homes. And why did the CEO of Vestas write in 2011 to the Minister of Environment for Denmark's DoE stating:

in future low frequency noise will dictate and increase the distance requirements to neighbours for close to half of the projects that we are already aware of...".

Thirdly, if low frequency noise is so benign then what is the problem about including it's measurement in any assessment of impacts? All that will be required is instrumentation to capture the full range of frequencies.

Fourthly, governments continue to rely on acoustic engineers to prepare official guidance both on exposure to wind turbine noise, including the upper limits of dosage and duration, and on separation

distances, despite the availability of experts on noise and health. In this, acousticians routinely exceed their area of competence and a lack of physiological expertise is a major methodological flaw rendering any conclusions unreliable.

Fifthly, There is no routine testing for compliance post construction and therefore no feedback on the planning of future wind farms. In cases where complaints have led to noise audits revealing noncompliance, the receptors have sometimes been compensated but no feedback has informed the compliance process.

Finally, there is no mechanism for the collection of information on impacts on nearby residents. An independent academic, epidemiological clinical study of the effects of wind turbine noise on host communities, is urgently required.

In short, this informative article reveals a fundamental reason why regulatory authorities are unable to understand why people complain. To an absence of compliance testing, regulatory review and a mechanism for complaint, should be added Nelson's proverbial 'blind eye' – use of a measurement scale that will not reveal the problem.

Summary to:

The effect of a common wind shear adjustment methodology on the assessment of wind farms when applying ETSU-R-97

MAS Environmental - 27th October 2011

Introduction. MAS Environmental have undertaken a detailed study of methods used to account for wind shear in UK assessment of wind turbine noise impact. The full study can be downloaded from the MAS Environmental website[1]. This paper summarises the main issues in a simplified form to try to explain the consequences of the findings of the study.

In the UK planning policy supports the use of ETSU-R-97 to rate and assess noise from wind farms. At the time of publication in 1997, wind turbines were of a height of about 30m to the hub. Modern day turbines are often 80m to the hub and hence the swept area of the blades is much greater. With the increase in hub height of the turbines also came problems with wind shear affects and turbine noise impact.

Wind shear. Wind shear can be described as the change in wind speed with height. Wind speed differs with height and usually wind speed increases with increasing height. High wind shear is when there is a much faster wind speed at upper heights than at lower heights. Low wind shear is when the wind speeds at upper and lower heights are similar. Wind shear can have an adverse affect on turbine noise impact under high wind shear conditions.

In high wind shear conditions there is a faster wind speed at upper heights where tall wind turbine hub heights and blades are likely to be. High wind speed results in high turbine energy generation and hence high noise output.

[1]http://www.masenv.co.uk/uploads/STUDYREPORTComparison%20of%20thearticleandETSUW111004FINAL_sec.pdf

Meanwhile, due to high wind shear conditions, there is a much lower wind speed near the ground. This means that there is little wind generated background noise at dwellings to mask turbine noise. Thus, under high wind shear the situation arises where there is maximum turbine noise output (due to high wind speeds at turbine hub height) but very low background noise levels near ground level (due to much lower wind speeds and little wind generated background noise).

Accounting for wind shear. When ETSU-R-97 was written turbines were smaller and hence the effects of wind shear were not observed. The noise impact assessment methodology and rating of turbine noise impact in ETSU-R-97 does not account for wind shear effects. In 2009 a group of acousticians published an alternative method to that set out in ETSU-R-97 for assessing noise impact from wind turbines in the Institute of Acoustics magazine 'Acoustics Bulletin', referred to hereon as "the article method"[2]. It was argued that this revised assessment methodology would address noise impact from wind turbines and the affect of wind shear.

The article method differs in the way it approaches assessment of wind turbine noise compared to that set out in ETSU-R-97. ETSU-R-97 states that background noise levels should be referenced to 10m high measured wind speed. Although ETSU-R-97 does not factor for the affects of wind shear, wind shear can still be accounted for in keeping with ETSU-R-97 by adjusting predicted turbine noise levels to reflect differing levels of wind shear.

In contrast, the article method adjusts background noise levels for wind shear even though the affect of wind shear is on turbine noise. Under high wind shear conditions, the article method assumes that predicted turbine noise is the same as under lower wind shear conditions, but that the background noise level measured at a specific wind speed now occurs at a higher wind speed. It was argued by the authors of the article method that this would have the effect of accounting for wind shear in turbine noise impact assessment, suggesting a lower turbine noise limit at higher wind speeds compared to ETSU-R-97.

[2] Bowdler, D. et al (2009) "Prediction and assessment of wind turbine noise", *Acoustics Bulletin*, March/April 2009: p.35

MAS study. Research was conducted by MAS to test the assumptions of the article method and its suitability as an alternative assessment methodology to ETSU-R-97 as written.

Using data gathered from a number of proposed wind farm sites across the country, MAS were able to compare predicted turbine noise impact using both the article method and using the assessment procedures identified in ETSU-R-97 and adjusting predicted turbine noise for wind shear.

The suitability of the article method was judged by comparing the margin provided by each method between the predicted turbine noise and the turbine noise limit. With regard to protecting the local community from adverse noise impact, it is better for an assessment methodology to suggest that predicted turbine noise will exceed the limit than for it not to. Similarly, it is better, if turbine noise does not exceed the limit, for the assessment methodology to suggest that predicted turbine noise will be closer to the limit than it is for it to suggest that it will be well below the limit. This is simply so that communities can be better informed as to the likelihood of adverse noise impact; it provides a better prediction of the safety margin[3].

The two methods were therefore assessed by comparing how likely each method was to suggest a breach of turbine noise limits or to show turbine noise levels closer to turbine noise limits. Positive values in the results indicate that the ETSU-R-97 compliant methodology provides greater protection for communities as it predicts less headroom or margin between turbine levels and limits. Negative values indicate that the article method is more likely to predict that turbine noise levels will exceed limits (or be closer to turbine noise limits) and hence negative values indicate that the article method provides better protection for communities. The values in the results identify the extent of the difference in protection between the two methods with a higher value denoting a greater level of protection of one method over the other.

---

[3] This can be alluded to driving and speed cameras - would a driver prefer the car speedometer to calculate speed using a method that generally showed compliance with a speed limit, even when that was not the case, or one that was more likely to show that the speed limit was broken?

Results. The overall results of the analysis are presented in table 1 below. The data was assessed for all wind speeds between 3-12m/s and also for the critical range of 5-7m/s. The wind speed range of 5-7m/s is critical for two reasons. Firstly, it is between these medium wind speeds that predicted turbine noise is most often seen to exceed the limit. Secondly, it was suggested that the article method would provide best protection for communities in the range 5-7m/s. The data was also assessed for two different commonly occurring wind shear conditions, α=0.25 and α=0.4.

Table 1: Summary of results from all sites assessed

	All wind speeds (3-12m/s)		Critical wind speeds (5-7m/s)	
	α=0.25	α=0.4	α=0.25	α=0.4
% no gain from adopting article method	77	80	91	96
% gain from adopting article method	23	21	9	5
% no difference between methods	6	5	1	1
% loss of protection adopting article method	72	75	91	95

No gain. Where there is no gain from using the article method this is the combination of '0' values (no difference) and positive values (loss of protection using the article method, advantage to using the ETSU method).

Gain to using the article method. Negative values are cases where the article method provides greater control over noise levels, i.e. where there is an advantage to using the article method.

No difference. Where there is no difference between the two methods the value is 0 hence neither positive or negative.

Loss of protection using the article method. Positive values are cases where the ETSU method provides greater protection; the greater the value the greater the protection. This is where the ETSU method is more advantageous and there is a loss of protection from using the article method.

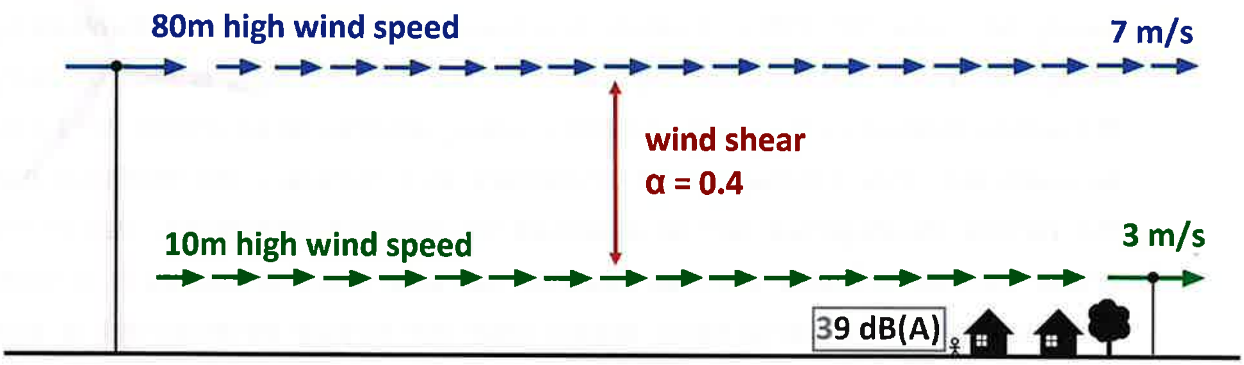
Table 1 above clearly shows that across all wind speeds for both wind shear exponents assessed that there is no gain in adopting the article method. In 72-75% of cases analysed the article method actually resulted in a loss of protection to communities. Looking only at the critical wind speeds of 5-7m/s nearly all cases (91-95%) resulted in a loss of protection to communities by using the article method. The implication of the above results is that by using the article method to assess wind turbine noise, adverse noise impact will rarely be predicted. This is beneficial for developers as it increases the likelihood that the turbine development will be approved for planning permission. Use of the article method provides a worse situation for local communities as it is more likely to result in adverse noise impact once the turbine development is built despite there being no indication of it at the planning stage and little means for reducing or resolving noise impact post development.

Postscript. Not only is the article method unlikely to indicate adverse noise impact at the planning stage, but once the development is operational the article method virtually removes the ability for local communities to enforce controls over reasonable turbine noise impact. This is explained step by step below.

Compliance testing - ETSU-R-97 vs Article method

1. This is the typical situation occurring:

Figure 1: typically occurring situation (medium-high wind shear)



Facts from the above situation:

→ Wind speed at hub height (80m) = 7m/s
(wind turbine(s) near maximum noise output)

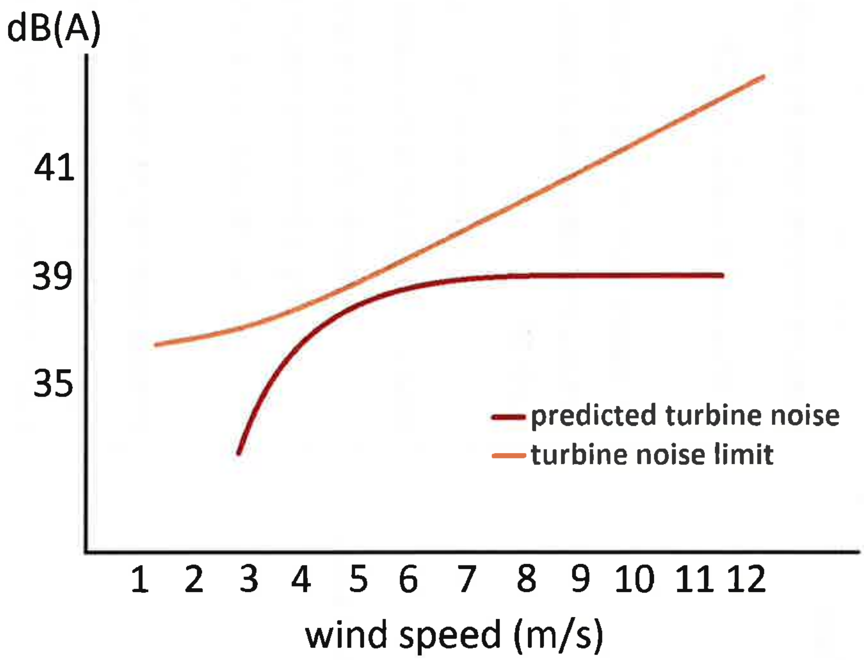
→ Wind speed at nearby housing (10m) = 3m/s
(low background noise levels)

→ Actual wind shear conditions between 10m and 80m height $\alpha=0.4$

→ Measured turbine noise at nearby housing = 39dB(A)

2. Assume the graph below showing predicted turbine noise and turbine noise limits is applicable for both compliance testing according to ETSU-R-97 and the article method. The MAS study found that commonly the turbine noise limit line was similar whichever method was used, especially at the critical wind speeds (5-7m/s) where exceedace is likely.

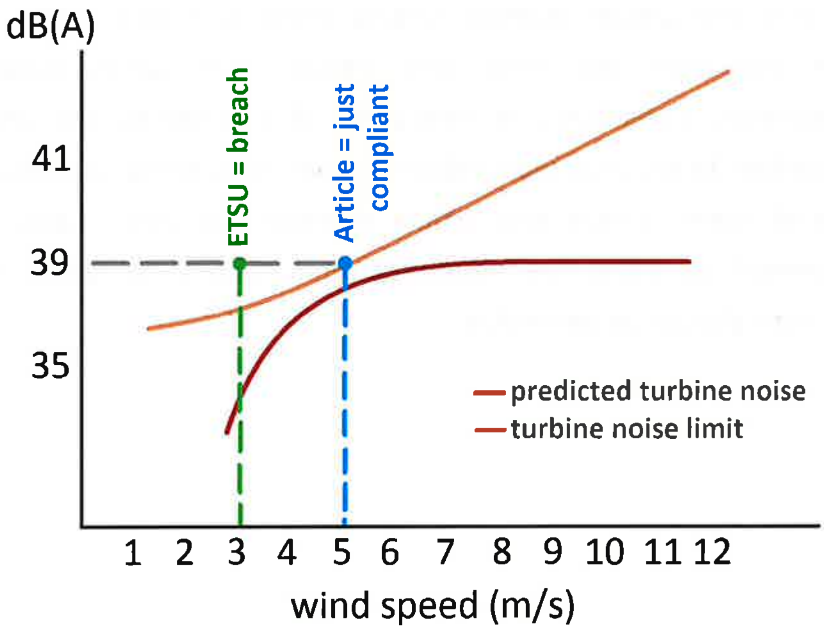
Figure 2: graph showing predicted turbine noise and turbine noise limit



3. Compliance test:

	ETSU compliance testing methodology	**Article method compliance testing methodology**
1. Determine turbine noise level	Measure turbine noise at dwelling = **39 dB(A)**	Measure turbine noise at dwelling = **39 dB(A)**
2. Determine wind speed	Measure 10m high wind speed = **3m/s.**	**a.** Measure or calculate hub height wind speed =**7m/s.** **b.** Derive 10m height wind speed using the following formula and assuming a standard ground roughness of z_0=0.05: $V_1/V_2 = \ln (h_1 / z_0) / \ln (h_2 / z_0)$ Where: V_1 is the wind speed (m/s) at a height of h_1 metres above the ground, V_2 is the wind speed (m/s) at a height of h_2 metres above the ground. Derived 10m height wind speed: $V_{10}/V_{80} = \ln (10 / 0.05) / \ln (80 / 0.05)$ $V_{10}/7 = \ln (10 / 0.05) / \ln (80 / 0.05)$ $\mathbf{V_{10} = 5m/s}$
3. Check compliance	See graph below (**green** line)	See graph below (**blue** line)

Figure 3: Compliance with turbine noise limit (ETSU versus article)



In the event of a complaint, analysis would follow either of the two paths depending whether assessed under ETSU-R-97 or using 'standardised' wind speeds as adopted by the article method.

As shown in figure 3 above ETSU-R-97 compliance testing methodology shows a breach of permitted turbine noise levels, and hence unreasonable noise impact as reflected by the presence of complaints. The article method suggests that turbine noise levels are compliant.

ETSU-R-97 automatically accounts for wind shear conditions as it measures turbine noise levels and 10m high wind speed under conditions representative of those that cause the complaint. In the above example the wind shear conditions causing complaint are equal to α=0.4. The article method fails to account for the actual conditions causing the complaint because of the common assumptions used in the formulae used to derive 10m wind speed height. It does not measure the actual 10m wind speed but derives it from hub height. By doing this it only ever assumes wind shear conditions of α=0.16. As demonstrated above, this lower wind shear value assumes that the wind speed at 10m is higher that it is likely to be when complaints occur. In the example above it assumes that the 10m height wind speed is 5m/s rather than the 3m/s that is actually occurring. This means that using the article method turbine noise will very rarely be shown to breach the permitted limit and hence even when turbine noise is unreasonable, compliance is indicated. This removes the ability for local communities to enforce reasonable turbine noise limits. It effectively renders any wind farm, where the article method has been used, incapable of enforcement as ETSU-R-97 intended and subject to higher turbine noise levels than should be permitted.

PUBLIC HEALTH STATEMENT

Re:
Doraville Wind Farm

by

Mariana Alves-Pereira, Ph.D.

September 2nd, 2019

Brief Biographical Background
(Full *Curriculum Vitae* and *List of Publications* are included in Appendix 1 of this Statement.)

Mariana Alves-Pereira holds a B.Sc. in Physics (State University of New York at Stony Brook), a M.Sc. in Biomedical Engineering (Drexel University) and a Ph.D. in Environmental Sciences (New University of Lisbon). She joined the multidisciplinary research team investigating the biological response to infrasound and low frequency noise in 1988, and was the team's Assistant Coordinator from 1999 until 2015. Recipient of three scientific awards, and author and co-author of over 50 scientific publications (including peer-reviewed and conference presentations), Dr. Alves-Pereira is currently Associate Professor at Lusofona University (Lisbon, Portugal) having taught Biophysics and Biomaterials in health science programs (nursing and radiology), as well as Physics and Hygiene in workplace safety & health programs. Additionally, she now actively contributes to an International Consortium of Scientists investigating the health effects of infrasound and low frequency noise among human and animal populations, in both occupational and residential settings. Prof. Alves-Pereira is a U.S./ E.U. citizen and can readily be reached at: m.alvespereira@gmail.com.

ANNEX 6

To the Planning Appeals Commission
Re: Doraville Wind Farm

I respectfully request that my Statement be considered within these proceedings given the grave nature of Public Health issues that are at stake for citizens living within in the vicinity of wind power stations.

1. Purpose of this Statement

On August 22, 2019, I received an email from Mr. Owen McMullan and Ms. Mary McKenna, of Tyrone County, requesting that I submit this Statement, given my extensive expertise on the matter of the health effects caused by long-term exposure to *infrasound and low frequency noise*—a type of toxic pollutant that is generated by wind turbines.

2. Why is there an issue?

Under the current proposal for the Doraville Wind Power Station (a.k.a. 'wind farm'), several homes will be located in its vicinity (See Fig. 1)[1].

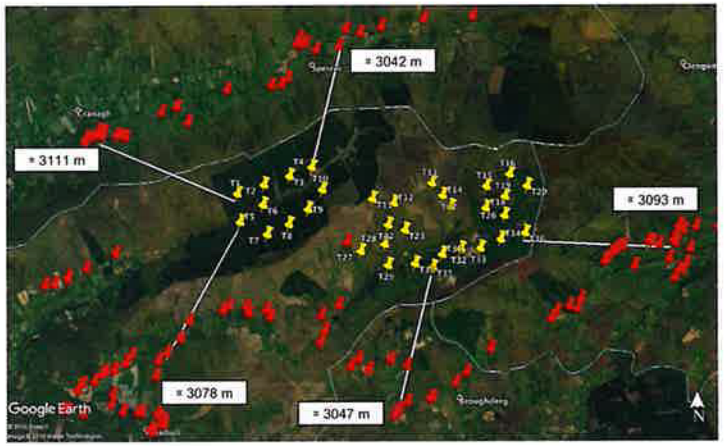


Figure 1. Google Earth image showing the proposed 33 wind turbines of the Doraville Wind Power Station in yellow tacks. Red tacks indicate homes. The distances corresponding to the white lines are indicated in the labels.

[1] Positions of the towers were determined by latitude/longitude coordinates, as provided in the relevant documentation. Positions of homes were determined visually, and with the aid of Google street view.

Of particular concern are the homes that are slated to have multiple wind turbines in more than one cardinal direction. For example, see home circled in white in Figure 2.

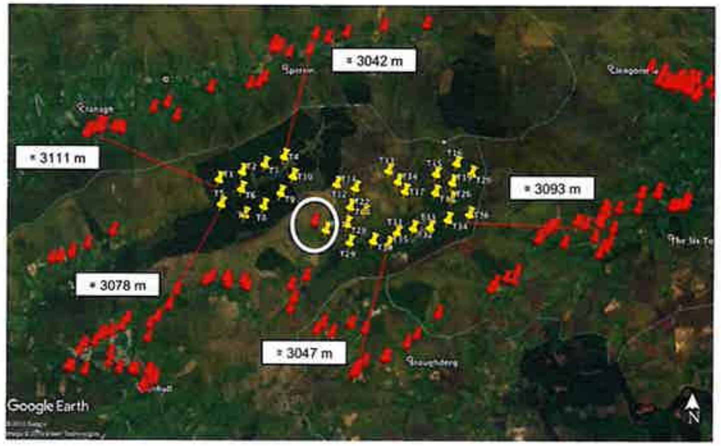


Figure 2. Google Earth image of the proposed Doraville wind power station (yellow tacks) and homes (red tacks). The home inside the white circle is of particular concern.

The proposed Doraville Wind Power Station is not the only one in this area.
Figure 3 shows other wind power stations in the area.

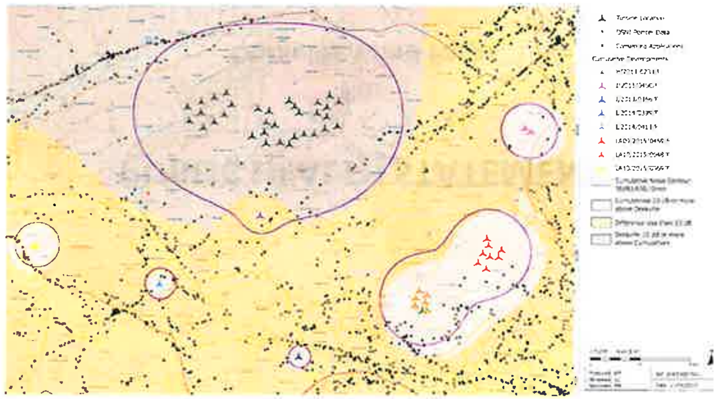


Figure 3. Image dated 11 April 2017, showing the proposed Doraville wind power station as well as other wind power stations in the area. (Reproduced from Turley Appendix Special Report 1.)

3. What is this Toxic Pollutant?

Formally, it is called "infrasound and low frequency noise" (ILFN).
Typically, it comes under the category of 'noise' and / or 'non-ionizing radiation.'
In the European Community this type of 'noise' is not legislated.

4. What happens to people's health when this toxic pollutant is in their homes due to the close proximity of wind power stations?

It is a gradual process—not like a 'zapping' action. Initially, after wind power stations are fully commissioned near residential dwellings, families may not feel an immediate impact. This lulls them into a sense that "everything will be fine," and they remain within the toxic environment.

However, often within the first 5-7 months of exposure, family members will begin to wake up tired. They will begin to feel increasingly annoyed and more aggressive, particularly if there is a history of prior ILFN exposure (such as military duty, for example), or if family members are pubescent or pre-pubescent adolescents. In ILFN-contaminated homes, families *sleep in* the toxic environment, greatly accelerating the onset of debilitating disease.

Sleep deprivation and the likely development of brain lesions in the hippocampus (as seen in laboratorial experiments) and in the brainstem (as seen in exposed workers), begin to explain the cognitive impairment displayed by these individuals, sometimes accompanied by uncontrolled emotional states or transient absences of consciousness. As exposure time accumulates, increasingly disabling health conditions develop. These can compromise the respiratory and gastrointestinal systems, as well as the organs of vision and hearing. Since citizens are forced to remain in their homes under these toxic circumstances, severe and debilitating health deterioration is merely a question of time.

Until recently, the effects of ILFN on health were mostly investigated within the context of occupational settings. These studies were designed to investigate various types medical outcomes while simulating occupational exposures, i.e., large amounts of infrasound exposure during several hours per day. When ILFN is in the home, levels can be significantly lower than in occupational settings, but *exposure time is much longer and can occur during sleep-time*, i.e., the worker goes home (ceases exposure) at the end of the work-shift, but no such respite exists in situations of residential contamination.

Appendix 2 provides a Book Chapter[2] dedicated to this topic, as well as a Summary of the chapter for laypersons.

---

[2] Alves-Pereira M, Rapley B, Bakker HHC, Summers R. (2019) Acoustics and Biological Structures, IN: Acoustics of Materials. Abiddine ZE, Ogam E (eds). IntechOpen, London. — Appendix 2
DOI: 10.5772/intechopen.82761. https://www.intechopen.com/online-first/acoustics-and-biological-structures

5. How could this possibly be true?
There would be sick people everywhere!

- **Case Report 1[3]: Ireland—Abandoned Home**

Figure 4 shows a home in Ireland that had to be abandoned given the onset of severely debilitating health issues (*ongoing legal proceedings*).

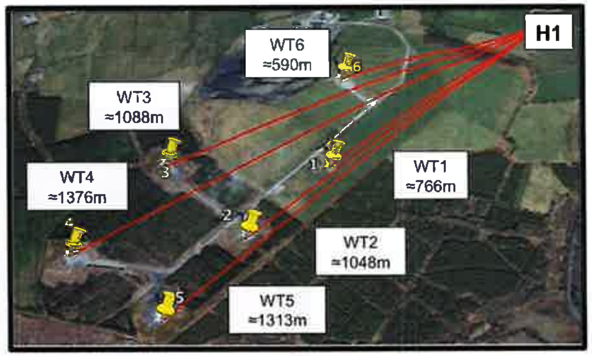


Figure 4. Google Earth image showing 6 wind turbine towers (yellow) located between ≈590m and ≈1376 m from a residential dwelling (H1) —Ireland. (North points upward.)

Compared to the Doraville wind power station, this case has a much smaller amount of wind turbines (6 *versus* 33).

Similar to the Doraville Wind Power Station, these wind turbines are placed at a higher elevation than the home.

In this case, the wind turbines are not surrounding the home in multiple cardinal directions.

In this home, the youngest child was formally diagnosed with epilepsy at age 7. The oldest child (age 19) was formally diagnosed with post-traumatic stress disorder.

(Please see Appendix 3 for scientific acoustical documentation of this case.)

[3] Alves-Pereira M, Bakker HHC, Rapley B, Summers R (2018). Infrasound and Low Frequency Noise – Does it affect human health? Engineers Ireland Journal, Jan 23. — Appendix 3. http://www.engineersjournal.ie/2018/01/23/ilfn-infrasound-low-frequency-noise-turbine-health/

- **Case Report 2[4]: Germany—Abandoned Bedroom & Bunker Bedroom**

Figure 5 shows a home in Germany where 20 turbine towers were erected in the southern and eastern sides of the home (*ongoing legal proceedings*).

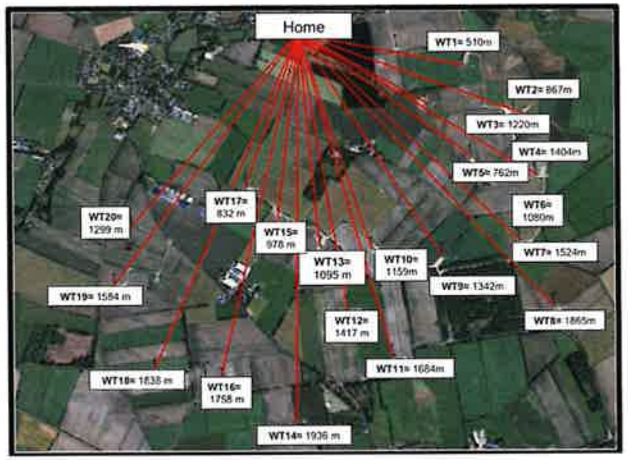


Figure 5. Google Earth image showing 20 wind turbine towers located between ≈ 0.5—2 km from a residential dwelling —Germany. (North points upward.)

Again, as with the Irish home above, the turbine towers do not surround the home in all cardinal directions. Here, unlike the Irish case and the proposed Doraville wind power station, the land is flat.

Although numerous, the number of machines in this German case is still less than the proposed Doraville wind power station (20 *versus* 33).

Studies would have to be conducted of each individual home in the vicinity of the proposed Doraville wind power station to ascertain whether similar situations to this German case are present. The home circled in white in Figure 2 (for example) is certainly a contender.

These German homeowners develop their business at this location and are, therefore, unable to abandon their home. Their teenage children, however, were promptly sent away to boarding schools given their accelerated and very evident behavioral and metabolic changes. The health deterioration of this family has been documented in the German media.

[4] Alves-Pereira M, Krough C, Bakker HHC, Summers R, Rapley B (2019) Infrasound and low frequency noise guidelines – Antiquated and irrelevant for protecting populations. Proceedings of the 26th International Congress on Sound & Vibration, Montreal, Canada, July 7-11, 2019—Peer-Reviewed Conference Paper. – Appendix 4

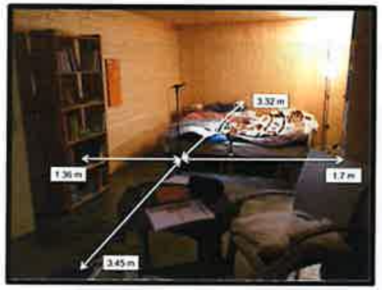
In order to be able to continue running their business, this German family was forced to abandon their master bedroom and construct an underground bunker so as to achieve some sort of respite against the aggression of this toxic pollutant. Figure 6 shows the abandoned and bunker bedrooms.

Figure 6.

A

(A)
The Master Bedroom facing East and overlooking the neighboring lake (see Fig. 5) — Abandoned due to ILFN contamination.

B



(B)
The Bunker Bedroom is built deep underneath the home, where respite from the toxic pollutant is achieved "except when the winds are from the East."

In the Bunker Bedroom, respite from the toxic pollutant is achieved "except when the winds are from the East." This is easily explained by looking at Figure 5, showing the towers closest to the home on the eastern side of the property.

This family seeks to sleep away from their home as frequently as possible.

(Please see Appendix 4 for scientific acoustical documentation of this case).

- **Case Report 3[5]: Denmark—Abandoned Home and Collapsed Business**

Figure 7 shows a home in Denmark where the family owned and operated a mink farm since 1990 (*ongoing legal proceedings*).

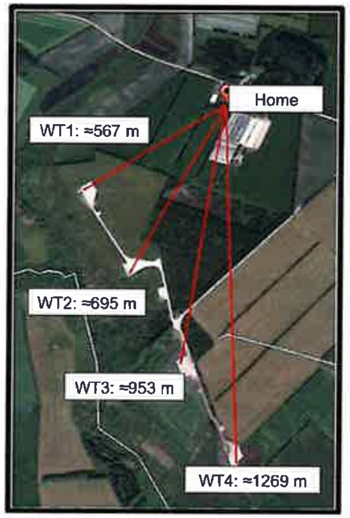


Figure 7. Google Earth image showing 4 wind turbine towers located between ≈567—1269 m from a residential and mink farm complex —Denmark. (North points upward.)

These 4 turbine towers began operating in 2013.
The home was abandoned in 2015.
After massive amounts of (documented) animal death, the mink farm closed in January 2019,

Even though the family no longer inhabited the home, the mink farm continued operations, requiring the property- and farm-owner to remain on the location for extended periods of time. In 2018, the 57-year-old rural property owner was formally diagnosed with post-traumatic stress disorder.

As compared to the proposed Doraville wind power station, here the land is flat, the property is not surrounded by machines in all cardinal directions, and there are only four wind turbines.

(Please see Appendix 5 for scientific acoustical documentation of this case).

[5] Alves-Pereira M, Bakker HHC (2017) Occupational and Residential Exposures to Infrasound and Low Frequency Noise in Aerospace Professionals: Flawed Assumptions, Inappropriate Quantification of Acoustic Environments, and the Inability to Determine Dose-Response. Scientific J Aerosp Eng Mech 1(2):83-98. — Appendix 5.

6. If it is really the case that wind turbines produce a toxic acoustic pollutant, then why are wind power stations being built all over the world?

Apparently, mostly due to ignorance, but perceived economic benefits are also playing an important role.

7. What is the safe distance between wind power stations and residential areas?

Science does not know.

Wind turbine acoustics signatures have been documented in a home 12 km away from the nearest tower (unpublished data gathered by our field-studies).

Other teams in Finland (The Aunio Group[6]) and Australia (Flinders University[7]) have also documented infrasound levels in homes 'far away' from the wind power station responsible for the emissions.

8. *You will be told that:*
Infrasound cannot be heard by humans and therefore poses no threat to human health.

This position perpetuates a scientifically indefensible position: *what you can't hear won't hurt you*.

This is an ancient assumption, stemming from early 20th century work on the telephone. Given the necessity of focusing on human speech intelligibility and hearing in order to perfect telephone communications, all parts of 'sound' that were inaudible to humans were deemed irrelevant.

Please see the publication offered in Appendix 3 for more historical details.

There are countries that *do have* specific legislation enacted in order to protect their populations against infrasound.

Figure 8 gives an example of permissible exposure levels for *both* occupational and residential situations, specifically for 2, 4, 8 and 16 Hz—all within the infrasound range.

[6] https://www.auniogroup.com
[7] https://news.flinders.edu.au/blog/2019/06/19/wind-farm-noise-recorded-almost-9km-away/

No.	Premise	Sound pressure levels, dB, in octaval bands of averaged geometric frequencies, Hz				General sound pressure level dB "Lin"
		2	4	8	16	
1.	Different jobs inside industrial premises and production areas:					
	- Different physical intensity jobs	100	95	90	85	100
	- Different intellectual emotional tension jobs	95	90	85	80	95
2.	Populated area	90	85	80	75	90
3.	Living and public premises	75	70	65	60	75

Figure 8. Legislated permissible exposure levels for infrasound in different situations.[8]

9. *You will be told that:*
Wind power stations exist in many countries and no one is complaining.

That would be an untruth.

10. *You will be told that:*
Because of 'global warming,' wind power stations are of crucial importance.

That would be another untruth, even recently verified by researchers from Harvard University:

> *In two papers — published today in the journals Environmental Research Letters and Joule — Harvard University researchers find that the transition to wind or solar power in the U.S. would require five to 20 times more land than previously thought, and, if such large-scale wind farms were built, would warm average surface temperatures over the continental U.S. by 0.24 degrees Celsius.*[9]

11.
Residential ILFN Contamination

Figure 3 above shows other wind power stations that are planned or already operational in the same area as the proposed Doraville wind power station.

[8] In: Stepanov, V. Biological Effects of Low Frequency Acoustic Oscillations and their Hygienic Regulation. State Research Center of the Russian Federation: Moscow (2000). https://apps.dtic.mil/dtic/tr/fulltext/u2/a423963.pdf
[9] Burrows, L (2018) The down side to wind power. The Harvard Gazette, 4 October. https://news.harvard.edu/gazette/story/2018/10/large-scale-wind-power-has-its-down-side/

By erecting the proposed Doraville wind power station, many homes will have even more machines surrounding their homes, in different cardinal directions than up until now.

The existence of machines in multiple cardinal directions means that the number of "good days" (i.e., when the wind doesn't blow much) could be severely curtailed. This leads to a more prolonged exposure to the toxic pollutant, thus accelerating the onset of debilitating illnesses.

A perusal of Figures 1 thru 3 shows that many other family dwellings have a very high probability of having moderate to severe ILFN contamination in their homes, as exemplified in the three case reports presented herein, and documented in peer-reviewed publications (appendices 3-4). Our team has already acoustically documented many homes in Tyrone County, Northern Ireland.

In my opinion, it is highly likely that in each and every one of these homes, citizens' health will become severely impacted—it is merely a question of time.

12.
Precautionary Principle

The very debilitating adverse health effects caused by ILFN exposure have been scientifically documented in occupational settings since the 1960's. Science already knows what happens to the (proverbial) canary in the mine.

Wind power stations are the latest type of industrial complexes that are bringing toxic ILFN into the homes, often continuously over a 24-hour period.

To my knowledge, there is no formal 'noise' guideline or ordinance in Ireland or the European Union that can provide any basis for curtailing the emissions of this agent of disease.

Just as with asbestos, second-hand smoking, and leaded fuels or, more recently, plastics and glyphosate products, the health effects are being made evident *before* legislative bodies have enacted clauses for the specific purpose of protecting the health of human populations.

In the interest of medium-to-long-tem public health of the population and their offspring, I strongly recommend that this project be denied.

Curriculum Vitae

Personal information

First name / Surname	**Mariana Alves-Pereira**
Address	Rua do Viveiro, 402, 1E Estoril 2765-294 Portugal
Telephone	Mobile: +351-961753209
E-mail	m.alvespereira@gmail.com
Skype	marianna-alves-pereira
Nationality	Portugal

Academic Background

Date	2010
Title of qualification awarded	**Doctoral degree in Environmental Sciences**
Name and type of organisation providing education	Universidade Nova de Lisboa, Caparica, Portugal
Date	2000
Title of qualification awarded	**Masters degree in Biomedical Engineering**
Name and type of organisation providing education	Drexel University Philadelphia, PA, USA
Date	1995
Title of qualification awarded	**Bachelors degree in Physics**
Name and type of organisation providing education	State University of New York Stony Brook, NY, USA
Dates	1990
Title of qualification awarded	**12th year High School Diploma**
Name and type of organisation providing education	Algés Secondary School Lisbon, Portugal
Dates	1988
Title of qualification awarded	**10th-11th years High School – Area of Technological Sciences**
Name and type of organisation providing education	Fontes Pereira de Melo Secondary School Porto, Portugal

Scientific Awards

2006 - Prevent More Live Better Scientific Research Award
Diagnosis of Vibroacoustic Disease for Legal & Forensic Purposes.
Attributed by the Instituto de Segurança Higiene e Saúde no Trabalho (Portuguese Governmental Institute for Safety, Hygiene & Health in the Workplace).

2005 - Thomé Villar/Boehringer Ingelheim Research Award
Participation of the Central Airways in Vibroacoustic Disease.
Attributed by the Portuguese Lung Society (Sociedade Portuguesa de Pneumologia).

1999 - Young Investigator Award Finalist
Pericardial Thickening in Commercial Airline Flight Crew.
Attributed by the Space Medicine Branch of the Aerospace Medical Association (USA).

Expertise

Acoustics	Infrasound and low frequency noise (ILFN) exposure. Conducted extensive acoustical measurements and analyses in 1/3- and 1/36-octave band, dB Linear, within industrial, urban and residential areas.
Clinical Medicine	Design, implementation and data analyses of clinical studies pertaining to ILFN-exposed populations, including gathering of patient medical and noise exposure histories.
Cellular Biology	Interpretation of light and electron microscopy imaging comparing ILFN-exposed vs. non-exposed cell and tissues of both human and animal models. Analyses of the biological responses to ILFN exposure based on principles of materials and structural engineering and on cytoskeleton dynamics.
Bioengineering	Analysis and interpretation of the response of actin- and tubulin-based structures to ILFN exposures. First to associate cellular and tissue tensegrity architecture to better understand the biological response observed in ILFN-exposed specimens.
International Expert Witness & Consultant	-- Vibroacoustic Disease -- Effects of ILFN on occupationally- or environmentally-exposed human populations.

Teaching Experience

Associate Professor since 2010
Adjunct Professor since 2005.
Assistant Professor since 2002

Dates	Since 2009
Main activities and responsibilities	Coordinating/ Teaching: Physics (Occupational Safety & Health Program) Epidemiology (Occupational Safety & Health Program) Workplace Safety & Health (Safety & Security Program)
Name and address of employer	School of Economic Sciences & Organizations Universidade Lusófona Campo Grande 376, 1749-024 Lisbon, Portugal
Type of business or sector	Higher education
Dates	2007-2013
Main activities and responsibilities	Teaching: Biophysics Lab (Pharmaceutical Sciences Program)
Name and address of employer	School of Health Sciences and Technologies Universidade Lusófona Campo Grande 376, 1749-024 Lisbon, Portugal
Type of business or sector	Higher education
Dates	2005-2007
Main activities and responsibilities	Teaching: Physics (Nursing Program), Coordinating/ Teaching: Biomaterials (Pre-Bologna Radiology Program) Non-ionizing Radiation (Pre-Bologna Radiology Program) Experimental Statistics (Pre-Bologna Radiology Program)
Name and address of employer	Ribeiro Sanches School of Health Sciences Universidade Lusófona Rua dos Telhais aos Olivais, 8-8ª, 1900-693 Lisbon, Portugal
Type of business or sector	Higher education
Dates	2002-2005
Main activities and responsibilities	Coordinating/ Teaching: Acoustical Pollution (Environmental Engineering Program)
Name and address of employer	Department of Environmental Sciences & Engineering Universidade Nova de Lisboa Quinta da Torre, 2829-516 Caparica, Portugal
Type of business or sector	Higher education

Work Experience

Dates	1988-2013
Occupation or position held	**Senior researcher, Assistant Coordinator for the Vibroacoustic Disease Project**
Main activities and responsibilities	Measure low frequency noise; Patient interviews; Interpreting electron microscopy imaging; Data analyses; Preparation of scientific papers for publication; Oral presentations at international scientific meetings and conferences; Organization of scientific conferences; Expert court witness.
Name and address of employer	Centro da Performance Humana, Estrada Nacional 10, Edificio Cinema, 1º Piso, 2615 Alverca, Portugal
Type of business or sector	Biomedical research in occupational medicine (non-for-profit enterprise)
Dates	2010-2012
Occupation or position held	**Administrator**
Main activities and responsibilities	Liaison between NASA officials and European Governmental officials and private enterprises; Procure projects, actions and activities related to sustainable energy and environmental issues of mutual interest to NASA; Preparation of status reports; Oral presentations of ongoing projects at NASA/C3P Annual Technical Workshops.
Name and address of employer	Center for Pollution Prevention (C3P)
Type of business or sector	Ministry of Environment (non-for-profit enterprise)
Dates	2002-2005
Occupation or position held	**Fellowship recipient**
Main activities and responsibilities	Write, enact and develop research project funded by Portuguese Government (POCTI/FCT): "Low frequency noise in public transportation systems in the Greater Lisbon area"
Name and address of employer	IMAR – Instituto do Mar, Pólo da Faculdade de Ciênicias e Tecnologia, Universidade Nova de Lisboa, Quinta da Torre, 2829-516 Caparica, Portugal
Type of business or sector	Higher education / Research
Dates	Feb-Jul 2000
Occupation or position held	**Associate researcher**
Main activities and responsibilities	PCR studies investigating the genetic expression of ubiquitin and ciclogenase-2 in cells exposed to cadmium.
Name and address of employer	Department of Biological Sciences, Hunter College, City University of New York
Type of business or sector	Higher education / Research
Dates	1991-1995
Occupation or position held	**Librarian**
Main activities and responsibilities	Catalogue new books and scientific journals; Manage book lending; Assist with inquiries.
Name and address of employer	Math/Physics Library State University of New York, Stony Brook, NY, USA
Type of business or sector	Academic
Dates	1988-1990
Occupation or position held	**Technical translator**
Main activities and responsibilities	Quality control inspection manuals for the Lockheed C-130 Hercules, P-3P Orion, and Aerospatiale SA-330 Puma aircraft; Avionics, fuel systems and ground support equipment manuals; Scientific research papers developed by the Medical Division Research Team.
Name and address of employer	OGMA-Indústria Aeronautica de Portugal Parque Aeronautico de Alverca, 2615-173 Alverca, Portugal
Type of business or sector	Aeronautical industry

Dates	1982-1985
Occupation or position held	**Summer-hire** (Commercial Section, US Air Force Section, US Information Services)
Main activities and responsibilities	Administrative tasks; Written and simultaneous translations; Public relations. In 1985, collaborated in the organization of President Ronald Reagan's official visit to Lisbon.
Name and address of employer	United States Embassy Av. das Forças Armadas, 1600-081 Lisbon, Portugal

Training Programs

Dates	2001
Title of qualification awarded	**Epidemiological Surveillance Technician**
Name and type of organisation providing education	Institute of Preventive Medicine, School of Medicine, University of Lisbon
Dates	1990
Title of qualification awarded	**C-130 Hercules: Specialization in Engine, Propellers and Auxiliary Power Unit.**
Name and type of organisation providing education	Lockheed Martin Official Training Center OGMA-Indústria Aeronautica de Portugal Parque Aeronautico de Alverca, 2615-173 Alverca, Portugal
Dates	1987
Title of qualification awarded	**Computer programmer** (DOS, DBase III, Cobol, WordStar)
Name and type of organisation providing education	Instituto de Tecnologia Avançada para a Educação Porto, Portugal

Languages

Native speaker: **English/Portuguese**

Other languages: **French, Spanish**

Relevant publications

Alves-Pereira M, Bakker HHC (2017) *Occupational and residential exposures to infrasound and low frequency noise in aerospace professionals: Flawed assumptions, inappropriate quantification of acoustic environments, and the inability to determine dose-response.* Scientific Journal on Aerospace Engineering and Mechanics, 1(2):83-98.

Alves-Pereira M, Castelo Branco NAA (2007) *Vibroacoustic disease: Biological effects of infrasound and low frequency noise explained by mechanotransduction cellular signaling.* Progress Biophysics & Molecular Biology, 93: 256-279.

Alves-Pereira M, Joanaz de Melo J, Castelo Branco, NAA (2005) *Pericardial biomechanical adaptation to low frequency noise stress.* In: A. Méndez-Vilas (ed.) Recent Advances in Multidisciplinary Applied Physics. Elsevier: London, 2005: 363-7. (ISBN: 978-0-08-044648-6)

Alves-Pereira M (1999) *Noise-induced extra aural pathology. A review and commentary.* Aviation, Space and Environmental Medicine, 70 (3, Suppl.): A7-A21.

(Annex I: Complete List of Publications)

LISTING OF SCIENTIFIC PUBLICATIONS

Mariana Alves-Pereira, Ph.D.

2019

Alves-Pereira M, Rapley B, Bakker HHC, Summers R. (2019) **Acoustics and Biological Structures** IN: Acoustics of Materials. Abiddine ZE, Ogam E (editors). IntechOpen, London. DOI: 10.5772/intechopen.82761.
https://www.intechopen.com/online-first/acoustics-and-biological-structures

Alves-Pereira M, Bakker HHC, Rapley B, Summers R. (2019) **Residential acoustical environments with predominant lower-frequency components: Why measuring inside the home is important. – Submitted for publication**

Alves-Pereira M, Krough C, Bakker HHC, Summers R, Rapley B (2019) **Infrasound and low frequency noise guidelines – Antiquated and irrelevant for protecting populations. – Submitted for publication.** Proceedings of the 26th International Congress on Sound & Vibration, Montreal, Canada, July 7-11, 2019. (Peer-Reviewed Conference Paper, No. 682)

2018

Alves-Pereira M, Bakker HHC, Rapley B, Summers R. (2018). **Infrasound and Low Frequency Noise – Shall we measure it properly?** Engineers Ireland Journal. (Jan 23)
http://www.engineersjournal.ie/2018/01/23/ilfn-infrasound-low-frequency-noise-turbine-health/

2017

Alves-Pereira M, Bakker HHC (2017) **Occupational and Residential Exposures to Infrasound and Low Frequency Noise in Aerospace Professionals: Flawed Assumptions, Inappropriate Quantification of Acoustic Environments, and the Inability to Determine Dose-Response.** Scientific J Aerosp Eng Mech 1(2):83-98.

Bakker HHC, Alves-Pereira M, Summers SR (2017) **Citizen Science Initiative: Acoustical Characterisation of Human Environments.** Proceedings International Conference Biological Effects of Noise (ICBEN 2017). Zurich, Switzerland, No. 3653, 12 pages.

Bakker, H. H. C., Rapley, B. I., Summers, S. R., Alves-Pereira, M., Dickinson, P. J. (2017). **An Affordable Recording Instrument for the Acoustical Characterisation of Human Environments**. Paper presented at the ICBEN 2017, Zurich, Switzerland (Paper No. 3654).

Rapley, B., Alves-Pereira, M., Bakker H (2017) **The inadequacy of the A-frequency weighting for the assessment of adverse effects on human populations**. Paper presented at ICBEN 2017, Zurich, Switzerland (Paper No. 3873).

Rapley, B. I., Bakker, H. H. C., Alves-Pereira, M., Summers, S. R. (2017). **Case Report: Cross-sensitisation to infrasound and low frequency noise.** Paper presented at the ICBEN 2017, Zurich, Switzerland (Paper No. 3872).

2015

Castelo Branco NAA, Alves-Pereira M, Martinho Pimenta A, Reis Ferreira J (2015) **Clinical protocol for evaluating pathology induced by low frequency noise exposure**. Euronoise 2015, Maastricht, The Netherlands, 31 May-3 Jun, 6 pages.

Castelo Branco NAA, Alves-Pereira M, Martinho Pimenta A, Reis Ferreira J (2015) **Low frequency noise-induced pathology: contributions provided by the Portuguese wind turbine case**. Euronoise 2015, Maastricht, The Netherlands, 31 May-3 Jun, 5 pages.

2014

Alves-Pereira M, Castelo Branco NAA. **Letter to the Editor re: "How the factoid of wind turbines causing vibroacoustic disease came to be 'irrefutably' demonstrated"**. Australian & New Zealand Journal Public Health 2014; 38(2): 191-192.

Mendes AP, Bonança I, Jorge A, Alves-Pereira M, Castelo Branco NAA, Caetano M, Oliveira N, Graça A, Santos C, Ferraria R. **Voice acoustic profile of males exposed to occupational infrasound and low-frequency noise.** Laryngology & Voice 2014; 4(1): 12-20.

2012

Mendes AP, Graça A, Jorge A, Alves-Pereira M, Castelo Branco NAA, Freitas A, Laranjeira M, Bonança I. **The effects of ILFN-exposure on voice acoustic parameters of commercial cabin crewmembers.** Laryngology & Voice 2012; 2(2): 70-80.

Alves-Pereira M. **Review of the wind turbine health study: Report of independent expert panel**, as prepared for the Massachusetts Department of Environmental Protection & Massachusetts Department of Public Health. March 2012.
http://docs.wind-watch.org/MassDEP-wind-health-2-Alves_Pereira.pdf

2010

Alves-Pereira M. **Infrasound and low frequency noise: Quantification in several rural and urban environments.** Revista Lusófona de Ciências e Tecnologias da Saúde 2010 7(1): 91-108. (Bilingual)
http://revistas.ulusofona.pt/index.php/revistasaude/article/view/1237/1003

Castelo Branco NAA, Costa e Curto T, Mendes Jorge L, Cavaco Faísca J, Amaral Dias L, Oliveira P, Martins dos Santos J, Alves-Pereira M. **Family with wind turbines in close proximity to home: follow-up of the case presented in 2007.** Proceedings of the 14th International Meeting on Low Frequency Noise, Vibration and Its Control. Aalborg, Denmark, 9-11 June, 2010, 31-40.

2009

Alves-Pereira M, Castelo Branco NAA. **Infrasound and low frequency noise dose responses: contributions**. Revista Lusófona de Ciências e Tecnologias da Saúde 2009 6(1): 31-44. (Bilingual)
http://revistas.ulusofona.pt/index.php/revistasaude/article/view/725/605

Alves-Pereira M., Castelo Branco NAA. **Understanding the Biological Responses Elicited by Low Frequency Noise Exposure: Contributions to Vibroacoustic Disease Research** (No. 079R-Oral presentation). Second International Fascia Research Congress, Amsterdam, The Netherlands, 27-30 October, 2009.

Castelo Brnaco NAA, Alves-Pereira M. **Production of Functional Collagen Units in the Absence of Inflammatory Processes as a Response to Low Frequency Noise Exposure** (No. J_075-Oral presentation). Second International Fascia Research Congress, Amsterdam, The Netherlands, 27-30 October, 2009.

Alves-Pereira M, Castelo Branco NAA. **Low Frequency Noise Exposure Destroys Tubulin- and Actin-based Structures** (No. 077-Poster presentation). Second International Fascia Research Congress, Amsterdam, The Netherlands, 27-30 October, 2009.

Oliveira P, Martins dos Santos J, Mendes JJ, Alves-Pereira M, Castelo Branco NAA. **Perivasculo-Ductal Connective Tissue in the Parotid Gland of Wistar Rats Exposed to Low Frequency Noise** (J_092-Poster presentation). Second International Fascia Research Congress, Amsterdam, The Netherlands, 27-30 October, 2009.

2008

Mendes AP, Graça A, Santos CP, Galvão A, Carvalho RO, Sousa MJ, Alves-Pereira M, Castelo Branco NAA. **Voice acoustic analyses in airline cabin crewmembers.** Proceedings Internoise2008. Shangai, China, 2008; No. IN-08-595, 13 pages.

Mendes AP, Graça A, Santos CP, Galvão A, Carvalho RO, Sousa MJ, Alves-Pereira M, Castelo Branco NAA. **Voice acoustic analyses in commercial airline pilots.** Proceedings Internoise2008. Shangai, China, 2008; No. IN-08-591 , 11 pages.

2007

Alves-Pereira M, Castelo Branco NAA. **Vibroacoustic disease: Biological effects of infrasound and low frequency noise explained by mechanotransduction cellular signaling.** Progress Biophysics & Molecular Biology 2007; 93: 256-279.

Alves-Pereira M, Castelo Branco NAA. **On the impact of infrasound and low frequency noise on public health: 2 cases of residential exposure.** Revista Lusófona de Ciências e Tecnologias da Saúde 2007; 4(2): 186-200. (Bilingual)
http://revistas.ulusofona.pt/index.php/revistasaude/article/view/670/564

Castelo Branco NAA, Reis Ferreira J, Alves-Pereira M. (2007). **Respiratory pathology in vibroacoustic disease: 25 years of research.** Revista Portuguesa Pneumologia 2007; XIII (1): 129-135.

Alves-Pereira M, Castelo Branco, NAA. **The scientific arguments against vibroacoustic disease.** Proceedings Internoise2007. Istanbul, Turkey, 2007; No. IN-07-505, 7 pages. (ISBN: 80-01-03055-5)

Alves-Pereira M, Castelo Branco, NAA. **Public health and noise exposure: the importance of low frequency noise.** Proceedings Internoise2007. Istanbul, Turkey, 2007; No. IN-07-137, 10 pages. (ISBN: 80-01-03055-5)

Alves-Pereira M, Castelo Branco, NAA. **Infrasound and low frequency noise dose responses: contributions.** Proceedings Internoise2007. Istanbul, Turkey, 2007; No. IN-07-443, 10 pages. (ISBN: 80-01-03055-5)

Alves-Pereira M, Castelo Branco, N.A.A. **In-home wind turbine noise is conducive to vibroacoustic disease.** *Proceedings of the Second International Meeting on Wind Turbine Noise*, Lyon, France, Sep 20-21, Paper No. 3, 11 pages.

Castelo Branco, NAA, Monteiro M, Reis Ferreira R, Mendes CP, Alves-Pereira M. **Diagnosing vibroacoustic disease for legal purposes.** Proceedings Internoise2007. Istanbul, Turkey, 2007; No. IN-07-506, 8 pages. (ISBN: 80-01-03055-5)

Castelo Branco, NAA, Monteiro M, Reis Ferreira R, Monteiro E, Alves-Pereira M. **Bronchoscopy in vibroacoustic disease I – Pink Lesions.** Proceedings Internoise2007. Istanbul, Turkey, 2007; No. IN-07-507, 7 pages. (ISBN: 80-01-03055-5)

2006

Castelo Branco NAA, Alves-Pereira M. **A doença vibroacústica**. Revista Segurança 2006; XLI (171-Supl Março/Abril):1-20.

Mendes A, Alves-Pereira M, Castelo Branco NAA. **Voice acoustic patterns of patients diagnosed with vibroacoustic disease**. Revista Portuguesa Pneumologia 2006; XII (4): 375-382.

Reis Ferreira J, Mendes CP, Alves-Pereira M, Castelo Branco NAA. **Respiratory squamous cell carcinomas in vibroacoustic disease.** Revista Portuguesa Pneumologia 2006; XII (5): 539-544.

Reis Ferreira J, Albuquerque e Sousa J, Foreid P, Antunes M, Cardoso S, Alves-Pereira M, Castelo Branco NAA. **Abnormal respiratory drive in vibroacoustic disease.** Revista Portuguesa Pneumologia 2006; XII (4): 369-374.

Reis Ferreira J, Monteiro MB, Tavares F, Serrano I, Monteiro E, Mendes CP, Alves-Pereira M, Castelo Branco NAA. **Involvement of central airways in vibroacoustic disease – Thomé Villar/Boehringer Ingelheim Award 2004**. Revista Portuguesa Pneumologia 2006; XII (2): 93-105.

Da Fonseca J, Martins dos Santos J, Castelo Branco NAA, Alves-Pereira M, Grande N, Oliveira P, Martins AP. **Noise-induced gastric lesions: A light and scanning electron microscopy study of the alterations of the rat gastric mucosa induced by low frequency noise.** Central European Journal of Public Health 2006; 14 (1): 35-38.

Alves-Pereira M, Castelo Branco NAA. **Biotensigridade – O novo modelo da célula e a doença vibroacústica. [Biotensegrity – the new cell model and vibroacoustic disease]**. XXII Congresso de Pneumologia/IV Congresso Luso-Brasileiro de Pneumologia, Centro de Congressos do Estoril, 8-10 Dezembro 2006. Revista Portuguesa de Pneumologia; XII (6-Suplemento): S110. (Abstract) (Portuguese)

Monteiro E, Alves-Pereira M, Castelo Branco NAA. **As células em escova e a doença vibroacústica. [Brush cells and vibroacoustic disease]**. XXII Congresso de Pneumologia/IV Congresso Luso-Brasileiro de Pneumologia, Centro de Congressos do Estoril, 8-10 Dezembro 2006. Revista Portuguesa de Pneumologia; XII (6-Suplemento): S111. (Abstract) (Portuguese)

Castelo Branco NAA, Monteiro M, Reis Ferreira J, Alves-Pereira M. **O aparelho respiratório na doença vibroacústica. [The respiratory tract in vibroacoustic disase]**. XXII Congresso de Pneumologia/IV Congresso Luso-Brasileiro de Pneumologia, Centro de Congressos do Estoril, 8-10 Dezembro 2006. Revista Portuguesa de Pneumologia; XII (6-Suplemento): S109. (Abstract) (Portuguese)

Castelo Branco NAA, Monteiro M, Tavares F, Monteiro E, Reis Ferreira J, Alves-Pereira M. **Aspectos morfológicos da basal sub-epitelial respiratória em doentes com a doença vibroacústica. [Morphological aspects of the basal subepithelium in vibroacoustic disease patients]**. XXII Congresso de Pneumologia/IV Congresso Luso-Brasileiro de Pneumologia, Centro de Congressos do Estoril, 8-10 Dezembro 2006. Revista Portuguesa de Pneumologia; XII (6-Suplemento): S112. (Abstract) (Portuguese)

2005

Alves-Pereira M, Joanaz de Melo J, Castelo Branco, NAA. **Pericardial biomechanical adaptation to low frequency noise stress**. IN: A. Méndez-Vilas (ed.) Recent Advances in Multidisciplicnary Applied Physics. Elsevier: London, 2005: 363-7. (ISBN: 978-0-08-044648-6)

Alves-Pereira M, Joanaz de Melo J, Castelo Branco, NAA. **Actin- and tubulin-based structures under low frequency noise stress**. IN: A. Méndez-Vilas (ed.) Recent Advances in Multidisciplinary Applied Physics. Elsevier: London, 2005: 955-79 (ISBN: 978-0-08-044648-6)

Alves-Pereira M, Joanaz de Melo J, Castelo Branco, NAA. **Low frequency noise exposure and biological tissue: reinforcement of structural integrity?** IN: A. Méndez-Vilas (ed.) Recent Advances in Multidisciplinary Applied Physics. Elsevier: London, 2005: 961-6 (ISBN: 978-0-08-044648-6)

Da Fonseca J, Martins dos Santos J, Castelo Branco NAA, Alves-Pereira M, Grande NR, Oliveira P. **Noise-induced duodenal lesions.** European Journal of Anatomy 2005; 9(1): 29-33.

Alves-Pereira M, Marques MC, Castelo Branco NAA. **Biological mechanisms and targets of low frequency noise exposure.** Proceedings 12th International Congress on Sound & Vibration, Lisbon, Portugal, July 11-14, 2005: No. 526 (9 pages).

Alves-Pereira M, Fragata JI, Monteiro E, Sousa Silva D, Castelo Branco NAA. **The pericardium in vibroacoustic disease III – A new structure.** Proceedings 12th International Congress on Sound & Vibration, Lisbon, Portugal, July 11-14, 2005: No. 569 (8 pages).

Alves-Pereira M, Motylewski J, Kotlicka E, Castelo Branco NAA. **Low frequency noise legislation.** Proceedings 12th International Congress on Sound & Vibration, Lisbon, Portugal, July 11-14, 2005: No. 582 (8 pages).

Alves-Pereira M. **Low frequency noise exposure as a confounding factor in biomedical science.** Proceedings 12th International Congress on Sound & Vibration, Lisbon, Portugal, July 11-14, 2005: No. 583 (8 pages).

Alves-Pereira M. **...And again low frequency noise – A possible solution.** Proceedings 12th International Congress on Sound & Vibration, Lisbon, Portugal, July 11-14, 2005: No. 584 (8 pages).

Castelo Branco NAA, Marques MC, Alves-Pereira M. **Physiopathology of vibroacoustic disease.** Proceedings 12th International Congress on Sound & Vibration, Lisbon, Portugal, July 11-14, 2005: No. 563 (6 pages).

Cunha Ribeiro L, Crespo FF, Freire I, Afonso H, Castelo Branco MSN, Marques MC, Alves-Pereira M, Castelo Branco NAA. **Hemostasis and coagulation changes in vibroacoustic disease.** Proceedings 12th International Congress on Sound & Vibration, Lisbon, Portugal, July 11-14, 2005: No. 564 (8 pages).

Castelo Branco NAA, Reis Ferreira J, Marques MC, Alves-Pereira M. **Auto-immune disorders in vibroacoustic disease.** Proceedings 12th International Congress on Sound & Vibration, Lisbon, Portugal, July 11-14, 2005: No. 565 (6 pages).

Araujo A, Carranca J, Alves-Pereira M, Castelo Branco NAA. **Echocardiography in vibroacoustic disease.** Proceedings 12th International Congress on Sound & Vibration, Lisbon, Portugal, July 11-14, 2005: No. 567 (9 pages).

Castelo Branco NAA, Fragata JI, Martins AP, Monteiro E, Alves-Pereira M. **The pericardium in vibroacoustic disease I – morphological features.** Proceedings 12th International Congress on Sound & Vibration, Lisbon, Portugal, July 11-14, 2005: No. 568 (9 pages).

Castelo Branco NAA, Fragata JI, Marques MC, Monteiro E, Alves-Pereira M. **The pericardium in vibroacoustic disease II – cellular death pathways.** Proceedings 12th International Congress on Sound & Vibration, Lisbon, Portugal, July 11-14, 2005: No. 570 (8 pages).

Reis Ferreira J, Mendes CP, Alves-Pereira M, Castelo Branco NAA. **Respiratory pathology in vibroacoustic disease - Current findings.** Proceedings 12th International Congress on Sound & Vibration, Lisbon, Portugal, July 11-14, 2005: No. 571 (7 pages).

Monteiro MB, Reis Ferreira J, Mendes CP, Serrano I, Tavares F, Alves-Pereira M, Castelo Branco NAA. **Respiratory pathology in vibroacoustic disease – Specific morphological changes.** Proceedings 12th International Congress on Sound & Vibration, Lisbon, Portugal, July 11-14, 2005: No. 572 (9 pages).

Foreid P, Martinho Pimenta AJF, Alves-Pereira M, Castelo Branco NAA. **Neuropsychological issues in vibroacoustic disease - Current findings.** Proceedings 12th International Congress on Sound & Vibration, Lisbon, Portugal, July 11-14, 2005: No. 573 (10 pages).

Foreid P, Martinho Pimenta AJF, Alves-Pereira M, Castelo Branco NAA. **Neurological issues in vibroacoustic disease – Epilepsy.** Proceedings 12th International Congress on Sound & Vibration, Lisbon, Portugal, July 11-14, 2005: No. 574 (9 pages).

Reis Ferreira J, Albuquerque e Sousa J, Foreid P, Antunes M, Alves-Pereira M, Castelo Branco NAA. **Neurological issues in vibroacoustic disease - Respiratory control.** Proceedings 12th International Congress on Sound & Vibration, Lisbon, Portugal, July 11-14, 2005: No. 575 (6 pages).

Foreid P, Martinho Pimenta AJF, Alves-Pereira M, Castelo Branco NAA. **Behavioural and psychological changes in vibroacoustic disease.** Proceedings 12th International Congress on Sound & Vibration, Lisbon, Portugal, July 11-14, 2005: No. 576 (9 pages).

Da Fonseca J, Mirones J, Martins dos Santos J, Oliveira O, Alves-Pereira M, Castelo Branco NAA. **Gastrointestinal problems in vibroacoustic disease.** Proceedings 12th International Congress on Sound & Vibration, Lisbon, Portugal, July 11-14, 2005: No. 577 (8 pages).

Martins dos Santos J, Albuquerque e Sousa J, Marques MC, Monteiro E, Alves-Pereira M, Castelo Branco NAA. **Urinary system – Current findings and ongoing studies.** Proceedings 12th International Congress on Sound & Vibration, Lisbon, Portugal, July 11-14, 2005: No. 578 (8 pages).

Casetlo Branco NAA, Alves-Pereira M. **Personal experiences of vibroacoustic disease patients with occupational or environmental exposures.** Proceedings 12th International Congress on Sound & Vibration, Lisbon, Portugal, July 11-14, 2005: No. 579 (7 pages).

Castelo Branco NAA, Alves-Pereira M, Araújo A, Reis Ferreira J, Joanaz de Melo. **Environmental vibroacoustic disease – An example of environmental low frequency noise exposure.** Proceedings 12th International Congress on Sound & Vibration, Lisbon, Portugal, July 11-14, 2005: No. 580 (8 pages).

Castelo Branco NAA, Rodriguez E, Alves-Pereira M. **Forensic features in vibroacoustic disease studies**. Proceedings 12th International Congress on Sound & Vibration, Lisbon, Portugal, July 11-14, 2005: No. 581 (9 pages).

2004

Castelo Branco NAA, Alves-Pereira M. **Vibroacoustic disease**. Noise & Health 2004; 6(23): 3-20.

Castelo Branco NAA, Monteiro E, Costa e Silva A, Martins dos Santos J, Reis Ferreira J, Alves-Pereira M. **The lung parenchyma in low frequency noise exposed Wistar rats.** Revista Portuguesa Pneumologia 2004; X (1): 77-85.

Martins dos Santos J, Grande NR, Castelo Branco NAA, Zagalo C, Oliveira P, Alves-Pereira M. **Lymphatic lesions in vibroacoustic disease**. European Journal Lymphology 2004; 12(40): 17-20.

Alves-Pereira M, Joanaz de Melo J, Marques MC, Castelo Branco NAA. **Vibroacoustic disease – the response of biological tissue to low frequency noise**. Proceedings 11th International

Meeting on Low Frequency Noise and Vibration and its Control. Maastricht, Holland, 2004; 295-308.

Alves-Pereira M, Joanaz de Melo J, Motylewski J, Kotlicka E, Castelo Branco NAA. **Biomedical research, legislation and the low frequency noise contaminant.** Proceedings 11th International Congress on Sound & Vibration. St. Petersburg, Russia, 2004; 1729-1736.

Alves-Pereira M, Joanaz de Melo J, Castelo Branco NAA. **Public transportation and low frequency noise: a health hazard?** Proceedings 11th International Congress on Sound & Vibration. St. Petersburg, Russia, 2004; 1761-1766.

Alves-Pereira M, Joanaz de Melo J, Castelo Branco NAA. **Low frequency noise in subways**. Proceedings Internoise2004. Prague, Czech Republic, 2004; No. 641, 5 pages. (ISBN: 80-01-03055-5)

Alves-Pereira M, Joanaz de Melo J, Castelo Branco NAA. **Low frequency noise in trams**. Proceedings Internoise2004. Prague, Czech Republic, 2004; No. 642, 5 pages. (ISBN: 80-01-03055-5)

Alves-Pereira M, Joanaz de Melo J, Castelo Branco NAA. **Low frequency noise in trains**. Proceedings Internoise2004. Prague, Czech Republic, 2004; No. 643, 5 pages. (ISBN: 80-01-03055-5)

Alves-Pereira M, Joanaz de Melo J, Motylewski J, Kotlicka E, Castelo Branco NAA. **Biomedical research and the low frequency noise contaminant**. Proceedings Internoise2004. Prague, Czech Republic, 2004; No. 644, 7 pages. (ISBN: 80-01-03055-5)

Castelo Branco NAA, Alves-Pereira M. **Vibroacoustic disease- what is known to date.** Proceedings 11th International Meeting on Low Frequency Noise and Vibration and its Control. Maastricht, Holland, 2004; 269-284.

Araujo A, Alves-Pereira M, Joanaz de Melo J, Castelo Branco NAA. **Environmentally-induced vibroacoustic disease in a suburban family.** Proceedings 11th International Congress on Sound & Vibration. St. Petersburg, Russia, 2004; 1767-1774.

Castelo Branco NAA, Alves-Pereira M. **Vibroacoustic disease- current concepts**. Proceedings 11th International Congress on Sound & Vibration. St. Petersburg, Russia, 2004; 1775-1782.

Castelo Branco NAA, Alves-Pereira M. **Vibroacoustic disease - update of current knowledge**. Proceedings Internoise2004. Prague, Czech Republic, 2004; No. 613, 8 pages. (ISBN: 80-01-03055-5)

Araujo A, Alves-Pereira M, Joanaz de Melo J, Castelo Branco NAA. **Vibroacoustic disease in a ten-year-old male.** Proceedings Internoise2004. Prague, Czech Republic, 2004; No. 634, 7 pages. (ISBN: 80-01-03055-5)

Foreid P, Martinho Pimenta AJF, Alves-Pereira M, Castelo Branco NAA. **Neurophysiological aspects of vibroacoustic disease.** Proceedings 11th International Congress on Sound & Vibration. St. Petersburg, Russia, 2004; 1737-1744.

Reis Ferreira J, Mendes CP, Antunes M, Alves-Pereira M, Castelo Branco NAA. **Loss of the neurological control of breathing in vibroacoustic disease patients.** Proceedings 11th International Congress on Sound & Vibration. St. Petersburg, Russia, 2004; 1745-1752.

Castelo Branco NAA, Fragata JI, Martins AP, Monteiro E, Alves-Pereira M. **Pericardial cellular death in vibroacoustic disease.** Proceedings 11th International Congress on Sound & Vibration. St. Petersburg, Russia, 2004; 1753-1760.

Mendes CP, Reis Ferreira J, Alves-Pereira M, Castelo Branco NAA. **Vibroacoustic disease and respiratory pathology I - Tumours.** Proceedings Internoise2004. Prague, Czech Republic, 2004; No. 636, 5 pages. (ISBN: 80-01-03055-5)

Reis Ferreira J, Albuquerque e Sousa J, Mendes CP, Antunes M, Alves-Pereira M, Castelo Branco NAA. **Vibroacoustic disease and respiratory pathology II – PCO_2 response.** Proceedings Internoise2004. Prague, Czech Republic, 2004; No. 637, 6 pages. (ISBN: 80-01-03055-5)

Monteiro M, Reis Ferreira J, Mendes CP, Alves-Pereira M, Castelo Branco NAA. **Vibroacoustic disease and respiratory pathology III – Tracheal & bronchial lesions.** Proceedings Internoise2004. Prague, Czech Republic, 2004; No. 638, 5 pages. (ISBN: 80-01-03055-5)

Reis Ferreira J, Albuquerque e Sousa J, Mendes CP, Antunes M, Alves-Pereira M, Castelo Branco NAA. **Vibroacoustic disease and respiratory pathology IV – Lung & pleura in a lung cancer patient.** Proceedings Internoise2004. Prague, Czech Republic, 2004; No. 639, 4 pages. (ISBN: 80-01-03055-5)

Reis Ferreira J, Mendes CP, Monteiro M, Marques MC, Alves-Pereira M, Castelo Branco NAA. **Vibroacoustic disease - associated respiratory pathology.** Proceedings 11th International Meeting on Low Frequency Noise and Vibration and its Control. Maastricht, Holland, 2004; 285-294.

2003

Alves-Pereira M, Reis Ferreira J, Joanaz de Melo J, Motylewski J, Kotlicka E, Castelo Branco NAA. **Noise and the respiratory system.** Revista Portuguesa Pneumologia 2003; IX: 367-79.

Castelo Branco NAA, Monteiro E, Costa e Silva A, Reis Ferreira J, Alves-Pereira M. **Respiratory epithelia in Wistar rats.** Revista Portuguesa Pneumologia 2003; IX: 381-88

Castelo Branco NAA, Monteiro E, Costa e Silva A, Reis Ferreira J, Alves-Pereira M. **Respiratory epithelia in Wistar rats born in low frequency noise plus varying amount of additional exposure.** Revista Portuguesa Pneumologia 2003; IX (6): 481-492.

Castelo Branco NAA, Gomes-Ferreira P, Monteiro E, Costa e Silva A, Reis Ferreira J, Alves-Pereira M. **Respiratory epithelia in Wistar rats after 48 hours of continuous exposure to low frequency noise.** Revista Portuguesa Pneumologia 2003; IX (6): 474-79.

Alves-Pereira M, Joanaz de Melo, J, Motylewski J, Kotlicka E, Castelo Branco NAA. **Vibroacoustic disease II: The biological and acoustical basis of low frequency noise induced pathology.** Institute of Acoustics (U.K.) 2003; 25(Pt 2): 72-78.

Alves-Pereira M, Castelo Branco NAA. **Ciliated cells, cochlear cilia and low frequency noise.** Proceedings 8th International Conference on Noise as Public Health Problem (ICBEN). Rotterdam, Holland, 29 June-3 July, 2003: 366-367. (ISBN: 90-807990-1-7)

Alves-Pereira M, Joanaz de Melo J, Motylewski J, Kotlicka E, Castelo Branco NAA. **Occupational exposure to low frequency noise.** Proceedings 8th International Conference on Noise as Public Health Problem (ICBEN). Rotterdam, Holland, 29 June-3 July, 2003: 28-29. (ISBN: 90-807990-1-7)

Alves-Pereira M, Joanaz de Melo J, Motylewski J, Kotlicka E. Castelo Branco NAA. **Legislation hinders low frequency noise research.** Proceedings Scuola Superiore. G. Reiss Romoli (SSGRRw), L'Aquila, Italy, 2003; No. 103: 7 pages.

Castelo Branco NAA, Martinho Pimenta AJ, Reis Ferreira J, Alves-Pereira M. **Monitoring vibroacoustic disease.** Proceedings Scuola Superiore. G. Reiss Romoli (SSGRRw), L'Aquila, Italy, 2003; No. 102: 5 pages.

Araujo A, Pais F, Lopo Tuna JMA, Marvão JH, Alves-Pereira M, Castelo Branco NAA. **Audio- and echocardiograms in vibroacoustic disease.** Proceedings 8th International Conference on Noise as Public Health Problem (ICBEN). Rotterdam, Holland, 29 June-3 July, 2003: 115-117. (ISBN: 90-807990-1-7)

Castelo Branco NAA, Barreira R, Crespo FF, Freire I, Afonso H, Castelo Branco MSN, Alves-Pereira M. **Hemostasis & Coagulation changes in airline pilots.** Proceedings 8th International Conference on Noise as Public Health Problem (ICBEN). Rotterdam, Holland, 29 June-3 July, 2003: 118-199. (ISBN: 90-807990-1-7)

Castelo Branco NAA, Monteiro E, Alves-Pereira M. **The effects of low frequency noise on rat trachea.** Proceedings 8th International Conference on Noise as Public Health Problem (ICBEN). Rotterdam, Holland, 29 June-3 July, 2003: 378-379. (ISBN: 90-807990-1-7)

Castelo Branco NAA, Monteiro E, Alves-Pereira M. **In utero low frequency noise exposure in rats – I.** Proceedings 8th International Conference on Noise as Public Health Problem (ICBEN). Rotterdam, Holland, 29 June-3 July, 2003: 372-373. (ISBN: 90-807990-1-7)

Castelo Branco NAA, Monteiro E, Alves-Pereira M. **In utero low frequency noise exposure in rats – II.** Proceedings 8th International Conference on Noise as Public Health Problem (ICBEN). Rotterdam, Holland, 29 June-3 July, 2003: 374-375. (ISBN: 90-807990-1-7)

Castelo Branco NAA, Fragata JI, Martins AP, Monteiro E, Alves-Pereira M. **Pericardial cellular death in vibroacoustic disease.** Proceedings 8th International Conference on Noise as Public Health Problem (ICBEN). Rotterdam, Holland, 29 June-3 July, 2003: 376-377. (ISBN: 90-807990-1-7)

Castelo Branco NAA, Fragata JI, Monteiro E, Alves-Pereira M. **Pericardial features in vibroacoustic disease patients**. Proceedings 8th International Conference on Noise as Public Health Problem (ICBEN). Rotterdam, Holland, 29 June-3 July, 2003: 380-381. (ISBN: 90-807990-1-7)

Castelo Branco NAA, Monteiro E, Martins dos Santos J, Alves-Pereira M. **Low frequency noise and intra-cellular edema**. Proceedings 8th International Conference on Noise as Public Health Problem (ICBEN). Rotterdam, Holland, 29 June-3 July, 2003: 378-379. (ISBN: 90-807990-1-7)

Lousã N, Monteiro E, Alves-Pereira M, Castelo Branco NAA. **Rat cochlea exposed to low frequency noise**. Proceedings 8th International Conference on Noise as Public Health Problem (ICBEN). Rotterdam, Holland, 29 June-3 July, 2003: 43-45. (ISBN: 90-807990-1-7)

Reis Ferreira J, Mendes CP, Castelo Branco NAA, Monteiro E, Alves-Pereira M. **The human lung and pleura in vibroacoustic disease**. Proceedings 8th International Conference on Noise as Public Health Problem (ICBEN). Rotterdam, Holland, 29 June-3 July, 2003: 386-387. (ISBN: 90-807990-1-7)

Reis Ferreira J, Mendes CP, Castelo Branco NAA, Monteiro E, Alves-Pereira M. **The human trachea in vibroacoustic disease**. Proceedings 8th International Conf. Noise as Public Health Problem (ICBEN). Rotterdam, Holland, 29 June-3 July, 2003: 388-389. (ISBN: 90-807990-1-7)

Reis Ferreira J, Mendes CP, Antunes M, Martinho Pimenta J, Monteiro E, Alves-Pereira M, Castelo Branco NAA. **Diagnosis of vibroacoustic disease – preliminary report**. Proceedings 8th International Conference on Noise as Public Health Problem (ICBEN). Rotterdam, Holland, 29 June-3 July, 2003: 112-114. (ISBN: 90-807990-1-7)

Alves-Pereira M, Joanaz de Melo J, Castelo Branco NAA. **Pericardial biomechanical adaptation to low frequency noise stress**. Proceedings First International Meeting on Applied Physics, Badajoz, Spain, 2003; No. 354. (Abstract)

Alves-Pereira M, Joanaz de Melo J, Castelo Branco NAA. **Actin and tubluin-based structures under low frequency noise stress**. Proceedings First International Meeting on Applied Physics, Badajoz, Spain, 2003; No. 355. (Abstract)

Alves-Pereira M, Joanaz de Melo J, Castelo Branco NAA. **Low frequency noise exposure and biological tissue: reinforcement of structural integrity?** Proceedings First International Meeting on Applied Physics, Badajoz, Spain, 2003; No. 356 (Abstract)

Castelo Branco NAA, Fragata JI, Martins AP, Monteiro E, Alves-Pereira M. **Pericardial morphology in vibroacoustic disease.** Chest 2003; 124 (4): 213-4S. (Abstract)

Mendes CP, Reis Ferreira J, Martins AP, Monteiro E, Alves-Pereira M. **Morphological changes in the respiratory system of vibroacoustic disease patients.** Chest 2003; 124 (4): 213. (Abstract)

Reis Ferreira, J, Mendes CP, Antunes M, Alves-Pereira M, Castelo Branco NAA. **Respiratory drive in vibroacoustic disease.** Chest 2003; 124 (4): 214S. (Abstract)

Castelo Branco NAA, Reis Ferreira J, Monteiro E, Alves-Pereira M. **A traqueia humana na doença vibroacústica. [Human trachea in vibroacoustic disease]**. XL Reunião da Sociedade Anatómica Portuguesa. Escola de Medicina da Universidade Nova de Lisboa, 23 de Maio, 2003: No. 42 (Livro de Resumos). (Portuguese)

Castelo Branco NAA, Monteiro E, Martins dos Santos J, Alves-Pereira M. **Aspectos do glomerulo renal em ratos expostos a ruído de baixa frequência. [Aspects of kidney glomeruli in rats exposed to low frequency noise]**. XL Reunião da Sociedade Anatómica Portuguesa. Escola de Medicina da Universidade Nova de Lisboa, 23 de Maio, 2003: No. 43 (Livro de Resumos). (Portuguese)

Castelo Branco NAA, Reis Ferreira J, Monteiro E, Alves-Pereira M. **O pulmão e a pleura na doença vibroacústica. [The lung and pleura in vibroacoustic disease]**. XL Reunião da Sociedade Anatómica Portuguesa. Escola de Medicina da Universidade Nova de Lisboa, 23 de Maio, 2003: No. 44 (Livro de Resumos). (Portuguese)

Castelo Branco NAA, Fragata J, Martins AP, Monteiro E, Alves-Pereira M. **A morfologia do pericárdio na doença vibroacústica. [Pericardial morphology in vibroacoustic disease]**. XL Reunião da Sociedade Anatómica Portuguesa. Escola de Medicina da Universidade Nova de Lisboa, 23 de Maio, 2003: No. 45 (Livro de Resumos).(Portuguese)

Castelo Branco NAA, Fragata J, Martins AP, Monteiro E, Alves-Pereira M. **A morte celular no pericárdio de doentes com a doença vibroacústica. [Pericardial cellular death in vibroacoustic disease patients]**. XL Reunião da Sociedade Anatómica Portuguesa. Escola de Medicina da Universidade Nova de Lisboa, 23 de Maio, 2003: No. 46. (Livro de Resumos) (Portuguese)

Castelo Branco NAA, Monteiro E, Martins dos Santos J, Alves-Pereira M. **Aspectos do parênquima pulmonar em ratos expostos a ruído de baixa frequência. [Aspects of lung parenchyma in rats exposed to low frequency noise]**. XL Reunião da Sociedade Anatómica Portuguesa. Escola de Medicina da Universidade Nova de Lisboa, 23 de Maio, 2003: No. 48 (Livro de Resumos). (Portuguese)

2002

Castelo Branco NAA, Alves-Pereira M, Martins dos Santos J, Monteiro E. **SEM and TEM study of rat respiratory epithelia exposed to low frequency noise.** In: Science and Technology Education in Microscopy: An Overview, A. Mendez-Vilas (Ed.), Formatex: Badajoz, Spain, 2003; Vol. II: 505-33. (ISBN: 84-607-6699-3)

Castelo Branco NAA & Colleagues. **Response to Letter to the Editor "Vibroacoustic Disease"**. Aviations, Space and Environmental Medicine, 2002; 73(8): 829-30.

Alves-Pereira M, Castelo Branco NAA. **Low frequency noise and vibroacoustic disease: ignored in the workplace.** American Industrial Hygiene Conference. June 3-6, 2002, San Diego, California, USA.

2001

Alves-Pereira M, Castelo Branco MSNA, Motylewski J, Pedrosa A, Castelo Branco NAA. **Airflow-induced infrasound in commercial aircraft.** Proc Internoise2001, The Hague, Holland, 2001: 1011-14. (ISBN: 9080655422)

Alves-Pereira M, Motylewski J, Castelo Branco NAA. **Low frequency noise onboard commercial aircraft.** Proceedings 8th International Congress Sound & Vibration, July 2001, Hong Kong, P.R. China: 525-32.

Araujo A, Pais F, Lopo Tuna JMC, Alves-Pereira M, Castelo Branco NAA. **Echocardiography in noise-exposed flight crew.** Proc Internoise2001, The Hague, Holland, 2001: 1007-10. (ISBN: 9080655422)

Torres R, Tirado G, Roman A, Ramirez R, Colon H, Araujo A, Pais F, Lopo Tuna JMC, Castelo Branco MSNAA, Alves-Pereira M, Castelo Branco NAA. **Vibroacoustic disease induced by long-term exposure to sonic booms.** Proc Internoise2001, The Hague, Holland, 2001: 1095-98. (ISBN: 9080655422)

Pedrosa A, Alves-Pereira M, Castelo Branco MSNAA, Motylewski J, Castelo Branco NAA. **Infrasound in the cockpits and cabins of commercial aircraft.** Aviation, Space and Environmental Medicine 2001; 72(3): 253. (Abstract)

Alves-Pereira M, Castelo Branco NAA. **...And again low frequency noise.** Aviation, Space and Environmental Medicine 2001; 72(3): 254 (Abstract).

2000

Barreira R, Crespo FF, Freire I, Afonso H, Castelo Branco MSA, Alves-Pereira M, Castelo Branco NAA. **Hemostasis and coagulation changes in commercial airline pilots.** Aviation, Space and Environmental Medicine 2000; 71(3): 319. (Abstract)

Motylewski J, Alves-Pereira M, Castelo Branco NAA. **Infrasound analysis onboard commercial airline cockpits.** Aviation, Space and Environmental Medicine 2000; 71(3): 343. (Abstract)

Lousã N, Sousa Pereira A, Alves-Pereira M, Monteiro E, Grande NR, Castelo Branco NAA. **Morphological changes in the cochlear cilia of Wistar rats exposed to low frequency noise.** Aviation, Space and Environmental Medicine 2000; 71(3): 301. (Abstract)

1999

Alves-Pereira M. **Noise-induced extra aural pathology. A review and commentary.** Aviation, Space and Environmental Medicine 1999; 70 (3, Suppl.): A7-A21.

Castelo Branco NAA, Rodriguez E, Alves-Pereira M, Jones DR. **Forensic aspects of vibroacoustic disease.** Aviation, Space and Environmental Medicine 1999; 70(3, Suppl.): A145-51.

Alves-Pereira M, Castelo Branco NAA. **Vibroacoustic Disease: The need for a new attitude towards noise.** Proceedings International Conference on Public Participation & Information Technologies, 1999; October 20-22, Lisbon: 340-7.

http://www.citidep.pt/papers/articles/alvesper.htm

Alves-Pereira M, Motylewski J, Araújo A, Pais F, Lopo Tuna JMC, Delgado J, Lewin PA, Nowicki A, Castelo Branco NAA. **Pericardial thickening in commercial airline flight crew.** Aviation, Space and Environmental Medicine 1999; 70(4): 412. (Abstract)

Águas AP, Alves-Pereira M, Monteiro E, Sousa Pereira A, Grande NR, Castelo Branco NAA. **Features of cellular death in pericardia of vibroacoustic disease patients.** Aviation, Space and Environmental Medicine 1999; 70(4): 413. (Abstract)

Delgado J, Motylewski J, Alves-Pereira M, Nowicki A, Lewin PA, Castelo Branco NAA. **The pilots' dilemma: cosmic radiation above 30 000 ft and infrasound below 30 000 ft.** Aviation, Space and Environmental Medicine 1999; 70(4): 413. (Abstract)

Motylewski J, Alves-Pereira M, Delgado J, Nowicki A, Lewin PA, Castelo Branco NAA. **Noise assessment in commercial airliners.** Aviation, Space and Environmental Medicine 1999; 70(4): 413. (Abstract)

1998

Alves-Pereira M. **Noise assessment and noise-induced extra-aural pathology.** Proc IberoAmer Inter Meet Acoustics 1998; Lisbon, Portugal, In: Bento Coelho JL, Fradique J eds., Acústica 98. Soc. Port. Acústica: Lisbon, 1998: 323-26.

Alves-Pereira M, Castelo Branco N, Águas AP, Sousa Pereira A, Monteiro E, Grande NR. **Adaptação da estrutura do pericárdio à exposição ocupacional a ruído inteso de baixa frequência. [Pericardial adaptation to occupational low frequency noise exposure].** XXXIII Reunião Anual da Sociedade Portuguesa de Microscopia Electrónica e Biologia Celular. Porto, 9-11 de Dezembro, 1998. (Portuguese)

Águas AP, Alves-Pereira M, Monteiro E, Sousa Pereira A, Grande NR, Castelo Branco NAA. Aspectos da morte celular no pericárdio de doentes com a doença vibroacústica. **[Aspects of cellular death in the pericardium of vibroacoustic disease patients].** XXXIII Reunião Anual da Sociedade Portuguesa de Microscopia Electrónica e Biologia Celular. Porto, 9-11 de Dezembro, 1998.

Chapter

Acoustics and Biological Structures

Mariana Alves-Pereira, Bruce Rapley, Huub Bakker and Rachel Summers

Abstract

Within the context of noise-induced health effects, the impact of airborne acoustical phenomena on biological tissues, particularly within the lower frequency ranges, is very poorly understood. Although the human body is a viscoelastic-composite material, it is generally modeled as Hooke elastic. This implies that acoustical coupling is considered to be nonexistent at acoustical frequencies outside of the human auditory threshold. Researching the acoustical properties of mammalian tissue raises many problems. When tissue samples are investigated as to their pure mechanical properties, stimuli are not usually in the form of airborne pressure waves. Moreover, since the response of biological tissue is dependent on frequency, amplitude, and time profile, precision laboratory equipment and relevant physiological endpoints are mandatory requirements that are oftentimes difficult to achieve. Drawing upon the viscoelastic nature of biological tissue and the tensegrity model of cellular architecture, this chapter will visit what is known to date on the biological response to a variety of different acoustic stimuli at very low frequencies.

Keywords: infrasound, low frequency noise, health, cellular biology, tissue morphology

1. Introduction

Airborne pressure waves are ubiquitous in all human environments and have played vital roles in the survival, evolution, and development of the human species. Under certain conditions, airborne pressure waves can be perceived as "sound" by the human auditory system. Under other conditions, they may be perceived as a whole-body or partial-body vibration. Some airborne pressure waves are not consciously perceived at all. As human societies developed and became more technological, airborne pressure waves emanating from human-made devices became ubiquitous and "noise" became a more serious issue. By the late nineteenth century, noise and health studies began to flourish. In the early twentieth century, the telephone and growing industrialization led to more in-depth studies of the human hearing function. In 2011, a WHO document on the burden of diseases reflected the seriousness of the ongoing "noise problem" [1].

The only airborne pressure waves considered of consequence for human health were those that could be *heard*, i.e., "what you can't hear can't hurt you" (**Figure 1**). This notion justified the development of acoustic measuring devices and methodologies that concentrated solely on the audible portion of the acoustical spectrum.

Within the audible segment (20–20,000 Hz), human auditory acuity is not evenly distributed, and is more sensitive within the 800–7000 Hz range than it is to airborne acoustic events occurring below 500 Hz or above 15,000 Hz. Thus, early on, scientists understood that in order to protect human hearing function and speech intelligibility, the entire audible segment need not be considered, but rather, only the frequencies at which the acuity was highest: 800–7000 Hz range. The development of the A-frequency weighting and the resulting deciBel-A (dBA) metric allowed acousticians and health professionals to assess acoustical environments simulating this variability of human auditory acuity.

Figure 2 shows the frequency response curve for the dBA metric, clearly following the human auditory response to airborne acoustic pressure waves.

While the dBA metric proved to be key for the protection of hearing and speech intelligibility, it was insufficient for the assessment of airborne pressure waves occurring outside of the 800–7000 Hz range. **Figure 3** emphasizes the 800–7000 Hz range within the dBA metric, and **Figure 4** shows its application at 10 Hz. The dBA metric is, therefore, unsuited for evaluating airborne pressure waves occurring at frequencies below 800 Hz. Health effects that may be developing due to exposures

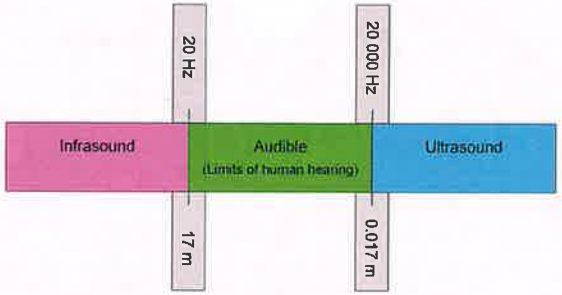


Figure 1.
Acoustical spectrum showing the classical three segments (infrasound, audible, and ultrasound) with the frequency and wavelength indicated at the cutoff of each segment.

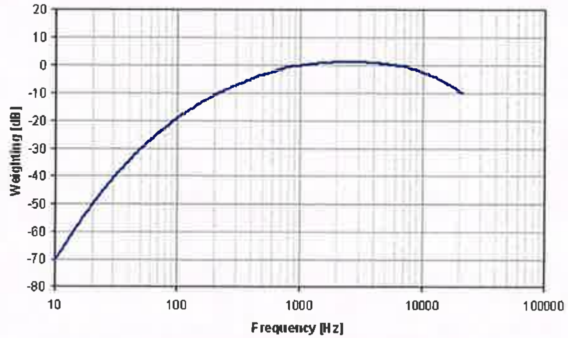


Figure 2.
Frequency response curve for the deciBel-A metric (dBA) commonly used in noise-related legislation [2].

DOI: http://dx.doi.org/10.5772/intechopen.82761

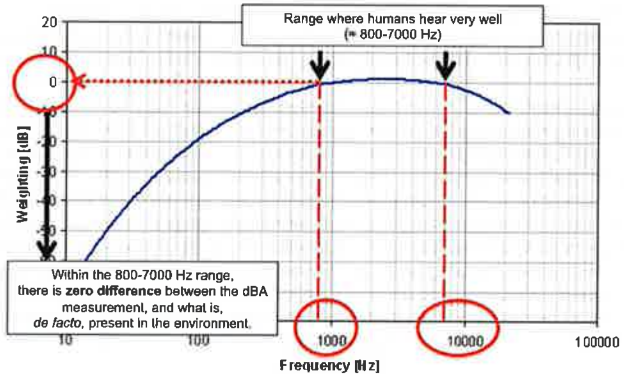


Figure 3.
Frequency response curve for the dBA metric applied to the range of highest human auditory acuity. Within this frequency range, the dBA measurement will accurately reflect the airborne acoustical energy present in the environment.

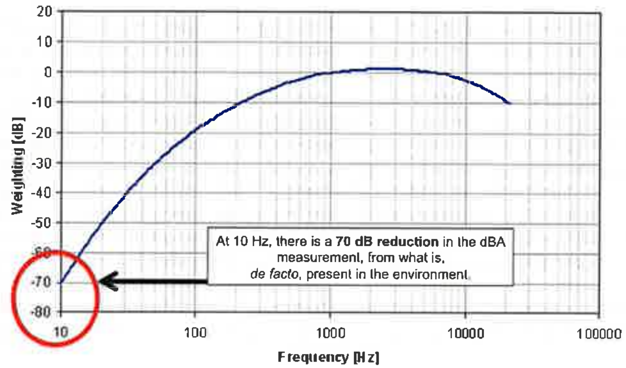


Figure 4.
Frequency response curve for the dBA metric applied to infrasonic frequency ranges, showing a 70 dB difference when evaluated at 10 Hz. Within these lower frequency ranges, the dBA metric will significantly underestimate the airborne acoustical energy present in the environment.

at these lower frequencies cannot be properly studied if the dBA metric is being used to characterize acoustical environments.

There is a shortage of studies that properly evaluate the biological response to infrasonic (≤20 Hz) or lower frequency (≤200 Hz) airborne pressure waves. Three important reasons for this have been provided above: the rudimentary segmentation of the entire acoustical spectrum into merely three "blocks" (compare to segmentation of the electromagnetic spectrum), the unsuitability of the dBA metric to quantify airborne acoustical pressure waves at these lower frequencies, and the ingrained notion that "what you can't hear can't hurt you." These major hindrances have been crystallized into mainstream science [3] and have served to significantly impede scientific inquiry and human health protection.

The goal of this chapter is to consolidate what is known on the biological response to airborne pressure waves occurring within the infrasonic and lower frequency ranges. A biomedical engineering approach is taken, whereby biological organisms are viewed as structures of composite materials, with significant visco-elastic components and organized in accordance with the principles of tensegrity architectures. When airborne pressure waves impact these types of structures, the biological response will depend on the type of biomaterial under study, it will exhibit anisotropic properties, and it will vary nonlinearly with exposure time. Depending on the physical properties of the airborne pressure waves (including time profiles) and on the biostructure under study, mechanical perturbations are relayed into cells and tissues through a variety of different pathways that, to date, still remain unclear.

2. Biomaterials and human anatomy

2.1 Viscoelasticity

Viscoelasticity is an attribute given to bodies that exhibit both viscous and elastic behaviors beyond the classical Hooke's elastic model [4]. Viscoelastic materials have three distinct properties not contemplated by Hookean models: creep, stress relaxation, and hysteresis. Most biological materials have viscoelastic behaviors.

In a Hookean (or purely elastic) material, total deformation depends on total load, and no further deformation occurs even if load is maintained. In viscoelastic materials, however, when sufficient stress is applied and maintained, they may continue to deform, even though stress load remains unaltered. This property is called *creep*.

In a purely elastic material, the strain within the material is constant throughout the application of the load; it does not vary with time, but only with the amount of applied stress. In viscoelastic materials, when stress is applied and maintained, strain can decrease with time. This property is called *stress relaxation*.

Consider repetitive or cyclical loads on materials. In purely elastic materials, periodic loads will not alter the stress-strain curve. The pathway taken by the material to deform is exactly the same pathway it takes to return to its original, equilibrium position. In viscoelastic materials, however, the return to equilibrium may be different than the pathway used to get to the point of deformation (The word pathway is here loosely used, and is meant to encompass all spatial, temporal and energetic components of these types of movements.) This property is called *hysteresis*.

2.2 Tensegrity structures

Many structures in the natural world are organized in accordance with the principles of tensegrity architecture—elements providing discontinuous compression are held together through elements of continuous tension [5]. **Figure 5** shows several examples of tensegrity structures.

Depending on the properties of the airborne pressure waves and biomaterial under study, the propagation of mechanical perturbations throughout these types of structures can reach long distances, without loss of structural integrity.

2.3 Cellular and tissue mechanotransduction

Cells and tissues are organized in accordance with the principles of tensegrity architecture [8, 9]. This means that in addition to biochemical signaling,

DOI: http://dx.doi.org/10.5772/intechopen.82761

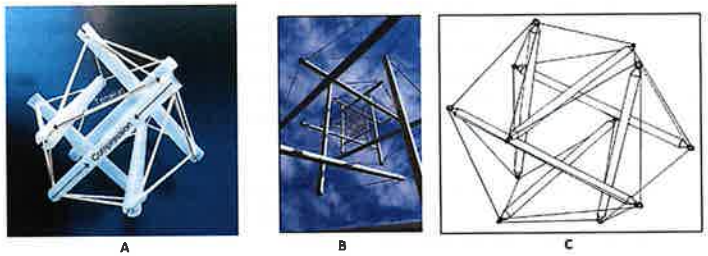


Figure 5.
Tensegrity structures. A. Model showing elements of continuous tension and discontinuous compression. B. Needle tower, by Kenneth Snelson, in the Hirshhorn sculpture garden (USA) [6]. C. Icosahedron, first designed by Buckminster Fuller in 1949 [7].

cells also communicate with their surroundings through mechanical signals. Mechanosensitive receptors exist on cell surfaces, and mechanosensitive junctions interconnect cells, thus forming tissues. Depending on the physical properties of the airborne pressure waves and biomaterials under study, external airborne mechanical perturbations can elicit a mechanical response, which, in a larger, macroscopic view, can lead to clinically pathological situations.

2.4 The fasciae

The fascia is a sheet of connective tissue that uninterruptedly extends from head to toe, suspended from the skeleton, and that provides the integrated supporting framework for maintaining anatomical and structural form [10, 11]. That external mechanical perturbations elicit responses at large distances away from the point of entry is a well-known concept among scientists and health professionals who study fasciae. When presented with external airborne pressure waves, fasciae can respond by changing their structural properties: *from a mechanical point of view, the fasciae are organized in chains to defend the body against restrictions. When a restriction goes beyond a specific threshold, the fasciae respond by modifying their viscoelasticity, changing the collagenic fibers, and transforming healthy fascial chains into lesioned chains* [10]. One of the fascia's key roles is that of shock absorption.

Connective tissue structures are ubiquitous forming all external surfaces of vessels, nerves, organs, and muscles, and at the cellular level, the extra-cellular matrix that surrounds and communicates with each individual cell. In addition to maintaining structural integrity, the fasciae are the first line of defense against external perturbations, playing important physiological roles in mobilizing the immune system.

3. Laboratorial studies, field studies, and biological outcomes

Studying the effects of infrasonic or lower-frequency airborne pressure waves on biological structures is a very complex undertaking, whether it be on cell cultures, on animal models, or on human populations. Laboratorial studies, occupational field studies, and residential field studies all have their own strengths and weaknesses. When the latter go unrecognized, however, experimental design flaws can ensue. In this section, the attributes of these different experimental setups are discussed, and their weaknesses and strengths are explored. Together with the preceding section, this serves as a preamble to Section 4, where the results of experimental studies are described in detail.

3.1 Laboratorial studies

Laboratories where infrasonic and lower frequency airborne pressure waves can be applied in a controlled manner are in short supply worldwide, and those that do exist are mostly associated with military installations. Laboratories emitting airborne pressure waves with infrasonic and lower frequency components cannot be randomly placed within residential environments; issues with neighbor disturbance and public health would curtail its use. Moreover, the equipment used to generate the airborne pressure waves is, typically, very large and very expensive, and few sectors of society (other than military or space exploration industries) would have the need for an extensive use of these types of installations.

In these laboratory settings, continuous or pulsed-trains of single-tone airborne pressure waves can be applied, as well as, broadband exposures that can be accurately characterized. The fact that exposure times and acoustic parameters can be precisely controlled is one of the strengths of laboratorial studies, allowing for continuous time exposures, or occupationally simulated exposure schedules. Immediate (hours or days) versus long-term (weeks or months) effects can also be explored.

There are numerous types of biological outcomes that can be studied under laboratorial conditions. Light-, electron- and atomic-force microscopy can be used to study cellular and tissue structural properties, as well as their chemical composition and content of bio-reactive elements. Polymerase chain reaction (PCR) techniques can provide information on messenger RNA (mRNA) expression, allowing for the identification of key pathways. With pharmacological intervention or gene knockout specimens, specific signaling molecules and pathways involved in the elicited responses can be pinpointed. Additionally, control populations for comparison are fairly easy to achieve—they are simply not subjected to the laboratorial exposures.

3.2 Occupational field laboratories

Occupational environments are exceptional field laboratories, as both short-term (several months) and long-term (years) effects can be investigated in more realistic acoustic environments. Typically, different workstations have different acoustical features that can greatly depend on different machinery regimens. For occupational field laboratories, acoustical characterizations of the workplace(s) must be comprehensively undertaken and time exposures to each type of environment should be scored.

Exposure times at work must be differentiated from exposure times away from work, i.e., when the work shift ends, workers leave the field laboratory, but additional exposures to infrasonic or lower frequency airborne pressure waves may be incurred (e.g., recreational, transportation). These must be documented. Significant confounding factors may be introduced unless each subject's residential area is scrutinized and prior-exposure histories probed for fetal, childhood, and adolescent exposures.

Possible biological outcomes within occupational field studies are more limited when compared to laboratory exposures. Noninvasive testing can be imprecise, and the minimally invasive testing (such as a blood chemistry analysis, X-ray, or MRI) may also not be sufficiently precise to yield relevant data. It is also the case that scientific knowledge on relevant biological outcomes that can be noninvasively evaluated in exposed humans is still absent or, at best, very incomplete.

DOI: http://dx.doi.org/10.5772/intechopen.82761

Survivorship bias is a well-known confounding factor in human population studies. In occupational environments, workers with more time on-the-job are those who have survived throughout the years of professional activity, while workers with less time in professional activity may exhibit more severe biological outcomes. This phenomenon is often misinterpreted leading to inconclusive or erroneous conclusions.

Control populations for exposures to infrasonic and lower frequency airborne pressure waves have been a very difficult proposition, given the ubiquitous nature of this stressor. One of the solutions to this profound problem is the scoring of subjects into different groups as per their exposure. Within this context, control groups are composed of individuals who have the least amount of cumulative (prior and present) exposure, and not of individuals with zero exposure.

Different professions can provide different field laboratories, both in terms of acoustic environment and time exposure schedules. For example, long-haul truck drivers are typically exposed for more than 8 hours daily and, oftentimes, sleep in the truck while it is idling, or while refrigeration systems are continuously operating. Workers onboard ships, submarines, offshore oilrigs, aircraft, and spacecraft (for example) can be exposed to significant amounts of infrasonic and lower frequency airborne pressure waves for weeks or months at a time. The wealth of information waiting to be gleaned from these types of field laboratories is breathtaking.

3.3 Residential field laboratories

Field laboratories in urban, suburban, and rural residential settings are generally designed to investigate environmental health effects due to human-made infrasonic and lower frequency airborne pressure waves. Typically, these sources are associated with industrial complexes or infrastructure that, in turn, are usually linked with important economic interests. In general, the amount and type of infrasonic and lower frequency airborne pressure waves contaminating a home will depend on the machine operation and/or the use of the infrastructure. For example, in most urban and suburban areas, airports must close down between the hours of midnight and 5 am. Some factories do not have night shifts and therefore also have daily shutdown periods. Large refrigeration units, hydroelectric dams, and large volume highways, however, must be kept running 24/7 and can also be viewed as continuous sources of infrasonic and lower frequency airborne pressure waves. Wind turbines are the latest addition to these type of sources although they are almost exclusively within rural areas.

Comprehensive characterization of the acoustic environments in the different residential areas must be undertaken (e.g., master bedroom, children's bedrooms, living-lounge areas), since room-resonance phenomena can significantly modify the acoustic environment that is originally being induced and driven by external, incoming airborne pressure waves. Additionally, wind can also influence the spectrum, intensity and type of infrasonic and lower frequency airborne pressure waves that exist within a room. This differentiation is readily achieved with proper acoustic evaluations.

Residential exposure times are much more difficult to control, as they can differ from room to room and on an hourly basis. Moreover, subjects may also be sleeping within the "contaminated" environments, which can severely aggravate biological outcomes. If exposure is concomitantly occurring during sleep and waking hours (e.g., homemakers, workers from home, farmers), then biological outcomes may be further aggravated. Leaving the home can be equated with a biological recovery period (i.e., nonexposure period).

Short-, medium- and long-term effects can be studied in residential settings when the implementation of a new infrastructure or industrial complex is known to be coming to the area. Biological outcomes should strive to be either noninvasive or minimally invasive, and prior-exposure histories are fundamental for achieving useful statistical data.

4. Past relevant studies

Numerous studies conducted over the decades have shed light on the biological response to infrasonic and lower frequency airborne pressure waves and associated symptomatic complaints. Due to space limitations, this discussion will only deal with some of the vascular and collagenous abnormalities, cardiomyocyte changes, and the hippocampus responses, as induced by different types of exposures. For reasons explained in the section "Introduction," all studies using the dBA metric have been eliminated from consideration (with one exception in an occupational setting). Selected studies mostly focus on the cellular and tissue changes observed in laboratory, occupational, and residential settings, using light and electron microscopy. The sequence in which the studies are presented does not follow the classical anatomical order.

4.1 Vascular changes

In the mid-1960s, within a military setting, the immediate exposure to 10–60 Hz, at 118–140 dB, for 2 minutes, induced disturbances of the visual field as reported by all five human subjects [12]. In 1985, laboratorial animal studies exposed rats to tonal 8 Hz at 100–140 dB, 3 hours daily, for 5, 10, 15, or 25 days, and examined the blood and lymph networks of the palpebral (eyelid) and bulbar (eye globe) conjunctiva. *Day 5*: narrowing of all parts of the conjunctiva blood network was observed, with decreased blood capillary lumens. Capillaries, precapillaries, and arterioles were twisted, and blood component agglomerations were identified in venous vessels. *Day 10*: conjunctiva capillaries were twisted and large vessel diameters were decreased. *Day 15:* blood and lymph vessel tonus had changed, and stagnation was present. *Day 25:* failure of tissue homeostasis was aggravated. Capillary penetration was increased, as seen through tissue enlargement, and significant agglutination was observed in the large vessels [13].

In a similar study, animals were exposed to 8 Hz at 100 dB, or to 16 Hz at 100 dB, 3 hours daily, for 1 month. Clinical and morphological evaluations were conducted at days 3, 7, 15, 30, and also post-exposure at days 30, 60, and 90. *Day 3:* clinical changes were not observed, but morphological changes were present: edema in the upper and middle areas of the eyelid derma and heterogeneous blood filling of vessels with extra-vascular erythrocytes were also observed. Fine focal hemorrhages were identified under the corneous layer of the eyelid. Sclera exhibited edema, and blood vessels were filled heterogeneously with stasis and extra-vascular intraconjunctive hemorrhages. In the 8-Hz group, moderate edema was present near the optical nerve, and the 16-Hz group exhibited perineural hemorrhages in the optical nerve. *Day 7:* in both groups, conjunctiva blood vessels had expanded and arteries in the oculus fundus were narrower and twisted. Eyelid edema of the derma was identified in both groups. The most pronounced vascular changes were found in the eyelid conjunctiva: stasis, edema, and pericapillary hemorrhages. Sclera capillaries were overfilled with blood and extra-vascular hemorrhages were observed. *Day 15:* in both groups, conjunctiva vessels were narrower and twisted, and ocular globe conjunctiva exhibited nonvascularized

areas. Vascular changes as seen previously were more expressed: edema, paresis state in capillaries (erythrocyte stasis), and extra-vascular erythrocytes. The iris exhibited narrower vessels. *Day 30:* narrowed and twisted vessels were clinically detected, with ocular fundus arteries and veins significantly narrowed and twisted, more pronounced in the 16-Hz group. In the eyelid conjunctiva, derma exhibited the same vascular changes seen before: edema and erythrocyte stasis. Sclera arteries and veins were larger, overfilled with blood, and with the presence of extra-vascular focal and diffuse hemorrhages with conjunctiva involvement. At all time points, the 16-Hz group disclosed more destruction than the 8-Hz group. *Day 60 (30 days post-exposure)*: clinical evaluations revealed less twisted and narrow arteries and veins, but morphological recovery was slower. In the 8-Hz group, moderate regeneration was observed in the eyelid conjunctiva epithelium. In the 16-Hz group, predominant retinal damage persisted. *Day 90:* no clinical changes were observed in either group [14].

Within an occupational setting (reinforced concrete factory), vessel changes in the palpebral and bulbar conjunctiva, and in the retina, were investigated among 214 workers (age range: 20–58 years), with 1–30 years of employment. Workers were divided into two groups:

- *Control group* (n = 54): not occupationally exposed to significant levels of infrasonic and lower frequency airborne pressure waves.

- *Exposed group* (n = 160): tonal 8 and 16 Hz at 96–100 dB, simultaneously with non-tonal 20–500 Hz at 91–93 dBA.

The exposed group was divided into subgroups as per years of professional activity. **Table 1** describes each subgroup and the vessel abnormalities found. No such abnormalities were found in the control population [14].

Within a different occupational setting (aircraft industry), ocular changes were studied in 23 male workers (average age: 42, range: 32–58 years). Lesions

Occupational exposure time	**1–2 yrs**	**3–10 yrs**	**11–20 yrs**	**20–30 yrs**
Number of workers	21	84	36	19
Palpebral and bulbar arteries (%)				
Enlarged	0	82	8	0
Narrow	0	17	91	100
Twisted	0	80	100	100
Retinal arteries (%)				
Enlarged	0	0	0	0
Narrow	0	91	100	100
Twisted	0	90	100	100
Retinal veins (%)				
Enlarged	0	87	11	0
Narrow	0	13	88	100
Twisted	0	75	97	100

Table 1.
Percentage of abnormal vessel changes seen in the palpebral and bulbar conjunctiva and retina among occupationally exposed workers [14].

were observed in the blood-retinal barrier in 19 workers (lesion types: 13 inactive, 2 active, 4 mixed). Choroidal circulation was altered in 14 workers (late perfusion with chronic features). Changes in retinal circulation were observed in four workers (type: 1 occlusive, 1 exudative, 2 mixed). Three workers presented with optic neuropathy (1 papillitis, 2 optic atrophy), and one exhibited sensorial retinal macular detachment [15]. The immediate effects of tonal exposures with 8 Hz at 130 dB, 2 hours daily, for 1, 7, 14 and 21 days, also revealed a breakdown of the blood-retinal barrier in the rat eye [16].

These studies strongly suggest that under the impact of infrasonic and lower frequency airborne pressure waves, a vascular response is mounted by ocular structures and could be related to decreased visual acuity in workers. Data in **Table 1** seem to indicate that, as exposure time progressed, vessels that were initially enlarged ceased to exist, apparently being replaced with narrower and twisted vessels. Enlarged vessels usually suggest the need for an increased blood supply. However, given the sustained mechanical insult, making the vessels narrower and twisting them throughout the structures may, in fact, reflect a more efficient blood delivery system.

This concept is further reinforced by the observation of narrow and twisted blood vessels in the gastric mucosa of rats, exposed to non-tonal, occupationally simulated (aircraft industry) acoustic environments characterized as 6.3–25 Hz at 70–90 dB and 40–500 Hz at 90–100 dB. Continuous exposure was applied, and evaluations occurred at 1, 3, 5, 9, and 13 weeks. In *3–5 weeks*, the gastric submucosal layer exhibited significantly increased thickness, when compared to non-exposed controls. This increased thickness was due to the proliferation of type IV collagen. Arterial walls disclosed significant intima and media thickening, ruptured internal elastic lamina, and thrombotic changes. In *9–13 weeks*, neoangiogenesis was observed, with the appearance of tortuous and twisted vessels. The authors concluded that, in the stomach, continuous exposure induced fibrosis that could be linked with neoangiogenesis, since collagen type IV is also an early marker of neoangiogenesis [17]. One of the earliest studies investigating the long-term effects of airborne pressure waves on gastric complaints was conducted in 1968, in a residential setting where changes in gastric function were associated with aircraft noise [18]. Within occupational settings, an increase in gastric complaints was documented among boiler-plant workers, 2 years after the implementation of mandatory hearing protection devices [19]. Among aircraft industry workers, gastrointestinal problems were among the earliest to appear after 1–4 years of professional activity [20].

Vascular changes were also identified in the liver structures of animals exposed to 2, 4, 8, or 16 Hz, at 90–140 dB, 3 hours daily, for 5–40 days. Exposures to 2 or 4 Hz induced less damage than exposures to 8 and 16 Hz. *Single, 3-hour exposures:* with 2 or 4 Hz and 90 dB, no changes were observed in the hepatic structures, while at 100–110 dB, liver parenchyma disclosed single fine hemorrhages. At 120 dB, increased arterial wall diameters were observed, as well as capillary lumen expansion, indicating the development of ischemia. At 130–140 dB, the number of hemorrhagic events increased, as did the number of affected hepatocytes. With 8 or 16 Hz exposures, damaged hepatocytes were present in the ischemic and non-ischemic areas. *Days 5–15:* more pronounced hepatocyte changes were seen. *Days 25–40*: a gradual death of changed hepatocytes was observed [21].

Hemorrhagic events in the lung were documented as early as 1969, within the Soviet and US space exploration studies, in dogs exposed to occupationally simulated (spaceflight) wide-band frequency range at 105–155 dB, for 1.5 or 2 hours. Hemorrhages up to 3 mm in diameter were observed beneath the pleura. As exposure time and decibel level increased, the number of hemorrhages increased but never

exceeded 3 mm in diameter. Microscopic analyses of the hemorrhagic sections disclosed ruptured capillaries and larger blood vessels [22]. In a laboratory setting, rats received tonal exposures to 2, 4, 8, or 16 Hz at 90–140 dB, 3 hours daily, for 40 days. Analysis time points were conducted after 3 hours, at 5, 10, 15, 24, and 40 days of exposure, as well as during post-exposure times. *Single, 3-hour exposures:* with 2 or 4 Hz at 90–110 dB, mosaic hemorrhages were observed under the pleura, covering the entire lung surface. With 8 Hz at 110 dB, more hemorrhagic expression was observed. With 8 or 16 Hz at 120–140 dB, larger hemorrhagic foci were disclosed. Within the alveolar capillary network and postcapillary venules, vessel diameters were increased with 2 or 4 Hz at 90–110 dB, leading to large hemorrhages and perivascular edema. Erythrocyte overflow in alveolar capillaries was observed with 8 or 16 Hz at 110 dB. With 8 or 16 Hz at 120 or 140 dB, lung tissue exhibited large hemorrhagic foci in the connective tissue septa of the bronchi-pulmonary segments. In all exposure types, capillary changes were followed by alveolar epithelium desquamation and basal membrane denudation. *Longer exposures:* with 8 Hz at 120 dB, acinuses became filled with erythrocytes, and interstitial hemorrhagic foci caused a strong deformation of the respiratory bronchioles. With 8 or 16 Hz at 140 dB, ruptured vascular walls were observed leading to decreased alveolar lumen [23].

The highly invasive bronchoscopic evaluation with biopsy was performed among a group of volunteer subjects, with occupational or residential exposures to infrasonic and lower frequency airborne pressure waves, as detailed in **Table 2**.

Bronchoscopic observations in all patients revealed small submucosal, vascular-like lesions ("pink" lesions), located distally in both tracheal and bronchial trees, and uniformly distributed bilaterally near the spurs. Biopsies were performed on the abnormal mucosa (pink lesions) and on the apparently normal mucosa (outside of the pink lesions). In the non-pink areas, some vessel wall thickening was visible. In the pink areas, the basal membrane disclosed abnormal neovascularization, with thickened blood vessel walls and scarce lumen. No gender differences were identified [24].

4.2 Collagen and connective tissue

Collagen, composed of triple-helix tropocollagen chains, is the most abundant protein in the human body, a key component of the fasciae, and is produced by fibroblast cells. It has long since been considered as the "steel" of the human body [25], but its energy storage capacity has been shown to be 10 orders higher than in spring steel [26]. Different types of collagen have different mechanical properties. Type IV collagen (increased in the exposed gastric mucosa [17]—see above), is organized into X-shaped structures and is commonly found in the basal membrane of arterial walls, hence its increased expression during angiogenesis.

In *day 5* of the eyelid-and-bulbar-conjunctiva animal studies (see above [13]), collagen fibers in the connective tissue were enlarged, as were some fibroblast nuclei; on *day 10*, adipose cells in the connective tissue had been redistributed and positioned in the vascular areas of the conjunctiva. In the second animal study described above [14], *day 3* included edema of the sclera causing separation of collagen filaments in the 16 Hz group, and by *day 7*, this was observed in the 8-Hz group as well; *day 15:* focal and disseminated disorganization of sclera collagen fibers was observed in both groups; *day 30:* homogenization and disorganization of collagen in the derma while, in the sclera, collagen fibers were persistently separated due to edema, with some undergoing dystrophic and necrotic changes. Slow regeneration was observed during the post-exposure periods.

In the lungs of dogs studied within the scope of space exploration (see above [22]), focal enlargement of the alveoli involved the stretching of connective tissue

Profession/type of exposure	Gender	Age	Smoking
Aircraft technician	Male	48	Mild
Aircraft technician	Male	52	No
Aircraft technician	Male	59	Mild
Combat pilot	Male	61	No
Helicopter pilot	Male	59	Moderate
Aircraft pilot	Male	54	No
Merchant marine	Male	37	No
Military helicopter nurse	Female	56	No
Flight attendant	Female	36	No
Flight attendant	Female	39	No
Flight attendant	Female	40	No
Homemaker	Female	54	Mild
Homemaker	Female	59	No

Table 2.
Description of subjects who received bronchoscopic evaluations with biopsy [24].

structures of alveoli walls. In the biopsy images of the bronchoscopic study (see above [24]), non-pink areas disclosed a thickened basement membrane with abnormal amounts of collagen, while the pink areas disclosed an even thicker membrane with very large amounts of collagen. The abnormal neovascularization was embedded within collagen bundles. Retraction of structures neighboring the collagen fibers was not observed. A marked reinforcement of the cytoskeleton and intercellular junctions was seen in the pink areas, as compared to non-pink areas. The five individuals that disclosed images of collagen fiber degeneration and disruption also tested positive for antinuclear antibodies.

Under an occupationally simulated acoustic environment, characterized as 20–200 Hz at 70–90 dB (aircraft industry), and occupationally simulated exposure schedules (8 hours daily, 5 days weekly, weekends in silence), focal interstitial fibrosis was found in the lung parenchyma of rats after a cumulative 4000-hour exposure. Additionally, thickened alveoli walls and dilated alveoli were observed [27]. Tracheal epithelium in similarly exposed rats disclosed significant subepithelial fibrosis [28, 29], and with longer occupationally simulated exposures, the subepithelial layer became composed of hyperplastic collagen bundles, some with a degenerative pattern. Cellular edema was also observed [28, 30].

Within an occupational setting (aircraft industry) and investigating long-term outcomes, high-resolution CT scans of the lungs and respiratory function tests were provided to 21 nonsmoker male workers, who were divided into two groups: with (n = 7, average age: 42) and without (n = 15, average age: 36) complaints of airflow limitations. There was a significant relationship between the presence of symptoms and images of lung fibrosis through the CT scan. No differences existed among the groups when comparing the percentage of predicted values of lung function [31].

Fasciae abnormalities have been most prominently studied in the pericardia of exposed workers, subsequent to autopsy findings in an aircraft industry worker that disclosed a grossly thickened pericardium [32]. Pericardial morphological changes were studied among 12 male workers: three aircraft technicians, four fixed-wing aircraft pilots, four helicopter pilots, and one long-haul truck driver. Pericardial samples were removed with informed consent of the patient and Ethics Committee

DOI: http://dx.doi.org/10.5772/intechopen.82761

approval, at the beginning of cardiac surgery (prescribed for other reasons by the National Healthcare Service). In all cases, there were no visual adherences, or inflammatory aspects and pericardia were grossly thickened. The classical, three pericardial layers were identified: serosa, fibrosa, and epipericardium. However, in all cases, the fibrosa had split in two and, in between, a new layer of loose tissue was observed, consisting of vessels, nerves, arteries, and lymphatics surrounded by adipose tissue. Both fibrosa layers were composed almost entirely by wavy, interwoven collagen bundles, surrounded by numerous cytoplasmic extensions (whose mother cell was difficult to identify), and interspersed with some elastic fibers. The new, loose tissue layer sandwiched in between the split fibrosa contained blood and lymphatic vessels, adipose tissue, and nerves. Both the loose tissue layer and the fibrosa layers contained macrophages and vascular hyperplasia, also seen in lymphatic vessels [33–36]. Pericardial and cardiac valve thickening has also been confirmed through echocardiography studies in occupational settings (aircraft [37] and commercial-airline industries [38]), with thickness increasing with increasing exposure time. In residential settings, pericardial and valve thickening [39] and increased arterial stiffness [40] were observed in populations chronically exposed to military-training exercises [39], and transportation systems [40].

4.3 Heart cells and tissues

In 1983, electron microscopy techniques were used to study animal myocardia exposed to single and multiple infrasonic exposures of 4–16 Hz at 90–150 dB, 3 hours daily, for 45 days, and post-exposure time points were included. No changes were observed with single exposures at 4–6 Hz and at less than 100 dB, when compared to non-exposed controls. *Single exposure with 4–10 Hz at 120–125 dB:* induced decreased arterial diameter and capillary expansion, with resulting focal ischemia. Images of intracellular myocytolysis were frequently found. These processes were reversible. *Multiple exposures with 4–10 Hz at 120–125 dB for 5–25 days:* ventricle fibrillation and subsegmental contractures in ischemic foci were identified. Myofibril fragmentation was observed in the Z-line, sarcoplasmic reticulum structures were absent, cell nuclei were deformed, and chromatin was found accumulated under the nuclear membrane. *post-exposure:* intracellular regeneration was concomitant with damaged cells. In surviving cells, mitochondria were increased in number and size, and both myofilaments and sarcoplasmic reticulum elements were being created. Intracellular regeneration was slow and ended with the creation of Z-lines, after which myofibrils became normal and myocardiocytes completely recovered. *Single exposure with 10–15 Hz at 135–145 dB:* more pronounced myocardial damage, with partial death of myocardiocytes, resulting in myocardiocyte dystrophy. Damaged cells included chromatin condensation and redistribution to the nuclei membrane. Less damaged cells regenerated after 5–10 days post-exposure. *Multiple exposures with 10–15 Hz at 135–145 dB:* persistent myocardial ischemia related to vascular changes and accompanied by cardiocyte damage. After 15–25 days post-exposure, recovered cells began functioning normally despite the presence of abnormal structures within the cellular cytoplasm, namely, giant mitochondria [41].

Cardiac injury was studied in rat cardiomyocytes exposed to tonal 5 Hz at 130 dB, 2 hours daily, for 1, 7, or 14 days. *Days 1–7:* SERCA2 (sarcoplasmic reticulum Ca^{2+} ATPase 2, an enzyme with calcium-transporting properties and involved in the decomposition of ATP into ADP) was significantly increased, and swollen mitochondria were observed in the cardiomyocytes. *Day 7:* SERCA2 was significantly decreased and an increased number of swollen mitochondria were observed. *Day 14:* SERCA2 was significantly decreased and platelet aggregation was found in the intercellular substance. Intercellular calcium ion (Ca^{2+}) concentration significantly increased with increasing exposure time [42]. With similar exposure protocols, another study repeated the SERCA2 and intercellular Ca^{2+} concentrations, but also included evaluations of the expression of whole cell L-type Ca^{2+} currents (WLCC) and the mRNA expression of a subunit of the L-type Ca^{2+} channel (LCC). SERCA2 and intercellular Ca^{2+} concentrations behaved as described immediately above, while the expression of WLCC and mRNA expression of LCC increased with increasing exposure time [43].

For three continuous months, rats were exposed to non-tonal, occupationally simulated (aircraft industry) acoustical environments characterized as 6.3–25 Hz at 70–90 dB and 40–500 Hz at 90–100 dB. Ventricular cardiac muscle and interstitial fibrosis were quantified and compared to non-exposed controls. Exposed rats disclosed a 97.5% increase in fibrosis in the left ventricle, an 81.5% increase in the interventricular septum, and an 83.7% increase in the right ventricle. No significant differences were found in the mean values of cardiac muscle in the left and right ventricles, when compared to non-exposed controls. However, the fibrosis-to-muscle ratio was significantly higher in the exposed rats, indicating significant ventricular myocardial fibrosis [44].

In another study, rats were exposed to a non-tonal, occupationally simulated (textile mill) environment rich in infrasonic and lower frequency components, under an occupationally simulated schedule (8 hours daily, 5 days weekly, weekends in silence), for 1, 3, 5, and 7 months. Ventricular coronary artery caliber, artery wall thickness, and size of arterial perivascular tissue were quantified in a total of 130 arteries (61 exposed and 69 controls). No changes were observed in arterial lumen caliber, and in arterial wall thickness, when compared to non-exposed controls. Perivascular tissue was more prominent in the exposed samples and seemed to exhibit fibrotic development. Lumen-to-wall ratio showed no differences, while wall-to-perivascular-tissue ratio showed a significant increase, as compared to non-exposed controls [45].

In animals exposed to 2–20 Hz peaking at 114 dB, for 28 continuous days, ventricular arteries were studied as to the dimensions of lumen, wall, and perivascular space. An additional group of animals received the same exposure but were treated with dexamethasone (a corticosteroid). Blind evaluation of 31 arteries disclosed increased perivascular spaces in the exposed groups, reflected in the significantly reduced wall-to-perivascular-space ratio, as compared to non-exposed controls. No changes were observed in the lumen-to-wall ratio. With dexamethasone treatment and exposure, no differences were observed in the wall-to-perivascular-space ratio, as compared to controls, suggesting an underlying inflammatory mechanism [46].

Gap junctions are a fundamental component of intercellular communication, allowing inorganic ions and small water-soluble molecules to pass directly from one cell's cytoplasm to another. Gap junctions are formed by protein complexes (connexons) each composed of six subunits made of the protein connexin. Cardiac connexin43 (Cx43) is a component of gap junctions, and its reduction in combination with increased collagen deposition and interstitial fibrosis has been associated with ventricular arrhythmias [47]. Within this context, rats were exposed to non-tonal, occupationally simulated (aircraft industry) acoustical environments characterized by 6.3–25 Hz at 70–90 dB and 40–500 Hz at 90–100 dB, for three continuous months. Immunohistochemical quantification of Cx43 was conducted on the left ventricle, interventricular septum, and right ventricle. Significantly decreased Cx43-to-muscle ratios were found in the exposed rats, as compared to non-exposed controls, suggesting the possibility of arrhythmogenic consequences [48].

4.4 The hippocampus

Prior studies have shown that the hippocampus is involved in learning and memory impairment, such as that seen in rodents after infrasound exposure [49]. The hippocampus—located between the cerebral hemispheres and the brainstem—was classically considered as part of the limbic system. The hippocampus proper is divided into four regions (CA1, CA2, CA3, and CA4), each with different input and output pathways. The Dentate Gyrus (DG) is an additional hippocampus structure and that contributes to the formation of new episodic memories, and spontaneous exploration of novel environments. In the central nervous system (CNS), neuroglia consists of the non-neuronal cells (oligodendrocytes, astrocytes, ependymal cells, and microglia) and is often referred to as the connective tissue of the brain. Glial cells surround neurons to hold them in place, supply them with oxygen and nutrients, insulate them from one another, destroy pathogens, and remove dead neurons.

Glial fibrillary acidic protein (GFAP) is an intermediate filament protein expressed by numerous cells within the CNS, and although its exact function remains unknown, it appears to be involved in maintaining the mechanical strength of astrocytes. The expression of GFAP was studied in the brains of mice exposed to 16 Hz at 130 dB, 2 hours daily, for 1, 7, 14 21, or 28 days. GFAP expression was increased in the hippocampus, cortex, and hypothalamus in a time-dependent manner [50].

Corticotrophin releasing hormone (CHR) is a peptide hormone involved in the stimulation of the pituitary synthesis of ACTH (adrenocorticotropic hormone) as part of the hypothalamic-pituitary-adrenal axis' response to stress. Corticotrophin releasing hormone-receptor 1 (CHR-R1) has wide expression in the CNS. It plays important roles in fear learning and consolidation in the amygdala, in stress-related modulation of memory function in the hippocampus, and in arousal regulation in the brainstem. Prior studies showed that infrasound exposures caused an upregulation of CRH and CRH-R1 in neurons of the hypothalamic paraventricular nucleus [51]. Recent studies have also shown that CRH is expressed in activated microglial cells [52]. Within this context, rats and *in vitro* cultured microglial cells were exposed to 16 Hz at 130 dB for 2 hours, after which changes in CHR-R1 were examined. *In vivo* exposure disclosed activation of microglial cells and an upregulation in the expression of CRH-R1 in the hypothalamic periventricular nucleus. *In vitro* exposure disclosed that, in the absence of neurons, microglial cells were activated and CRH-R1 expression was upregulated. These data suggest that both neurons in the hypothalamic periventricular nucleus and microglial cells are effector cells for infrasound-elicited responses [51].

The transient receptor potential cation channel, subfamily V, member 4 (TRPV4) protein acts as a calcium channel that is also mechanosensitive. It plays important roles in the systemic regulation of osmotic pressure by the brain, in skeletal growth and structural integrity, in airway and lung function, retinal and inner ear function, and in pain. Animals were exposed to 8 or 16 Hz at 90, 100 or 130 dB, 2 hours daily, for 14 days. Rat learning and memory abilities were most severely impaired with 16 Hz at 130 dB at days 7 and 14, with prominent loss of hippocampal CA1 neurons, as compared to non-exposed controls. Significant astrocyte and microglial activation was seen in the hippocampus after days 1 and 7, and before neuronal apoptosis became evident. *In vivo* pharmacological intervention causing the inhibition of glial activation protected against neuronal apoptosis. *In vitro*, exposed glial cells released proinflammatory cytokines, a key factor for neuronal apoptosis. In both *in vivo* and *in vitro*, expression levels of

TRPV4 were increased as compared to non-exposed controls. Pharmacological or knock-out intervention of TRPV4 in cultured glial cells decreased the levels of inflammatory cytokines and attenuated neuronal apoptosis. This study also demonstrated the involvement of calmodulin and protein kinase C signaling pathways in the response to infrasonic exposures. These data suggest that TRPV4 expressed by glial cells is potentially a key factor in infrasound-induced neuronal impairment [53].

Neonatal rat hippocampal astrocyte cultures were exposed to 16 Hz at 130 dB for 15, 30, 60, 90, 120, and 240 minutes. Extra-cellular glutamate levels increased with increasing exposure time, and at 90 min, there was a 100% increase over baseline. The astroglial expression of Cx43 (connexin43—see above) was increased, as compared to non-exposed controls, as was the synthesis of Cx43 mRNA. Through additional evaluations using pharmacological and knock-out interventions, the authors concluded that infrasonic exposures induced astrocytes to release glutamate, and that Cx43 gap junctions were required for the exposure-induced glutamate release [54].

The endocannabinoid system includes lipid-based retrograde neurotransmitters, expressed throughout the CNS, and involved in fertility, pregnancy, pre-and postnatal development, appetite, pain-sensation, mood, and memory. Animals were exposed to 16 Hz at 130 dB, 2 hours daily, for 14 days. Cannabinoid (CB) receptors 1 and 2 in the CA1 hippocampal region of the exposed rats were downregulated in a time-dependent manner, as compared to non-exposed controls. Apoptotic cells in the CA1 only became obvious after day 5, and cell death coincided with the decreased expression of CB receptors. Through pharmacological intervention, activation of CB receptors significantly reduced the number of apoptotic cells, ameliorated the behavior performance of exposed rats, and reduced the infrasound-elevated levels of proinflammatory cytokines. These data suggest that CB receptors could potentially serve as promising targets for future treatments against infrasound-induced injury [55].

Fibroblasts synthesize extracellular matrix (glycosaminoglycans, reticular, and elastic fibers) and collagen, and, in addition to their structural role, fibroblasts are also important for mounting the immune response to tissue damage. Fibroblast growth factors (FGF) signal through fibroblast growth factor receptors (FGFR). The fibroblast growth factor 2/fibroblast growth factor receptor 1 (FGF2/FGFR1) signaling pathway was investigated in animals and in cultured astrocytes, exposed to 16 Hz at 150 dB, 2 hours daily, for 1, 3, or 7 days. In both experimental models, astrocyte activation increased with exposure time and astrocyte-expressed FGFR1 was downregulated as compared to non-exposed controls. Pharmacological intervention using FGF2 exerted an inhibitory effect on infrasound-induced astrocyte activation, inhibited the elevation of proinflammatory cytokines, upregulated the expression of FGFR1, and alleviated neuron loss in CA1 hippocampus region. Inhibition of the FGF2/FGFR1 pathway aggravated astrocyte-mediated inflammation after infrasonic exposure. The authors concluded that astrocyte-mediated inflammation was involved in infrasound-induced neuronal damage and that the FGF2/FGFR1 pathway played a key role [56].

In a laboratory setting, rats were exposed to tonal 8 Hz at 140 dB, 2 hours daily, for 3 days. A post-exposure, 1-week time point was also established. Significant damage of hippocampus morphology was observed in exposed rats, and recovery was seen after 1 week of post-exposure. Neuronal apoptosis was significantly increased after 24- and 48-hour exposures, as compared to non-exposed controls, and then decreased after 1 week post-exposure. Expression of heat shock protein 70 (HSP70) peaked at 24 hours and was decreased at 48 hours [57].

5. Conclusions

Exposure to infrasonic and lower frequency airborne pressure waves can cause cellular and tissue damage depending on frequency, dB-level, and exposure time, while the viscoelastic properties inherent to biological tissues impart a nonlinear response to this type of acoustic stressor. The complex mechanosensitive and biochemical cellular signaling pathways mediating this cellular damage have not yet been pinpointed, although fasciae structures and connective tissues (including the neuroglia) seem to be the most sensitive under longer term exposures. Immediate exposures appear to induce inflammatory processes that do not seem to be maintained with longer exposures.

Widespread vascular involvement (not limited to the biological structures addressed herein) was observed in palpebral and bulbar conjunctiva and retina, gastric mucosa, liver structures, lungs, pleura and tracheae, alveoli, pericardia, and coronary arteries. This vascular response may (unsuspectingly) be the underlying cause of many symptomatic complaints. Cognitive deficits oftentimes documented within residential field laboratories may not merely be due to sleep deprivation, but also to hippocampal neuronal damage. Fasciae morphogenesis speaks to the demand on the whole-body structural integrity elicited by this type of external mechanical insult, while collagenous growths and hemorrhagic events of a focal nature may reflect concomitant resonance phenomena.

Recovery periods are not linear, and 2-hour daily exposures imply a 22-hour nonexposure period. This presents a problem for continuous exposures, such as those encountered in some professional activities and most residential environments. The underlying objectives of most of the studies discussed herein are related to occupational exposures and do not consider continuous exposures at less than 90 dB, nor are pressure pulsed trains presented within the laboratorial acoustic environments. In residential environments, however, these attributes are often present. The simulation of residential exposures does not appear to have yet been integrated into laboratory settings and protocols.

The whole-body response also elicits the immune system, affects organs of the reproductive system, changes receptor cells in the vestibular semicanals and auditory cochlea, and induces genotoxic effects, including teratogenesis. This is a pioneering field of science, still in its infancy and urgently requiring scientists from multidisciplinary areas of study because, ultimately, the health of human populations and their offspring must be protected.

Conflict of interest

None.

Author details

Mariana Alves-Pereira[1*], Bruce Rapley[2], Huub Bakker[3] and Rachel Summers[3]

1 Lusófona University, Lisbon, Portugal

2 Atkinson and Rapley Consulting, Palmerston North, New Zealand

3 Massey University, Palmerston North, New Zealand

*Address all correspondence to: m.alvespereira@gmail.com

DOI: http://dx.doi.org/10.5772/intechopen.82761

References

[1] WHO. The Burden of Disease from Environmental Noise. Copenhagen: WHO Europe; 2011

[2] Dirac Dirac Delta Science & Engineering Encyclopedia. A-weighting. 2017. Availble from: diracdelta.co.uk

[3] WHO. Environmental Noise Guidelines for the European Region. Copenhagen: WHO Europe; 2018

[4] Ross Ethier C, Simmons CA. Introductory Biomechanics: From Cells to Organisms. Cambridge: Cambridge University Press; 2007

[5] Motro R. Tensegrity: Structural Systems for the Future. London: Hermes Science Publishing; 2003

[6] WikiCommons. Needle Tower by Kenneth Snelson in Hirshhorn Sculpture Garden. Photo by Ben Stephenson. https://commons.wikimedia.org/wiki/File:Converging_Pattern.jpg

[7] WikiCommons. Tensegrity Icosahedron. Design first exhibited by Buckminster Fuller in 1949. Line Drawing by Bob Burkhardt. https://commons.wikimedia.org/wiki/File:Tensegrity_Icosahedron.png

[8] Ingber DE. The architecture of life. Scientific American. 1998;**278**:48-57

[9] Ingber DE. Mechanobiology and diseases of mechanotransduction. Annals of Medicine. 2003;**35**:1-14

[10] Paoletti S. The Fasciae: Anatomy, Dysfunction and Treatment. English edition. Seattle: Eastland Press; 2006

[11] Lindsay M, Robertson C. Fascia: Clinical Applications for Health and Human Performance. Delmar: Clifton Park; 2008

[12] Mohr GC, Cole JN, Guild E, von Gierke HE. Effects of low-frequency and infrasonic noise on man. Aerospace Medicine. 1965;**36**:817-824

[13] Svigovyi VI, Kuklina OI. State of the hemolymph circulatory bed of the conjunctiva as affected by infrasound. Gigiena Truda i Professional'nye Zabolevaniya. 1985;**6**:51-52. [Article in Russian]

[14] Kosacheva TI, Svidovyi VI, Alekseev VN, Kovalenko VI. Influence of noise and infrasound on the vision organs. Meditsina Truda i Promyshlennaia Ekologiia. 2001;(6):34-38. [Article in Russian]

[15] Van Zeller P, Tavares C, Mackay Freitas A, Oliveira A, Castelo Branco NAA. Fluorangiographic study of the ocular fundus in systemic vibration disease. Revista Portuguesa de Medicina Militar. 1991;**39**:67-70. ISSN 0482-7171 [Article in Portuguese]

[16] Qiu P, Zhang Z, Jiang Y, Gou Q, Wang B, Gou L, et al. Effect of infrasound on ultrastructure and permeability of rat's blood-retinal barrier. Zhonghua Yan Ke Za Zhi. 2002;**38**:499-501. [Article in Chinese]

[17] Fonseca J, Martins dos Santos J, Oliveira P, Laranjeira N, Águas A, Castelo Branco NAA. Noise-induced gastric lesions: A light and electron microscope study of the rat gastric wall exposed to low frequency noise. Arquivos de Gastroenterologia (Brazil). 2012;**49**:82-88

[18] Kim CY, Ryu JS, Hong SS. Effect of aircraft noise on gastric function. Yonsei Medical Journal. 1968;**9**:149-154

[19] Cohen A. The influence of a company hearing conservation program on extra-auditory problems in workers. Journal of Safety Research. 1976;**8**:146-162

[20] Castelo Branco NAA. The clinical stages of vibroacoustic disease. Aviation, Space and Environmental Medicine. 1999;**70**(Suppl):A32-A39

[21] Nekhoroshev AS, Glinchikov VV. Morphological research on the liver structures of experimental animals under the action of infrasound. Aviakosmicheskaia i Ekologicheskaia Meditsina. 1992;**26**:56-59. [Article in Russian]

[22] Ponomarkov VI, Tysik A, Kudryavtseva VI. Biological action of intense wide-band noise on animals. Problems of Space Biology. NASA TT F-529. 1969;7:307-309

[23] Svidovyi VI, Glinchikov VV. The effect of infrasound on pulmonary structure. Gigiena Truda i Professional'nye Zabolevaniya. 1987;1:34-37. [Article in Russian]

[24] Reis Ferreira JM, Monteiro MB, Tavares F, Serrano I, Monteiro E, Mendes CP, et al. Involvement of central airways in vibroacoustic disease patients. Revista Portuguesa de Pneumologia. 2006;**12**:93-105. [Thomé Villar/Boehringer Ingelheim Award]

[25] Fung YC. Biomechanics: Mechanical Properties of Living Tissues. New York: Springer-Verlag; 1993

[26] Shewry PR, Tatham AS, Bailey A, editors. Elastomeric Proteins. Cambridge, UK: Cambridge University Press; 2003

[27] Grande NR, Águas AP, Sousa Pereira A, Monteiro E, Castelo Branco NAA. Morphological changes in the rat lung parenchyma exposed to low frequency noise. Aviation, Space and Environmental Medicine. 1999;**70**(Suppl):A70-A77

[28] Castelo Branco NAA, Alves-Pereira M, Martins dos Santos J, Monteiro E. SEM and TEM study of rat respiratory epithelia exposed to low frequency noise. In: Mendez-Vilas A, editor. Science and Technology Education in Microscopy: An Overview. Vol. II. Badajoz (Spain): Formatex; 2003. pp. 505-533. ISBN: 84-607-6699-3

[29] Castelo Branco NAA, Gomes-Ferreira P, Monteiro E, Costa e Silva A, Reis Ferreira JM, Alves-Pereira M. Respiratory epithelia in Wistar rats after 48 hours of continuous exposure to low frequency noise. Revista Portuguesa de Pneumologia. 2003;**IX**:473-479

[30] Castelo Branco NAA, Monteiro E, Costa e Silva A, Reis Ferreira JM, Alves-Pereira M. Respiratory epithelia in Wistar rats born in low frequency noise plus varying amount of additional exposure. Revista Portuguesa de Pneumologia. 2003;**IX**:481-492

[31] Reis Ferreira JM, Couto AR, Jalles-Tavares N, Castelo Branco MSN, Castelo Branco NAA. Airway flow limitation in patients with vibroacoustic disease. Aviation, Space and Environmental Medicine. 1999;**70**(Suppl):A63-A69

[32] Castelo Branco NAA. A unique case of vibroacoustic disease. A tribute to an extraordinary patient. Aviation, Space and Environmental Medicine. 1999;**70**(Suppl):A27-A31

[33] Castelo Branco NAA, Águas AP, Sousa Pereira A, Monteiro E, Fragata JIG, Tavares F, et al. The human pericardium in vibroacoustic disease. Aviation, Space and Environmental Medicine. 1999;**70**(Suppl):A54-A62

[34] Castelo Branco NAA. Fragata JI, Martins AP, Monteiro E, Alves-Pereira M. The pericardium in vibroacoustic disease. I—Morphological features. In: Proceedings of the 12th International Congress on Sound & Vibration (ICSV12); Lisbon, 11-14 July 2005; Lisbon. Red Hook (NY): Curran Associates; 2005. pp. 1363-1371. ISBN: 978-1-62748-149-6

[35] Castelo Branco NAA. Fragata JI, Marques MC, Monteiro E, Alves-Pereira M. The pericardium in vibroacoustic disease. II. Cellular death pathways. In: Proceedings of the 12th International Congress on Sound & Vibration (ICSV12); Lisbon, 11-14 July 2005; Lisbon. Red Hook (NY): Curran Associates; 2005. pp. 1380-1387. ISBN: 978-1-62748-149-6

[36] Alves-Pereira M, Fragata JI, Monteiro E, Sousa Silva D, Castelo Branco NAA. The pericardium in vibroacoustic disease. III—A new structure. In: Proceedings of the 12th International Congress on Sound & Vibration (ICSV12); Lisbon, 11-14 July 2005. Red Hook (NY): Curran Associates; 2005. pp. 1372-1379. ISBN: 978-1-62748-149-6

[37] Marciniak W, Rodriguez E, Olsowska K, Botvin I, Araujo A, Pais F, et al. Echocardiography in 485 aeronautical workers exposed to different noise environments. Aviation, Space and Environmental Medicine. 1999;**70**(Suppl):A46-A53

[38] Araujo A, Pais F, Lopo Tuna JMC, Alves-Pereira M, Castelo Branco NAA. Echocardiography in noise-exposed flight crew. In: Proceedings of Internoise 2001; The Hague, 27-30 Aug 2001; Reston (VA); INCE-USA. 2001. pp. 1007-1010. ISBN: 9080655422

[39] Torres R, Tirado G, Roman A, Ramirez R, Colon H, Araujo A, et al. Vibroacoustic disease induced by long-term exposure to sonic booms. In: Proceedings of Internoise 2001; The Hague, 27-30 Aug 2001; Reston (VA); INCE-USA. 2001. pp. 1095-1098. ISBN: 9080655422

[40] Foraster M, Eze IC, Schaffner E, Vienneau D, HÉritier H, Endes S, et al. Exposure to road, railway and aircraft noise and arterial stiffness in the SAPALDIA study: Annual average noise levels and temporal noise characteristics. Environmental Health Perspectives. 2017;**125**:097004. DOI: 10.1289/EHP1136

[41] Alexeev SV, Glinchikov VV, Usenko VR. Infrasound induced myocardial ischemia in rats. Gigiena Truda i Professional'nye Zabolevaniya. 1983;**8**:34-38. [Article in Russian]

[42] Pei Z, Sang H, Li R, Xiao P, He J, Zhuang Z, et al. Infrasound-induced hemodynamics, ultrastructure, and molecular changes in the rat myocardium. Environmental Toxicology. 2007;**22**:169-175. DOI: 10.1002/tox.20244

[43] Pei Z, Zhuang Z, Xiao P, Chen J, Sang H, Ren J, et al. Influence of infrasound exposure on the whole L-type calcium currents in rat ventricular myocytes. Cardiovascular Toxicology. 2009;**9**:70-77. DOI: 10.1007/s12012-009-9037-3

[44] Antunes E, Oliveira P, Borrecho G, Oliveira MJR, Brito J, Águas A, et al. Myocardial fibrosis in rats exposed to low frequency noise. Acta Cardiologica. 2013;**68**:241-245

[45] Antunes E, Oliveira P, Oliveira MJR, Brito J, Águas A, Martins dos Santos J. Histomorphometric evaluation of the coronary arterial vessels in rats submitted to industrial noise. Acta Cardiologica. 2013;**68**:285-289

[46] Lousinha A, Oliveira MJ, Borrecho G, Brito J, Oliveira P, Oliveira de Carvalho A, et al. Infrasound induces coronary perivascular fibrosis in rats. Cardiovascular Pathology. 2018;**37**:39-44

[47] Jansen JA, van Veen AA, Bosch AA, van der Nagel R, Vos MA, Bakker JM, et al. Arrhythmia vulnerability of aged haploinsufficient Cx43 mice is determinant by heterogeneous downregulation of Cx43 combined

with increased fibrosis. Circulation. 2008;**118**:S494

[48] Antunes E, Borrecho G, Oliveira P, Brito J, Águas A, Martins dos Santos J. Immunohistochemical evaluation of cardiac connexin43 in rats exposed to low-frequency noise. International Journal of Clinical and Experimental Pathology. 2013;**6**:1874-1879

[49] Yuan H, Long H, Liu J, Qu L, Chen J, Mou X. Effects of infrasound on hippocampus-dependent learning and memory in rats and some underlying mechanisms. Environmental Toxicology and Pharmacology. 2009;**28**:243-247. DOI: 10.1016/j.etap.2009.04.011

[50] Mou X, Chen J, Li L, Jia KY, Qiu JY. Expression and distribution of glial fibrillary acidic protein in the brain of the mouse exposed to infrasound. Chinese Journal of Physical Medicine and Rehabilitation. 2001;**2**:76-78

[51] Du F, Yin L, Shi M, Cheng H, Xu X, Liu Z, et al. Involvement of microglial cells in infrasonic noise-induced stress via upregulated expression of corticotrophin releasing hormone type 1 receptor. Neuroscience. 2010;**167**:909-919. DOI: 10.1016/j.neuroscience.2010.02.060

[52] Kritas SK, Saggii A, Cerulli G, Caraffa A, Antinolfi P, Pantalone A, et al. Corticotropin-releasing hormone, microglia and mental disorders. International Journal of Immunopathology and Pharmacology. 2014;(2):163-167

[53] Shi M, Du F, Liu Y, Li L, Cai J, Zhang GF, et al. Glial cell-expressed mechanosensitive channel TRPV4 mediates infrasound-induced neuronal impairment. Acta Neuropathologica. 2013;**126**:725-739. DOI: 10.1007/s00401-013-1166-x

[54] Jiang S, Wang YQ, Xu CF, Li YN, Guo R, Li L. Involvement of connexin43 in the infrasonic noise-induced glutamate release by cultured astrocytes. Neurochemical Research. 2014;**39**:833-842. DOI: 10.1007/s11064-014-1277-3

[55] Ma L, He H, Liu X, Zhang G, Li L, Yan S, et al. Involvement of cannabinoid receptors in infrasonic noise-induced neuronal impairment. Acta Biochimica et Biophysica Sinica (Shanghai). 2015;(8):647-653. DOI: 10.1093/abbs/gmv049

[56] Shi YJ, Shi M, Xiao LJ, Li L, Zou LH, Li CY, et al. Inhibitive effects of FGF2/FGFR1 pathway on astrocyte-mediated inflammation in vivo and in vitro after infrasound exposure. Frontiers in Neuroscience. 2018;**12**:582. DOI: 10.3389/fnins.2018.00582

[57] Zhang MY, Chen C, Xie XJ, Xu SL, Guo GZ, Wang J. Damage to hippocampus of rats after being exposed to infrasound. Biomedical and Environmental Sciences. 2016;**29**:435-442. DOI: 10.3967/bes2016.056

CHAPTER SUMMARY

Acoustics and Biological Structures

M. Alves-Pereira, B. Rapley, H. Bakker, R. Summers

In: Acoustics of Materials,
A.E.A. Fellah (editor), IntechOpen, London, UK, 2019
ISBN 978-953-51-6833-1

This chapter consolidates what is known to date of the biological effects of airborne pressure waves occurring within the infrasonic and lower frequency ranges of the acoustical spectrum, and that are commonly referred to as infrasound and low frequency noise (ILFN).

In the **Introduction**, three reasons are given as to why there is a shortage of studies that properly evaluate the biological response to ILFN:

1) The rudimentary segmentation of the acoustical spectrum, as shown in Figure 1 (compare to the much greater segmentation of the electromagnetic spectrum);
2) The inappropriate use of the dBA metric to quantify ILFN, as explained by Figures 2-4; and
3) The indoctrinated, but scientifically indefensible, notion that "what you can't hear can't hurt you".

The basic principles related to biomaterials as related to ILFN exposure are provided in the section **Biomaterials and Human Anatomy.** The viscoelastic properties of biological materials impart a non-linear response to biological outcomes. Knowledge on cellular and tissue architecture, as well as on the basic human anatomy of the fasciae, can provide insight as to how airborne pressure waves can cause lesions in biological tissues, leading to clinically verifiable pathology.

The subsequent section, **Laboratorial Studies, Field Studies and Biological Outcomes**, describes the three most prevalent study setups: laboratory and field-laboratory studies within occupational or residential environments. Advantages and disadvantages of each type of experimental setup are explored.

In Laboratory studies:

a) Acoustic parameters can be precisely quantified and varied;
b) Exposure time can be precisely controlled;
c) There are numerous biological outcomes that can be examined.

In Occupational field-laboratories:

a) Acoustic parameters can be quantified but not varied in a scientifically controlled manner.
b) Concomitant non-occupational exposures (after the end of the workday) must be accounted for.
c) Prior ILFN exposures (fetal, childhood, adolescence) must be tallied.
d) The type of biological outcomes that can be explored are much more restricted.

In Residential field-laboratories:

a) Acoustic parameters are more difficult to quantify because, typically, they vary more with time than in occupational field-laboratories.
b) All areas internal and external to the residence must be acoustically characterized.

c) Concomitant ILFN exposures occurring outside of the home (occupational, recreational) must be accounted for.
d) Prior ILFN exposures (fetal, childhood, adolescence) must be tallied.
e) The types of biological outcomes that can be explored are very limited.

Specific biological outcomes in ILFN exposed humans and animal models are described in Section 4, **Past Relevant Studies**. Specifically,

1) Vascular structures,
2) Collagen and connective tissue,
3) Heart cells and tissues, and
4) The hippocampus region of the brain.

Vascular structures
Under ILFN exposures, the demands of the organism's blood flow can be substantial, leading to the development of twisted and tortuous arteries in the ocular (Table 1) and gastric structures, in both human and animal models. This could partially explain the reduced vision acuity reported in ILFN-exposed individuals, as well as the gastrointestinal complaints documented in citizens living near airports, or in "noise-exposed" industrial workers. Hemorrhagic events and other vascular abnormalities were observed in respiratory system structures in animal models, and in humans exposed to occupational or residential ILFN (Table 2).

Collagen and connective tissue
Collagen is considered to be the steel of the human body. Under long-term ILFN exposure, there is an increased production of collagen in the vascular and respiratory system structures than can manifest as clinical symptoms. This feature is partially explained by the architectural and viscoelastic properties of biomaterials, as explained in Section 2.

Heart cells and tissues
ILFN exposed individuals commonly report heart arrhythmias. Laboratory studies have shown that conditions associated with ventricular arrhythmias develop in animals exposed to ILFN. Additionally, cardiomyocytes exposed to ILFN developed abnormal structures that persisted much time after ILFN exposure ceased.

The Hippocampus
Learning and memory impairment develops in animals exposed to ILFN. It has been shown that ILFN-induced neuronal death can occur in the hippocampus, and can therefore be responsible for the observed cognitive deficits (unrelated to sleep disorders).

In **Conclusion**, exposure to infrasonic and lower frequency airborne pressure waves can cause cellular and tissue damage depending on frequency, dB-level, and exposure time, while the viscoelastic properties inherent to biological tissues impart a nonlinear response to this type of acoustic stressor. The underlying objectives of most of the studies discussed herein are related to occupational exposures and do not consider continuous exposures at less than 90 dB, nor are pressure pulsed trains presented within the laboratorial acoustic environments. In residential environments however, these attributes are often present. The simulation of residential exposures does not appear to have yet been integrated into laboratory settings and protocols. The whole-body response also elicits the immune system, affects organs of the reproductive system, changes receptor cells in the vestibular semi-canals and auditory cochlea, and induces genotoxic effects, including teratogenesis. This is a pioneering field of science, still in its infancy and urgently requiring scientists from multi-disciplinary areas of study because, ultimately, the health of human populations and their offspring must be protected.

Engineers Ireland Journal
January 23, 2018
Available at: http://www.engineersjournal.ie/2018/01/23/ilfn-infrasound-low-frequency-noise-turbine-health/

Infrasound and Low Frequency Noise – Shall we measure it properly?

Mariana Alves-Pereira
School of Economic Sciences and Organizations (ECEO), Lusófona University, Lisbon, Portugal

Huub Bakker
School of Engineering and Advanced Technology, Massey University, Palmerston North, New Zealand

Bruce Rapley
Atkinson & Rapley Consulting, Palmerston North, New Zealand

Rachel Summers
School of People, Environment and Planning, Massey University, Palmerston North, New Zealand

On the *Engineers Ireland* website, a search on "infrasound" or "low frequency noise" yields zero results. A search on "noise" however, yields 39 results. Why is it that infrasound and low frequency noise (ILFN) is still such a taboo subject? While it is improbable that this particular question will be answered here, an exposé of ILFN will be provided with a brief historical account of how and why ILFN was ultimately deemed irrelevant for human health concerns.

Infrasound and Low Frequency Noise (ILFN) are airborne pressure waves that occur at frequencies ≤ 200 Hz. These may, or may not, be felt or heard by human beings. In order to clarify concepts, in this report the following definitions are used: *acoustic phenomena:* airborne pressure waves that may or may not be perceived by humans; *sound:* acoustic phenomena that can be captured and perceived by the human ear; *noise*: sound that is deemed undesirable; *vibration:* implies a solid-to-solid transmission of energy.

Harvey Fletcher, the Telephone and the deciBel

In the early part of the 20th-century, Harvey Fletcher of the Western Electrics Laboratories of AT&T, was tasked with improving the quality of reception in the telephone. To generate the sounds in a telephone earpiece, he used an a.c., voltage and had some of his colleagues rate the loudness of the sound received compared to the quietest tone heard. The company was already using a logarithmic scale to describe the power in an electrical cable and it made sense to rate the loudness of the sounds also on a logarithmic scale related to the quietest voltage that could just be heard. Initially he called this metric a "sensation unit" but later to commemorate their founder Alexander Graham Bell, they renamed it the "Bel." A tenth of a Bel became known as the deciBel, corrupted to decibel, which has stuck with the scientific community to this day.

Fletcher-Munson Equal Loudness Curves and the dBA metric

To address the problem of industrial noise in the early 20th century, measurement was essential, as was a metric. At that time, researchers were critically aware that the readings on a sound level meter did not represent how loud or intense the sound was with respect to the subject's perception of hearing. From a biomedical perspective, this concept of perception is subjective, and changes between individuals and over timescales from minutes to decades. These serious constraints notwithstanding, it was acknowledged that some average measure of loudness would have some value for medicine and public health.

Harvey continued his research with Wilden Munsen, one of his team, by varying the frequency of the electricity to give pure tones, to which it is understood twenty-three of his colleagues listened to different levels of loudness, again through a simple telephone earpiece. (It is assumed they all had good hearing). They were then asked to score the sounds for equal loudness to that generated by an alternating current at 1000 cycles per second. The level of the sound of course depended on the voltage applied, which could be measured. It is important to note two significant constraints here: The sounds were 'pure' sine waves, which are not common in nature, and the headphones enclosed the ear of the subject. This is a very unnatural way to listen to a very unnatural sound.

The numerical results of this study are known as the Fletcher-Munsen Curves (Fig 1). The (logarithmic) units of these curves are known as "phons," and the inverse of the 40 phon curve forms the basis of the A-frequency weighting scale used everywhere today (Fig 2).

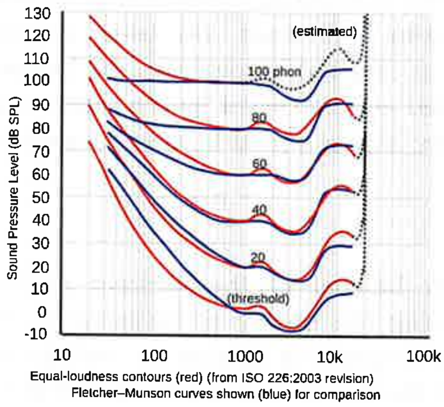


Figure 1. Fletcher Munson Curves [2]

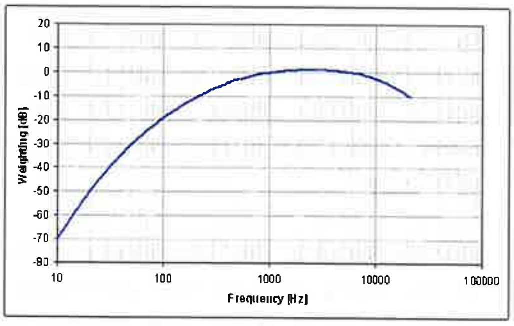


Figure 2. A-weighting frequency response curve [3]

The minimum pressure required for humans to perceive sound at 1000 Hz is considered to be 20 micropascal, or an intensity of 10^{-12} watts per square meter. This corresponds to 0 phon on Figure 1, and 0 dBA in Figure 2. For all its shortcomings, the A-Weighting has endured for decades and has become the *de facto* standard for environmental noise measurement. But is the A-weighting sufficient for all circumstances? The answer is an emphatic "No." It relates to the perception of loudness, which heavily discounts all frequencies below 1000 Hz and ends at 20 Hz. This 20-Hz limit was a consequence of equipment limitations of the 1920s and 30s, but has remained as the lower limit of human hearing to this day. The assumption that harm from excessive noise exposure is directly related to the perception of loudness has also remained to this day. Observe in Fig 2 that, at 10 Hz, there is a 70-dB difference between what is measured and what is, *de facto*, present in the environment. In other words, three-and-a-half orders of magnitude of energy are discounted at this frequency. The implications for public health are considerable, and within this line of reasoning, any event below 20 Hz becomes of no consequence whatsoever, and more so because it is not implicated in the classical effects of excessive noise exposure: hearing loss.

There are also issues of time and frequency resolution. Acoustic phenomena are time varying events. A 10-min average of acoustic events can hide more than it reveals. Similarly, segmenting frequencies into octave or 1/3-octave bands for analysis can also hide much that needs to be seen. Today, affordable and highly portable equipment can record acoustical environments, and allow for post-analysis in sub-second time increments and 1/36-octave resolution. Waveform analysis from the sound file directly can achieve an even better resolution.

Preliminary Results from Field Studies Conducted in Ireland

The following results, recently obtained in field-studies conducted in Ireland (Jul-Nov 2017), show why such resolution is needed to understand ILFN-rich environments. The classical metric (in dBA, 10-min averages and 1/3-octave bands) will be contrasted with what is needed for human health-related concerns (in dB with no frequency weighting, and resolutions of 0.2s and 1/36-octave bands), and not merely compliance with regulations.

Equipment and Methods

Acoustical environments were recorded with a SAM Scribe FS recording system, a 2-channel recorder with sampling rates up to 44.1 kHz at 16-bit resolution and linear response down to almost 0.1 Hz [4-6]. Recordings were saved as uncompressed WAV files including the 1000 Hz/94 dB reference calibration tone prior to and after measurements. Windshields were placed on both microphones during the entire measurement sessions. Microphones were attached to tripods at approximately 1.5 m above the ground.

Location

Five homes located around the same industrial wind turbine (IWT) development have been the object of study. The data presented here refers to Home 1 (Fig 3). Table 1 shows the dates and times of all recordings that have been made to date in this Home. The recordings selected for analysis and presentation herein were chosen on their educational value.

Table 1.
Dates and times of recordings.

Home No.	Date	Time	Blue Channel	Red Channel
1	04 Jul 05 Jul 10 Oct	04:05 – 06:48 15:33 – 17:50 17:40 – 18:43	In child's bedroom-1	In child's bedroom-2

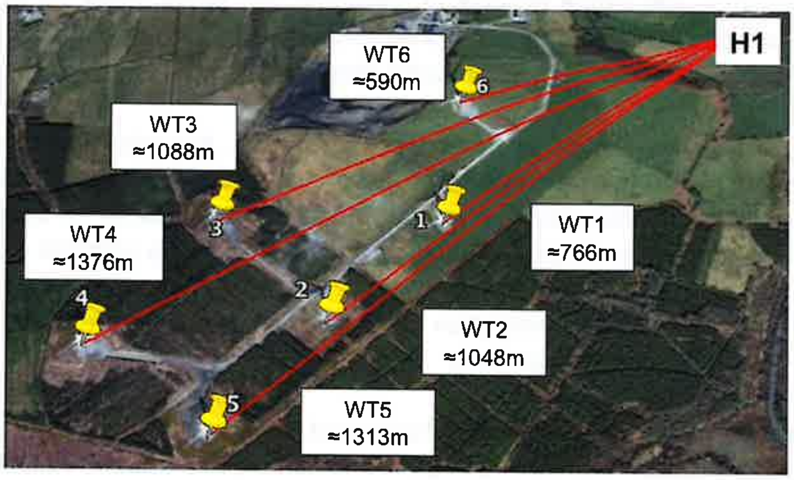


Figure 3. Reconstruction using a Google Earth Image and showing the relative position of Home 1 and each of the six industrial wind turbines.

Results

The information classically obtained with the dBA metric, 1/3-octave bands and 10-min averaging (on October 10th, 2017, at 18:30) is given in Figures 4 and 5. Weather conditions obtained from Met Éireann for the closest weather tower at this time were as follows: Air temperature: 14ºC, Precipitation: 0.1 mm, Mean Sea-Level Pressure: 1006.0 hPa, Wind Speed: 5.1 m/s (10 kt), Wind Direction: Southwest (200º az).

The values obtained for the sound pressure level and 1/3-octave bands are seen in Figures 4 and 5. The overall dBA metric (red bars labelled "Tot") reflects the sound that humans would hear if they were present in this environment. The sound pressure level in dBLin metric (grey bars labelled "Tot"), reflect the amount of acoustic energy to which humans are concomitantly exposed. The growing discrepancy between the two can be seen as the frequency falls below 1000 Hz.

Figure 6 shows the sonogram corresponding to the same 10-min period. This visual representation of time- and frequency-varying acoustic events provides much more information than the classical approach (Figs 4 and 5). Here short-term events can be seen in the region of 20-50 Hz (Fig 6). Tonal components can be seen at 10 Hz and 20 Hz that are not steady in amplitude and may be amplitude modulated, i.e., where the amplitude of the pressure is not continuous and varies periodically with time. The 10-min averages, used in almost all legislation, hide these variations and are representative only of tonal components that are essentially unvarying over the 10-min period in question.

The periodogram (Fig 7) over the same 10 minutes shows that there are distinct tonal components that form a harmonic series. When IWTs are the source of ILFN, the rotating blades generate repeated pressure waves as each blade replaces the previous one at any position. A harmonic series is formed with the "blade pass frequency" as the fundamental frequency (0.8 Hz here). These harmonics constitute what is called the *wind turbine signature* [7], which is impossible to identify using the classical dBA, 1/3-octave, 10-min averaging methodology.

Final Thoughts

Health concerns associated with excessive exposure to ILFN in the workplace have been around since the industrial boom in the 1960s [8]. In recent years, however, residential neighbourhoods have also begun to be flooded with ILFN [9-14]. The Family living in Home 1, for example, has abandoned their residence due to severe health deterioration in all family members. *Accredited acousticians cannot ascertain compliance levels for ILFN because there are none* - the vast majority of regulations worldwide do not cover this part of the acoustic spectrum. Nevertheless, Public Health Officials and Agencies should fulfil their job descriptions by becoming aware of the limitations of current noise guidelines and regulations. Alternatives exist to gather the acoustic information relevant to the protection of human populations, in both occupational and residential settings. Noise regulations and guidelines need urgent updating in order to appropriately reflect ILFN levels that are dangerous to human health.

Home 1 – A-weighting, 1/3 octave bands (0.5 Hz – 4000 Hz), 10–min average - Red Channel

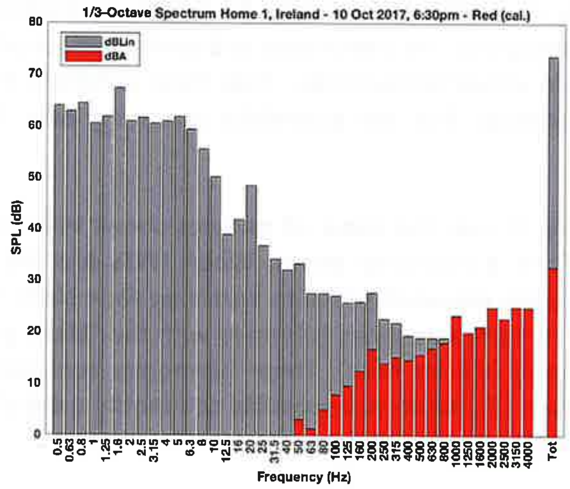


Figure 4. Data covers a 10-min interval analyzed between 0.5–4000 Hz, in 1/3-octave bands, as recorded in Home 1, on 10 Oct 2017, at 18:30 (red microphone, i.e. inside child's bedroom-2).
The red bars are A-weighted values, while the gray bars indicate the acoustic energy that is, *de facto* present, in dBLin. In this environment, the human being would perceive through the ear an overall A-weighted pressure-level of approximately 34 dBA (Tot - red bar), while being concomitantly exposed to an overall acoustic pressure-level of approximately 74 dBLin (Tot – grey bar).

Home 1 – A-weighting, 1/3 octave bands (0.5 Hz – 1000 Hz), 10–min average - Red Channel

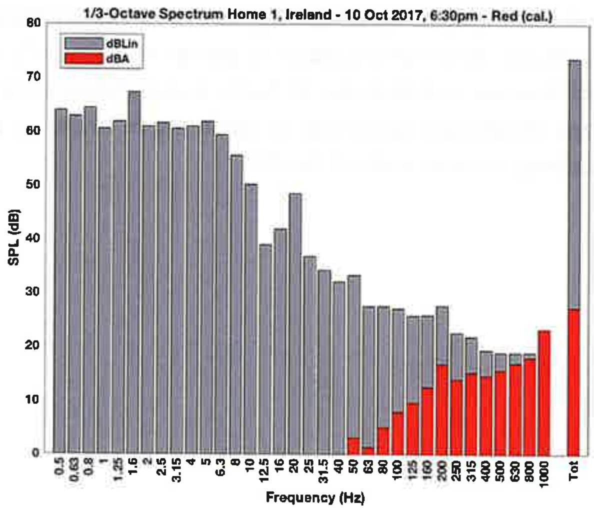


Figure 5. Data covers a 10-min interval analyzed between 0.5–1000 Hz, in 1/3-octave bands, as recorded in Home 1, on 10 Oct 2017, at 18:30 (red microphone, i.e. inside child's bedroom-2). The red bars are A-weighted values, while the gray bars indicate the acoustic energy that is, *de facto* present, in dBLin. In this environment, the human being would perceive through the ear an overall A-weighted pressure-level of approximately 26 dBA (Tot - red bar), while being simultaneously exposed to an overall acoustic pressure-level of approximately 74 dBLin (Tot – grey bar).

Home 1 – No weighting, 1/36 octave bands (0.5 Hz – 1000 Hz), 0.2 s average - Red Channel

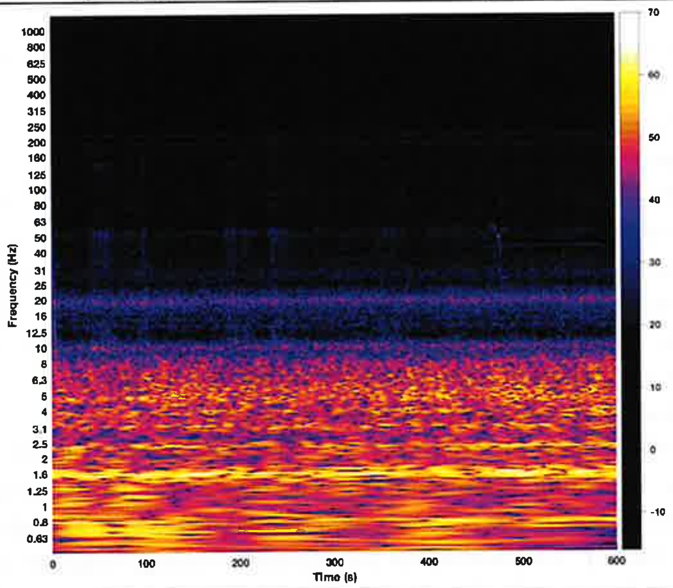


Figure 6. Sonogram that covers the same 10-min interval (600 s) as in Figures 4 and 5 showing time-varying features. The colour-coded bar on the right indicates sound pressure level values in dB Linear (no weighting). The horizontal line seen at 20 Hz is not a continuous tone because over the 600 s, its pressure level (colour-coded data) varies. A strong (yellow) acoustic phenomenon can be seen to exist at 1.6 Hz and also at 0.8 Hz.

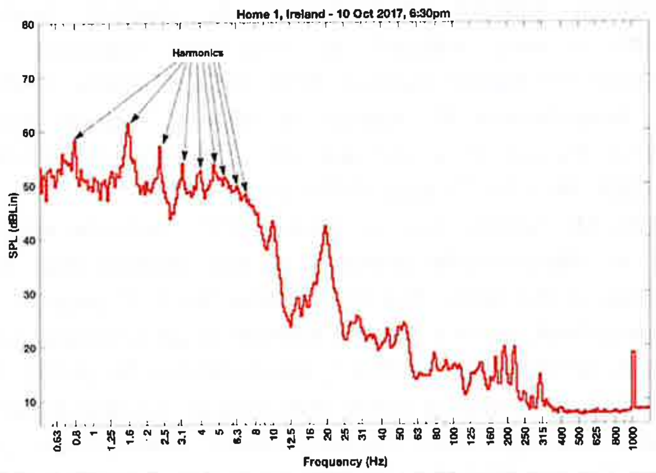


Figure 7. Periodogram covering the same 10-min interval (600 s) as in Figs 4-6, and analyzed between 0.5–1250 Hz. The blade pass frequency of the IWT is 0.8 Hz. Harmonics of this fundamental frequency are

shown in the figure. Each frequency band composing the harmonic series has a well-defined peak, e.g., the horizontal line seen in Figure 7 at 20 Hz is represented here as a peak at 20 Hz.

References

[1] Dickinson P (2006). Changes and challenges in environmental noise measurement. Acoustics Australia, 34 (3), 125-129.

[2] Wikicommons (2017). Fletcher-Munson Curves. https://commons.wikimedia.org/wiki/File:Lindos4.svg

[3] Dirac (2017). Dirac Delta Science & Engineering Encyclopedia, A-Weighting. http://diracdelta.co.uk/wp/noise-and-vibration/a-weighting/

[4] Atkinson & Rapley Consulting Ltd (2017). Specification sheet for the SAM Scribe FS Mk 1. www.smart-technologies.co.nz

[5] Primo Co, Ltd. (Tokyo, Japan) (2017). Specification sheet for the electret condenser microphone, custom-made, model EM246ASS'Y. http://www.primo.com.sg/japan-low-freq-micro

[6] Bakker HHC, Rapley BI, Summers SR, Alves-Pereira M, Dickinson PJ (2017). An affordable recording instrument for the acoustical characterisation of human environments. ICBEN 2017, Zurich, Switzerland, No. 3654, 12 pages.

[7] Cooper S (2014). The Results of an Acoustic Testing Program Cape Bridgewater Wind Farm. Prepared for Energy Pacific (Vic) Pty Ltd, Melbourne, Australia. http://www.pacifichydro.com.au/files/2015/01/Cape-Bridgewater-Acoustic-Report.pdf

[8] Alves-Pereira M (1999). Noise-induced extra aural pathology. A review and commentary. Aviation, Space and Environmental Medicine, 70 (3, Suppl.): A7-A21.

[9] Torres R, Tirado G, Roman A, Ramirez R, Colon H, Araujo A, Pais F, Lopo Tuna JMC, Castelo Branco MSNAA, Alves-Pereira M, Castelo Branco NAA (2001). Vibroacoustic disease induced by long-term exposure to sonic booms. Internoise2001, The Hague, Holland, 2001: 1095-98. (ISBN: 9080655422)

[10] Araujo A, Alves-Pereira M, Joanaz de Melo J, Castelo Branco NAA (2004). Vibroacoustic disease in a ten-year-old male. Internoise2004. Prague, Czech Republic, 2004; No. 634, 7 pages. (ISBN: 80-01-03055-5)

[11] Alves-Pereira M, Castelo Branco, NAA (2007). In-home wind turbine noise is conducive to vibroacoustic disease. Second International Meeting on Wind Turbine Noise, Lyon, France, Sep 20-21, Paper No. 3, 11 pages.

[12] Castelo Branco NAA, Costa e Curto T, Mendes Jorge L, Cavaco Faísca J, Amaral Dias L, Oliveira P, Martins dos Santos J, Alves-Pereira M (2010). Family with wind turbines in close proximity to home: follow-up of the case presented in 2007. 14th International Meeting on Low Frequency Noise, Vibration and Its Control. Aalborg, Denmark, 9-11 June, 2010, 31-40.

[13] Lian J, Wang X, Zhang W, Ma B, Liu D (2017). Multi-source generation mechanisms for low frequency noise induced by flood discharge and energy dissipation from a high dam with a ski-jump type spillway. International Journal of Environmental Research and Public Health, 14 (12): 1482.

[14] Rapley BI, Bakker HHC, Alves-Pereira M, Summers SR (2017). Case Report: Cross-sensitisation to infrasound and low frequency noise. ICBEN 2017, Zurich, Switzerland (Paper No. 3872).

26th INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
7-11 July 2019, Montreal

INFRASOUND AND LOW FREQUENCY NOISE GUIDE-LINES: ANTIQUATED AND IRRELEVANT FOR PROTECT-ING POPULATIONS

Mariana Alves-Pereira
ECEO, Universidade Lusófona, Lisbon, Portugal
email: m.alvespereira@gmail.com

Carmen Krogh
The Society for Wind Vigilance (Not-For-Profit Incorporation) & Magentica Research Group (Not-For-Profit Incorporation), Ontario, Canada
e-mail: carmen.krogh@gmail.com

Huub H. C. Bakker
Massey University, Palmerston North, New Zealand
e-mail: H.H.Bakker@massey.ac.nz

S. Rachel Summers
Massey University, Palmerston North, New Zealand
e-mail: s.r.summers@massey.ac.nz

Bruce I. Rapley
Smart Technologies, Palmerston North, New Zealand
e-mail: Consultant@smart-technologies.co.nz

Background: Over the past two decades, the increasing and unregulated production of infrasound and low frequency noise (ILFN, ≤200 Hz) has led to a considerable rise in associated noise complaints and health-related issues. The most recent of such ILFN sources are industrial wind turbines (IWT). Acoustical field-data was collected within a home located in the vicinity of IWT, to which the AUC Rule 012 and its requirements were applied. In Ontario, IWT noise complaints were gathered under the Freedom of Information legislation. **Goal:** To explore the usefulness of current noise control rules when protecting human populations against ILFN generated by IWT.

Keywords: industrial wind turbines, residential exposure, health, dBA, acoustic signatures

1. Background

The unbridled installation of industrial wind turbines (IWT) in different countries on different continents has brought a *very old problem* [1] to centre stage: the health effects induced by excessive exposure to anthropogenic (i.e., artificially generated, human-made) airborne pressure waves occurring within the lower ranges of the acoustical frequency spectrum (a.k.a. infrasound (<20 Hz) and low frequency noise (≤200 Hz), or, ILFN, given the absence of a more precise nomenclature). The goal of this report is to (yet again) emphasize the long-standing problem of anthropogenic ILFN impacting human health, this time using IWT as a source-example.

2. Industrial wind turbine 'noise' in Canada

2.1 IWT 'noise' complaints in Ontario

The government of Ontario, Canada has a process for reporting environmental pollution that offers a pollution reporting "hotline," managed by the Ministry of Environment, Conservation and Parks (MOECP), and which includes noise pollution complaints [2]. People living in proximity to IWT projects have used this service to submit Incident Reports/Complaints (IR/C) regarding environmental noise and associated adverse health effects. In order to evaluate the effectiveness of this process of reporting IWT 'noise,' government IR/C records were obtained through a request made under the province of Ontario's Freedom of Information legislation [3] by the community group coalition Wind Concerns Ontario [4].

Findings were presented during a citizen appeal of an IWT project held before the Ontario Environmental Review Tribunal [4]. Testimony included factual evidence based on the official government IR/C records submitted by residents living in proximity to operating IWT [5]. The total number of Incidents filed officially with the MOECP between 2006 and the end of 2016 was 4,574. Only 1% of the reports received a "priority" response, another 30% were deemed as "deferred," and records showed that in more than 50% of the Complaints, there was no ministry response [5]. Regarding health effects, notes by the Ministry's Provincial Officers included statements from citizens reporting "headache, sleep deprivation, annoyance, and ringing or pressure sensation in the head and ears" [5]. These health effects were reported many times, and also included children [5].

2.2 Rule 012 for Noise Control in Alberta

In the Province of Alberta, the Utilities Commission has Rule 012 [6] dedicated to *Noise Control* that encompasses "an avenue for the submission of noise complaints relating to a facility and the process for addressing noise complaints" [7]. Rule 012 imposes a limit based on a minimum basic sound level to which various adjustments are made:

Permissible Sound Level	=	Basic sound level	+	Daytime adjustment	+	Class A adjustment	+	Class B Adjustment	+	Class C adjustment

The basic sound level begins at 40 dBA L_{eq} and increases depending on the number of houses nearby and proximity of heavily travelled roads. The Daytime adjustment is an increase of 10 dBA between 7 am and 10 pm. Class A adjustments address seasonal variation and non-representative ambient monitoring. Class B adjustments are made for temporary increases in noise generation. Class C adjustments are made when the ambient wind increases to a level that masks the generated noise. On the matter of low-frequency components, Section 3.2 states: "If available, C-weighted sound pressure level (dBC) minus the A-weighted sound pressure level (dBA) is to be considered in the noise model…to identify the potential for low frequency noise impacts." The procedure then described in

Section 4.5 and Appendix 5 is required only when low frequency noise is identified subsequent to the complaint investigation. Therefore, the difference between the overall C-weighted sound level and the A-weighted sound level must be calculated for all pertinent recordings and the periodograms analysed for sharp peaks in the 20–250-hertz region. Only if both the dBC – dBA difference is greater than 20 dB *and* sharp peaks are identified, is a more comprehensive investigation of ILFN required.

3. IWT in Germany – Case Report

3.1 Background

Beginning in 2014, the Hogeveen family residing in Schleswig-Holstein, Germany, described the symptoms (to the media) that they and their children had been developing after 20 IWT were commissioned within a 2-km radius of their home [8-10]. The children—who exhibited increased aggressiveness and unexplained nosebleeds—were promptly sent to boarding school to avoid further health deterioration. The Hogeveens had to remain in the home since it is also their place of work (sports medicine and physical therapy centre), while persistently enduring dizziness, headaches, sensations of pressure on the chest and lungs, ear-aches, swollen tonsils, and ocular and oral inflammations [8-10]. But, they abandoned their upstairs bedroom and constructed a bunker-bedroom deep in the basement of the home. This has provided some respite, except when winds are easterly. Acoustical recordings were conducted simultaneously in both abandoned and bunker bedrooms, taking wind conditions into account.

3.2 Materials and methods for acoustic capture

Data were captured with a SAM Scribe FS (Full Spectrum) system (Model: Mk1, Atkinson & Rapley, Palmerston North, New Zealand) [11,12]. This two-channel recorder measures at sampling rates up to 44.1 kHz, and delivers data streams via USB to a Windows notebook computer, storing it as uncompressed wav files to hard disk. GPS information is also stored as metadata in the files, and this includes a digital signature. The manufacturer's frequency response curve shows a microphone capsule very close to linear over the 1-1000 Hz range used in this study (0.5-1000 Hz: ± 0.5 dB; 1-10 kHz: ± 2dB; 10-20 kHz: ± 4dB) (custom-made Model No.: EM246ASS'Y, Primo Co, Ltd, Tokyo, Japan) [13]. Acoustic data was processed in Matlab (The MathWorks, USA) using narrow-band filters complying with the ANSI® S1.11-2004 and IEC 61260:1995 standards. All data presented herein were captured a sampling rate of 11.025 kHz and recorded as uncompressed WAV files, including the required reference calibration tone (Type I Calibrator, 1000 Hz/94 dB). Windshields were placed on both microphones during the entire measurement periods. Microphones were attached to tripods at approximately 1.5 m above the ground. The recordings selected for analysis and presentation herein were chosen on their educational value, and are shown in Table 1.

Table 1: Samples selected for analysis and presentation herein.

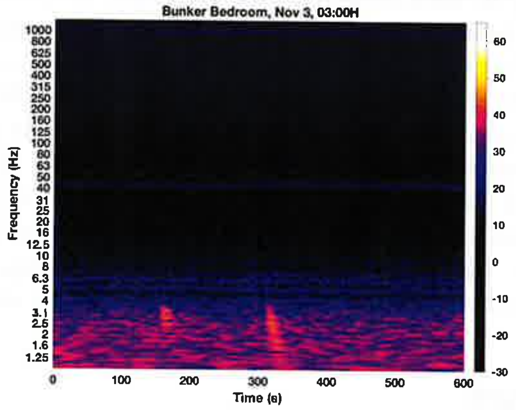
Sample	Date	Time	Wind Speed (m/s)	Wind Direction
Lo wind	03NOV17	03:00	0.9	290°
Hi wind	01NOV17	14:00	7.6	290°

3.3 Abandoned vs. Bunker bedrooms

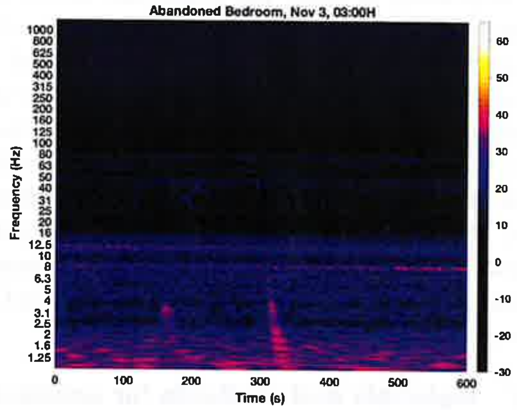
Significant and distinctive differences were found between the two environments that survived changes in wind speed and wind direction. Figure 2A-D compares the sonograms of the simultaneous recordings captured in both locations, under both wind speeds. All disclose some tonal components (horizontal lines) although these appear more prominent in the abandoned bedroom than in the bunker bedroom. The abandoned bedroom discloses larger SPL values between approximately 5-40 Hz in low wind conditions (0.9 m/s, Fig. 2B), and between 6.3-40 Hz in the high-wind conditions (7.6 m/s,

Fig. 2D). Within those frequency bands, distinct peaks at 8 and 12 Hz, as well as a peak at 80 Hz, are present in the abandoned bedroom, but absent from the bunker bedroom. Apart from some wind-gust noise—seen as vertical features broadening and moving to the right with decreasing frequency—the sonograms tend to show that the character of the sound does not change throughout the 10-minute periods and so the periodograms, shown in Figure 3, are representative of the sound over those intervals. (The continuous, 1000-Hz tone seen in the quieter recordings is due to electronic noise within the SAM Scribe Mk1, eliminated in the more recent SAM Scribe models.)

Wind speed 0.9 m/s and westerly wind (290°) on 03 Nov 2017, at 03:00H.

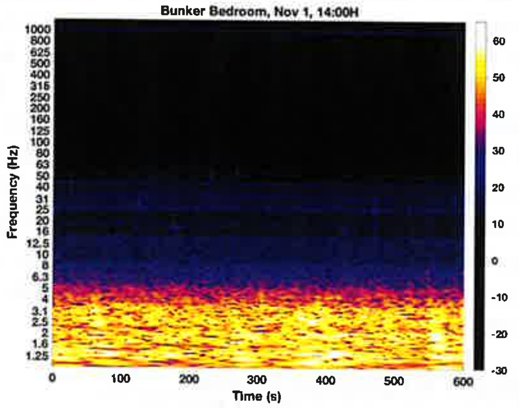


A. Bunker bedroom.

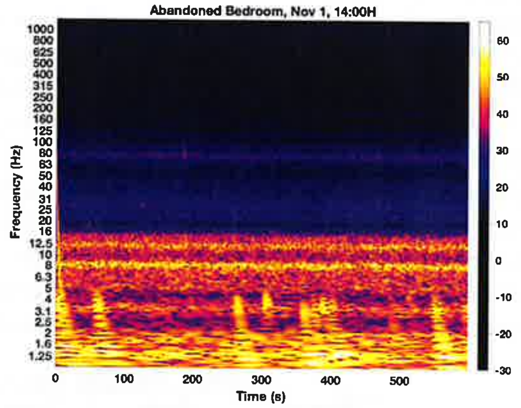


B. Abandoned bedroom.

Wind speed 7.6 m/s and westerly wind (290°) on 01 Nov 2017, at 14:00H.



C. Bunker bedroom.

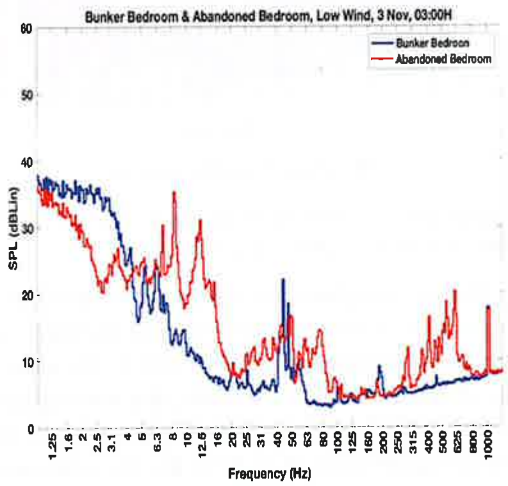


D. Abandoned bedroom.

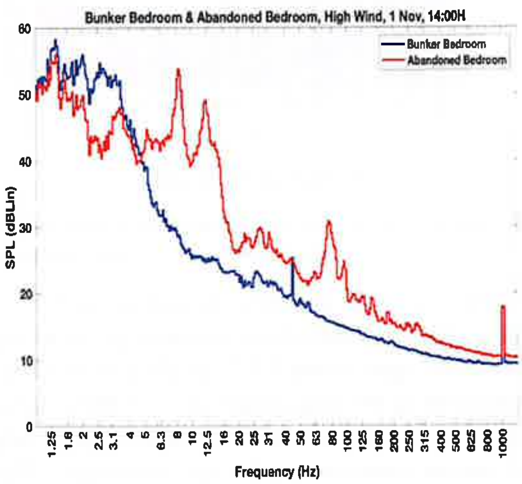
Figure 2: Sonograms covering a 10-min interval (600 s) and analyzed between 1–1250 Hz. The color-coded bar on the right indicates SPL in dBLin.

In the abandoned bedroom, the shapes and positions of the peaks at the three frequencies (8, 12 and 80 Hz, Fig. 3) are quite distinct, are clearly identifiable and independent of wind speed. Particularly visible in Fig. 3 is the similarity in the profile, occurring simultaneously in both locations, at the lower limiting frequencies of these measurements, i.e., approximately from 0.1 Hz to 2.5 Hz or to 4.5 Hz. The acoustical events responsible for these readings seem to impact both locations in the same manner, independent of wind conditions. The wavelengths corresponding to the airborne acoustical events at these frequency values are, approximately, 76 m (4.5 Hz) to 3430 m (at 0.1 Hz). The source of these phenomena remains unclear.

At low wind speed (0.9 m/s), the bunker bedroom displays a continuous tone at approximately 50 Hz. This can be seen as a horizontal line in the sonograms (Fig. 2A and 2C), as peaks in the classical analysis (Fig. 4), and as narrow peaks in the corresponding periodogram (Fig. 3). Usually, these tones are attributed to electrical appliances that may be present in the environment, and that do not vary with wind conditions. This is much less obvious in the abandoned bedroom (Fig. 2B and 2D) since no appliances are currently present. In the abandoned bedroom, tones that are not present in the bunker bedroom can be identified at 8 Hz, 12.5 Hz and 80 Hz (Fig. 3). These tones are present at low wind speed and increase in sound pressure level with higher wind speeds, while maintaining the consistency of their shape.



A. Bunker vs. Abandoned bedrooms. Wind speed 0.9 m/s, westerly wind (290°), 03 Nov 2017, at 03:00H.



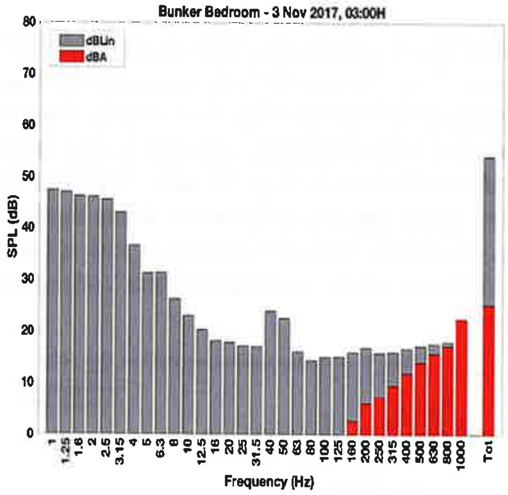
B. Bunker vs. Abandoned bedrooms. Wind speed 7.6 m/s, westerly wind (290°), 01 Nov 2017, at 14:00H

Figure 3: Periodograms covering the same 10-min intervals as in Figure 2 (analyzed between 1–1250 Hz), comparing the bunker and abandoned bedrooms at low and high wind speeds. The abandoned bedroom has consistently higher SPL levels than the bunker bedroom within the 4-40 Hz range, with very distinct shapes. At the lowest frequencies (≤2 Hz), SPL variations in both rooms have similar shapes and positions.

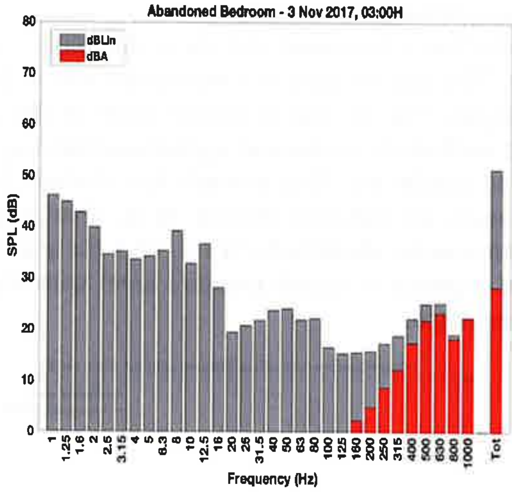
4. Discussion and Conclusions

Figure 4 shows ⅓-octave analyses obtained from a 10-min average, corresponding to the period shown in Figure 2A-B. In the bunker bedroom, the unweighted SPLs (Fig. 4A, grey bars) show a broad peak at about 50 Hz (or two narrower peaks on slightly either side). The highest SPLs are recorded below about 4 Hz. Unweighted SPLs in the abandoned bedroom (Fig. 4B, grey bars) show peaks at 8 and 12.5 Hz. There is relatively more energy in the abandoned bedroom above 4 Hz, but less below this. In both cases A-weighted SPLs (red bars) merely reflect that which humans would *hear* if present. As per Rule 012, this is the type of data required to establish permissible exposure levels.

Rule 012 was informally applied to the data obtained from the Hogeveen home. No recordings were made outside of the residence so the interior recordings used would a) be quieter than outside recordings and b) have a higher proportion of ILFN. The basic sound level is the lowest, 40 dBA, since it has less than 9 nearby dwellings within a 451-metre radius and is further than 500 m from a heavily travelled road. (Since outside night-time levels in the absence of IWT were impossible to measure, a 35-dBA level is assumed for the remainder of these calculations.)



A. Bunker Bedroom.



B. Abandoned bedroom.

Figure 4: These ⅓-octave frequency histograms cover the same 10-min interval as shown in Fig. 2A and B, wind speed 0.9 m/s and westerly wind (290°) on 03 Nov 2017, at 03:00H.

Two Class A adjustments are required. Assuming that a complaint is made in wintertime (the season during which these recordings were made), there is a +5 dBA adjustment. The ambient sound level with operational IWT is already 5 dBA below the basic sound level of 40 dBA, therefore, the adjustment is the maximum of +10 dBA. Since the sum of these two is +15 dBA, the maximum possible of +10 dBA is taken. For the Class B adjustment, two cases were considered: no increase occurs and one increase occurs for up to 60 days. This will give an adjustment of 0 dBA for the first case and +5 dBA for the second. The night time limit is therefore 40 dBA + 10 dBA + 0 dBA = 50 dBA for the base case, and 55 dBA is permissible for one period a year of up to 60 days. The daytime limit is the night-time value + 10 dBA = 60 dBA. The C-weighted and A-weighted overall sound levels for the 10-minute intervals captured on 01 and 03 November are shown in Table 2.

Table 2: dBC-dBA applied to the German data

	dBA Leq 10-min	**dBC Leq 10-min**	**Difference**
Bunker bedroom (01Nov)	35.7	56.2	20.5
Abandoned bedroom (01 Nov)	39.4	60.9	21.5
Bunker bedroom (03 Nov)	30.9	39.9	9.0
Abandoned bedroom [03 Nov)	33.7	42.7	9.0

Since these aspects of Rule 012 are stipulated in A-weighted sound levels, and the controversial features of IWT emissions are all in the ILFN regions, it is not surprising to find that these thresholds would very rarely be breached by IWT. The conclusion is that these aspects of Rule 012 are largely irrelevant. Moving, then, to the sections of Rule 012 dealing with ILFN, the question of whether significant components exist is determined by section 3.2 [7]. The difference in C-weighted and A-weighted sound levels must be 20 dB or more *and* there must be prominent, sharp peaks between 20 and 250 Hz. Figure 3 shows that there are prominent, sharp peaks in the bunker bedroom (blue lines) between 40 and 50 Hz. The abandoned bedroom does not show sharp peaks, therefore, they are not considered tonal, even though they are prominent. From the differences in the C-weighted and A-weighted sound levels, it can be seen that only the recording made on November 1, with high wind speeds, exceeds the 20-dB threshold. Ironically, this is because of the increased wind noise in the

ILFN regions. Section 4.5 (4) however, states that measurements should not be taken during high-wind-speed conditions for exactly this reason. Therefore, this aspect of the Rule also fails to catch the important soundscape features. Had it done, and the requirements of section 4.5 were met, the maximum penalty would be the addition of 5 dBA to the measured sound levels. If these then exceeded the limits (between 50 dBA and 60 dBA as above) then the operator would be required to implement noise attenuation measures and confirm that ILFN was no longer an issue.

When IWT are the source of ILFN, the rotating blades generate a series of pressure pulses at the 'blade pass frequency' (BPF), which is seen as a harmonic frequency series called *wind turbine signature* [14]. When synchronous IWT rotate at a constant rate, regardless of the wind speed, they will share a common harmonic series [15]. The IWT near the Hogeveen home are asynchronous, their BPF changes with wind speed. Given the sheer number of these IWT at the site, a single ('clean') IWT signature was not a reasonable expectation. Nevertheless, an analysis of the existence of harmonic series was conducted on the recordings of the abandoned bedroom, at low and high wind speeds.

Figure 5 shows the 1–100-Hz region of Fig. 3 with the harmonic series starting at 1.36 Hz added as dashed lines. The two main peaks at 8 and 12 Hz appear on this harmonic series as the 6^{th} and 9^{th} harmonics (H6 and H9). There is a large peak at 1.36 Hz for the higher wind speed. The 8 and 12 Hz peaks also appear on the harmonic series starting at 2.04 Hz; there is a small peak at 2.04 Hz. There is also a peak at 6.8 Hz on this series for the lower wind speed. A further harmonic series starting at 0.68 Hz includes these three peaks (1.36 Hz, 2.04 Hz and 6.8 Hz) as well as the broad peak at 3.45 Hz. There is no suggestion that peaks have moved between the two wind speeds although neither of the peaks (1.36 and 2.04 Hz) is seen at the lower wind speed. Note that the resonant frequencies of the bedroom are in the order of 60 Hz and upwards, with the peak just below 80 Hz likely being one such. The peaks discussed above are therefore less than $^1/_{10}$ of the cavity resonant frequencies and are not likely to be attributable to these phenomena.

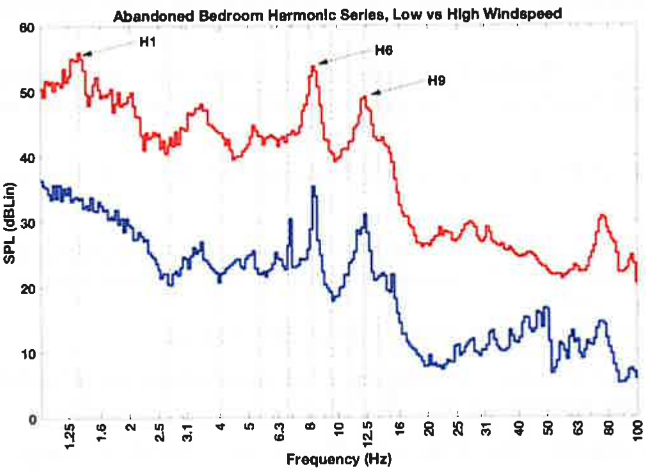


Figure 5: Comparison of data captured in the abandoned bedroom, at low (0.9 m/s-blue) and high (7.6 m/s-red) wind speeds, and same wind directions (290°). Harmonics of 1.36 Hz are shown as vertical, dashed lines.

A re-evaluation of legislation regarding population exposure to ILFN has been urgently required for decades [1]. The Canadian regulations here applied are similar to other regulations worldwide, and equally unsuitable *if* the goal is to protect human health against chronic ILFN exposures. Symptomatic complaints currently being ignored and/or misdiagnosed will predictably lead to a burden on future healthcare costs. Although the proliferation of IWT is bringing this agent of disease [16] to centre stage, the biases regarding how human health is impacted by airborne pressure waves (audible or not and whatever the source) continue to impede a proper scientific investigation [17], and consequently, proper protection of human populations and their offspring.

Acknowledgements: Author MAP would like to thank the Hogeveens for their kind contributions to acoustical data collection. Author CK would like to thank Wind Concerns Ontario for its contribution to the collection of citizen complaint information.

Financial Disclosure: Due to their efforts in the creation of the SAM Scribe system, authors HHCB, BIR and SRS have a financial interest in the SAM Scribe system.

REFERENCES

1 Alves-Pereira, M. Noise-induced extra aural pathology. A review and commentary. *Aviation, Space and Environmental Medicine*, **70** (3, Suppl.), A7-A21, (1999).

2 Ministry of Environment, Conservation and Parks. Spills Action Line. (2019). Retrieved January 11, 2019. https://www.ontario.ca/page/report-pollution-and-spills.

3 Wind Concerns Ontario. http://www.windconcernsontario.ca/

4 Environmental Review Tribunal. North Stormont v. Ontario (MOECC). Case No. 18-028. Appeal by Concerned Citizens of North Stormont of a Renewable Energy Approval, filed May 22, 2018. Retrieved January 27, 2019: http://elto.gov.on.ca/tribunals/ert/case-search/

5 Ministry of Environment and Climate Change. Ontario Environmental Review Tribunal. Nation Rise Wind Power Project. Renewable Energy Approval Appeal Case number 18-028. Concerned Citizens of North Stormont v. Director, Ontario, Witness Statement by Wilson EJ (June 20, 2018). PDF copy available on request.

6 Alberta Utilities Commission. Rule 012. http://www.auc.ab.ca/Shared%20Documents/rules/Rule012.pdf.

7 Alberta Utilities Commission. Description of Rule 012. http://www.auc.ab.ca/Pages/Rules/Rule012.aspx.

8 Kaeding, E.F. [The curse of repowering – A long descent]. *Die Tageszeitung*, 21 September 2014. (In German) https://www.taz.de/Archiv-Suche/!5032786&s=hogeveen/.

9 Wetzel, D. [Energy Danish Debate - Does the infrasound of wind turbines make you sick?]. *Die Welt*, 02 March 2015. (In German) https://www.welt.de/wirtschaft/energie/article137970641/Macht-der-Infraschall-von-Windkraftanlagen-krank.html.

10 Jung, F. [In Nordfriesland - The couple complains: 'Wind turbines make us sick']. *Schleswig Holstein Zeitung*, 02 January 2016. (In German) https://www.shz.de/deutschland-welt/politik/ehepaar-klagt-windraeder-%20machen-uns-krank-id12344191.html.

11 Atkinson & Rapley Consulting Ltd. Specification sheet for the SAM Scribe FS Mk 1. 2017. www.smart-technologies.co.nz.

12 Bakker, H.H.C., Rapley, B.I., Summers, S.R., Alves-Pereira, M., Dickinson, P.J. An affordable recording instrument for the acoustical characterisation of human environments. *Proceedings of International Conference in the Biological Effects of Noise*, Zurich, Switzerland, 18-22 June, (2017). http://www.icben.org/2017/ICBEN%202017%20Papers/SubjectArea05_Bakker_P40_3654.pdf.

13 Primo Co, Ltd. Specification sheet for the electret condenser microphone, custom-made, model EM246ASS'Y. Tokyo, Japan, 2017. http://www.primo.com.sg/japan-low-freq-micro.

14 Cooper, S. The results of an acoustic testing program Cape Bridgewater Wind Farm, prepared for Energy Pacific (Vic) Pty Ltd, Melbourne, Australia, (2014).

15 Alves-Pereira, M., Bakker H.H.C., Rapley, B., Summers, R. Infrasound and low-frequency noise – does it affect human health? *Engineers Ireland Journal*, 23 Jan (2018). http://www.engineersjournal.ie/2018/01/23/ilfn-infrasound-low-frequency-noise-turbine-health/

16 Alves-Pereira, M., Rapley, B., Bakker H.H.C., Summers, R. Acoustics and biological structures. IN: Abiddine, Z.E., Ogam, E. (eds), *Acoustics of Materials*, IntechOpen, London, UK (2019). DOI: 10.5772/intechopen.82761. https://www.intechopen.com/online-first/acoustics-and-biological-structures.

17 World Health Organization. Environmental Noise Guidelines for the European Region. Copenhagen, WHO Europe (2018). ISBN 978 92 890 5356 3. http://www.euro.who.int/en/publications/abstracts/environmental-noise-guidelines-for-the-european-region-2018.

Alves-Pereira and Bakker. Scientific J Aerosp Eng Mech 2017, 1(2):83-98
Volume 1 | Issue 2

THE SCIENTIFIC PAGES

The Scientific Journal of Aerospace Engineering and Mechanics

Research Article Open Access

Occupational and Residential Exposures to Infrasound and Low Frequency Noise in Aerospace Professionals: Flawed Assumptions, Inappropriate Quantification of Acoustic Environments, and the Inability to Determine Dose-Response Values

Mariana Alves-Pereira[1]* and Huub HC Bakker[2]

[1]School of Economic Sciences and Organizations, Lusófona University, Portugal

[2]School of Engineering and Advanced Technology, Massey University, New Zealand

Abstract

Professionals within the aerospace industry are often required to remain within acoustic environments characterized by a predominance of low frequency and infrasound components. Safety-and-health-in-the-workplace officials are mindful of the threat these extreme environments can pose to the hearing function. Noise-exposed professionals are, therefore, frequently provided with a plethora of ear protection devices to shield this vital human sense. The vast majority of noise-protection guidelines and regulations, however, are inappropriate to protect aerospace professionals against acoustic environments rich in Infrasound and Low Frequency Noise (ILFN) because they are based on the flawed premises that ILFN only affects humans through the aural pathway, and that dynamics are unimportant. Consequently, the numerical values needed to estimate potential harm to people (dose-response levels) are not routinely obtained or assessed. The goals of this paper are to inform a) Aerospace professionals who are consistently exposed to acoustic environments rich in ILFN, about how this agent of disease is being incorrectly evaluated leading to improper worker protection; and b) Noise control and health professionals who work within the aerospace industry, about new methodologies in acoustical evaluations pertinent to infrasound and low frequency noise dose-response values. New sources of ILFN are increasingly present in the vicinity of residential environments, quite possibly eliminating biological recovery periods for noise-exposed aerospace workers. This paper details the inadequacy of the use of the dBA metric and 1/3-octave-band analysis when protecting workers (and the public) against excessive ILFN exposures. The complexities associated with acoustical evaluation in conjunction with objective and pertinent medical outcomes are discussed, and the need for narrowband analyses in routine evaluation procedures is emphasized.

Keywords

Infrasound, Low frequency noise, dBA, Narrow-band analysis, Occupational exposure, Environmental exposure, Pathology

Introduction

In a widely read paper published by the World Health Organization (WHO), *Burden of disease from environmental noise* [1], the long-term effects of excessive noise exposure were shown to be worrisome, at best. Historically, noise exposures were deemed to be detrimental to the hearing function, i.e., people exposed to loud noise were more likely to become deaf, or hearing impaired. Consequently, only a portion of the acoustical spectrum was focused upon - the one containing the frequencies responsible for hearing loss.

This restricted segment of the acoustical spectrum, called 'the audible portion', ranges from 20 Hz to 20 kHz. Within this wide range of frequencies, though, not all of them are equally responsible for deafness or

***Corresponding author:** Mariana Alves-Pereira, School of Economic Sciences and Organizations (ECEO), Lusófona University, Campo Grande, 376, 1749-024 Lisbon, Portugal, E-mail: m.alvespereira@gmail.com

Received: February 16, 2017; **Accepted:** July 20, 2017; **Published online:** July 22, 2017

Citation: Alves-Pereira M, Bakker HHC (2017) Occupational and Residential Exposures to Infrasound and Low Frequency Noise in Aerospace Professionals: Flawed Assumptions, Inappropriate Quantification of Acoustic Environments, and the Inability to Determine Dose-Response. Scientific J Aerosp Eng Mech 1(2):83-98

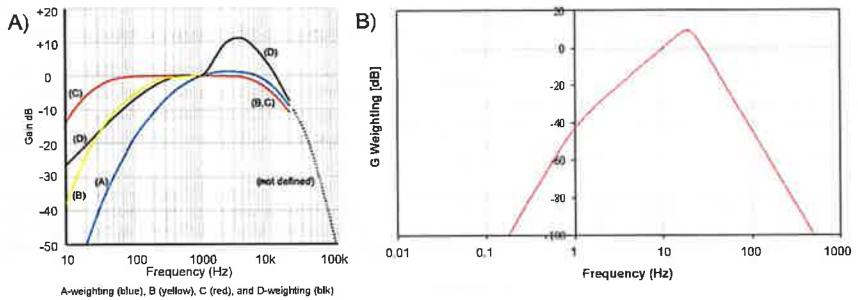


Figure 1: Acoustic Weighting Curves A) Weighting curves for A-weighting (A), B-weighting (B), C-weighting (C) and D-weighting (D) [40]. B) G-weighting Curve [41].

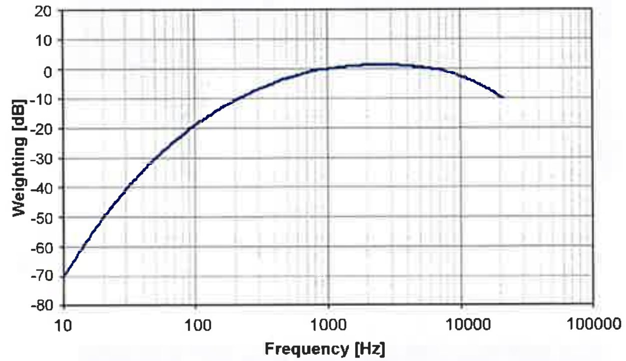


Figure 2: Frequency Response Curve for the A-weighting Network at 10 Hz, well within the ILFN region, the error is approximately a 70 dB reduction, i.e., what is measured is 70 dB less than what is actually present in the environment [42].

hearing loss. Deafness due to excessive noise exposure is predominantly a consequence of loss of hearing function within the 250-8000 Hz range, i.e., deafness at frequencies above 8000 Hz or below 250 Hz is not as relevant for speech intelligibility as are those contained within the 250-8000 Hz range. Health-related acoustical evaluations were thus urged to focus on this particular range of frequencies. This required measuring instrumentation that would eliminate all the frequencies considered irrelevant to human hearing impairment, i.e., all extending beyond the 250-8000 Hz range. Infrasound and Low Frequency Noise (ILFN) (< 200 Hz) was, therefore, deemed irrelevant for the purposes of protecting human health.

The human ear responds to sound non-linearly, both in terms of frequency and sound pressure level. Hence the development of filters (with specific frequency-weighting curves) designed to simulate the non-linear sensitivity of human hearing. Measuring sound levels with one of these filters would then better represent the human perception of the sound. Figure 1 shows examples of A-, B-, C- and D-weighting curves (Figure 1A), and the more recent G-weighting curve, developed for ILFN-rich environments (Figure 1B).

Under the dBA metric, acoustical energy contained in other portions of the spectrum are de-emphasized (< 250 Hz and > 8000 Hz) or deemed irrelevant for evaluation (< 20 Hz, or 'infrasound', and > 20 kHz, or 'ultrasound'). Regulations have been guided by these principles, leading to the ubiquitous capture of information within the restricted segment of the acoustical spectrum (20 Hz - 20

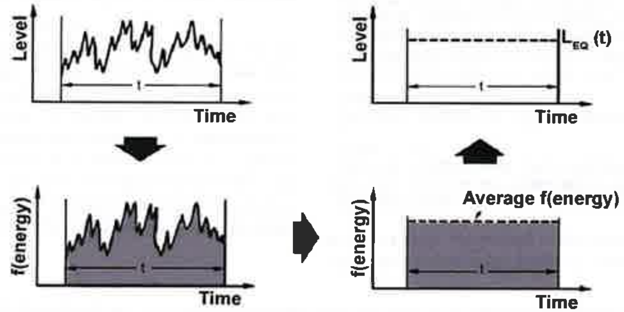


Figure 3: Mathematical treatment applied to a time-varying signal. The resulting, constant Leq value represents the same amount of energy (area in grey under the curve) contained in the original time-varying signal [43].

kHz), and with the A-weighting being applied. Figure 2 shows the frequency response curve for the A-weighting filter, which is relatively flat between 800 - 8000 Hz. When measuring frequencies < 200 Hz with an incorporated A-weighting network, the numerical value obtained for the sound pressure level presents with a 10 to 70 dB error. While the A-weighting system seems to yield good results for hearing protection, it is clearly inadequate for assessing the amount of acoustical energy present in the ILFN ranges, because these lower frequency components are discounted; for example, a reduction of about 70 dB at 10 Hz (Figure 2).

Two additional difficulties exist when evaluating acoustic environments: a) They are constantly varying in time (seconds); and b) They do so continuously across the entire acoustical spectrum. Hence, to enable analyses, both time and frequency parameters need to be segmented. To transform a time-varying signal into some manageable number, the concept of time-averaged sound level was developed (Leq). Figure 3 sketches the mathematical treatment given to a time-varying signal, such as an airborne pressure wave.

Occupational and health issues consider long term exposures in LAeq (A-weighted, time-averaged sound level), and allow short testing samples as representative of an 8-hour day exposure. Many environmental regulations, on the other hand, mandate 10-minute time averages of LAeq, so that values are not skewed by intermittent loud sounds. Either way, information on the dynamic, time-dependent portion of the acoustic environment is diluted when the signal has significant variations in time and is segmented into 10 min or 1 hour windows.

The 'audible' frequency spectrum was segmented into 'octave' and '1/3-octave' bands, facilitating further analyses for noise control evaluations. Although data resolution was improved with the 1/3-octave bands analyses, this methodology still only provides a crude resolution of the acoustic environment. Figure 4A compares octave band and 1/3-octave band measurements. In the pre-digital era, investigations of finer resolution were very involved, complex and beyond the means of general acoustic investigations.

When no weighting network is incorporated into the acoustic signal capture, measurements are un-weighted (unfiltered), and the metric written as dBLin (linear) to distinguish it from other forms of deciBel. Figure 4B shows the difference between the overall dBA and dBLin levels in an environment where ILFN components are predominant. While the overall dBA level reflects what a human would hear, the dBLin level reflects the acoustical energy to which the body is exposed.

There are further limitations related to accuracy when the frequency spectrum is segmented into 1/3-octaves. This method ignores the exact problem that impulsive sounds (perceived as irritating or not) will be invisible in such LAeq measures. For example, a single gunshot would have little, if any, impact upon a 10 minute dBA-level average but would hardly fail to wake a sleeper. In terms of urban population health, the inappropriateness of using the dBA metric to assess ILFN-rich environments was recognized almost two decades ago by the WHO: "When prominent low-frequency components are present, measures based on A-weighting are inappropriate. However, the difference between dBC (or dBLin) and dBA will give crude information about the presence of low-frequency components in noise" [2].

It is not uncommon to address the maximum dBC level or dBLin level in order to 'squeeze out' more acoustical information from measurements obtained with leg-

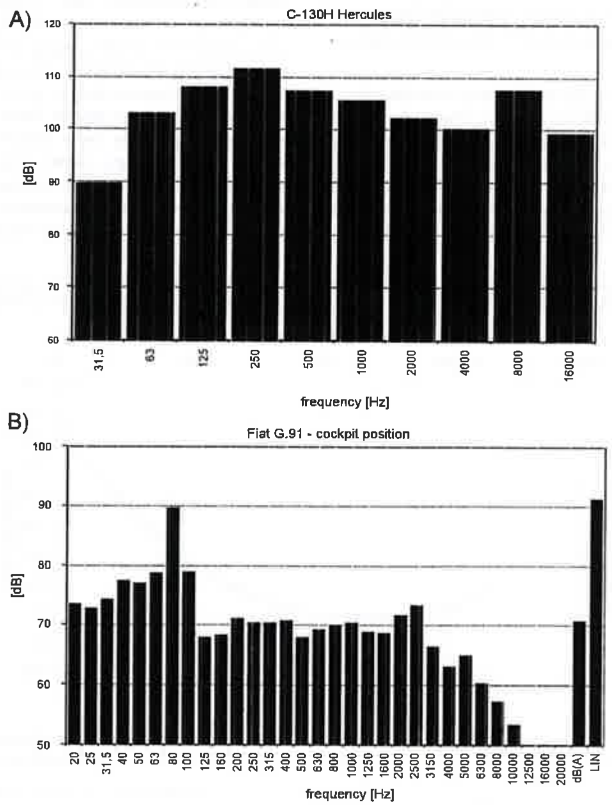


Figure 4: A) Octave band frequency distribution analysis radiated by a C-130 Hercules at normal power setting [44]; B) 1/3-octave band frequency distribution analysis inside the Fiat G-91 cockpit. The two bars on the right indicate the dBA and dBLin levels, respectively. The much lower dBA level when compared to the dBLin level reflects the numerical reduction imposed by the A-weighting Network [45].

islated methodologies. However, a more detailed numerical characterization of acoustic environments within the ILFN range is needed, in order to establish dose-response values for human protection.

Interface between acoustical phenomena and the human body

The WHO publication *International Classification of Diseases* (ICD-10 2016) [3], dedicates Chapter 20 to "External causes of morbidity and mortality", and block W20-W49 refers to "Exposure to inanimate mechanical forces":

W42 - Exposure to noise Incl.: Sound waves, Supersonic waves

W43 - Exposure to vibration Incl.: Infrasound waves [3].

Airborne acoustical phenomena interact with the human body when mechanical coupling occurs between the oncoming mechanical force and a particular tissue or tissue system of the human body. This brings the issue of ILFN health effects into the field of materials engineering. Biological tissues are viscoelastic materials, i.e., they possess the properties of creep, relaxation and hysteresis. Moreover, they feature anisotropy, i.e., equal forces applied in different directions yield different results. Biological material, particularly when considering whole-body effects, cannot be modeled as a simple Hookean elastic; and neither can its response when immersed in an ILFN-rich environment.

Prof. Donald Ingber (Wyss Institute, Harvard University), proposed decades ago that animal cells were constructed in accordance with principles of tensegrity [4-6], i.e., architectures consisting of elements providing continuous tension, and elements providing discontinuous compression [7]. By modeling the cell as a tensegrity structure instead of the prior, elastic continuum model, it was possible to begin to understand cellular mechanotransduction, i.e., inter- and intra-cellular communication established via mechanical signals, as opposed to biochemical signals [8,9 for example]. Mechanotransduction and cellular tensegrity architectures are essential to understanding the specific structural changes in ILFN-exposed cells, as seen through light and electron microscopy [10-12]. These mechanically-induced cellular effects are not accounted for under current noise protection legislation, guidelines and procedures, as they do not respond to acoustical energy via the aural-perception pathway.

Mechanical coupling between airborne pressure waves and the human body is known to occur at the ear; the design of which is an engineering marvel. Mechanical coupling between airborne pressure waves and other regions of the body are acknowledged to exist only if the acoustic energy is at sufficient amplitude (i.e., if the event is perceivable by human senses), otherwise, effects are (perhaps erroneously) considered to be irrelevant or non-existent.

The response of biological tissue to ILFN is frequency-dependent. An early example is a study conducted in 1969 (within the scope of the Soviet and US space programs), where dogs were exposed to ILFN-rich environments at sound pressure levels ranging from 105 to 155 dB. This induced multiple hemorrhages in the lung tissue that "never exceeded 3 mm in diameter" [13]. Increasing the dB-level of the environment did not increase the size of the hemorrhagic areas, but rather, their number. In the early 1990's, Professors Nekhoroshev and Glinchikov (St. Petersburg Academy of Sciences, Russia) exposed laboratory animals to infrasound (8-16 Hz) at 120-140 dB, for 3 hr daily, for 1, 5, 10, 15, 25, and 40 days, and found different morphofuntional changes in the cellular structures of myocardium and liver tissues when compared to controls [14,15]. These changes varied with frequency, exposure time and exposure level. For the past three decades, another team led by pathologist Col. Castelo Branco (Portuguese Air Force), has systematically studied both workers and animal models exposed to ILFN. As a result, the clinical evolution of the signs and symptoms consistently observed in aeronautical technicians was established in 1999 [16], supported by numerous collateral studies in human populations and animal models in subsequent years [17-19]. Since then, this ILFN-induced pathology, (termed Vibroacoustic Disease - VAD), has also been identified (as per objective clinical testing) in residential settings [20-22].

Certain, narrow frequency ranges can elicit a specific response from one type of tissue and not another, located adjacently, because each type of material has its own creep, relaxation and hysteresis coefficients. Each tissue type also possesses its own mechanical resonance frequency. Hence, at the electron microscopy level of ILFN-exposed tissue, the re-organization of inter- and intra-cellular architectures seem to reflect a mechanical reinforcement required to maintain structural integrity [23,24].

In Workplace Safety, vibration is considered as that which is transmitted into the human body through solid-to-solid contact, i.e., contact with a chain-saw (hand-arm vibration) or a vibrating platform (whole-body vibration). To measure vibration, accelerometers are used instead of microphones. With ILFN, impacts to the human body occur via a different interface: air-to-solid, or rather, air-to-composite viscoelastic material. Modeling human response to ILFN exposure based on solid-to-solid interfaces has not, therefore, proven very successful.

ILFN dose-response values - the need for narrow-band analyses

Dose-responses for ILFN exposures must be frequency dependent if they are to properly protect humans from excessive exposure to ILFN-rich environments. The determination of dose-responses for ILFN exposure has been scientifically impossible to achieve, however, because the ILFN in itself is not being quantified during routine acoustical evaluations. This is the point where the ILFN-rich occupational and environmental exposures meet. Both require precise ILFN measurements if human populations are to be properly protected from this agent of disease, whether at work or in the home.

For decades, the biomedical world has been in dire need for proper scientific instrumentation to objectively quantify ILFN-rich acoustic environments. Given that current instrumentation discards much of the information that characterizes an acoustic environment (at the behest of regulations) precluding any real scientific analysis, it becomes obvious that current general-sound-level measurement instrumentation is not suited to requirements.

The limitations of dBA methodology and 1/3-octave segmentation with respect to ILFN, can be resolved by the application of analyses using no weighting and by a proper signal capturing of the acoustic environment. This would allow a more precise identification of events that occur within frequency bands that are narrower than the 1/3-octave segmentation, and of periodic signals that occur in the time domain. Narrow band analyses can provide information that would permit the identification of discrete signals (e.g., tones or harmonics) forming acoustic signatures that are not evident with the dBA-1/3-octave methodology [25,26]. This is shown in the next sections.

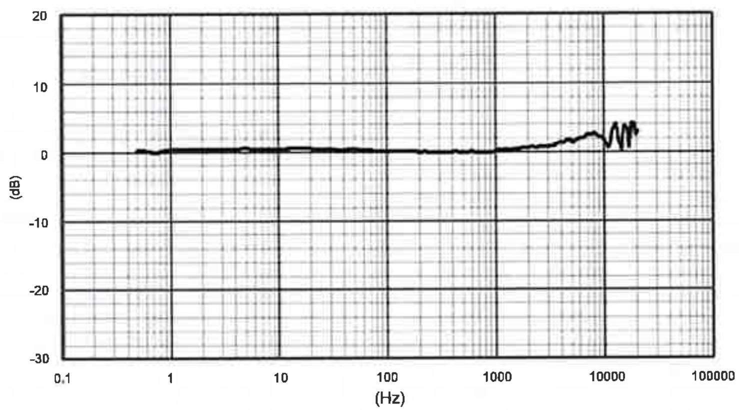


Figure 5: Frequency response curve for the microphones used by the SAM Scribe Mk1 system [29].

Material and Methods

Instrumentation

The equipment used for acoustic capture was a SAM Scribe Full Spectrum (FS) system (Model: Mk1, Atkinson & Rapley, Palmerston North, New Zealand) [27,28]. It consists of a two-channel device that can measure at sampling rates up to 44.1 kHz, and that delivers data streams via USB to a Windows notebook computer, storing it as uncompressed wav files to hard disk. GPS information is also stored as metadata in the files, and this includes a digital signature. The system can accurately record from 0.1-1000 Hz, as per the manufacturer frequency response of the two electrets condenser microphones (custom-made Model No.: EM246ASS'Y, Primo Co, Ltd, Tokyo, Japan), Figure 5 [29].

The SAM Scribe FS unit has two switches: one enables a 1 Hz high-pass filter to remove unwanted 'micro-barom' events below 1 Hz, and the other enables a + 20 dB gain boost. All measurements were conducted with the 1 Hz filter enabled and with the 20 dB gain boost disabled. All measurements are reported from 1-800 Hz, and were captured with a sampling rate of 11.025 kHz.

Measurement methodology

Hookean Elastic vs. Viscoelastic Material. 1) In a Hookean (or purely elastic) material, total deformation depends on total load, and no further deformation occurs even if load is maintained. In viscoelastic materials, however, when stress is applied and maintained, they may continue to further deform, even though stress load remains unaltered. This property is called creep. 2) In a purely elastic material, the strain within the material is constant throughout the application of the load; it does not vary with time, only with the amount of applied stress. In viscoelastic materials, when stress is applied and maintained, strain can decrease with time. This property is called stress relaxation. 3) Consider repetitive or cyclical loads on materials. In purely elastic materials, periodic loads will not alter the stress-strain curve. The pathway taken by the material to deform is exactly the same pathway it takes to return to its original, equilibrium position. In viscoelastic materials, however, the return to equilibrium may be different than the pathway used to get to the point of deformation. (The word pathway is here loosely used, and is meant to encompass all spatial, temporal and energetic components of these types of movements.) This property is called hysteresis.

A 'microbarom' is a transient change in air pressure caused by events such as shutting a door. This can cause the microphone to saturate, causing clipping, and, in any case, is not generally part of the acoustic environment being studied and should not, therefore be included in the analysis.

All measurements were recorded to uncompressed wav file including the required reference calibration tone prior to and after measurements. Calibration tones were produced with a Type I calibrator (part of the SAM Scribe system) at 1000 Hz/94 dB. Calibration of the system rests on the manufacturer's frequency-response curve for the Primo microphone capsule (Figure 5) as well as comparison calibrations between 6.3 Hz and 1000 Hz of the full system against a Larsen-Davis 831 sound level meter with a current National Association of Testing Authorities (Australia) calibration certificate. The manufacturer's frequency response curve shows that the microphone capsule is very close to linear over the 1-1000 Hz range used in this study.

Wind-shields were always placed on both microphones during measurements. Microphones were attached to tripods at approximately 1.5 m above the ground. After microphone positioning and initial calibration, at least three 10 min segments of data were captured at each location. Both microphones were placed at the same location, along the same axis, approximately 20 m apart from each other, as limited by cable distance (5 m + 15 m). One microphone (red) was always placed at approximately 22 m from the shed entrance, and the second microphone (blue) was placed at approximately 42 m from the shed entrance (see below).

Measurements were performed on a rotating basis between locations, and on different days - 16, 30, and 31 December, 2016. This acoustical evaluation is part of an international, citizen-based research effort into the health effects caused by excessive exposure to ILFN, and to which the authors contribute [30]. Within this context field-sites, such as this one, become available due to the efforts of citizen scientists.

Selection of locations

Data was gathered at a farm where the residential home is in the vicinity of the animal sheds (Figure 6). This preliminary data was selected for presentation due to: a) Its pedagogical strength for clarifying the difference between the type of data obtained through narrow-band analyses and legislated methodologies; b) The relative location of the home within the ILFN-rich acoustic environment (Figure 6A); and c) The possibility of gathering clues that may contribute to an explanation of different animal behavior in the presence of anthropogenic ILFN, depending on animal-shed location (Figure 6B).

The anthropogenic sources of ILFN in question are four, 3-MW Industrial Wind Turbines (IWT), 150 m in total height (hub height + ½ blade diameter) [31]. Figure 6A shows the relative positions of the home and animal sheds to the IWTs.

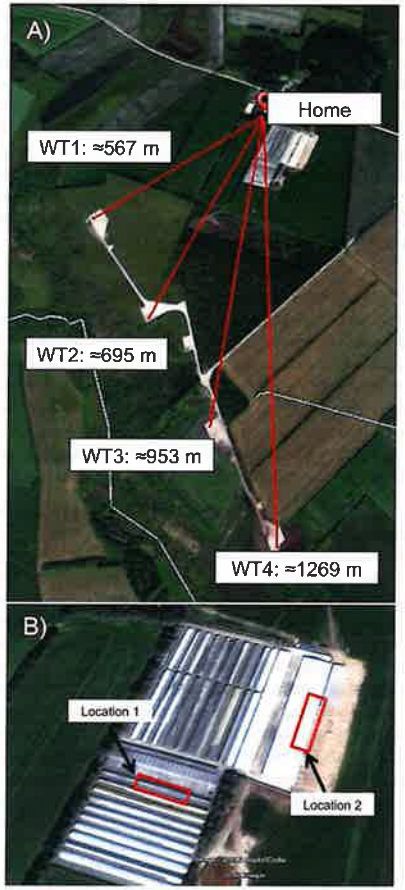


Figure 6: Images reconstructed from Google Earth A) Relative positioning of each of the 4 WT to the residential home and adjacent animal sheds; B) Definition of Location 1 and Location 2.

Locations 1 and 2 were suggested by the property owner as two locations where animal pups responded differently when IWT were rotating. Figure 7 shows the different construction types of the animal sheds in Location 1 and Location 2. Location 1 is a shed of older, wooden construction, with an interior space approximately 2.5 m in height and 75 m in length (Figure 7A). Location 2 is a more modern shed, mostly made of metal,

Figure 7: Animal shed structures have different constructions styles A) Animal shed of Location 1; B) Animal shed of Location 2.

Table 1: Date and time of acoustical measurements per location.

	Date	Time
Location 1	16 Dec	14:34 - 15:10
	30 Dec	13:25 - 14:02
	30 Dec	17:01 - 18:05
	30 Dec	22:59 - 00-16
	31 Dec	03:28 - 04:37
	31 Dec	08:21 - 09:22
Location 2	16 Dec	15:30 - 16:10
	30 Dec	11:16 - 12:06
	30 Dec	14:11 - 15:28
	30 Dec	20:32 - 21:42
	31 Dec	00:25 - 01:41
	31 Dec	04:40 - 05:58

with an interior space approximately 7.0 m in height, and 110 m in length (Figure 7B). Both contain water-supply systems for the animals that may produce specific and identifiable signatures within the acoustic environment. Since IWT rotation began, the property-owner has opted to maintain his breeding male animals in Location 1 rather than in Location 2. Table 1 tallies the measurements conducted at Location 1 and Location 2 in 2016.

Wind speed

In the case of this anthropogenic ILFN source (IWT), acoustical emissions output depend on the wind speed. (IWT power output graphs concurrent with these measurement sessions are unavailable).

Weather data was obtained from the Danish Meteorological Institute, corresponding to the monitoring tower closest to the farm, approximately 35 km away. Air pressure values were unavailable. Although the lack of *in loco* weather monitoring equipment led to imprecise numerical values, the goal of this data is not to relate specific wind speeds to specific IWT acoustical emissions, but rather to compare ILFN components under two different IWT regimens, at two different locations. Weather data

Table 2: Weather data and IWT operation.

	16 Dec 2016 - Baseline	30 Dec 2016 - ILFN-rich
Wind speed (m/s)	0.5 - 1.5	4.0 - 6.5
Wind direction	south-southwest	southwest
Temperature (°c)	0 - 1	6 - 8
Rel. humidity (%)	90 - 100	90 - 95
Precipitation (mm)	0	< 0.5
IWT rotation	no	yes
Hour of video footage	14:38, 14:42	11:20, 13:30, 15:40

Table 3: Definition of the 10 min measurement segments selected for scrutiny.

Location	IWT Rotation	Location Classification	Date	Time
1	No	*Baseline*	16 Dec	14:40
	Yes	*ILFN-rich*	30 Dec	17:30
2	No	*Baseline*	16 Dec	15:50
	Yes	*ILFN-rich*	30 Dec	11:20

is given in Table 2.

Results

Acoustic data was processed in Matlab (The MathWorks, USA) using narrow-band filters complying with the ANSI® S1.11-2004 and IEC 61260:1995 standards, as well as FFTs.

Table 3 shows the measurement segments selected for scrutiny.

Figure 8 and Figure 9 show the traditional 1/3-octave spectra and the total dBA and dBLin levels, in Locations 1 and 2 respectively, under baseline conditions. Figure 10 and Figure 11 show the same numerical data but represented as narrow-band analyses.

Similarly, Figure 12 and Figure 13 show the traditional 1/3-octave spectra and the total dBA and dBLin levels, in Locations 1 and 2 respectively, under ILFN-rich conditions. Figure 14 and Figure 15 show the same numerical data but represented as narrow-band analyses.

For ease of presentation herein, only the results corresponding to the blue microphone (placed at approximately 42 m from the entrance of the sheds) are presented.

Preliminary analysis

16 - 20 Hz:

Baseline: Both Location 1 and Location 2 exhibit a continuous acoustical phenomenon with strong tonal characteristics occurring at around 16 Hz (Figure 10 and Figure 11). This could be associated with the water systems installed in the shed to feed the animals. Water could distinctly be heard running in the background in Location 1, but less so in Location 2.

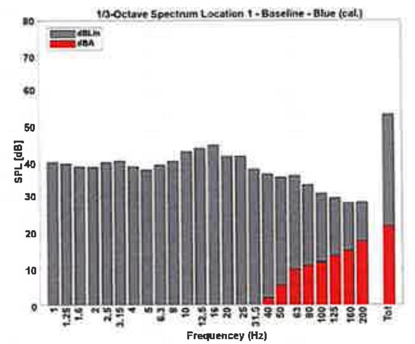


Figure 8: Location 1, Older Shed, at 14:40 on Dec 16. Representative data over a 10-min interval and analyzed between 1-200 Hz.

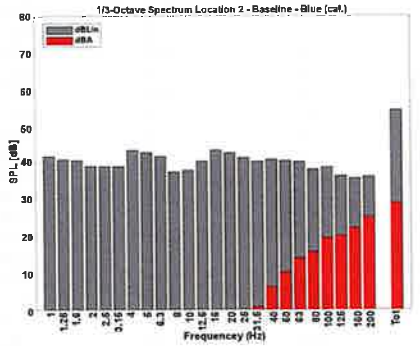


Figure 9: Location 2, Newer Shed, at 15:50, on Dec 16. Representative data over a 10-min interval and analyzed between 1-200 Hz.

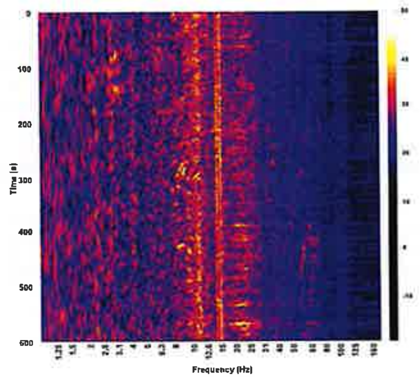


Figure 10: Location 1, Older Shed, at 14:40 on Dec 16. Representative data over a 10-min interval and analyzed between 1-200 Hz.

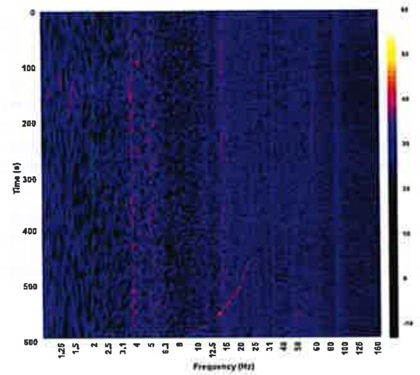


Figure 11: Location 2, Newer Shed, at 15:50, on Dec 16. Representative data over a 10-min interval and analyzed between 1-200 Hz.

ILFN-rich: In Location 1, the continuous acoustical phenomenon, seen at around 16 Hz in the baseline (Figure 10), is still visible in Figure 14, but is no longer distinguishable from other acoustical events in Figure 15 (baseline, Figure 11). The apparent constancy of this acoustical feature in at least three of the four situations seems to suggest some permanent equipment, and hence the animal water supply system is a good contender.

Concurrent with the existence of IWT rotation, a new acoustical phenomenon, not present in either baseline, appears at 20 Hz and in both locations. The non-continuous coloring of this line shows that pressure level was not continuous. Further analysis (Figure 16 and Figure 17) shows that this 20 Hz phenomenon was equally prominent in Location 2 (newer shed) as in Location 1 (older shed).

10-12.5 Hz:

Baseline: Given the continuous nature of the acoustical event that occurs between 10-12.5 Hz (Figure 10), this might also be associated with the operational water systems, or other equipment necessary to maintain the animals.

ILFN-rich: Below 12.5 Hz, both locations see an increase in their acoustical energy.

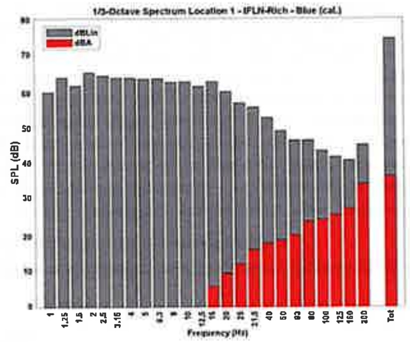


Figure 12: Location 1, Older Shed, at 17:30 on Dec 30. Representative data over a 10-min interval and analyzed between 1-200 Hz.

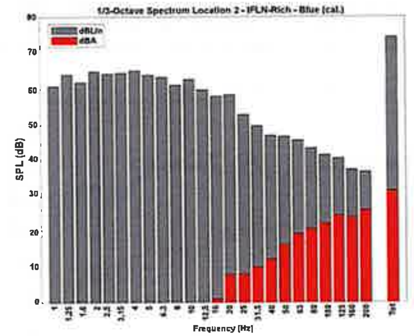


Figure 13: Location 2, Newer Shed, at 11:20, on Dec 30. Representative data over a 10-min interval and analyzed between 1-200 Hz.

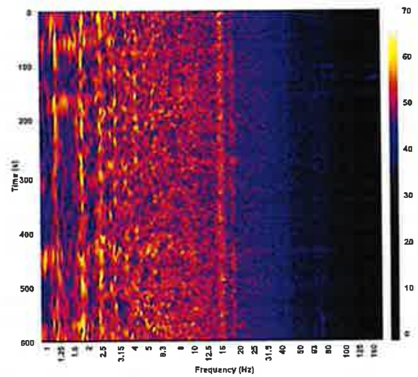


Figure 14: Location 1, Older Shed, at 17:30 on Dec 30. Representative data over a 10-min interval and analyzed between 1-200 Hz.

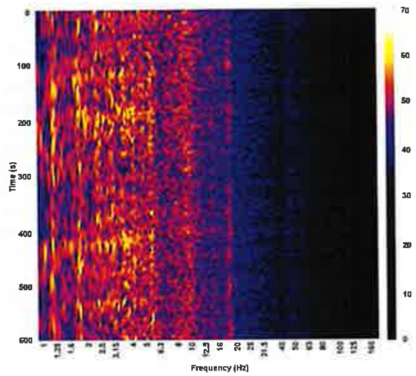


Figure 15: Location 2, Newer Shed, at 11:20, on Dec 30. Representative data over a 10-min interval and analyzed between 1-200 Hz.

< 5 Hz:

Baseline: In Location 2, the continuous phenomena occurring between 4-6.3 Hz could be related to the newer water supply system. 'Spurts' of acoustical energy are visible at the lowest frequency ranges (≤ 2 Hz), in both locations but seemingly more prominently in Location 1 (Figure 10). The source of these 'spurts' is, as yet, unknown.

ILFN-rich: The continuous acoustical phenomena occurring at 4-6.3 Hz in Location 2 during baseline (Figure 11) is no longer visually distinguishable in Figure 15. The 'spurts' of acoustical energy identified at ≤ 2 Hz in both Locations during baseline, are only vaguely visible in the ILFN-rich situation. In this lowest range of frequencies, both locations still seem to exhibit acoustical phenomena in spurts but, now, some of them contain more acoustical energy (Figure 14 and Figure 15).

dBA methodology:

Baseline: Location 2 exhibits a higher total dBA level (44.9 dBA) (Figure 9 and Table 4) than Location 1 (38.6 dBA) (Figure 8 and Table 5). While this seems to be opposite of what is seen in the respective sonograms (Figure

10 and Figure 11), it must be recalled that dBA emphasizes acoustical phenomena that occur above 200 Hz. Indeed, as that region is approached, Location 2 exhibits more acoustical energy than Location 1. This can also be seen in Figure 8, where Location 1 exhibits a dip in the pressure levels starting at approximately 50 Hz, and that is not present in Location 2 (Figure 9). Similarly, the corresponding sonogram

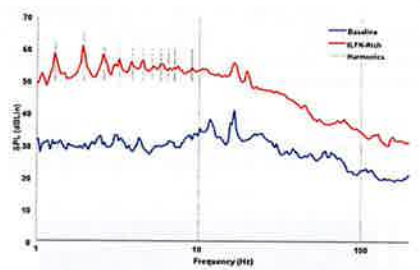


Figure 16: Narrow-band spectra comparing Location 1 - 14:40 on Dec 16 (Baseline) with Location 1 - 17:30 on Dec 30 (ILFN-rich). Representative data over a 10-min interval and analyzed between 1-200 Hz.

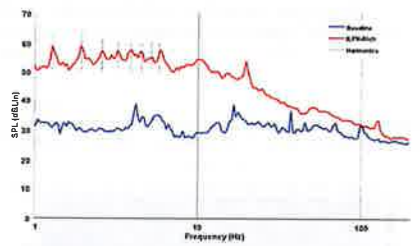


Figure 17: Narrow-band spectra comparing Location 2 - 15:50, on Dec 16 (Baseline) with Location 2 - 11:20, on Dec 30 (ILFN-rich). Representative data over a 10-min interval and analyzed between 1-200 Hz.

Table 4: Data tables for 1/3-Octave-Band and dBA analyses. 1/3-Octave-Band Analysis of location 2 (New Shed), baseline, at 15:50, on Dec 16 (Figure 9).

Frequency (Hz)	SPL (dBLin)	SPL (dBA)
1.0	41.9	-106.7
1.3	41	-99.6
1.6	40.7	-91.9
2.0	39.1	-85.5
2.5	39.1	-77.6
3.2	39.1	-69.7
4.0	43.3	-57.5
5.0	42.8	-50.3
6.3	41.8	-43.6
7.9	37.4	-40.4
10.0	37.8	-32.6
12.6	40.3	-23.1
15.8	43.3	-13.3
20.0	42.6	-7.9
25.1	41.4	-3.4
31.6	40.2	0.8
39.8	40.9	6.2
50.1	40.5	10.2
63.1	40.2	14
79.4	38.1	15.6
100.0	38.6	19.5
125.9	36.2	20.1
158.5	35.5	22.2
199.5	36	25.1
251.2	38.4	29.8
316.2	41.7	35.1
398.1	43.8	38.9
501.2	41	37.8
631.0	38.8	36.9
794.3	39.4	38.5
Overall	55.3	44.9

Table 5: Data tables for 1/3-Octave-Band and dBA analyses. 1/3-Octave-Band Analysis of location 1 (Old Shed), baseline, at 14:40, on Dec 16 (Figure 8).

Frequency (Hz)	SPL (dBLin)	SPL (dBA)
1.0	39.9	-108.7
1.3	39.6	-101
1.6	38.7	-93.9
2.0	38.7	-85.9
2.5	39.9	-76.8
3.2	40.4	-68.4
4.0	38.8	-62.1
5.0	37.8	-55.2
6.3	39.2	-46.1
7.9	40.2	-37.6
10.0	42.9	-27.5
12.6	43.8	-19.6
15.8	44.7	-12
20.0	41.6	-8.9
25.1	41.7	-3
31.6	38	-1.4
39.8	36.6	2
50.1	35.6	5.4
63.1	36.2	10
79.4	33.5	11
100.0	31	11.9
125.9	29.8	13.7
158.5	28.4	15.1
199.5	28.6	17.8
251.2	29	20.4
316.2	33.7	27.1
398.1	38.6	33.8
501.2	37.4	34.1
631.0	30.8	28.9
794.3	29.5	28.7
Overall	53.6	38.6

(Figure 10) presents with several black areas in the >125 Hz region, while Location 2 has none (Figure 11). The fact that the total dBLin level is higher in Location 2 than in Location 1 (55.3 dBLin vs. 53.6 dBLin, Table 4 and Table 5, respectively), attests to the fact that more acoustical energy exists in Location 2 than in Location 1. This would seem to indicate that the elevated pressure levels occurring within the 10-25 Hz range in Location 1 (Figure 10, yellow areas) do not outweigh the evenly distributed pressure levels (> 125 Hz, in blue) shown in Location 2 (Figure 11).

ILFN-rich: In terms of 1/3-octave and dBA analyses, contrary to baseline, Location 1 now exhibits a higher total dBA level (53.4 dBA) (Figure 12 and Table 6) than Location 2 (44.9 dBA) (Figure 13 and Table 4), although the total dBLin values of both Locations are nearly identical (74.4 and 74.2 dB, Table 6 and Table 7, respectively).

Narrow-band-spectra methodology: Regarding the narrow-band spectra (Figure 16) a first peak can be seen at approximately 1.3 Hz with further peaks at 1.9, 2.6, 3.2, 3.8, 4.5, 5.2, 5.9 and 9 Hz. The blade passing frequency of an IWT consists of the number of times the blades rotate past the vertical tower structure, per second. Through video footage during the ILFN-rich measurements, that number was identified and the blade passing frequency was calculated as 0.65 Hz. These peaks correspond to a harmonic series with a fundamental frequency close to 0.65 Hz, and thus constitute an integral part of the IWT acoustical signature.

In Location 2, harmonics are not as prominent (Figure 17) as in Location 1, but peaks can still be seen at 1.3, 1.9, 2.6, 3.2, 3.9, 4.4, 5.2 and 5.9 Hz - again, acting as a signature of an IWT with a blade-pass frequency of about 0.65 Hz. An FFT of this frequency range (Figure 18) also shows these peaks.

Discussion

Large-scale public health epidemiological studies of residential ILFN contamination

Several exploratory studies have been conducted by governmental agencies [32-34] regarding the health effects of residential ILFN exposure. Many base their acoustical data on models (as per the dBA-1/3-octave methodology) rather than real, *in loco*, field measurements. Moreover, the unawareness of the importance of prior ILFN exposure histories when assessing health endpoints among study and control populations, predictably leads to statistically inconclusive results. As a consequence, many of the more classical groups of scientists who continue to defend the archaic notion "what you can't hear won't hurt you" feel justified in so doing. In the most recent French survey on the topic, results confirmed that: "wind turbines are sources of infra sounds and low-frequency sounds. However, the hearing

Table 6: Data tables for 1/3-Octave-Band and dBA analyses. 1/3-Octave-Band analysis of location 1 (Old Shed), ILFN-rich, at 17:30, on Dec 30 (Figure 12).

Frequency (Hz)	SPL (dBLin)	SPL (dBA)
1.0	59.4	-89.1
1.3	63.1	-77.4
1.6	60.8	-71.8
2.0	64.9	-59.7
2.5	64	-52.7
3.2	63.4	-45.4
4.0	63.5	-37.4
5.0	63.3	-29.8
6.3	63.3	-22.1
7.9	62.4	-15.4
10.0	62.5	-8
12.6	61.2	-2.1
15.8	62.3	5.6
20.0	59.8	9.3
25.1	56.6	11.9
31.6	55.4	15.9
39.8	52.5	17.9
50.1	48.8	18.6
63.1	46.2	20
79.4	46.2	23.7
100.0	43.3	24.2
125.9	41.6	25.5
158.5	40.7	27.3
199.5	45.1	34.2
251.2	49.8	41.2
316.2	49.1	42.5
398.1	50.7	45.9
501.2	49.2	46
631.0	49.9	48
794.3	46.8	46
Overall	74.4	53.4

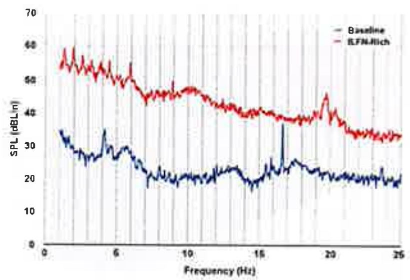


Figure 18: FFT power spectrum comparing Location 2 - 15:50, on Dec 16 (Baseline) with Location 2 - 11:20, on Dec 30 (ILFN-rich). Representative data over a 10-min interval and analyzed between 1-25 Hz.

thresholds for infra sounds and low frequencies of up to 50 Hz were not exceeded" [34]. Within the context of VAD studies, residential exposures have been investigated using the same clinical endpoints as those that were found relevant for ILFN-exposed aeronautical technicians [20-22]. These document the accelerated onset of symptoms among families exposed to residential ILFN (generated by a grain terminal [21] and by IWTs [22]) when compared to occupational exposures.

Narrow-band analysis methodology vs. dBA methodology data for IWT-generated ILFN

The benefit of narrow-band analysis becomes obvious by the identification of discrete peaks in the presence of IWT rotation, and that are absent when IWT are not rotating (Figure 17 and Figure 18). These peaks have been identified as the harmonics of a fundamental frequency, whose value precisely coincides with that of the IWT blade-pass frequency (as verified by video footage). This type of information is impossible to obtain with the dBA-1/3-octave methodology.

As many acousticians would quickly point out, the increased acoustical energy in the shed caused by rotating IWT is indistinguishable from that caused by the wind (Figure 10 vs. Figure 14 and Figure 11 vs. Figure 15). Blowing wind outside will increase the acoustical energy in the ILFN range within practically any structure (whether or not it is heard by humans). Identifying specific acoustic signatures associated with IWT operation (as demonstrated in Figure 16, Figure 17 and Figure 18), can help pin-point the contributions made by the blowing wind (structure resonance), and differentiate those from anthropogenic ILFN. But this cannot be accomplished with the dBA-1/3-octave methodology, as shown in Figure 8, Figure 9, Figure 12 and Figure 13.

Narrow-band analysis can also provide information that may in the future be relevant for dose-response values, and which the dBA-1/3-octave methodology cannot. For example, in the specific examples shown for the ILFN-rich locations (Figure 14 and Figure 15), Location 2 has similar acoustical energy at 20 Hz as Location 1. And yet, it is in Location 1 that the animal owner prefers to keep his breeding males. This may suggest that the frequencies that are more important for understanding the abnormal animal behavior (as reported by the owner) are not within the 20 Hz region.

Concomitant occupational and residential ILFN exposures in aerospace workers

In the summer of 2015, the home near the animal-sheds was abandoned by the family. IWTs had begun rotating in September 2013, and the ensuing health deterioration of family members demanded their removal. To this day, however, the property owner must return there everyday to care for the animals that are his livelihood. As in other ILFN-contaminated residences [35], this farmer's health

Table 7: Data tables for 1/3-Octave-Band and dBA analyses. 1/3-Octave-Band analysis of location 2 (New Shed), ILFN-rich, at 11:20, on Dec 30 (Figure 13).

Frequency (Hz)	SPL (dBLin)	SPL (dBA)
1.0	60.8	-87.8
1.3	63.9	-76.7
1.6	61.8	-70.8
2.0	64.7	-60
2.5	63.9	-52.8
3.2	64.3	-44.5
4.0	65	-35.8
5.0	63.6	-29.4
6.3	63.1	-22.3
7.9	60.8	-17
10.0	62.4	-8
12.6	59.4	-4
15.8	57.6	1
20.0	58.3	7.8
25.1	52.6	7.9
31.6	49.4	9.9
39.8	46.6	12
50.1	46.4	16.2
63.1	45.3	19.1
79.4	43.1	20.6
100.0	41.2	22.1
125.9	40.4	24.3
158.5	37.1	23.8
199.5	36.5	25.6
251.2	37.8	29.1
316.2	40.7	34.1
398.1	42.9	38.1
501.2	40.7	37.5
631.0	37.5	35.6
794.3	37.5	36.6
Overall	74.2	44.9

continues to deteriorate considerably, having most recently been diagnosed with Post-Traumatic Stress Disorder.

Aerospace workers who are exposed to occupational ILFN greatly benefit from the recovery periods encountered in their homes (presumably absent of anthropogenic ILFN) [16,19,36]. A growing segment of the world population, however, particularly from rural and suburban areas, has been confronted with ILFN-contamination in their homes. Some of these families include aerospace professionals (and other occupationally exposed ILFN workers), who are now exposed to ILFN both at work and at home.

The ongoing citizen-based research effort into ILFN-induced pathology to which these authors contribute [30] includes providing proper acoustical evaluations to participating citizens' properties, and also providing pertinent medical diagnostic tests, including the established VAD diagnostic tests [16,21,37]. Within this context, initial steps include obtaining personal and medical histories from each participating citizen. Histories are ob-

tained through one-on-one interviews that can last over 2 hours. Some of the citizens already interviewed include aerospace workers who are (or were) occupationally exposed to ILFN environments. Of these, some were already sleeping in ILFN-rich homes (due to anthropogenic sources), while others were expected to have sources of anthropogenic ILFN constructed near (< 3 km) their residential areas. Clinical information revealed in the interviews and corroborated by accompanying medical documentation, has been reiterating the association between symptom gravity and overall ILFN exposure.

People exposed to ILFN at work and at home see an acceleration of the onset of ILFN-induced pathology when compared to individuals who 'only' have ILFN exposure at work (assuming similar fetal, childhood and adolescent ILFN exposures). Individuals who are only exposed to ILFN-rich environments in the home see an accelerated onset of symptoms when compared to those who are only exposed to occupational ILFN-rich environments [20-22]. The reasons for this are twofold: on the one hand, when ILFN-exposed workers leave their place of employment, they undergo a biological respite from the agent of disease; on the other hand, ILFN-rich environments in the home are usually synonymous with sleeping in an anthropogenic ILFN-rich environment. Biological processes that only occur during sleep time are now occurring in the presence of an agent of disease [38].

Limitations of this study

When laboratorial studies are conducted using airborne acoustical phenomena, environmental parameters can be controlled with more or less ease. In real environments, however, an acoustic environment will not be homogeneous over any significant area or any significant time. Outdoors the environment may be reasonably homogeneous over tens of meters (apart from the interference effects from multiple sound sources creating 'heightened noise zones' possibly only a few meters across [39]). However, indoor environments can vary significantly over distances less than a meter. Furthermore, the acoustical differences between the two locations may have been due to time-wise changes between recording times.

Conclusions

This report highlights the difference in acoustical information gathered with two distinct methods of analysis: one sanctioned by current legislation and guidelines, and focused on protecting hearing impairment (dBA-1/3-octave methodology); the other, sanctioned by the bio-physical sciences and focused on protecting whole-body health (narrow-band methodology). The latter provides important information on the temporal and frequency profiles that are crucial for understanding how ILFN affects human health (considering both immediate and long-term effects).

The archaic notion of "what you can't hear won't hurt you" is reflected in the dBA-1/3-octave methodology, i.e., the hearing sensory pathway is the only one through which ILFN can adversely affect humans. This position is incompatible with the Scientific Method and with evidence-based medicine when quantifying a potential agent of disease, such as ILFN.

The clinical evolution of ILFN-induced pathology greatly depends on exposure-time patterns. Individuals, who work in ILFN-rich environments and simultaneously live in ILFN-rich homes, may see an accelerated onset of specific symptoms when compared with individuals who only live in the ILFN-rich home, with no prior or current history of occupational ILFN exposure. Therefore, the increasing number of ILFN-rich acoustic environments within rural residential dwellings poses a serious problem for ILFN-exposed aerospace workers, as their biological recovery periods (that occur when away from the ILFN-rich environment) may be greatly reduced, or even become non-existent.

In order to protect populations from excessive and harmful ILFN exposure, serious epidemiological studies under the auspices of 'Public Health' must be undertaken. An important step in that direction is taken here, showing the importance of departure from the established guidelines and legislation in order to obtain a scientifically useful quantification of the agent of disease under scrutiny.

Acknowledgements

The authors would like to thank Mr. Kaj Bank Olesen for allowing acoustical measurements on his property, and also Mr. Boye Janssen for acquiring all relevant DMI weather information. The authors also thank Mr. Finn Nielsen for all logistical support in Denmark.

Financial Disclosure

Due to his efforts in the creation of the SAM Scribe system, author HHCB has a financial interest in the SAM Scribe system.

Disclaimer

The authors of this paper:

1) Do not harbor anti-technology sentiments;

2) Consider industrial activities to be important to modern technological societies;

3) Have scrutinized the data under one and only on agenda - pure scientific inquiry;

4) Are not producing a report arguing against industrial complexes;

5) Are not producing an environmental noise assessment report focused on wind turbines;

6) Provided all acoustical evaluations and analyses pro bono.

References

1. World Health Organization (2011) Burden of disease from environmental noise.
2. World Health Organization (1999) Guidelines for community noise. In: Berglund B, Lindvall T, Schwela DH, World Health Organization, Geneva.
3. World Health Organization (2016) International Classification of Diseases. ICD-10 Version 2016.
4. Ingber DE (1993) Cellular tensegrity: defining new rules of biological design that governs the cytoskeleton. J Cell Sci 104: 613-627.
5. Ingber DE (2003) Mechanobiology and diseases of mechanotransduction. Ann Med 35: 564-577.
6. Ingber DE (2004) Mechanochemical basis of cell and tissue regulation. Mech Chem Biosyst 1: 53-68.
7. Motro R (2003) Tensegrity - Structural systems for the future. Hermes Science Publishing Limited, London, UK.
8. Sun Z, Guo SS, Fässler R (2016) Integrin-mediated mechanotransduction. J Cell Biol 216: 445-456.
9. Xu GK, Li B, Feng XQ, et al. (2016) A tensegrity model of cell reorientation on cyclically stretched substrates. Biophys J 111: 1478-1486.
10. Castelo Branco NA, Águas AP, Sousa Pereira A, et al. (1999) The human pericardium in vibroacoustic disease. Aviat Sp Environ Med 70: 54-62.
11. Castelo Branco NA, Gomes-Ferreira P, Monteiro E, et al. (2003) Respiratory epithelia in Wistar rats after 48 hours of continuous exposure to low frequency noise. Rev Port Pneumol 9: 473-479.
12. Alves-Pereira M, Joanaz de Melo J, Castelo Branco NA (2005) Pericardial biomechanical adaptation to low frequency noise stress. In: A Méndez-Vilas, Recent Advances in Multidisciplinary Applied Physics. Elsevier, London, UK, 363-367.
13. Ponomar'kov VI, Tysik Ayu, Kudryavtseva VI, et al. (1969) Biological action of intense wide-band noise on animals. In: Problems of Space Biology. NASA TT F-529, 307-309.
14. Nekhoroshev AS, Glinchikov VV (1992) Morphological research on the liver structures of experimental animals under the action of infrasound. Aviakosm Ekolog Med 26: 56-59.
15. Nekhoroshev AS, Glinchikov VV (1991) Effect of infrasound on morphofunctional changes in myocardium exposed to infrasound. Gig Sanit 12: 56-58.
16. Castelo Branco NA (1999) Clinical stages of vibroacoustic disese. Aviat Space Environ Med 70: 32-39.
17. Castelo Branco NA, Alves-Pereira M (1999) Vibroacoustic disease. Aviat Space Environ Med 70: 1-153.
18. Castelo Branco NA, Alves-Pereira M (2004) Vibroacoustic disease. Noise Health 6: 3-20.
19. Alves-Pereira M, Castelo Branco NA (2007) Vibroacoustic disease: Biological effects of infrasound and low frequency noise explained by mechanotransduction cellular signaling. Prog Biophys Mol Biol 93: 256-279.
20. Torres R, Tirado G, Roman A, et al. (2001) Vibroacoustic disease induced by long-term exposure to sonic booms. Proceedings Internoise 2001, The Hague, Holland, 1095-1098.
21. Araujo A, Alves-Pereira M, Joanaz de Melo J, et al. (2004) Vibroacoustic disease in a ten-year-old male. Proceedings Internoise 2004, Prague, Czech Republic.
22. Alves-Pereira M, Castelo Branco NA (2007) In-home wind turbine noise is conducive to vibroacoustic disease. Wind Turbine Noise, Lyon, France.
23. Alves-Pereira M, Joanaz de Melo J, Castelo Branco NA (2005) Actin- and tubulin-based structures under low frequency noise stress. In: A Méndez-Vilas, Recent Advances in Multidisciplinary Applied Physics. Elsevier, London, UK, 955-979.
24. Alves-Pereira M, Joanaz de Melo J, Castelo Branco NA (2005) Low frequency noise exposure and biological tissue: reinforcement of structural integrity? In: A Méndez-Vilas, Recent Advances in Multidisciplinary Applied Physics. Elsevier, London, UK, 961-966.
25. Cooper S (2014) The Results of an Acoustic Testing Program Cape Bridgewater Wind Farm. Energy Pacific (Vic) Pty Ltd, Melbourne, Australia.
26. Cooper S (2015) Soundscape of a wind farm, Cape Bridgewater experience. Proceedings of the 170th Meeting of the Acoustical Society of America, Jacksonville, FL, USA.
27. www.smart-technologies.co.nz
28. Bakker H, Rapley B, Summers R, et al. (2017) An affordable recording instrument for the acoustical characterisation of human environments. Proceedings International Conference Biological Effects of Noise, Zurich, Switzerland.
29. http://www.primo.com.sg/japan-low-freq-micro
30. Bakker HHC, Alves-Pereira M, Summers SR (2017) Citizen Science Initiative: Acoustical Characterisation of Human Environments. Proceedings International Conference Biological Effects of Noise, Zurich, Switzerland.
31. http://vindinfo.dk/english.aspx
32. Health Canada (2014) Wind turbine noise and health study.
33. National Health and Medical Research Council of Australia (2013) Systematic review of the human health effects of wind farms.
34. French Agency for Food, Environmental and Occupational Health & Safety (ANSES) (2017) Exposure to low-frequency sound and infrasounds from wind farms: improving information for local residents and monitoring noise exposure.
35. Castelo Branco NA, Alves-Pereira M, Martinho Pimenta A, et al. (2015) Low frequency noise-induced pathology: contributions provided by the Portuguese wind turbine case. Euronoise 2015, Maastricht, The Netherlands.
36. Castelo Branco NA, Rodriguez E, Alves-Pereira M, et al. (1999) Vibroacoustic disease: some forensic aspects. Aviat Sp Environ Med 70: 145-151.
37. Castelo Branco NA, Alves-Pereira M, Martinho Pimenta A, et al. (2015) Clinical protocol for evaluating pathology induced by low frequency noise exposure.
38. Nissenbaum MA, Aramini JJ, Hanning CD (2012) Effects of industrial wind turbine noise on sleep and health. Noise Health 14: 237-243.
39. Rapley BI, Bakker HHC (2010) Sound, Noise, Flicker and the

Citation: Alves-Pereira M, Bakker HHC (2017) Occupational and Residential Exposures to Infrasound and Low Frequency Noise in Aerospace Professionals: Flawed Assumptions, Inappropriate Quantification of Acoustic Environments, and the Inability to Determine Dose-Response. Scientific J Aerosp Eng Mech 1(2):83-98

Human Perception of Wind Farm Activity. In: Atkinson, Rapley Consulting, Palmerston North, New Zealand, 235-236.

40. https://commons.wikimedia.org/wiki/File:Acoustic_weighting_curves_(1).svg
41. Dirac Delta Science & Engineering Encyclopedia (2017) G-weighted overall level.
42. Dirac Delta Science & Engineering Encyclopedia (2017) A-Weighting.
43. https://www.fhwa.dot.gov/environment/noise/regulations_and_guidance/analysis_and_abatement_guidance/polguide01.cfm
44. Bento Coelho JL, Ferreira A, Serrano J, et al. (1999) Noise assessment during aircraft run-up procedures. Aviat Space Environ Med 70: 22-26.
45. Bento Coelho JL, Ferreira A, Serrano J, et al. (1994) Noise exposure in the aeronautical industry. Internoise 31: 741-744.

Nineteen Hertz and Below

An Infrasonic History of the Twentieth Century

SOPHIA ROOSTH

This is a history of a sound you cannot hear. Human hearing ranges, on average, between twenty and twenty thousand hertz, and infrasound vibrates at a frequency lower than twenty hertz, ever so slightly below the envelope of human audition.[1] Infrasound first rattled the scientific world in 1883, when the explosion of Krakatoa between the Indonesian islands of Java and Sumatra registered on barographs as subsonic vibrations powerful enough to circle the globe seven times.[2] Infrasound shuddered back into scientific attention immediately after World War II, when interest in infrasound oscillated between harnessing infrasonic vibrations as weapons and tuning into them as signatures or acoustic footprints of nuclear testing, unheard vibrations from a stealthy enemy. Because infrasonic vibrations are not easily dissipated by physical obstacles, they travel much farther than audible sound, a quality that makes them a useful means for measuring events occurring far away, from earthquakes and volcanoes to rocket launches. In 2011 the Comprehensive Nuclear Test Ban Treaty Organization presided over a controlled explosion in Israel's Negev desert to fine- tune their infrasonic-monitoring equipment; they found that the explosion was recorded by monitoring stations as far away as Mongolia.[3] In February 2013, infrasound sensors recorded the strongest infrasonic wave on record— a dense fireball blooming from the Chelyabinsk meteor as it exploded high above Russia's Ural Mountains. A report in *Science* described the "meteor's death throes" as emitting a piercing yet "silent scream," one that, while inaudible, nonetheless propagated powerful vibrations across great distances.[4]

As a liminal category alternately dubbed "unsound" or "sound- like,"[5] infrasound affords scholars the opportunity to interrogate sensorial ambiguity. Sound studies scholar Jonathan Sterne differentiates between sound and other vibrations: "As part of a larger physical phenomenon of vibration, sound is a product of the human senses and not a thing in the world apart from humans."[6] Such a definition authorizes sound studies to turn a deaf ear to those vibrations that are inaudible to humans yet are nonetheless key sensory capacities for nonhuman animals: ultrasonic vibrations among dolphins, bats, and dogs, for example, or infrasonic vibrations with which whales and elephants can communicate and anticipate danger in their immediate environments, such as earthquakes and tsunamis.[7] How, then, might sound studies admit into its purview (its percussion?) those aspects of the vibratory world that are not, strictly speaking, *sonic*? To productively draw sensory studies into conversation with multispecies science studies requires that the nonhuman *umwelt* be examined as rigorously and on the same footing as the human sensorium (and, indeed, to query the very notion of a singular and homogenous "human sensorium" in the first place).[8] A more capacious understanding of sound could consequently reorient its focus away from not only anthropocentric but also "earcentric" models of sonic perception in favor of an extracochlear modality that recognizes entire percussing bodies as vibratory sensory apparatuses.[9]

Once we retune hearing to incorporate the entire body, rather than ears alone, then the sensory hierarchy falls away. Sensory studies scholars consequently must admit the possibility that sound— or any other sense— cannot be studied (or experienced) in isolation but only on a spectrum with other sensory and affective states. Infrasound is on the fringe of the audible yet bleeds into the palpable. It occupies the threshold between hearing and the many other perceptual modalities that audition both complements and overlaps (most significantly, tactility and proprioception, but also nausea and dizziness, as well as affective, cognitive, and emotional states). The twentieth- century history of infrasound is one place to begin such a project, as it problematizes which vibrations do or do not count as "sound"; requires an extracochlear model of hearing; and attaches audition to somatic feelings and moods, including agitation, anxiety, irritability, and apprehensiveness.

In her history of vibration, Shelley Trower demonstrates how

nineteenth- century physiologists, poets, and spiritualists used sound "to make audible the silent vibrations that were shaping the experience of modernity."[10] Gillian Beer similarly notes late- nineteenth- century anxieties that attended the limits of perception: "Not only the distortion but the extreme tenuity of our senses was brought home as the subsonic, ultrasonic, and subsensible . . . began to surround and imbue the human."[11] Dovetailing with these histories, I find that infrasound became an increasingly salient cultural concern precisely during the midcentury moment when nuclear weapons testing, Cold War logics, and ecological consciousness inaugurated planetary thinking anew. A vibration that could circle the earth and indicate precarious or degraded environments crystallized widespread scientific and popular concerns about the hazards of modern geopolitical globality, which resonate to this day.

Auditing infrasound as it echoes from the mid- twentieth century to now allows sensory scholars to inquire into the epistemic status of that which is palpable yet unheard. How do our understandings of sound change when they are not vibrations acting *on* bodies but vibrations that resonate *with* and *within* our fleshy, pulpy selves? In this essay, I relate how infrasonic vibrations were cast as sonic weapons, as well as a signature of the use of atomic weapons— specifically, in order to monitor international compliance with the Limited and Comprehensive Nuclear Test Ban Treaties. I examine infrasound as both cause and register of human anxiety in a technological world suffused with vibrations both heard and unheard. Finally, I stray into infrasound's use as a way of debunking ghostly hauntings in order to tune in to infrasound as diagnostic of modern paranoias about the imperceptible risks to which we imagine ourselves exposed. At stake is the relation of sounds to vibrations, of vibrations to bodies, and of bodies to the vibrating and perilous environments in which they are nestled.

A Devastating Whistle: Silent Weapons in a Cold War

In 1941, infrasound reverberated through the pages of Robert Heinlein's speculative fiction novel *The Day after Tomorrow.* Originally serially published in *Astounding Science Fiction* as *Sixth Column* the same year as the attack on Pearl Harbor, Heinlein's book features American scientists who develop an infrasonic weapon designed to kill a Pan- Asian enemy alliance. Vibrations pitched at fourteen hertz struck fear in the hearts of America's enemies. Paging through Heinlein's xenophobic fantasy of vibrant infrasonic retribution, one reads, "Those damned subsonics give me the creeping horrors even when I know what's going on. . . . There's nothing like the fear of something you can't understand to break a man down."[12]

Stories about weaponizing infrasound were not, however, limited to science fiction novels— they also seeped into peer- reviewed scientific publications, popular science magazines, and mainstream and yellow journalism. Foremost among these was the strange tale of Russian- born French scientist Vladimir Gavreau.[13] Twenty years after the publication of *The Day after Tomorrow*, Gavreau, head of the Electroacoustics and Automation Laboratory of the *Centre National de la Recherche Scientifique* (CNRS), and his fellow researchers began to feel nauseated, dizzy, and unfocused. While investigating vibrations visible in the liquids found in his laboratory, Gavreau discovered that a defective industrial ventilator in a nearby building had caused a standing wave to vibrate below twenty hertz in his laboratory, though not in any adjacent laboratories. Upon disabling the fan, he and his colleagues immediately recovered. Intrigued by the connection between low- frequency vibrations and feelings of illness and unease, and in particular by the conundrum of "directive vibrations," Gavreau began researching whether infrasonic vibrations, while unheard, might nonetheless be physically palpable. What happens next, however, oscillates between fact and fiction, making it difficult to separate history from conspiracy theory. Some writers doubt to this day whether Gavreau existed, despite the fact that journal articles and patents bear his name.[14]

A 1967 issue of the *UNESCO Courier* speculated that Gavreau was researching a lethal "black noise," building a "devastating whistle" and a "mammoth organ pipe" twenty- four meters long that could disable or even kill enemy combatants by surrounding them in a sonic "envelope of death" or turning their internal organs into "jelly."[15] Researchers in his laboratory, the press reported, would be snatched from near death after their internal organs "hit critical resonance frequencies."[16] One champion of Gavreau was cut- up writer William S. Burroughs, who carried a clipping of a *Sunday Times* article about Gavreau in his wallet and showed it to several musicians he interviewed in the early 1970s. Burroughs explained to Led Zeppelin guitarist Jimmy Page,

> Professor Gavreau of France developed infra- sound as a military weapon. A powerful infra- sound installation can, he claims, kill everyone in a five- mile radius, knock down walls and break windows. Infra- sound kills by setting up vibrations within the body so that, as Gavreau puts it, "You can feel all the organs in your body rubbing together." The plans for this device can be obtained from the French Patent Office, and infra- sound generators constructed from inexpensive materials.[17]

Burroughs similarly sketched out Gavreau's story to David Bowie while interviewing him for *Rolling Stone* in November 1973; the two imagined making music that might "maim [the audience]."[18] Weaponized infrasound left an indelible impression on Bowie, who told Dick Cavett in a televised interview a year later that a "black noise bomb" that could destroy a city had been invented in France and that you could purchase the patent for less than four dollars.[19] Industrial musicians Throbbing Gristle, also devotees of Burroughs, incorporated infrasound into their live performances, as Throbbing Gristle synthesist Chris Carter explained, to "make people do things that they didn't want to do— making people feel ill and dizzy and stuff."[20] The band also bombarded squatters with infrasonic waves to force them out of Genesis P- Orridge's backyard.[21] Gavreau's "mammoth organ pipe" featured in a 1973 volume of Belgian feminist comic book *Yoko Tsuno*, in which the titular electrical engineer must rescue a famous organist from the villainous Karl Moebius and his destructive infrasonic *L'orgue Du Diable* (devil's organ).

Such anecdotes are, perhaps, symptomatic of Cold War paranoia heavily dosed with the coke- fueled avant- garde industrial and glam scenes of the early 1970s. Nonetheless, they persist in sober sources to this day; the Hastings Center issued a 2010 report warning its readers, "Acoustical weapons, which have not yet been perfected, would employ inaudible infrasound to resonate in body cavities and cause disorientation, nausea, vomiting, and bowel spasms."[22] Such hypothetical weapons are, in many ways, an insidious obverse to the use of sonic booms by the American military during the Cold War— in the 1964 Oklahoma Sonic Boom Experiment, citizens were regularly exposed to sonic booms (eight times a day over six months) to test the psychological repercussions of the "sound of freedom." In such exercises, "through sound, the state touched people's bodies," such that "the Cold War was mapped onto the field of sensory experience."[23] In *Sonic Warfare*, Steve Goodman notes how a "tactics of frequency" "brings into the field of power the dimension of unsound."[24] While the use of audible sound— loud, piercing noises and grating pop music— has been studied as part of the history of sonic warfare, from crowd control to human torture, panic over (or enthusiasm for) infrasonic weaponry draws our attention toward the specter of sounds *unheard*, transmitted from far away yet acting intimately on the bodily interior.

"The Voice of the Atmosphere"

Given that infrasound was already understood to be a weapon in itself, it is unsurprising that infrasound would soon also be enrolled as indexical of weaponry and hence a deterrent against the proliferation and testing of nuclear weapons. By the 1950s both the United States and the Soviet Union had set up infrasound monitoring stations in order to detect atmospheric nuclear testing.[25] Over two thousand nuclear weapons tests were conducted between 1945 and 1996; and in the first two decades following World War II, infrasound was an efficient mechanism for the US government to keep tabs on Soviet atmospheric weapons detonations.[26] "Studying VLF [very- low frequency] emissions produced by nuclear explosions," Douglas Kahn notes, "was part of a larger scientific task of producing and monitoring seemingly every possible electromagnetic and acoustical (seismic, infrasound) signal and chemical and isotopic signature from around the world."[27] The 1963 Limited Test Ban Treaty moved nuclear testing underground, where its monitoring became the province of seismic rather than infrasonic recording devices. Infrasound monitoring of nuclear weapons was revived again in the 1990s, when the Comprehensive Nuclear Test Ban Treaty was drafted and codified by the United Nations General Assembly.[28]

In the intervening years, a global network of infrasound stations were installed to monitor compliance with the Comprehensive Nuclear Test Ban Treaty (CTBT), the organization of which is headquartered in Vienna.[29] Sixty global infrasound stations are currently being built, and forty-five, at last count, are already functioning, registering infrasonic waves, and transmitting signals back to the Comprehensive Nuclear Test Ban Treaty Organization (CTBTO) headquarters in Vienna.[30]

Fig. 1. Infrasound monitoring station, Schauinsland, Germany. Image courtesy of the CTBTO Public Information, https:// www .ctbto .org.

When North Korea detonated nuclear weapons in 2010, scientists at the CTBTO offices knew hours later, before North Korea had made an official announcement.[31] In this respect, infrasound monitoring is not simply a technology deployed in the service of desired geopolitical harmony but rather functions as *harmonic geopolitics*.

While nuclear weapons detonations were rare occasions for most citizens, other sources of infrasound were growing increasingly commonplace. The same 1967 issue of the *UNESCO Courier* that publicized Gavreau's research also reported on the dangers of modern noise to human welfare. "The Danger of Sounds We Cannot Hear" blames infrasound for a host of conditions, from the discomfort experienced by airline passengers to dizziness, fatigue, and a "fluttering sensation" plaguing urban dwellers. Readers are warned that "inaudible noise, like an invisible enemy, is even more deadly than the noise we hear."[32] No longer thought of only as a literal weapon but also as an inaudible yet deadly by- product of modernity, infrasound had bifurcated.

In May 1976, scientists at the Lamont- Doherty Earth Observatory, Columbia University's atmospheric infrasound station, began registering what researcher William Donn reported as "strange signals [that] began to appear . . . at about the same time on alternate days."[33] After several weeks, the researchers realized that they were recording the first Concorde flights landing at Dulles International Airport. They used the resulting infrasonic vibrations, which were degradations of the Concorde's "sonic boom," as an atmospheric probe to listen to what Donn called "the voice of the atmosphere." Following the Concorde's rumblings, Donn noted small atmospheric differences that registered on morning and afternoon flights, in summer and in autumn; and in so doing, he realized that environmental change could be monitored by listening to infrasonic frequencies.[34]

Around the same time, physicians began attending to infrasound's possible effects on the body. No longer concerned with infrasound as a weapon, it was now recognized as a resonant, inaudible, yet potentially hazardous and inescapable artifact of urban modernity— a subauditory miasma. A literature review published in *Lancet* in 1973 noted that different parts of the body resonated at various frequencies— "for example, the abdomen at about 10 Hz. . . . Abdomen vibrations may cause distress and sickness, whilst excessive chest vibration may interfere with the normal respiratory system."[35] The authors were careful to note, however, that while infrasound may be detrimental to one's health, one person's nuisance was another's pleasure; "Chest vibrations," they wrote, "incidentally are a welcome effect at discotheques and pop concerts, where the music is felt as well as heard— the total experience."[36] The attention to our bodies as entities already vibrating in tune with the infrasonic environment triggered concerns that the wrong kind of infrasound might be deleterious, even fatal. The medicalization of infrasound built on earlier anxieties that infrasound might be weaponized, joining them to worries over the ways in which a vibratory ecosystem might impact, penetrate, and resonate with human bodies.

In 1980, physician Nuno Castelo Branco was appointed the chief medical officer at an aircraft manufacturing and repair facility owned and operated by the Portuguese Air Force. He began noting strange symptoms and behavior among his employees, which he chalked up to their long- term exposure to infrasonic vibrations.[37] He reported that several employees, in apparent fugue states or epileptic fits, would wan-

der dangerously close to spinning propellers, from which fellow colleagues would drag them away at the last minute. He named this condition "vibroacoustic disease." Castelo Branco compared diseases caused by acoustic vibrations to other conditions that result from invisible or impalpable environmental phenomena; "It is high time that scientists begin to view acoustical phenomena with a framework usually applied to electromagnetic phenomena," he pronounced.[38] Within the electromagnetic spectrum, for example, the eye registers light within a small range of frequencies. Electromagnetic waves beyond that frequency— most notably, x- rays— are unseen yet nonetheless profoundly hazardous to one's health. He proposed a similar model for vibratory phenomena; while not perceived by the human ear as sound, the acoustical spectrum nonetheless includes frequencies that can do serious bodily damage or be harnessed for medical diagnostics and therapies, as is the case with ultrasound.

Castelo Branco's work has in the last five years been bolstered by physicians studying a contested illness that was named wind turbine syndrome in 2009. Nina Pierpont, the pediatrician who coined the term, noted that infrasonic waves emanating from wind turbines cause "a sensation of internal quivering, vibration, or pulsation accompanied by agitation, anxiety, alarm, irritability, rapid heartbeat, nausea, and sleep disturbance."[39] Recall Robert Heinlein's science- fictional scientists railing against "those damned subsonics" giving them "the creeping horrors."[40] Though not recognized as a legitimate medical illness, people who live or work near industrial wind turbines report a wide variety of symptoms ranging from vertigo to nausea, irritability, annoyance, stress, and panic attacks.[41] Anxiety is here treated as a suite of symptoms triggered by resonance frequencies, similar in many respects to Vladimir Gavreau's report half a century earlier. If anxiety and paranoia was once a side effect of what infrasound vibrations might be indexical of, now infrasound itself is identified as the immediate cause of embodied anxiety. If infrasound was once considered a rarity, triggered by a rogue nuclear blast or a defective generator, for those who today identify as suffering from vibroacoustic disease or wind turbine syndrome, it is an unavoidable blight, a vibration blanketing the modern technologically mediated globe.

In the last ten years, infrasound monitoring facilities are increasingly being repurposed toward monitoring and predicting environmental risks— earthquakes, tsunamis, volcanoes, meteors hurtling toward earth from outer space— in addition to anthropogenic phenomena such as nuclear explosions and rocket launches. Though built to eavesdrop on clandestine nuclear tests, infrasound is now a burgeoning and globalized data- collection project aiming to hearken the vibratory world, a "soundtrack to catastrophe."[42] A *Science* article reported on the rumbling of Mt. Etna in the summer of 2001: "The shaking mountain, with its roiling ash cloud, acted like a giant transmitter, triggering pressure waves that undulated through the atmosphere."[43] Volcanoes register signature infrasonic vibrations in advance of exploding, giving CTBT stations a few minutes' to hours' lead time in warning communities living nearby. In 2013 the CTBTO signed an agreement with the director of the Geophysical Survey of the Russian Academy of Sciences allowing Russians to receive data from infrasound stations in order to deliver near- real- time global tsunami warnings.[44] Russia, the country for which infrasound monitoring stations were built in the United States in the first place, is now a steward of infrasonic vibrations.

The retooling of CTBT stations to monitor and predict volcanoes and earthquakes filters infrasound's previous technological uses, refashioning the enemy not as a political threat but an environmental one. In this regard, infrasound might be considered, following sound-installation artist Raviv Ganchrow, to be "the bandwidth of the Anthropocene," because "environmental infrasound exhibits an intermingling of large- scale human industrialized activity with these other earth- and atmosphere-related frequencies."[45] Such technoecological vibrations are, to quote Douglas Kahn, "emissaries of earth magnitude" that allow globalized auditing of an imagined "whole earth" absent the technological surveillance afforded by "the 'earthrise' and 'blue marble' photographs of the 1960s and 1970s" or contemporary GPS satellites.[46]

Conclusion: A Shiver in the Air

In the early 1980s a British engineer named Vic Tandy started doing design work for a company that manufactured medical equipment. Working in the company's laboratory one evening, he began to feel unwell: "There was a feeling of depression, occasionally a cold shiver."[47] Sitting at his desk writing, he "began to feel increasingly uncomfortable"— "sweating but cold," he reported, "and the feeling of depression was no-

ticeable. . . . It was as though something was in the room with" him. He had the uncanny sense of being watched. He saw a ghostly apparition appear on his left, moving, he later wrote, as one "would expect a person to." He felt a chill in the room, and his hair stood on end. When he turned his head, the apparition vanished.

The following morning, Tandy, an amateur fencer, was sharpening his fencing blade in the laboratory, when he noticed that it quivered at a regular frequency. Using acoustic equipment, he investigated the lab and found that there was a standing infrasonic wave in the laboratory vibrating close to nineteen hertz, which was caused by a new fan recently installed in the extraction system. Once the fan was replaced, the hauntings ceased. Tandy speculated that the infrasonic vibration was responsible for the feelings of unease and dread sometimes associated with ghostly hauntings. He even suggested that the spectral figure was caused by the viscous fluid in his eyeball vibrating at the same frequency as the standing wave, thereby distorting his vision and causing visual hallucinations. He made a modest career over the next few years as an amateur ghost hunter, traveling to other haunted sites— medieval cellars, moldering castles— in the United Kingdom in search of infrasonic waves.[48]

Infrasound cannot be contained by canonical definitions of "sound," nor has it ever been properly contained by scientific orthodoxy. From the alarmed report of a Soviet scientist's "devastating whistle" that could liquefy internal organs to science- fictional death rays to contested illnesses marked by feelings of quivering and vibratory dread, infrasound has, since its discovery, been associated with hidden, often sinister or malevolent forces, those which are all the more unsettling because exposure is unnoticed, even insensible. A liminal vibration propagating at the cusp of human audibility, ever so slightly below the threshold of human perception, invites all- too- human anxieties about the limits of our own capacity to sense and know the environment in which we are embedded.

The infrasonic calls attention to our embodiment, our status as sacs and pockets of quivering fluid and pulp that are submerged in and resonate with an uncertain environment— hence long- standing worries over vibrating vitreous humors, organs jellifying, and head- exploding sonic waves. Infrasound also pulsates with human panics over hidden forces and the limits of our ability to perceive them— phenomena not felt yet that endanger us. As such, infrasound is more than something unheard that indexes danger. Apprehending it makes people apprehensive about the various risks to which we imagine ourselves exposed—unseen enemies, unheard weapons, rogue states slipping past acoustic surveillance, degraded environments, risky labor, noisy cities, forces that are supernatural, perhaps malevolent, but always just beyond the limits of human perception.

Sophia Roosth is the Frederick S. Danziger Associate Professor in the Department of the History of Science at Harvard University. Roosth was the 2016 Anna-Maria Kellen Fellow of the American Academy in Berlin and the Joy Foundation Fellow of the Radcliffe Institute for Advanced Study (2013–14). Roosth has published in *Critical Inquiry, Representations, differences, American Anthropologist, Science,* and *Grey Room*. In her first book, *Synthetic: How Life Got Made* (Chicago: University of Chicago Press, 2017), Roosth asks what happens to life as a conceptual category when experimentation and fabrication converge. Her next book, *The Quick and the Dead* (under contract with Chicago), will offer a historically and ethnographically informed travelogue into the worlds of contemporary geobiologists, scientists seeking ancient microbial life-forms fossilized in stone.

NOTES

This article grew from a presentation I delivered at the "Sonic Skills Expert Meeting: Sound and Listening in Science, Technology, and Medicine, 1920s-Now" at Maastricht University in January 2014. I thank Karin Bijsterveld for her invitation. Stefan Helmreich, Hillel Schwartz, and Alma Steingart provided useful commentary on early versions of this piece. I also thank Erica Fretwell and two anonymous reviewers for *Resilience* for their feedback and editorial guidance.

1. Of course, the range of human audition is an abstraction, and each person's hearing range varies over the course of a lifetime as a result of repeated exposure to loud noises. Jonathan Sterne argues that such exposure can lead to audile scarification, an analysis he offers to resist the ableism implied by pathologizing age-related hearing loss. Jonathan Sterne, "Audile Scarification: Notes on the Normalization of Hearing Damage" (Department of the History of Science Public Annual Lecture, Harvard University, Cambridge, MA, April 21, 2016).

2. A barograph is a barometer that translates pressure into physical graphs. Daniel Clery, "Test Ban Monitoring: No Place to Hide," *Science* 325, no. 5939 (July 24, 2009): 382–85; Kate Ramsayer, "Infrasonic Symphony," *Science News* 165, no. 2 (2004): 26–28. See also Raviv Ganchrow, "Long Wave Synthesis," in *The Geologic Imagination*, ed. Lucas van der Velden, Mirna Belina, and Arie Altena (Amsterdam: Sonic Acts Press, 2015), 194–95.

3. David Fee et al., "Overview of the 2009 and 2011 Sayarim Infrasound Calibration Experiments," *Journal of Geophysical Research* 118, no. 12 (June 27, 2013): 6122–43.

4. Richard Stone, "Siberian Meteor Spurs Dash for Data, Calls for Safeguards," *Science* 339, no. 6124 (March 8, 2013): 1135.

5. Steve Goodman, *Sonic Warfare: Sound, Affect, and the Ecology of Fear* (Cambridge, MA: MIT Press, 2012); Paul C. Jasen, *Low End Theory: Bass, Bodies and the Materiality of Sonic Experience* (New York: Bloomsbury, 2016).

6. Jonathan Sterne, *The Audible Past: Cultural Origins of Sound Reproduction* (Durham, NC: Duke University Press, 2003), 11.

7. To review the literature on infrasonic communication among elephants, see Elia T. Ben-Ari, "A Throbbing in the Air: The Discovery of Infrasonic Communication among Elephants Has Given Researchers a Whole New Way of Hearing Things," *BioScience* 49, no. 5 (May 1, 1999): 353–58; Christian T. Herbst et al., "How Low Can You Go? Physical Production Mechanism of Elephant Infrasonic Vocalizations," *Science* 337, no. 6094 (August 3, 2012): 595–99; Katharine B. Payne, William R. Langbauer, and Elizabeth M. Thomas, "Infrasonic Calls of the Asian Elephant (*Elephas maximus*)," *Behavioral Ecology and Sociobiology* 18, no. 4 (February 1986): 297–301; Joyce H. Poole et al., "The Social Contexts of Some Very Low Frequency Calls of African Elephants," *Behavioral Ecology and Sociobiology* 22, no. 6 (June 1988): 385–92.

8. The multispecies turn in anthropology was inaugurated by a special issue of the journal *Cultural Anthropology*; S. Eben Kirksey and Stefan Helmreich, "The Emergence of Multispecies Ethnography," *Cultural Anthropology* 25, no. 4 (November 1, 2010): 545–76. On the *umwelt*, consult Jakob von Uexküll, *A Foray into the Worlds of Animals and Humans with a Theory of Meaning* (1934; repr., Minneapolis: University of Minnesota Press, 2010). Feminist science studies scholars have forged a path in exploring nonhuman sensoria: Donna J. Haraway, *When Species Meet* (Minneapolis: University of Minnesota Press, 2007); Eva Hayward, "More Lessons from a Starfish: Prefixial Flesh and Transspeciated Selves," *WSQ* 36, no. 3 (2008): 64–85; Eva Hayward, "Fingeryeyes: Impressions of Cup Corals," *Cultural Anthropology* 25, no. 4 (November 1, 2010): 577–99; Carla Hustak and Natasha Myers, "Involutionary Momentum: Affective Ecologies and the Sciences of Plant/Insect Encounters," *differences* 23, no. 3 (January 1, 2012): 74–118. See also Eduardo Kohn, *How Forests Think: Toward an Anthropology beyond the Human* (Berkeley: University of California Press, 2013).

9. Jasen coins the term *extracochlear* to describe low-frequency vibrations, such as bass, in *Low End Theory*. For another account of extracochlear hearing, consult Stefan Helmreich, "Underwater Music: Tuning Composition to the Sounds of Science," in *Oxford Handbook of Sound Studies*, ed. Karin Bijsterveld and Trevor J. Pinch (Oxford: Oxford University Press, 2012), 151–75, reprinted in Stefan Helmreich, *Sounding the Limits of Life: Essays in the Anthropology of Biology and Beyond* (Princeton: Princeton University Press, 2016), 137–54. Indeed, work broadening the understanding of sound has already been taken up by researchers in bioacoustics, who find that marine organisms such as crustaceans communicate via rasps and rumbles apprehended by their compatriots not with ears (for they have none) but as a full-body sensation propagated by mechanosensory hairs and antennae; see Douglas J. Colson et al., "Sound Production during Feeding in *Hippocampus* Seahorses (Syngnathidae)," *Environmental Biology of Fishes* 51, no. 2 (1998): 221–29; S. N.

Patek and R. L. Caldwell, "The Stomatopod Rumble: Low Frequency Sound Production in *Hemisquilla californiensis*," *Marine and Freshwater Behaviour and Physiology* 39, no. 2 (June 2006): 99–111; Sheila N. Patek, "Spiny Lobsters Stick and Slip to Make Sound," *Nature* 411, no. 6834 (May 10, 2001): 153–54; E. R. Staaterman et al., "Rumbling in the Benthos: Acoustic Ecology of the California Mantis Shrimp *Hemisquilla californiensis*," *Aquatic Biology* 13, no. 2 (August 4, 2011): 97–105.

10. Shelley Trower, *Senses of Vibration: A History of the Pleasure and Pain of Sound* (London: Continuum, 2012), 3–4.

11. Gillian Beer, "'Authentic Tidings of Invisible Things': Vision and the Invisible in the Later Nineteenth Century," in *Vision in Context: Historical and Contemporary Perspectives on Sight*, ed. Teresa Brennan and Martin Jay (New York: Routledge, 1996), 91.

12. Robert A. Heinlein [Anson McDonald, pseud.], *Sixth Column*, pt. 2, in *Astounding Science Fiction* 26, no. 2 (1941), 124, https://archive.org/stream/Astounding_v26n06_1941-02_dtsg0318-LennyS#page/n123/mode/2up.

13. Vladimir Gavreau, "Pneumatic Generators of Intense Ultrasound," *Journal of the Acoustical Society of America* 28, no. 4 (July 1, 1956): 803; Vladimir Gavreau, "Infrasound," *Science Journal* 4, no. 1 (1968): 33; Goodman, *Sonic Warfare*, 18–19; Alexander Rehding, "Of Sirens Old and New," in *The Oxford Handbook of Mobile Music Studies*, vol. 2, ed. Sumanth Gopinath and Jason Stanyek (Oxford: Oxford University Press, 2014), 77–106.

14. Seth Horowitz, *The Universal Sense: How Hearing Shapes the Mind* (New York: Bloomsbury, 2013).

15. Goodman, *Sonic Warfare*, 18–19; Horowitz, *Universal Sense*.

16. Goodman, *Sonic Warfare*, 18–19.

17. William Burroughs, "Rock Magic: Jimmy Page, Led Zeppelin, and a Search for the Elusive Stairway to Heaven," *Crawdaddy*, June 1975, https://arthurmag.com/2007/12/05/willima-burroughs-onled-zeppelin/. The article from which Burroughs quotes is Frank Dorsey, "Joshua Knew a Thing or Two," *Sunday Times*, April 16, 1967. The article does not mention a French patent on an infrasonic weapon.

18. Craig Copetas, "Beat Godfather Meets Glitter Mainman: William Burroughs Interviews David Bowie," *Rolling Stone*, February 28, 1974, http://www.rollingstone.com/music/news/beat-godfather-meets-glitter-mainman-19740228.

19. The relevant clip from the interview can be viewed at "David Bowie Talks about a Control Bomb on Dick Cavett Show—1974," YouTube video, 1:08, May 23, 2013, https://www.youtube.com/watch?v=cOLZerYmi_U.

20. Atte Oksanen, "Anti-Musical Becomings: Industrial Music and the Politics of Shock and Risk," *Secessio* 2, no. 1 (2013). https://secessio.wordpress.com/vol-2-no-1/anti-musical-becomings-industrial-music-and-the-politics-of-shock-and-risk/.

21. S. Alexander Reed, *Assimilate: A Critical History of Industrial Music* (Oxford: Oxford University Press, 2013).

22. Michael L. Gross, "Medicalized Weapons and Modern War," *Hastings Center Report* 40, no. 1 (2010): 34–43.

23. David Suisman, "The Oklahoma City Sonic Boom Experiment and the Politics of Supersonic Aviation," *Radical History Review* 2015, no. 121 (January 1, 2015): 170–71; David Suisman, "The American Environmental Movement's Lost Victory," *Public Historian* 37, no. 4 (November 1, 2015): 111–31.

24. Goodman, *Sonic Warfare*, 17.

25. Richard Stone, "Data Treasures of the Test Ban Treaty," *Science* 297, no. 5578 (2002): 41–43.

26. "Known Nuclear Tests Worldwide, 1945–98," *Bulletin of the Atomic Scientists* 54, no. 6 (November 1, 1998): 65–67. See also Hugh Gusterson, *Nuclear Rites: A Weapons Laboratory at the End of the Cold War* (Berkeley: University of California Press, 1996); Joseph Masco, *The Nuclear Borderlands: The Manhattan Project in Post–Cold War New Mexico* (Princeton: Princeton University Press, 2006); Silvan S. Schweber, *In the Shadow of the Bomb: Oppenheimer, Bethe, and the Moral Responsibility of the Scientist* (Princeton: Princeton University Press, 2007).

27. Douglas Kahn, *Earth Sound Earth Signal: Energies and Earth Magnitude in the Arts* (Berkeley: University of California Press, 2013), 111.

28. "Comprehensive Nuclear-Test-Ban Treaty," accessed June 24, 2018, https://www.ctbto.org/fileadmin/content/treaty/treaty_text.pdf; Hugh Gusterson, "The Virtual Nuclear Weapons Laboratory in the New World Order," *American Ethnologist* 28, no. 2 (May 1, 2001): 417–37.

29. David Brown et al., "The IDC Seismic, Hydroacoustic and Infrasound Global Low and High Noise Models," *Pure and Applied Geophysics* 171, nos. 3–5 (September 8, 2012): 361–75; Michael A. H. Headlin et al., "Listening to the Secret Sounds of Earth's Atmosphere," *Eos, Transactions, American Geophysical Union* 83, no. 48 (November 26, 2002): 557–65.

30. Preparatory Commission for the Comprehensive Nuclear Test Ban Treaty Organization, *Annual Report 2014* (Vienna, Austria: Comprehensive Nuclear Test Ban Treaty Organization, 2014), https://www.ctbto.org/fileadmin/user_upload/pdf/Annual_Report_2014/English/2014_AR_E_Complete.pdf; Clery, "Test Ban Monitoring."

31. Lars-Erik De Geer, "Reinforced Evidence of a Low-Yield Nuclear Test in North Korea on 11 May 2010," *Journal of Radioanalytical and Nuclear Chemistry* 298, no. 3 (August 27, 2013): 2075–83.

32. "The Danger of Sounds We Cannot Hear," in Gunther Lehmann, "Noise and Health," *UNESCO Courier*, July 1967, 26–31.

33. William L. Donn, "Exploring the Atmosphere with Sonic Booms; or How I Learned to Love the Concorde," *American Scientist* 66, no. 6 (1978): 724–33.

34. Nambath K. Balachandran, William L. Donn, and David H. Rind, "Concorde Sonic Booms as an Atmospheric Probe," *Science* 197, no. 4298 (1977): 47–49; William L. Donn et al., "Infrasound at Long Range from Saturn V, 1967," *Science* 162, no. 3858 (1968): 1116–20; William L. Donn and Nambath K. Balachandran, "Meteors and Meteorites Detected by Infrasound," *Science* 185, no. 4152 (1974): 707–9.

35. "Infrasound," *Lancet* 302, no. 7842 (December 15, 1973): 1368–69.

36. "Infrasound," 1368–69.

37. Mariana Alves-Pereira and Nuno Castelo Branco, "Vibroacoustic Disease: Biological Effects of Infrasound and Low-Frequency Noise Explained by Mechanotransduction Cellular Signalling," *Progress in Biophysics and Molecular Biology* 93 (2007): 256–79.

38. Alves-Pereira and Castelo Branco, "Vibroacoustic Disease," 259.

39. Nina Pierpont, *Wind Turbine Syndrome: A Report on a Natural Experiment* (Santa Fe: K- Selected Books, 2009), 270.

40. Heinlein, *Sixth Column*, 124.

41. Simon Chapman et al., "The Pattern of Complaints about Australian Wind Farms Does Not Match the Establishment and Distribution of Turbines: Support for the Psychogenic, Communicated Disease Hypothesis" *PLoS One* 8, no. 10 e76584 (October 2013); A. Farboud, R. Crunkhorn, and A. Trinidade, "'Wind Turbine Syndrome': Fact or Fiction?," *Journal of Laryngology and Otology* 127, no. 3 (March 2013): 222– 26; Magda Havas and David Colling, "Wind Turbines Make Waves: Why Some Residents Near Wind Turbines Become Ill." *Bulletin of Science, Technology, and Society* 31, no. 5 (October 1, 2011): 414– 26; Loren D. Knopper and Christopher A. Ollson, "Health Effects and Wind Turbines: A Review of the Literature," *Environmental Health* 10 (2011): 78; Jennifer D. Roberts and Mark A. Roberts, "Wind Turbines: Is There a Human Health Risk?," *Journal of Environmental Health* 75, no. 8 (April 2013): 8– 17; Alec N. Salt and James A. Kaltenbach, "Infrasound from Wind Turbines Could Affect Humans," *Bulletin of Science, Technology, and Society* 31, no. 4 (August 1, 2011): 296–302.

42. Hugh Raffles, *Insectopedia* (New York: Vintage, 2011), 330.

43. Stone, "Data Treasures of the Test Ban Treaty."

44. CTBTO, "CTBTO Head Visits Moscow, Signs Tsunami Warning Agreement," press release, https://www.ctbto.org/press-centre/highlights/2013/ctbto-head-visits-moscow-signs-tsunami-warning-agreement/.

45. Ganchrow, "Long Wave Synthesis," 184– 85.

46. Kahn, *Earth Sound Earth Signal*, 16, 17.

47. Vic Tandy and Tony Lawrence, "The Ghost in the Machine," *Journal of the Society for Psychical Research* 62, no. 851 (1998): 360– 64.

48. Vic Tandy, "Something in the Cellar," *Journal of the Society for Psychical Research* 64, no. 860 (2000): 129– 40. See also Mark Pilkington, "The Fear Frequency," *Guardian*, October 15, 2003.

pac Planning Appeals Commission

Park House
87/91 Great Victoria Street
BELFAST
BT2 7AG

Tel: 028 9025 7257 (direct line)
Tel: 028 9024 4710 (switch board)
Fax: 028 9031 2536

E-mail info@pacni.gov.uk
Website www.pacni.gov.uk

Dr Daniel Kane
28 Breckenhill Road
Doagh
BALLYCLARE
BT39 0TB

Your Reference:

Our Reference: 2013/A0169

Date: 21st August 2014

Dear Sir

THE PLANNING (NORTHERN IRELAND) ORDER 1991
APPEAL: Drumadarragh Windfarm Ltd
Amendments to proposed windfarm to include further reduction to 4 turbines (with an overall height of 77m - hub height 55m & blade diameter 44m) and amended layout of development. The proposal also includes turbine transformers electrical substation building (revised) widening of existing tracks construction of new access tracks and junctions and site entrance, turbine hardstands, underground electrical cables and communications lines, drainage works, a temporary site compound and all ancillary and associated works.
Drumadarragh Hill, Ballyclare

I enclose a copy of the Commission's decision.

Yours faithfully

[redacted]

---

pac Planning Appeals Commission

Appeal Decision

Park House
87/91 Great Victoria Street
BELFAST
BT2 7AG
T: 028 9024 4710
F: 028 9031 2536
E: info@pacni.gov.uk

Appeal Reference:	2013/A0169
Appeal by:	Drumadarragh Wind Farm Limited against the refusal of full planning permission.
Development:	Windfarm to include 4 turbines (with an overall height of 77 metres – hub height 55 metres and blade diameter 44 metres), turbine transformers, electrical substation building, widening of existing tracks, construction of new access tracks and junctions and site entrance, turbine hardstands, underground electrical cables and communication lines, drainage works, a temporary site compound and all ancillary and associated works.
Location:	Drumadarragh Hill, Ballyclare.
Application Reference:	U/2005/0281/F
Procedure:	Informal Hearing on 3rd and 4th June 2014
Decision by	Commissioner Alistair Beggs, dated 18 August 2014

Decision

1. The appeal is dismissed and full planning permission is refused.

Background

2. The appeal application was submitted in May 2005 and sought consent for 10 wind turbines with a maximum blade height of 107 metres (67 metre hub height). In January 2007 the application was amended to seek consent for 7 wind turbines with a maximum blade to tip height of 99.5 metres. In November 2007 the application was again amended to seek consent for 5 wind turbines of a maximum height of 99.5 metres. The 4 wind turbine scheme the subject of this appeal arose from an August 2008 amendment. The application was refused by the Department in November 2013 - the one reason for refusal being based on the proposal's noise impacts on residential amenity.

3. Throughout this decision reference is made to the properties marked H1-H45 on the Appellant's plan Figure C27. While some existing properties and un-built but approved buildings may not be identified on this plan I proceed on the basis of what the Appellant has identified unless I noted an obvious inaccuracy on the ground which would significantly influence my consideration.

Reasoning

4. The Department's reason for refusal raises the issue of turbine noise. Other main issues to be considered (raised by objectors) concern air traffic safety, landscape impacts, habitat and biodiversity, noise and shadow flicker, residential amenity, health and safety issues and haulage routes. The environmental, economic and social benefits of the proposal are also considerations.

5. The Department's case officer report of August 2009 recommended the current appeal proposal for approval, and the Department presented this opinion to Newtownabbey Borough Council (NBC) and Antrim Borough Council (ABC). However, this was not a decision and the Department were entitled to change their stance. The Appellant, concerned at this change, referred to pressure from local residents on the Department, Environmental Health Department's, Councillors, MLA's and Ministers, and to the Appellant's exclusion from specified meetings. However, such concerns over the application's processing are matters to be raised with the Department. Nor is it for me to consider the non statutory consultation exercises undertaken by the Appellant. The focus of this appeal is to consider the Department's reason for refusal and other material considerations raised in evidence.

General Energy Policy Background

6. The European Union (EU) Renewable Energy Directive set mandatory targets for increasing the level of renewable energy consumption in member states. The Climate Change Act requires gas emission reductions of at least 80% by 2050 and reductions in CO_2 emissions of at least 26% by 2020 against a 1990 baseline. The Department of Enterprise, Trade and Investment's (DETIs) Strategic Energy Framework (SEF) notes that it is likely that on-shore wind energy will continue to provide the largest proportion of renewable electricity generation in the period to 2020. The SEF sets a target of 40% of energy coming from renewable resources by 2020. These targets form the basis of the regional planning guidance relating to renewable energy.

7. The UK Renewable Energy Strategy sets out a path for the UK to meet its legally binding target to ensure that 15% of our energy comes from renewable resources by 2020. The document First Steps Towards Sustainability – a Sustainable Development Strategy for Northern Ireland (SDS) sets a 40% target (beyond 2025) of all electricity consumed in NI being obtained from indigenous renewable energy resources with at least 25% of this being generated by non-wind technologies. The SDS's Implementation Plan put forward commitments to meet the Strategy target of achieving a 25% reduction in NI's greenhouse gas emissions against 1990 levels by 2025.

Planning Policy

8. The Regional Development Strategy for Northern Ireland 2035 (RDS) does not provide operational planning policy for development control decisions, but emphasises the importance of cutting environmental costs by reducing the consumption of natural resources and energy from non renewable resources.

9. Regional planning policy for the countryside is found in Planning Policy Statement 21 - Sustainable Development in the Countryside (PPS 21). Its Policy CTY 1 identifies a range of types of development which in principle are considered to be acceptable in the countryside and that will contribute to the aims of sustainable development. One of these is renewable energy projects in accordance with Planning Policy Statement 18 – Renewable Energy (PPS18). This document's aim is to facilitate the siting of renewable energy generating facilities in appropriate locations in order to achieve Northern Ireland's renewable energy targets and realise the benefits of renewable energy.

10. Policy RE1 of PPS18 indicates that a proposal for renewable energy development will be permitted provided it will not result in an unacceptable adverse impact on specified criteria. The specified criteria relevant to this appeal are public safety, human health, residential amenity, visual amenity and landscape character, biodiversity, nature conservation and built heritage interests and local natural resources. The Policy's particular requirements for 'Wind Energy Development' are that such developments are not to have an unacceptable impact on visual amenity or landscape character; create a risk of bog burst or landslide, cause unacceptable magnetic interference or impact on aviation safety, or cause significant harm to the safety or amenity of sensitive receptors arising from noise, shadow flicker, ice throw and reflected light. Proposals are to take into consideration the cumulative impact of existing wind turbines. For wind farm development a separation distance of 10 times rotor diameter to occupied property, with a minimum distance not less than 500m, will generally apply. The wider environmental, economic and social benefits of all proposals for renewable energy projects are material considerations that will be given significant weight in determining whether planning permission should be granted.

11. PPS18 is supported by a Best Practice Guide (BPG) which provides background information on various renewable energy technologies. It is designed to contribute to the development management process. Also of relevance is the Supplementary Planning Guidance (SPG) 'Wind Energy Development in Northern Ireland's Landscapes'. It shares PPS18's aim to facilitate the siting of renewable energy generating facilities in appropriate locations within the built and natural environment in order to achieve NI's renewable energy targets and to realise the benefits of renewable energy. It gives broad strategic guidance in relation to landscape and visual impacts.

12. Considerable evidence was presented by objectors questioning the efficacy and appropriateness of the provisions of PPS18 and its associated BPG in matters related to noise and shadow flicker for example. However, while a number of countries, people and bodies promote other standards the NI Executive has decided that these documents provide the current guidance on which to assess wind turbines in this jurisdiction. It is not for this appeal to assess the merits of that guidance. Nevertheless, I do consider whether any of the evidence specific to this case suggests that the general methodology in these documents needs to be adjusted to accurately predict the proposal's impacts.

13. The proposal falls to be considered under the above policy context. As such it cannot be compared to the impacts of other development proposals such as dwellings which fall to be considered under a different policy context.

Performance of Wind Turbines

14. General criticisms of wind power in general were raised by objectors. However, such criticisms are inappropriate for consideration in the context of this individual appeal. For example, the question of whether wind turbines are more or less efficient or cost effective relative to other power sources is a matter for national and regional policy review. General concerns about wind farms' 'green credentials' and carbon release impacts are similarly beyond the scope of this appeal. The economic viability of the proposal is a matter for the developer.

Air Traffic Safety

15. Witnesses from Belfast international Airport (BIA) advised that the turbines would not protrude into any protected airspace – that is airspace in which obstructions would be seen to prejudice air traffic safety. However as the turbines would come into the line of sight of BIAs primary radar they could register as false tracks on air traffic control screens to the detriment of air traffic safety. The BIA witnesses though advised that it was likely that technical mitigation measures capable of preventing this issue arising would be developed within the lifetime of any planning permission. As such there is a reasonable prospect of BIA's suggested condition preventing development until a radar mitigation scheme was in place being achievable within the lifetime of any planning permission. What contribution, if any, the Appellant would make to the provision of such a scheme (either individually or with other developers) is a matter for them. While not a legal requirement it would be justifiable to seek the additional safety measure of placing warning lights on the turbines. Such lights are unlikely to be a significant visual presence for local residents. I conclude that subject to conditions there are no air traffic reasons to justify a refusal of the appeal.

Landscape and Visual Impacts

16. The SPG describes the key landscape characteristics of 130 landscape character areas (LCAs) across Northern Ireland and assesses their sensitivity to wind energy development. The appeal site is within LCA 125 Tardree Upland Pastures. The SPG notes this area's visually exposed character, though in some locations landscape sensitivity might be less - where ridges have a smooth profile; visibility is reduced by dips in the landform or by forestry, and the landscape has already been affected by man-made influences. The LCA is described as having a medium sensitivity to windfarm development. It is recommended that attempts be made to minimise visual clutter where turbines are seen in conjunction with pylons and cumulative impacts are to be very carefully considered.

17. Drumadarragh Hill is an elongated upland ridge running broadly north-west to south-east at the southern limits of the Antrim Plateau. Three turbines (T2-T4) are proposed on the Hill's eastern slopes and one (T1) lies just to the west of the ridge about the 280 metre contour. There are two existing wind farms to the north at Elliots Hill and Wolf Bog - the nearest proposed to existing turbine distance being about 1.3km. I bear in mind the different turbine sizes at these existing wind farms.

18. The information submitted in support of the current proposals considers only 4 viewpoints, VRP 10 to VRP 14. Any consideration of the viewpoints (VRP1 to VRP9) mentioned in previous submissions requires the assessment of information submitted for the larger 7 turbine proposal. Nevertheless, a reasoned analysis of the current proposal's visual impacts can be made and this is based on what I saw on site and not solely on the photomontages and wireframes provided by the Appellant. Overall, the wireframes give a reasonable representation of the turbines' likely impact and given what I saw on site I have no reason to question their general depiction of turbine height or spread.

19. While from VRP 1 to VRP 2 (near Templepatrick and south-west of Ballyclare) the proposal would cause an elongated stretch of turbines in the landscape, it would visually group with the existing Elliots Hill and Wolf Bog wind farms. The overall visual impact would be acceptable. From around VRP 3, north of Doagh distance, topography and vegetation means that the turbines would not have a significant visual impact. Near VRP 4 (north-east of 5 Corners) the proposed turbines would sit apart from those at Elliots Hill and Wolf Bog, elongating the spread of turbines in the landscape southwards. However, the existing intervening pylons would provide some degree of linkage between existing and proposed pylons and the proposals would therefore not be unduly obtrusive in the landscape. The same consideration applies to VPR 5, near the Tildarg Road/B94 junction. From VRP6, Tardee Mountain the proposed turbines would be distinct from those at Elliots Hill and Wolf Bog. However, in the panoramic view of an undulating landscape the impact would be slight with three of the proposed turbines being partly behind and below the Drumadarragh ridgeline.

20. Closer to the site, Around VRP 7, at Old Ballybracken Road, turbine T1 would be a prominent presence in the open ridge landscape. Views of the other three turbines would be restricted largely to their turning blades above the ridge line. The landscape can accommodate this intrusion. Further north along this road the broadly same consideration can be applied to VRP 11 at the property H19.

21. At VRP8, the entrance to the Elliots Hill Wind Farm, the proposed turbines would have a considerable visual presence. However, this view is already degraded with intervening existing electricity pylons and poles. The proposed scale, number and mid slope positions of turbines T3-T4 mean there would be no unacceptable further erosion of the landscape. The same consideration applies to the views from the Tildarg Road in the vicinity of VRP 9 and VRP 10. Near VRP 12 (broadly 900 metres from the nearest turbine) in front of dwellings H38-39 the turbines will be seen as a row in the context of Drumadarragh Hill's open landscape. All will be on the skyline with the T1 turbine being the most prominent and it has no visual linkage with the pylons in the landscape. The impact of the other turbines to the north however is reduced as they are situated more down slope. All-in-all, from this area there would be a moderate negative landscape impact. Near VRP14, at property H36, significant intervening vegetation means that there is a restricted appreciation of the open landscape beyond, and of the proposed turbines themselves.

22. At VRP 13, along the proposed site access track the T1 turbine would be a significant presence in the landscape, with only partial views of the blades of the other turbines visible. All would be seen with a backdrop of the Wolf Bog turbines. From this view and from Drumadarragh Road itself there would be no significant adverse landscape impact.

23. Overall. I broadly concur with the Department's Landscape Architects Branch who considered that. given the existing negative impact of electricity pylons and overhead power lines on the skyline, the limited number and height of turbines will not create any significant increase in cumulative effects in the landscape. It is not clear how the proposals could impact adversely upon the Antrim AONB to the north and north-east of the site.

24. The tracks to service the turbines broadly follow contour lines and this would minimise their landscape impact. Cables and drains will be out of view. The proposed substation building would be about the 260 metre contour and 80 metres south of turbine T2. While a sizeable building (17.5 metres long and 5.5 metres high) it is of a relatively simple design and of traditional slate and render finish. It is unlikely in the context of the overall proposal to be unduly obtrusive.

25. I now turn to consider the visual impact of the proposals on individual properties. For those properties to the west of the ridge the main impact will stem from the ridge top turbine T1. This turbine, 77 metres high to rotor tip. would sit some 40-50 metres above the closest properties some 600-700 metres distant along the Old Ballybracken Road. The eye will inevitably be drawn to this prominent turbine. Nevertheless, in considering the landscape and the juxtaposition of the turbine with such properties it is unlikely that its visual presence would be unacceptably dominant. For property H41, about 1.2 km to the south-east of T1 distance and vegetation around that property suggests that none of the turbines will be unduly dominant.

26. Houses H38 and H39 lie broadly about the 180 metre contour, and the T1 turbine while just over the ridge will lie about the 280 contour. While the house frontages face away from the turbines these dwellings have indoor living areas orientated towards the ridge. They also have extensive garden areas, with H38's being particularly open. There would be clear and ever present views of turbines. However, given the distant juxtaposition of the T1 turbine from these properties I am not persuaded that its visual presence would be unacceptable. The three other turbines with their position to the north-west of these properties are not likely to be a significant presence either. At property H36 the impact of the turbines would be limited by the surrounding vegetation, with generally the upper elements of the turbines being most visible. Views from upper rooms would be more extensive but overall given the orientation of the dwelling, the distance from the turbines and the vegetation the visual impacts would not be unacceptable.

27. All-in-all the proposal's negative visual impacts are insufficient to justify refusal of the appeal.

Biodiversity and Nature Conservation

28. The site lies within the Breckenhill and Drummadarragh Site of Nature Conservation Interest (SLNCI) as defined in the draft Belfast Metropolitan Area Plan (dBMAP). As this draft designation has not been the subject of an objection it is likely to remain in any adopted plan and must be accorded weight. The designation relates to wetland habitats contained within the area. Policy ENV 2 of Planning Policy Statement 2: Natural Heritage (PPS2) notes that planning permission will not be granted for development that would be liable to have an adverse effect on the nature conservation interests of a designated SLINCI. The Appellant's assessments indicate that the turbines would avoid the SLNCI's wetland habitats. The Northern Ireland Environment Agency (NIEA) note that the turbines have been located in areas of relatively low ecological value in the SLNCI's overall context, and as they have a land take of less than 1% of the overall site they are unlikely to have a significant adverse effect on the SLNCI.

29. Concerns were raised about the proposal's impacts upon wildlife and the inadequacy of assessments undertaken by the Appellant. However, the underestimation of wildlife numbers in earlier studies does not necessarily invalidate later studies. No alternative habitat assessments have been provided and, while objectors claim that direct observations showed that wildlife has not returned 10 years after the construction of the nearby Elliots Hill turbines, no detailed evidence was presented. The NIEA and the Royal Society for the Protection of Birds (RSPB) have no objection to the proposals subject to the imposition of conditions seeking appropriate mitigation measures.

30. The proposal's limited land take will have minimal or no detrimental effect on fauna on which bird and other animals would depend for food or shelter. Of the protected bird species identified the Hen Harrier, Merlin and Peregrine seem to be infrequent visitors to the site due to, for example, unsuitable habitats and disturbance from human activity. Curlews were identified nesting at the site and the potential for disturbance to them is high during construction works. Thus, avoiding construction works which would result in habitat change and disturbance during the avian breeding season would be necessary. This would also benefit the Snipe on the site as well as non protected bird species and Irish Hares who have the same breeding season. There is no persuasive evidence that bird communities would not resettle after construction disturbance and thereafter have a degree of tolerance towards the turbines and their noise. Similar habitats nearby would also allow for a degree of species displacement. While the risk of bird strike will always remain there is no compelling evidence to suggest that bird strike risk would be any more than negligible at this site either by itself or in combination with other turbines.

31. Badgers are protected by the Wildlife Order 1985 and whatever the extent of underground setts any works within 30 metres of active setts require a licence under that Order. I understand that this distance is measured from the sett entrance. The evidence is that the current proposal's tracks and turbines have been designed to avoid active and inactive setts. The Appellant's assessments also recommended that no construction works take place within 50 metres of such setts. Other mitigation measures include preventing night disturbance to these nocturnal creatures and the blocking of potential traps for badgers during

construction. The site presents little in the way of suitable roosting habitats or feeding locations for bats due to its generally open upland terrain. Suitable linear features for bats such as hedgerows do not exist - walls on the site would not be conducive to insect life. The Tildarg and Breckenhill dams about 1km to east of the turbines are more likely to be important bat feeding locations. A formal bat survey is unnecessary in this case.

32. The watercourses on site include the headwaters of the Loon Burn and Isleorr Water, important for salmonid production they may also contain brown trout populations. Objectors reported a fish kill at H31 and spring water contamination at H33 when the Wolf Bog wind farm was built. Against this the Department of Culture Arts and Leisure (DCAL) noted in 2005 that the proposed positions of the turbines would have a minimum direct impact to watercourses and fisheries interests. They and the Fisheries Conservancy Board advised that the mitigation measures in the ES should reduce risk to water quality and aquatic habitat during the construction period which presents the greatest risk to watercourses. The Department of Agriculture and Rural Development (DARD) and the Rivers Agency also have no objections to the proposal and the Council for Nature Conservation and the Countryside (CNCC) suggested monitoring and measuring of wetlands to allow for further mitigation if necessary.

33. Concerns were raised about when the wind farm could be constructed if the salmon spawning season of October to March and the avian breeding season of March to July had to be avoided. The Further Environmental Information (FEI) advises that the best practice drainage mitigation measures proposed to avoid impacts to water quality could be used to allow construction works to continue from October to March. This would involve, for example, directing surface water run-off to attenuation and silting ponds to encourage sediment deposition. Such matters could be conditioned by the time runoff reaches any watercourse it is unlikely to contain significant levels of suspended sediment to interfere with the aquatic environment. This would allow construction outwith the avian breeding season.

34. The Geological Survey for NI advises that it is an entirely reasonable conclusion that there is no potential for bog failure given the shallow nature of peat mapped and encountered on the site.

35. The proposal is unlikely to have an adverse effect on the nature conservation interests of the SLNCI, and there are no impacts on nature conservation or biodiversity interests which would justify its refusal.

Archaeology

36. The former field system within the site has been surveyed and the majority of it will remain untouched by the development. The NIEA Historic Monuments agree with the recommendations in the Environmental Statement (ES) for archaeological mitigation ahead of the proposed development. There are no archaeological impacts to warrant refusal of the proposal.

Noise

37. The BPG advises that well designed wind farms should be located so that increases in ambient noise levels around noise-sensitive developments are kept to acceptable levels with relation to existing background noise. This will normally be achieved through good design of the turbines and through allowing sufficient distance between the turbines and any existing noise-sensitive development so that noise from the turbines will not normally be significant. The BPG goes on to note that as a matter of best practice for wind farm development, the Department will generally apply a separation distance of 10 times rotor diameter to occupied property (with a minimum distance of not less than 500m). In applying this separation distance, any significant impact on sensitive noise receptors should be minimised, particularly with the increasing number of proposals for turbines in excess of 100 metres in height. Noise levels from turbines are generally low and, under most operating conditions, it is likely that turbine noise would be masked by wind-generated background noise. In this case all occupied properties in the vicinity of the proposed wind farm are outwith 10 rotor diameters of the proposed turbines and none are within 500 metres.

38. The BPG advises that the report, 'The Assessment and Rating of Noise from Wind Farms' (ETSU-R-97), describes a framework for the measurement of wind farm noise and gives indicative noise levels calculated to offer a reasonable degree of protection to wind farm neighbours, without placing unreasonable restrictions on wind farm development. The BPG goes on to say that this document should be used in the assessment and rating noise from wind energy developments. In May 2013 the Institute of Acoustics published "A Good Practice Guide to the application of ETSU-R-97 for the Assessment and Rating of Wind Turbine Noise" (IOAGPG). This document, which has been endorsed by the Environment Minister, gives detailed recommendations with regard to the factors to be taken into consideration in undertaking an ETSU-R-97 assessment.

39. The ETSU-R-97 document recommends limits for noise from wind farms at sensitive receptors. Essentially noting that noise should be limited to 5dB(A) above background, with a lower limit of between 35 and 40 dB(A) for daytime and a lower limit of 43dB(A) for night time. The higher night time limit reflects that people will generally be indoors at night. Limits above background noise to reflect the variation in turbine noise and background noise with wind speed are recommended. Absolute noise limits and margins above background should relate to the cumulative effect of wind turbines in the area contributing to the noise received at the properties in question. The ETSU-R-97 limits take into account blade swish and it is noted that guarantees are normally sought from turbine manufacturers that tonal noise will be below that requiring a penalty under the ETSU-R-97.

40. In considering existing background noise levels (excluding existing turbines) the Appellant took measurements from two representative noise locations to the east and west of Drumadarragh Hill, close to properties H19 & H20 and H38 & H39 respectively. There was no dispute that the appellant's assessment, found in Table 4.1 of Noise Impact Assessment Report 1743-R2, was robust. Differing, higher background noise levels for the now constructed Elliots Hill wind farm and the current Castlegore wind farm planning application were referred to. These

also suggest that the Appellant's assessment is robust, particularly in relation to Tildarg Road properties, but I am not persuaded that they should attract any further weight in this consideration. The Appellant's study is particular to this application, and it was open to them to provide measurements from other locations if it was thought that the representative background noise levels were conservative. Also, the Elliots Hill readings predated ETSU-R-97 guidance and the Castlegore wind farm measurements pertain to an undecided planning application.

41. Table 5.1 of Report 1743-R2 details the source sound power level for the proposed wind turbines (four Enercon E44, 55 metre hub height turbines) and this was not disputed. The tables in Appendix 5 of Report 1743-R2 then set out the proposal's predicted noise impacts on the H1-H44 properties, and similar tables for H45 are found in Report 1743-R6. Table 6.1 of report 1743-R2 sets out the maximum predicted exceedance of the proposal's wind turbine operational noise at H1-H44. These assessments were judged to be robust by all the parties and they indicate that only two properties, H19 and H36 (respectively west and east of Drumadarragh Hill), would exceed the lower daytime limit of 35dB (by 0.6dB and 1.5dB respectively). Mr Bowdler's assessment, for the Drumadarragh Residents Association (DRA) also suggested that the proposal's noise at H20 would also exceed the lower daytime limit.

42. As the Appellant has no control over the Elliots Hill and Wolf Bog turbines it is necessary to predict the noise that can be attributed to them. This requires an idea of what the source sound power levels for the relevant turbines are. Between the parties various technical reports were provided, all indicating different sound power levels for the same turbines. While the DRA and Department suggested that the highest sound power level should be used, I find nothing to suggest that those used by the Appellant in report 1743-R2 are unsound. Mr Hayes, for the Appellant, confirmed that his assessment was in line with good practice, by adding 2dB to sound levels for uncertainty. I bear in mind however that the atmospheric absorption levels referred to in IOAGPG would require 0.1 - 0.3dB to be added to the Appellant's calculations.

43. The Appellant's assessment of receptor noise levels associated with the operation of the existing wind farms is found at Table 7.3 of Report 1743-R2. Mr Hayes indicated that it would be appropriate to reduce the calculated noise levels at receptors by 2dB to account for mixed ground conditions instead of the hard ground conditions assumed in his study. This was not disputed. Taking that amendment into account Table 7.3 indicates that noise levels at three properties, H28, H29 and H30, would exceed the ETSU-R-97 daytime upper amenity hours noise criterion of 40dB by 1.1-1.2dB without the operation of the Drumadarragh wind farm. These properties are situated on Tildarg Road, south of Wolf Bog.

44. The Appellant contended that for the purposes of a cumulative noise assessment it should be assumed that the existing wind farms would operate within the noise limits relating to their approvals. However, neither existing wind farm has planning conditions relating to noise limits. An informative on the Elliots Hill approval notes that the operation of the turbines shall not increase average L_{A90} noise levels above the prevailing average L_{A90} background noise by more than 7.5 dB(A) or by more than 2.5dB(A) where clearly audible mechanical tones are present. An informative on the Wolf Bog approval sets out the ETSU-R-97 night-time limit, and a daytime limit the greater of the $L_{A90(10min)}$ background noise level plus 5dB(A) or 37.5dB(A) at wind speeds not exceeding 12 metres per second. Mr Hayes' using his representative background noise level for property H38 (Table 4.1) calculated that compliance with these informatives could potentially lead to noise levels of 41 - 42dB(A). Levels in excess of ETSU-R-97 limits.

45. The existing wind farms were designed to meet the limits set out in the informatives and the Department assumed that the existing turbines were operating with the informatives. However, no one could say at what levels they were actually operating, and the Appellant's own assessment is that they have the scope to break the upper ETSU-T-97 limits at certain properties. As the informatives are unenforceable there is nothing to prevent the existing wind farms making as much noise as they like, and the Department would have no locus to investigate the issue never mind consider enforcement action. This leaves statutory nuisance legislation as the only way to address noise issues emanating from these turbines. Thus, that the Department have not taken any action against the turbines is of no weight in this consideration. It also needs to be borne in mind that as they age turbine mechanics have the potential to become noisier.

46. The Appellant referred to figures for the proposed Whappstown wind farm (to the North of the existing turbines) which showed lower noise level predictions for the existing turbines than the Appellant had predicted. However, the full detail of these figures are not before me and relate to an undecided application where concerns over the accuracy of those noise levels have been raised by Council consultees. As such I focus on the assessments pertaining specifically to this appeal proposal.

47. Table 7.4 of Report 1743-R2 is based on the cumulative noise impact of the Elliots Hill, Wolf's Bog and Drumadarragh turbines. Taking into account the agreed 2dB reduction for ground conditions the figures in the table will reduce. For example, for property H33 Mr Hayes indicated that the noise level there would fall from 39.8dB to perhaps 38dB. He contended that that even if a property was downwind noise levels should not be expected to exceed ETSU limits. However, that table is predicated on the assumption that both the existing wind farms are in compliance with a noise limit of 37.5dB L_{A90} or Background L_{A90} plus 5dB. As noted above the Elliots Hill informative sets out a different limit and that would have an impact upon the figures set out in Table 7.4.

48. The Appellant indicated that property H45, the closest to the existing wind turbines, would not suffer any cumulative noise impact as the predicted noise level differences between the proposal and the existing wind farms were no closer than 10.9dB. It was contended that increasing the predicted noise levels from existing turbines would further reduce the noise influence of the Drumadarragh turbines on this property. While no-one disputed this view, Mr Bowdler noted that focussing on that property alone would be a 'red herring' and that all the other properties needed to be looked at. The issue of noise assessments in my experience is complicated and as Mr Hayes advised he did not know if increasing noise levels on existing turbines would bring noise level differences to no closer than 10dB at other properties. Thus, while at times the H45 property was referred to in evidence as the 'critical' or 'worst case scenario'

property I am not persuaded that it can be taken as an indication that the impacts on all other properties are acceptable.

49. Given the above it is unnecessary to consider what the appropriate ETSU-R-97 based cumulative day time lower noise limit for the area is. It is unsafe to assume that the existing turbines operate in conformity with their informatives, and they have the capacity to breach the ETSU-R-97 daytime upper amenity hours noise criterion of 40dB by themselves. In essence in terms of the limits there is no headroom available to allow the appeal proposal to proceed. It would be possible to condition noise emanating from the proposed turbines to within the limits suggested by the Appellant, but they will still add to the noise environment. There is no compelling information to demonstrate that that additional impact would not be discernible at certain wind directions and speeds at all the properties identified in the appellant's Map C27. As such it can only be concluded that the proposal would have an additional adverse impact on the existing noise environment and sensitive receptors within it.

50. The issue of Amplitude Modification (AM) was raised in objections. It was claimed that the phenomenon is present at Wolf Bog, and the experience at one of my site visits, where a 'thump' noise from Wolf Bog turbines, was heard suggests that this might be the case. However, the appeal proposal is for different turbines and there is no universally accepted methodology for fully predicting when AM may occur. In the absence of a detailed study advising that the combination of factors that can cause AM would be presented by the appeal proposal it is not a reason to justify refusal of the application. The BPG and ETSU-R-97 advise that there is no evidence that ground transmitted low frequency noise from wind turbines is at a sufficient level to be harmful to human health. There is no site specific study to indicate otherwise in this case.

51. The Department contended that even had ETSU-R-97 limits been met, certain properties (H25 - H30 on the Tildarg Road) would be subject to noise from turbines for a significantly greater period than was presently the case. Mr Bowdler judged that properties H31, H32 and H35 on Tildarg Road and down to H38 and H39 on Breckenhill Road should also be considered. The times when noise will be evident at any property depends upon wind speeds as well as wind direction. Dr Kane of H38 advised that turbine noise could be experienced at his property about 2.4km to the south-east of the existing turbines for 60-70% of the time. I note this perception, though Mr Hayes, considering a wind rose submitted in his evidence roughly calculated that from winds blowing from northerly directions noise might be experienced about 14% of the time at properties H25-H30. Winds from southerly directions might lead to noise being heard for 20% of the time. On that basis those properties could expect turbine noise to rise from 14% of the time to 34% of the time. Increases of around that amount would be a significant. The question is what would the impact be?

52. Residents of H38 and H34 advised that noise at their properties was unbearable with the resident of H34 advising of the problem with north-west winds for his property. I visited the site on two occasions when existing turbines were operational. On the afternoon of 27 May 2014 there was a light south-easterly wind. On this occasion at Tildarg Road noise from the Wolf Bog and Elliots Hill turbines was limited to a barely audible hum when wind levels dropped. Otherwise no turbine noise was discernible here or further afield. On the morning of 5 June, there was a stronger north-westerly wind. At Tildarg Road, near properties H28 to H30, about 700 metres from the existing turbines there was a constant hum audible, accompanied by a rhythmic swish. Occasionally a double swish was heard, probably due to the different turbines at Elliots Hill and Wolf Bog. When the wind dropped, turbine noise increased markedly, and the same effect was evident in the relatively sheltered location of the lane leading down to H27. The turbine noise was a distinct and constant artificial presence. No turbine noise was audible at other Tildarg Road locations or along the Ballybracken or Old Ballybracken Roads. Moving south along Breckenhill Road a constant hum was audible at H33, and when the wind speed dropped an occasional swish was also audible. At the entrance to H34 - background noise from trees was high, but when the wind dropped a loud 'thump' coinciding with the downbeat of the Wolf Bog turbines was audible. Near H38, when wind speed dropped, a constant hum was audible which could not be attributed to any source other than the turbines. No turbine noise was perceptible at other locations.

53. Given the above a number of properties, such as those at the properties H27-H30, would experience additional noise from the proposed wind farm whose nearest turbine is about 650m distant to the south-east. That noise in external areas has, whether meeting any ETSU-R-97 limit or not, given my experience the potential to be a disturbing presence. The additional level of exposure of these properties to such noise would be unacceptable. Other properties beyond are likely to have increased exposure to turbine noise as well, though the above noted properties are those most likely to be affected.

54. The Northern Health and Social Services Board HSSB advised that they had no specific concerns relating to health effects of the proposal on the population. I accept though that noise depending upon a number of factors could cause a lack of sleep and lead to other health issues. In this case the evidence from DRA indicates that a number of residents had no issue with previous wind farm developments in the area. Elliots Hill wind farm after it was constructed was seen as generally unobtrusive, but issues arose after Wolf Bog's construction. However, in only one case is there detailed evidence about health issues potentially related to turbine noise. While I give little weight to the Doctors Notes provided I found Mrs Kane of H38 to be a candid witness and I note the related informal noise diary and the example sleep recordings presented which were taken by Dr Hanning a Sleep Medium Consultant. While it was disputed whether reported symptoms could be attributed to another health condition I am satisfied that Mrs Kane had no pattern of headaches or sleepless nights until after Wolf Bog was erected and that she could not think of other factors to have caused the change in sleep patterns. I also have no reason to dispute that she sleeps better away from home. In such a situation Mrs Kane is likely to be more sensitive than most to an increase in exposure to turbine noise. So while there is insufficient evidence to demonstrate that the proposal would have any direct health impact, an increased level of stress is likely which will not assist any existing condition. This strengthens my concerns over the general increase in noise exposure that would be experienced at sensitive properties.

55. In relation to the impacts on tourism and local businesses I have considered the visual impacts of the proposals earlier. In relation to matters of noise it is noted that Mr Reade had looked at developing his business for camping, but that existing turbine noise had been an issue. However, no firm business/tourist

development proposals have been placed before me to consider. Accordingly, I simply note my earlier concerns about the increased noise environment.

56. Overall the proposal by adding to the existing noise environment would have an unacceptable adverse impact upon sensitive noise receptors in the vicinity.

Shadow Flicker

57. The BPG notes that under certain combinations of geographical position and time of day. the sun may pass behind the rotors of a wind turbine and cast a shadow over neighbouring properties. When the blades rotate, the shadow flicks on and off. The BPG notes that shadow flicker only occurs inside buildings where the flicker appears through a narrow window opening. The likelihood of this occurring and the duration of such an effect depends upon the direction of the turbines relative to a property: distance; turbine height and rotor diameter; time of year, the times during which turbines operate; frequency of bright sunshine and cloudless skies and wind prevailing wind direction. The BPG goes on to note that problems caused by shadow flicker are rare and that at distances greater than 10 rotor diameters from a turbine, the potential for shadow flicker is very low. Where shadow flicker could be a problem the BPG advises that developers should provide calculations to quantify the effect and where appropriate take measures to ameliorate the potential effect such as turning off a particular turbine at certain times. It is recommended that shadow flicker at neighbouring offices and dwellings within 500m should not exceed 30 hours per year or 30 minutes a day.

58. Shadow flicker, depending upon a number of variables, could have negative health consequences, and moving shadows falling across facades and amenity areas could adversely affect residential amenity. I have considered the various video clips provided by DRA. However, overall, those clips that could be opened simply indicate that shadow flicker can occur, and I could not discern any issue with the clip of the Wolf Bog turbines.

59. None of the proposed turbines comes within a 10 rotor distance (440 metres) of occupied buildings. The Appellant's ES contained an assessment of properties within an 800 meter radius of turbines in the original 10 turbine proposal. This assessment used industry standard software and no such alternative assessment is before me. I have no reason to judge that the inputs of turbines and property co-ordinates were wrong. The software accounted for matters such as ground contours, rotor diameter and hub heights, and by not taking account of vegetation and by simply identifying on what facades a shadow would fall it took a robust approach. Of the 25 properties within an 800 metre radius, 22 were expected to experience some shadow flicker if all the conditions for shadow flicker are met all the time. The assessment then logically factored in Met Office figures for local average sunshine hours over a 30 year period. The assessment concluded that the hours of shadow flicker at the houses within 800 metres of a turbine were within the range of 30 hours a year when adjusted for local conditions. I have no reason to dispute Ms Magee who, for the Appellant, indicated that the software would have picked up the potential for sequential shadow flicker as light moved behind a line of turbines. While turbine positions have changed since that study, the turbine numbers and sizes are now smaller and I judge that they would not result in any greater degree of shadow flicker than that identified in the ES.

60. I note the Wolf Bog shadow flicker study submitted by DRA which noted that shadow flicker would be evident from properties over 10 rotor diameters away. However, the Appellant's study was specific to this appeal site. The Appellant advised that no cumulative assessment of shadow flicker with existing turbines had been undertaken on the basis that the proposal's 10 times rotor diameter did not cross over the 10 rotor diameters of any other windfarm. I am not persuaded that this is an entirely robust approach as some element of shadow flicker can occur outwith such distances. However, there is insufficient evidence to conclude that unacceptable cumulative impacts are likely. While it was claimed that health issues had been caused locally by existing shadow flicker there is no detailed evidence of this before me to consider.

61. I do not see shadow cast per se to be an issue and the issue of reflected light can be ameliorated by semi-matt paint finishes on the turbine. Overall the issue of shadow flicker does not provide a justification for refusing the appeal.

Health and Safety

62. The Health and Safety Executive Northern Ireland (HSENI), while not a statutory consultee, advised that it had not received any reports of dangerous occurrences, accidents or cases of disease at wind farm developments in NI required by the reporting of Injuries, Diseases and Dangerous Occurrences Regulations (NI) 1997. Records provided of accidents relating to accidents elsewhere in the world do not demonstrate that the proposed wind farm is inherently unsafe. Other regulatory regimes deal with turbine safety. Given observed distances from gardens I am not persuaded that potential for ice throw is an issue. Given the existing presence of turbines in the area and having driven roads in the area the proposal is unlikely to be a significant distraction for road users.

Haulage route

63. The proposed haul route comes from Larne along the A36 to the junction with the B94 turning south. Loads will then turn right onto Tildarg Road South, left unto Breckenhill Road and right onto the Drumadarragh Road at Dickson's Corner before coming to the site entrance. A number of sharp bends will require modification and details of this are set out in the Appellant's supporting document dated August 2008. The modifications include alterations to road verges at 5 points and require for example the removal of stock proof fencing and gateways during the course of turbine deliveries. Areas will be stoned to accommodate the full turning circles and these areas are to be reinstated following construction. The document advises that full agreement with the relevant owners has been reached. Overall, these alterations are not excessive and the general condition of the affected road network is likely to cope with construction traffic. After construction traffic is unlikely to be significant. Roads Service has no objection to the proposal subject to conditions on the relocation of road signage and the formation of the site access.

64. The evidence suggests that no tree felling is required, though the clearance height of 4.6m required for delivery vehicles is likely to require the cutting back of low hanging branches at certain points. The raising of tree canopies to accommodate high vehicles is common, and the raising of levels proposed here would not be out of place. I am satisfied that there will be no unacceptable impact upon the health or appearance of affected trees.

Water Supply

65. Northern Ireland Water confirmed there is no water abstraction in the general area and that public water supplies come from an upland reservoir via pressurised water mains some 7km distant. They had no objections to the proposal.

Telecommunications

66. Consultees have not identified any insurmountable problems arising from the proposal for interference to radio systems. The issue of TV interference is one that can be, and customarily dealt with by a safeguarding condition as turbine's influence on TV and radio reception is of a predictable nature.

Decommissioning

67. Conditions regarding decommissioning are enforceable against successors in title and there is no compelling reason to question the efficacy of such an approach. A concern was raised that the concrete turbine bases, if left in the ground after decommissioning site would release harmful substances into watercourses. However, given the slow rate of decay of concrete I am not persuaded that this would be a significant issue in this location.

Property values

68. No detailed evidence of past impacts on property values arising from the presence of existing wind farms was presented, and there is no professional evidence from. for example. estate agents suggesting that property values will fall due to the proposed turbines. On that basis, and as many factors can determine property values I give little weight to concerns raised in this regard.

Environmental, Economic and Social Benefits and the Planning Balance

69. PPS18 requires these material considerations to be given significant weight in determining whether planning permission should be granted. Its Paragraph 4.1 notes that the Department will support renewable energy proposals unless they would have unacceptable adverse effects which are not outweighed by the local and wider environmental, economic and social benefits of the development.

70. I have no reason to conclude that the proposal would be denied a Grid connection. The proposal would contribute to meeting the environmental and targets referred to earlier and add to the diversity and security of energy supply. However the proposal would at best contribute 0.1% towards the NI renewable energy target set out in the SEF. That contribution needs to be seen in the context of DETI's most recent figures showing that 19.5% of NI's electricity needs are provided by renewable sources. Also, while the Appellant claimed that there was a slow rate of planning consents for wind farms, the 74 windfarms consented by the Department to date could provide in excess of 32% of NI's energy requirements. That figure excludes single wind turbines and other renewable energy sources. It is borne in mind that while no wind farm approval has yet lapsed, it is possible that schemes may not go ahead for a number of reasons such as, for example, grid connections. Nevertheless, while there is a way to go to meet targets, the above figures do not suggest to me that the NI targets are in danger of not being met.

71. It was indicated that at 2005 prices the scheme's installation would generate about £3.2M. While the turbines themselves (about 70% of the installation costs according to the Appellant) are likely to be imported there will be local economic

benefits from construction including the use of local labour and materials. Other local benefits would include fees payable to others including professionals. Such local spend will have knock on benefits for communities. There is little information on permanent employment though the ES notes that there will be infrequent though regular maintenance visits. Occasional technical problems will require maintenance visits from technical staff and a full time specialist may be required to carry out further operational controls from the control building. There would also be a degree of money coming into the economy from any future decommissioning and restoration works. It is also accepted that the proposal will generate a rates income of about £4000 per MW, and that benefits like this and rental income to a landowner have to be seen in the context of the projected 25 year lifespan of the turbines.

72. While some wind farms are signposted as tourist attractions, two wind farms already exist in the area and wind farms are now more common in the landscape. As such, and in the absence of a detailed assessment advising otherwise, I think it unlikely that the appeal proposal would be a significant tourist attractor by itself or add to the appeal of existing wind farms.

73. Considering all the above, and bearing in mind the substantial weight to be given to the benefits of the proposal I am not persuaded that they are of such a scale to justify the negative impact on residential amenity that would be caused by noise.

Conclusion

74. I have found that the proposal in conjunction with existing wind farms would have an unacceptable noise impact on sensitive receptors. This impact is not outweighed by the environmental, economic and social benefits of the proposal. As such the proposal is contrary to policy RE1 of PPS18. Given this and in the absence of any reason why the development is essential the proposal is also contrary to Policy CTY of PPS21. As such I sustain the Department's reason for refusal based on Policy RE1 of PPS18 and the objector's related concerns regarding noise impacts. Accordingly, the appeal must fail.

75. The DRA referred to the European Convention of Human Rights, namely Article 8 relating to the right to respect for private life and family life and in conjunction with that Article, Article 1 of the First Protocol which relates to the right to

protection of property. However, as I find that the appeal must fail, the ECHR is considered no further.

This decision relates to the following plans stamped refused by the Department on 15 November 2013.

Dept. Ref.		Scale:	Title:	Dwg. No.
01 (Rev D)	01	1:10560	Site Location Map	2410-D01
02 (Rev C)	02	1:2500	Site Layout Map	2410-D02
03 (Rev C)	03	1:2500	Site Layout Map	2410-D03
04 (Rev B)	05	1:200	Turbine Plan	2410-D05
05 (Rev B)	06	1:200	Turbine Elevations	2410-D06
06 (Rev A)	04	1:12500	Roads and Drainage Site Layout Master Plan	2410-D04
07 (Rev A)	07	As shown	Electrical Control Building, Plan, Section & Elevations	2410-D07
08 (Rev A)	09	1:50	Road Construction Details	2410-D09
09 (Rev A)	08	1:500	Proposed Site Entrance Details	2410-D08
10	04-1	1:1000	Roads and Drainage, Site Layout Plan Sheet 1	2410-D04-1
11	04-2	1:1000	Roads and Drainage, Site Layout Plan Sheet 3	2410-D04-2
12	04-3	1:1000	Roads and Drainage, Site Layout Plan Sheet 3	2410-D04-3
13	04-4	1:1000	Roads and Drainage, Site Layout Plan Sheet 4	2410-D04-4
14	04-5	1:1000	Roads and Drainage, Site Layout Plan Sheet 5	2410-D04-5
15	04-6	1:1000	Roads and Drainage, Site Layout Plan Sheet 6	2410-D04-6
17	04-7	1:1000	Roads and Drainage, Site Layout Plan Sheet 1 to 7	2410-D04-7

COMMISSIONER ALISTAIR BEGGS

Scientific Research Publishing

Open Journal of Social Sciences, 2017, 5, 80-107
http://www.scirp.org/journal/jss
ISSN Online: 2327-5960
ISSN Print: 2327-5952

Environmental Noise Pollution: Has Public Health Become too Utilitarian?

Alun Evans

Centre for Public Health, Queen's University Belfast, Belfast, UK
Email: a.evans@qub.ac.uk

How to cite this paper: Evans, A. (2017) Environmental Noise Pollution: Has Public Health Become too Utilitarian? *Open Journal of Social Sciences*, 5, 80-109.
https://doi.org/10.4236/jss.2017.55007

Received: March 16, 2017
Accepted: May 9, 2017
Published: May 12, 2017

Abstract

Environmental noise pollution is an ever-increasing problem. The various sources: Aircraft, Road Traffic and Wind Farms are reviewed, but the latter source, because of the intrusive, impulsive and incessant nature of the sound emitted, is the major focus of this review. Wind turbines produce a range of sound but it is the Infrasound and low frequency noise which deserves special attention. Infrasound is considered to be below the range of human hearing so it is not measured in routine noise assessments in the wind farm planning process. There is, however, evidence that many can register it and a sizeable minority is sensitive, or becomes sensitised to it. The actual route of transmission still requires elucidation. The net effect of the entire range of noise produced is interference with sleep and sleep deprivation. Sleep, far from being a luxury is vitally important to health and insufficient sleep, in the long term, is associated with a spectrum of diseases, particularly Cardiovascular. The physiological benefits of sleep are reviewed, as is the range of diseases which the sleep-deprived are predisposed to. Governments, anxious to meet Green targets and often receiving most of their advice on health matters from the wind industry, must commission independent studies so that the Health and Human Rights of their rural citizens is not infringed. Public Health, in particular, must remember its roots in Utilitarianism which condoned the acceptance of some *Collateral Damage* provided that the greatest happiness of the greatest number was ensured. The degree of *Collateral Damage* caused by wind farms should be totally unacceptable to Public Health which must, like good government, fully exercise the *Precautionary Principle*. The types of study which should be considered are discussed. Indeed, the father of Utilitarian Philosophy, Jeremy Bentham, urged that government policy should be fully evaluated.

Keywords

Environmental Noise Pollution, Wind Farms, Infrasound, Health Impacts,

Public Health, Utilitarianism, Collateral Damage, Precautionary Principle

1. Introduction

There are a number of emerging threats to Public Health, and some of these can be directly ascribed to human activity, chief among which are Global Warming, air pollution and environmental noise pollution. This paper will concentrate on the issue of environmental noise pollution and examine how modern Public Health has lived up to its responsibilities in controlling it. Over a century ago, the Nobel Prize-winning microbiologist, Robert Koch, predicted [1] "One day man will have to fight noise as fiercely as cholera and pest (plague)." The accuracy of this prediction is attested to by the statement [2] from the United States Environmental Protection Agency that, "The over-all loudness of environmental noise has been doubling every ten years in pace with social and industrial growth, and, if allowed to continue unchecked, the cost of alleviating it in the future may be insurmountable." Perhaps surprisingly, this statement is more than 40 years old, yet the problem has been growing, unchecked, ever since.

From an evolutionary perspective, an awareness of sound is essential to alert us of incipient danger, but our aural acuity may have left us vulnerable to when it is present in excess. The earliest problems arose with the introduction of noisy industrial processes a couple of centuries ago, which induced deafness [3]. We are now being bombarded with noise pollution from diverse sources, which predisposes us to a range of diseases. Light radiation ranges from Ultraviolet to Infrared, and apart from its intensity, its wavelength will determine its effect on the receiver: typically different wavelengths in the Ultraviolet range have different effects on our skin [4]. Similarly, it is not just the amplitude of noise which brings health consequences, but also, its "frequency content" (considering the sound as a stimulus rather than how frequency in the audible range is perceived as pitch).

Sound is caused by a series of pressure pulsations, or more broadly, by changes in air pressure. The spectrum of sound [4] frequency ranges from >1 to more than 20,000 cycles per second or Hz, with the range up to 20 Hz classified [5] as Infrasound, >20 - 200 Hz as low frequency sound (the lowest note on a piano has a frequency of 33 Hz and Middle C, 262 Hz [6]), >200 - 20,000 Hz as the human auditory range, and >20,000 Hz as Ultrasound. Strictly, pressure pulsations outside our auditory range cannot be described as sound but they are still able to exert an effect on us [5].

As with light, sound's effects on human health are not only determined by its intensity, or amplitude, but also by its frequency and the rate of change in amplitude. The term Infrasound is confusing, because how could sound which we are unable to hear have an effect on us? Perhaps a better way to look at it would be in terms of pressure pulsations. There is increasing evidence that Infrasound is perceived by the brain [7], and possibly by other sensory systems' vibratory receptors [8]: in the vestibular organ of balance, skin and joints, rather than by those transmitting auditory sensation [7]. Another problem with noise in the lower registers is that it persists longer, travels further and, thanks to diffraction, can turn corners [6].

This, from another evolutionary perspective, is no surprise. Many of our fellow mammals use Infrasound extensively for communication: e.g., giraffes, rhinoceroses, whales and elephants—the latter are capable of sensing distant thunderstorms, because of the Infrasound the storms emit, from over a hundred kilometres away [9], and set off in that direction in the knowledge that they will find water and green vegetation to consume. Humans carry a large range of genes which were acquired in our evolutionary past, but which are now redundant. Sometimes however, these are expressed, for example when, occasionally, someone grows a tail [10]. Olfactory receptor (OR) genes provide a good example of genes which humans possess but do not express. Mammals have over 1000 OR genes and these constitute the largest mammalian gene superfamily. In humans about 60% of these are pseudogenes and have been annulled through mutation [11]. In other primates, the pseudogene rate is about half of this. It is postulated that reduced chemosensory dependence in man drives this OR gene disruption. Individual differences in gene-expression might also explain why a small, but significant, proportion of the population may be more sensitive to the effects of Infrasound than others, and to noise in general [7]. An alternative hypothesis is that sufferers have been "sensitized" through past exposure [5], although both factors could contribute.

This review will concentrate on the adverse health effects associated with environmental noise, particularly those due to the Infrasound and low frequency noise emitted by industrial wind turbines. Some of the adverse health effects are due to sleep deprivation, and the evidence linking it to several diseases, particularly cardiovascular, will be discussed. The control of wind farm noise emissions, and its effectiveness, will be reviewed along with the appropriateness of the Guidelines governing noise limits, and where wind farms are sited. The studies which need to be mounted will then be described. The history of Public Health will be discussed, including the seminal role that Utilitarian Philosophy (the greatest happiness of the greatest number) played in its inception. The response of Public Health to new health threats will be evaluated in the light of the concepts of *Collateral Damage* and the *Precautionary Principle*. The overall aim is to evaluate the adverse health effects of industrial wind turbines and the adequacy of the Public Health response to the problems arising. In particular, the adequacy of the protection of the Health and Human Rights of rural citizens whose health is compromised by wind turbines will be scrutinized.

2. Literature Review

2.1. Extent of the Problem

The problem of noise pollution has been justly highlighted in two recent World Health Organisation reports. The first of these, entitled 'Night Noise Guidelines

for Europe', stated [12] that "… environmental noise is emerging as one of the major Public Health concerns of the twenty-first century." It observed that, "Many people have to adapt their lives to cope with the noise at night," and that the young and the old are particularly vulnerable. This is because hearing in young people is more acute and, in older people, a loss of hearing of higher sound frequencies renders them more susceptible to the effects of low frequency noise [13]. A more recent World Health Organisation report calculated [14] that more than a million healthy life years (Disability Adjusted Life Years) are lost due to environmental noise annually in western EU member states. The vast bulk of these are lost because of noise-induced sleep disturbance, followed by 'Annoyance.' This is a construct assembled from subjects' responses to a questionnaire, where subjects are asked to indicate their 'Level of Annoyance' on a scale [15]. Annoyance is a common finding reported in a population exposed to environmental noise. It is difficult to define accurately, but one authority maintains that it can result from noise interfering with daily activities, feelings, thoughts, sleep or rest, and might be accompanied by negative responses, such as anger, displeasure, exhaustion and stress-related symptoms [16]. It clearly is not a trivial state.

Sleep disturbance is serious if it leads to sleep deprivation [17], which is associated with a gamut of Cardiovascular Diseases (CVD), obesity, diabetes, and poor memory consolidation [1]. In an up-to-date meta-analysis of 160,867 subjects, in whom 11,702 cases occurred, insomnia symptoms were shown to be significantly associated with the risk of cardio-cerebral vascular events [18]; and even some cancers [19]. On top of this, inadequate sleep in children is associated with impaired memory and learning, poor cognitive function, mental health disorders, and obesity [20]. The mechanism for this is not well understood but it may be connected to higher levels of a cannabis-like chemical found in individuals who are deprived of sleep [21]. The latter is of concern because it tends to sow the seeds for diabetes and CVD in later life.

2.2. Importance of Sleep

There is an ever-mounting volume of research to show that sleep is essential for the brain and the physiological well-being of the entire body. Sleep deprivation interferes with learning, causing memory impairment because memory is laid down and reinforced during both the Slow Wave and Rapid Eye Movement phases of sleep. In mice, it has been shown that sleep plays a key role in promoting learning-dependent synapse formation and maintenance on selected dendritic branches, which contribute to memory storage [22]. There are a number of other adverse effects associated with sleep deprivation. Tired individuals are more likely to have road traffic accidents and injure themselves while operating machinery. During sleep, neurotoxins are removed from the brain [23]. Lately, an association between sleep deprivation and loss of brain volume has been demonstrated [24]. This study was based on serial MRI scans carried out in 147 community-dwelling adults. In addition, it has been demonstrated [25] that various inflammatory biomarkers are affected by sleep deprivation.

Sleep deprivation produced experimentally also very rapidly alters the expression in a wide range of genes, involving several body systems [26] [27]. This could explain the links between sleep deprivation and CVD where the putative intermediate risk factors include blood pressure, clotting factors, blood viscosity, and blood lipids and glucose [1]. The cardiovascular effects of environmental noise exposure have been reviewed recently in studies carried out in 11 countries. These compared aircraft, road and railway sources of noise: aircraft noise was identified as the most highly annoying, and railways the least [1]. It is unclear as to which frequencies are contributing most because very often the full acoustic spectrum is not assessed. Jet aircraft, in particular, produce Infrasound and low frequency noise in abundance, so people dwelling near airports suffer adverse health effects [28] [29].

Why has environmental noise pollution become such a problem? Air and road traffic have increased and industrial installations have tended to get bigger. There are noise limits set, but they may not always be enforced. The other aspect, which should be of great concern to Public Health, is that the cut-points established as safe for any factor whose risk is continuously distributed, are nearly always set too high—e.g., blood pressure and LDL cholesterol—and subsequently have to be revised downwards. Asbestos is a prime example, with the permitted level of asbestos being successively reduced over many years [30] until its use was banned in most developed countries. Airports invariably have night time restrictions on flying and road traffic noise tends to be less at night. Wind farms emit noise, sometimes for days on end, and this is a problem because they are being constructed in rural areas where background noise is low. It is a particular problem at night, because Infrasound persists long after the higher frequencies have been dissipated [6]. This paper will concentrate on the health effects of wind turbine noise, which has been shown [31] to be particularly troublesome because of its impulsive, intrusive and incessant nature.

2.3. Health Effects of Wind Turbine Noise

The major adverse health effects caused by wind turbines seem to be due to sleep disturbance and deprivation, with the main culprits identified as loud noise in the auditory range and low frequency noise, particularly Infrasound. This is inaudible in the conventional sense, and is propagated over large distances and penetrates the fabric of dwellings, where it may become amplified by resonance. A report [32] commissioned by the Scottish Government, which is investing in wind energy to a heroic degree, grudgingly accepts that wind turbine noise interferes with sleep. A recent Swedish study, conducted [33] on healthy volunteers in a sleep laboratory, has shown that the noise produced by wind turbines, particularly low frequency band amplitude modulation, is disruptive to sleep. This was indicated by an increase in electro-physiological awakenings, lighter sleep with more wakefulness, and reduced deep sleep and Rapid Eye Movement sleep.

A recent review identified [34] 146 potential papers assessing the effects of wind turbine noise, and after applying stringent criteria, came up with a shortlist of 18, of which eight were included in a meta-analysis. All studies were cross-sectional and a meta-analysis of six of these ($n = 2364$) revealed that the odds of being annoyed are significantly increased by wind turbine noise (OR: 4.08; 95% CI: 2.37 to 7.04; $p < 0.00001$). The odds of sleep disturbance were also significantly increased with greater exposure to wind turbine noise (OR: 2.94; 95% CI: 1.98 to 4.37; $p < 0.00001$). Four studies reported that wind turbine noise significantly interfered with Quality of Life. Furthermore, the visual perception of wind turbine generators was associated with a greater frequency of reported negative health effects. Visual perception and sound emissions (effects of emissions after propagation on the environment) are directly related to distance so studies need to carefully differentiate the two sources of annoyance to ensure that each is properly assessed.

Sleep deprivation has also been shown [35] to be associated with heart failure in the HUNT Study. The data are quite robust as they are based on 54,279 Norwegians free of disease at baseline (men and women aged 20 - 89 years). A total of 1,412 cases of heart failure developed over a mean follow-up of 11.3 years. A dose-dependent relationship was observed between the risk of disease and the number of reported insomnia symptoms: i) difficulty in initiating sleep; ii) difficulty in maintaining sleep; and iii) lack of restorative sleep. The Hazard Ratios were "0" for none of these; "0.96" for one; "1.35" for two; and, "4.53" for three; this achieved significance at the 2% level. This means that such a result could occur once by chance if the study were to be repeated 50 times. Significance is conventionally accepted at the 5% level.

Another important, recent study is MORGEN, which followed [36] nearly 18,000 Dutch men and women, free of CVD at baseline, over 10 - 14 years. In this period there were 607 events: fatal CVD, non-fatal Myocardial Infarction and Stroke. Adequate sleep, defined as at least seven hours a night, was a protective factor which augmented the benefits conferred by the absence of four traditional cardiovascular risk factors. For example, the benefit of adequate sleep equalled the protective contribution of not smoking cigarettes. Given that cigarette smoking is such a potent risk factor for CVD, this result is striking. The findings built on earlier ones from the MORGEN study [37]. It seems that adequate sleep is important in protecting against a range of CVDs which result when arteries of different sizes are compromised: large (coronary, cerebral) arteries in heart attacks and stroke, small arteries (arterioles) in heart failure. The mechanisms are obscure, but it is known, for example, that exposing mice to stress activates [38] hematopoietic stem cells, *i.e.* affects the immune system and accelerates atherosclerosis.

All of these studies share the weakness that they are "observational" as opposed to "experimental" and, as such, their results do not constitute "proof". The results from the experimental study of sleep deprivation of fairly short durations [26], which affected the expression of a large range of genes, sheds light on the

"Wind Turbine Syndrome (WTS)", a cluster of symptoms which includes sleep disturbance, fatigue, headaches, dizziness, nausea, changes in mood and inability to concentrate [39]. In this condition, Infrasound is a likely causal agent. Another report from HUNT has examined insomnia in almost 25,000 persons and has demonstrated [40] it to be a robust risk factor for incident physical and mental disease, which included several features of WTS.

This group has now shown, in another small intervention study, that mistimed sleep desynchronized from the central circadian clock has a much larger effect on the circadian regulation of the human transcriptome (*i.e.*, a reduction in the number of circadian transcripts from 6.4% to 1% and changes in the overall time course of expression of 34% of transcripts). This may elucidate the reasons for the large excess of cardiovascular events associated with shift work [27]. The results demonstrate that any interference in normal sleeping patterns is inimical to cardiovascular health.

The old admonition that "What you can't hear won't harm you" sadly isn't true. It is now known [41] that the organ of Corti in the cochlea (inner ear) contains two types of sensory cells: one row of inner hair cells which are responsible for hearing; and three rows of outer hair cells which are more responsive to low frequency sound. Another function of the outer hair cells is that, due to their extensibility, they can modify the sensitivity of the cochlea. This has relevance to low frequency hearing and also to detecting higher frequencies which are amplitude-modulated at lower, if not infrasonic, frequencies. The Infrasound produced by wind turbines is transduced by the outer hair cells and transmitted to the brain by Type II afferent fibres. The purpose is unclear as it results in sleep disturbance. This may well be the group which is also liable to travel sickness, which is a sizeable proportion of the population. Schomer and his colleagues have since advanced [42] the theory that as wind turbines increase in size they increasingly emit Infrasound with a frequency below 1 Hz (CPS). Below this frequency the otoliths in the inner ear respond in an exaggerated way in a susceptible minority who will suffer symptoms of WTS. Previously it was thought that the brain was only under the control of electrical and biochemical stimuli, but there is new evidence [43] that it is sensitive, in addition, to mechanical stimuli.

There were important studies carried out in the 1980s which appear to have been forgotten and which give a clue to the mechanisms involved. Danielsson and Landström carried out [44] a study in 20 healthy male volunteers who were bombarded with Infrasound for varying periods. Just 30 minutes' bombardment with 125 dB at 16 Hz resulted in a mean 8 mm increase in diastolic blood pressure. On the other hand, systolic BP was not affected, whereas the Pulse Pressure decreased. This could have important effects in those exposed to environmental Infrasound, for although the intensity may not be profound, chronic exposure might raise blood pressure a little. From a population perspective, this could raise the burden of CVD. Scientists at the University of Toronto Institute for Aerospace and the University of Waterloo found [45] variability in response in

volunteers exposed to Infrasound under laboratory conditions using Infrasound of 8 Hz. The adverse responses of some individuals closely resembled motion sickness. They postulated that individual differences in the reaction to Infrasound might be explained by variability of inner-ear structure or central adaptive mechanisms.

As far back as 1996, the International Standards Organisation acknowledged [46] that motion sickness arises from low frequency oscillatory motion below 1 Hz. The report cites: "...a range of microscopic organs (mechano-receptors) distributed in the living tissues throughout the body that variously signal changing pressure, tension, position, vibratory motion, etc." This is highly intriguing as it seems extremely plausible that the same effect obtains for Infrasound in the same frequency range and this requires urgent clarification. Indeed, the incidence of motion sickness can be predicted from the magnitude, frequency, and duration of vertical oscillation [47]. There is also mounting evidence that jet engine Infrasound can induce Vibro-acoustic Disease [48]. It is recognized [49] that around 15% - 20% of individuals are seriously affected by the Infrasound and low frequency noise produced by aircraft, particularly jets.

A recent economic assessment of US environmental noise as a cardiovascular health hazard suggested that a reduction of 5 dB would reduce hypertension by 1.4% and coronary heart disease by 1.8%, with an annual economic benefit of USD3.9 billion. The threshold for the noise-exposed group was >55 dBA LDN, though there is evidence in the literature that there may be important impacts at even lower levels of noise exposure [50]. Invariably in assessing noise exposure the average sound levels are assessed, whereas it may be that it is the peaks of sound which do the damage. In a study of seals kept in captivity, it was shown [51] that repeated elicitation of the acoustic startle reflex led to sensitization, subsequent avoidance behavior and induced fear conditioning. The data indicated that repeated startling by anthropogenic noise sources might have severe effects on long-term behavior.

An Iranian paper has lately reported [52] sleep disturbance in wind turbine workers, 53 of whom fell into three groups: mechanics, security staff and officials. The results showed that there was a positive and significant relationship between age, workers' experience, equivalent sound level, and the severity of sleep disorder. When age was constant, sleep disorders increased by 26% for each 1 dB increase in equivalent sound level. In situations where the equivalent sound level was constant, an increase in sleep disorder of 17% occurred for each year of work experience. There was a difference in sound exposure between the different occupational groups: the effect of noise in mechanics was 3.4 times greater than in the security group and about 6.5 times greater than in the official group. Sleep disorder caused by wind turbine noise was almost twice as high in the security group in comparison to the official group. It was concluded that the noise generated by wind turbines has health implications for everyone exposed to it.

In a study reported [53] from Japan, 15 subjects were experimentally exposed to various sound stimuli, including recorded aerodynamic noise and Infrasound, along with synthetic periodic sound, and were evaluated by electroencephalography. The induced rate of *alpha*1 rhythm decreased when the test subjects listened to all the sound stimuli and decreased further with reducing frequency. In particular, the induced rate of *alpha*1 rhythm, when the sound stimulus lay in the frequency band of 20 Hz, produced the lowest rate of all. It was concluded that the subjects cannot relax comfortably when exposed to Infrasound.

The European Metrology Research Programme (EMRP) has now established that everyone, at least all 16 of the healthy 18 - 25-year-old volunteers studied, can perceive Infrasound down to 8 Hz [54]. This was the lowest frequency investigated and it is likely that even lower frequencies can be perceived. 'Perception' was assessed using functional magnetic resonance imaging (fMRI) and a significant response was detected which was localized within the auditory cortex and which was present down to 8 Hz. The signal strength of the blood-oxygen-level dependent (BOLD) signal showed a minimum at 20 Hz, so a further investigation of BOLD-signal's dependence on the loudness was carried out. A decreasing dynamic range of hearing in this frequency range was noted, accompanied by the finding that even sound signals with sound pressure levels only slightly above the threshold will be registered as annoying.

Several details in the brain imaging results suggested that, at frequencies around about 20 Hz, the perception mechanism might change or is realized by a combination of different processes. One hypothesis is that a somatosensory excitation of the auditory cortex contributes at these frequencies [54]. Thus, the idea is floated that we are perceiving Infrasound directly through our body surface. This fits in with the concept of the vibration of body structures espoused by Persinger [6]. In the Cape Bridgewater study, in which turbines were intermittently turned on and off, the subject who could best predict whether or not the rotors were in motion or not was profoundly deaf [55].

The latest EMRP study conducted on 14 subjects has demonstrated [56], using fMRI, that Infrasound of 12 Hz administered at sound pressure levels just below the hearing threshold can induce changes in neural activity across several brain regions. Some of these regions are known to be involved in auditory processing, while others are recognized as playing key roles in emotional and autonomic control. Paradoxically, these effects were not observed when subjects were exposed to Infrasound of 12 Hz above the hearing threshold, because, apparently, the brain can adjust to it. These findings provide intriguing evidence that continuous exposure to subliminal Infrasound may be harmful to the human brain. Such physiological or even psychological effects could be mediated via a subconscious processing route. The transient up-regulation of these brain regions in response to Infrasound at this level may therefore reflect an initial stressor response, with symptoms becoming established through constant exposure.

The EMRP authors observe [56] that a large part of the Infrasound that we are exposed to in our daily environment is produced by continuous sources such as wind-turbines and traffic. They argue that it is these sources of constant and

subtle Infrasound, which may not attain a level exceeding the threshold of perception, which exert influences on the nervous system. Thus it seems that low levels of Infrasound really are capable of getting in 'under the radar'. It is this very level of Infrasound which authorities such as Leventhall state cannot harm you and which WHO dismisses as having no physiological or psychological effects [56].

In addition, wind turbines can, and do, cause accidents by collapsing, blade snap, ice throw, and even going on fire. They induce stress and psychological disorder from shadow flicker, which also has implications for certain types of epilepsy and autism. Even the current planning process, with its virtual absence of consultation, is stress inducing, as is the confrontation between landowners, who wish to profit from erecting turbines, and their neighbours, who dread the effects on their health. Finally, wind turbines considerably reduce the value of dwellings nearby and this has a negative long-term effect on their owners' and their families' health [57]. On top of this, increasing numbers of families will be driven into fuel poverty by spiralling electricity costs which are subsidizing wind energy.

2.4. Controlling Wind Farm Noise

Another aspect is that the instruments and methods used to assess the cut-points may be inappropriate or inaccurate. The United Kingdom's Batho Report of the Noise Review Working Party in 1990 identified [58] low frequency noise as having a serious effect on those exposed to it. It also commented that the use of the A-weighted scale to assess low frequency noise was not appropriate. The A-weighted scale was in fact designed to reflect the normal human auditory range for many common urban/suburban noise sources. The rationale for this derives from work published by Fletcher and Munson [59] in 1933 using pure tones and ear-occluding headsets (headphones) with the object of increasing the distance over which the human voice could be transmitted by telephone wire. The tests were therefore conducted in a setting intended to mimic the use of an ear-occluding headset, *i.e.*, a telephone. The use of occluded ears and pure tones is a totally artificial situation and not directly comparable to "free-field" hearing. Normal hearing occurs in "free field", without occluding the ear, and in the presence of many other background sounds.

When a noise emits more Infrasound and low frequency energy than usual, the use of A-weighted thresholds and measurements is not protective. If unweighted Infrasound measurements had been used to investigate Sick Building Syndrome, its generally accepted cause, Infrasound and low frequency rumble, could have been detected much earlier [60]. It has been known for a long time that fans turning inside buildings can make people sick [61] and there are questions remaining about the effects of even larger fans turning outside buildings [60], *i.e.* wind turbines.

The problem of Infrasound and low frequency noise was well-recognized in a Report by Casella Stanger, commissioned by DEFRA in 2001 [62] with the statement that: "It should not be regarded as formal guidance from DEFRA", but what is unclear is just when this advice was added. The Report advises, "For people inside buildings with windows closed, this effect is exacerbated by the sound insulation properties of the building envelope. Again, mid and high frequencies are attenuated to a much greater extent than low frequencies." It continued: "As the A-weighting network attenuates low frequencies by a large amount, any measurements made of the noise should be with the instrumentation set to linear." It drew heavily upon the Batho Report of 1990 [58]. In fact, these problems had already been elucidated and the measurement issues addressed in a trio of papers by Kelley and his colleagues in the 1980s [63] [64] [65]. Kelley and his colleagues began investigating a single turbine at Boone, North Carolina, in late 1979 when around 12% of families within 3 km where impacted by noise emissions from a single wind turbine. The 237-ft high 2 MW turbine with four cylindrical legs was perched "atop Howard's Knob" and the passage of the rotors past the legs caused low frequency pressure pulsations to be propagated into the structures in which the complainants lived. The situation was aggravated further by a complex sound propagation process controlled by terrain and atmospheric focusing. The report runs to 232 pages and is certainly comprehensive [64].

The annoyance was described as an intermittent "thumping" sound accompanied by vibrations. A "feeling" or "presence" was described, felt rather than heard, accompanied by sensations of uneasiness and personal disturbance. The "sounds" were louder and more annoying inside the affected homes. Some rattling of loose objects occurred. In one or two instances, structural vibrations were great enough to cause dust to fall from high ceilings and create an additional nuisance. The noise was found to be more persistent and perhaps more severe at night. Moreover, it was noted as being worse in small rooms, usually bedrooms. The impulsiveness of the emitted low frequency acoustic radiation was identified as a major factor in determining not only the level of potential annoyance to residents within a structure, but perception as well. Various recommendations were made concerning noise reduction [65].

Kelley and his colleagues' research was promoted at conferences on wind turbine noise but seems to have been ignored or forgotten, so the problem continues to be seriously underestimated. When measured using a tool which can detect it, levels of Infrasound and low frequency noise are disturbingly high, with 'sound pressure levels' greater than previously thought possible [66]. It has also been demonstrated that infrasonic noise interferes with the micro-mechanics of the human inner ear [67].

In February 2003, the UK Department of Trade and Industry launched [68] 'Our Green Energy Future,' which committed the country to wind energy. Despite the existence of the Casella Stanger Report warning about Infrasound and low frequency noise and its caveats about how it should be assessed, the Government used another Report dated May 2003 which told a rather different story [5]. Although a lot more comprehensive than the Casella Stanger Report [62], it

was aligned with the ETSU-R-97 recommendations [69] (see below). This is all rather reminiscent of the allegedly "Dodgy Dossier" which the then Prime Minister, Tony Blair, used to launch the UK's involvement in the Iraq war the same year. It was published by the same Government Department which had published the Casella Stanger Report two years before. This looked remarkably like the Government commissioning the report which would facilitate its energy policy.

The Report by Leventhall [5], who has acted as a noise consultant to wind companies, actually states, "The effects of Infrasound or low frequency noise are of particular concern because of its pervasiveness due to numerous sources, efficient propagation, and reduced efficiency of many structures (dwellings, walls, and hearing protection) in attenuating low frequency noise compared with other noise," but it seems that this was the work of a co-writer. Despite this, the message conveyed is that modern wind turbines are not an important source of Infrasound and the use of A-weighting is entirely adequate. The report also states that "Infrasound exposure is ubiquitous in modern life." This may be so, but Persinger makes [6] the point that naturally occurring Infrasound, including that produced within our own bodies, is random, whereas wind turbine Infrasound is pulsatile; and it is this quality which causes health problems.

The message concerning the appropriateness of using A-weighting in assessing sound has recently been reasserted by Leventhall and three of his fellow acousticians [70]. This was in spite of the fact that three of them had previously recommended, in joint and separate statements and publications, that Infrasound should be viewed as a source of adverse effects.

2.5. Wind Farm Guidelines

In the UK, the construction of wind farms is predicated on ETSU-R-97 which was organized by the wind industry, ably assisted by acousticians and others associated with the industry, without a single Sleep Physician, in 1996-1997 [69]. The authors state in the executive summary: "This document describes a framework for the measurement of wind farm noise and gives indicative noise levels thought to offer a reasonable degree of protection to wind farm neighbors, without placing unreasonable restrictions on wind farm development or adding unduly to the costs and administrative burdens on wind farm developers or local authorities." Despite these lofty ideals, a recent review observed [71]: "Exposure to wind turbines does seem to increase the risk of annoyance and self-reported sleep disturbance in a dose-response relationship. There appears, though, to be a tolerable level of around L_{Aeq} of 35dB. " This is about 6 dB less than the permitted ETSU-R-97 night time level, implying a doubling of the setback (assuming a decay of noise level of 6 dB per doubling of distance). The ETSU-R-97 recommendations were based on the turbines of the mid 1990s which had a hub-height of 32 m, whereas today's turbines are several times taller with blades that are much longer and more flexible.

Applying the ETSU-R-97 methodology, which is still in force, setback distances for human habitation from modern 2.5 - 3 MW turbines are in the region of 500 - 600 m. There are good reasons for believing that these setbacks are woefully inadequate. A 2013 Marshall Day Acoustics 'Examination of the significance of noise in relation to onshore wind farms' [72], commissioned by the Sustainable Energy Authority of Ireland, reproduces a graph from the Møller and Pedersen paper of 2011 [73]. This shows how the noise emitted by a turbine increases with size. In fact, a doubling in turbine generating capacity from 1 MW to 2 MW may result in slightly more than a doubling of the overall A-weighted sound power level, that is, an increase of more than 3 dB. Also, for a range of turbines with the same power generating capacity, sound level output can vary by several decibels. Moreover, it was noted that while audible sound increased with increasing turbine size, the emission of low frequency sound was disproportionally greater. Shifting the acoustic energy into the lower frequencies renders A-weighted measurements and guidelines even less applicable. These data applied to turbines up to 3.6 MW, but are expected to apply to even larger ones. It was noted that the relationship is not necessarily statistically significant, which may well be the case, but it is almost certainly biologically significant.

In Ireland, the current setback, introduced in 2006, is a mere 500 m, although there have been repeated promises by government to increase it [74]. There are also concerns about the use of average noise levels as these smooth out the peaks. It is these sound pressure peaks which may be sensitizing people to noise, as has been shown in the case of seals [51]. Averaging only serves to conceal important characteristics which exert adverse effects on living things.

In 2008, the distinguished American acoustic engineers, George Kamperman and Richard James, posed [75] the question: "What are the technical options for reducing wind turbine noise emission at residences?" They observed that there were only two options: i) increase the distance between source and receiver; or ii) reduce the source sound power emission. They added that neither solution is compatible with the objective of the wind farm developer to maximize the wind power electrical generation within the land available. They also highlighted the fact that Vestas' employees are not allowed to go within 400 m of a turbine while it is in motion. Turbines can produce Infrasound even when they are not running when wind excites the tower and blades. Long-range measurements from two different wind farms over a distance of 80 km have shown that Infrasound below 6 Hz has a propagation loss approximating to 3 dB per doubling of distance [76].

Lastly, carpeting the Irish landscape with wind turbines has led to a proliferation in power lines which come with their own health risks. An association between living close to high voltage power lines and the development of childhood leukemia has been consistently observed [77]. Recent epidemiological studies are in agreement with earlier findings of an increased risk of childhood leukemia with estimated daily average exposures above 0.3 to 0.4 μT. Although no mechanisms have been identified and consequently causality cannot be ascribed [77], in view of its serious nature the association cannot simply be ignored.

2.6. What Studies Should be Mounted?

Although the associations between noise pollution, particularly from Infrasound and low frequency noise, and ill health can be argued against, and there are gaps in our knowledge, there is sufficient evidence to cause grave misgivings about its safety. Further research, supported by adequate funding, remains necessary. Good and caring Government should entail acting with greater caution when its policies could jeopardize the Health and Human Rights of its people.

So what studies need to be mounted? Hessler and his colleagues, as well as upholding [70] the adequacy of A-weighting, pose the question: "Do wind turbines make people sick? That is the issue."

This paper, written by four "scientists in the wind turbine acoustical field" who "do not doubt for a moment the sincerity and suffering of some residents close to wind farms and other low frequency sources, and this is the reason all four would like to conduct, contribute or participate in some studies that would shed some light on this issue." This all sounds very laudable, but the basic contention of their paper is that there is no adverse human health effect from low frequency noise and Infrasound, provided that A-weighting is used to measure them and current guidelines are adhered to. What, precisely, qualifies them to pronounce on health issues is obscure.

They continue: "It must also be said that it is human nature to exaggerate grievances and that some qualitative measure must be made available to compensate affected residences." It is hard to assimilate the logic of this sentence, but the first part is clearly intended as an antidote to the residents' "sincerity and suffering" described earlier in the paragraph. It should be pointed out that babies, young children, and animals that are unable to "exaggerate grievances" are also seriously impacted when exposed to low frequency noise and Infrasound, eg badgers [78], pigs [79], crabs [80] and, perhaps, even plants [81]. The phrase "exaggerate grievances" is also redolent of accusing sufferers of hysteria, which is all rather cynical. A similar fate befell Myalgic Encephalomyelitis sufferers when they had their condition derisively dismissed as "Yuppie Flu", until in 2011, when it was finally accepted as a true disease entity and International Consensus Criteria were developed [82].

Some of the studies the "scientists" propose [70] are not particularly scientifically robust: e.g., National Surveys, collecting cross-sectional data which may reveal associations, which, no matter how strong, cannot establish causation, are slow, inconclusive and favor the *status quo*; and Noise Source Reduction, *i.e.* trying to reduce noise emissions from turbines, which seems welcome but oddly similar to the tobacco industry's attempts to reduce tar in tobacco while ignoring the fact that tobacco smoke contains a cocktail of noxious elements [83], as wind turbine noise certainly also does. For example, in addition to Infrasound, Amplitude Modulation related to wake interference between turbines [84] can effectively double the noise produced. This is particularly likely to occur when turbines are crowded too close together, which also reduces their output [85].

Some other suggestions are better such as Perception Testing to investigate whether receivers have the ability to detect a turbine's activity without actually seeing or hearing it. It seems that it is only a minority, albeit a significant one, which is impacted by it. Moreover, whichever pathway transmits Infrasound to the brain is immaterial as it is unquestionably registered there. As noted above, one person who is sensitive to feeling the pulsations has nerve deafness. Furthermore, published reports by acousticians who are sensitive to infrasonic pressure pulses should establish that people can feel them even when sound pressure levels are insufficient to achieve the threshold of audibility [86].

The Recommendation [70] concerning Simulation appears the most sensible, by duplicating and simulating low frequency noise and Infrasound with loudspeakers, and exposing volunteers to high and low levels, to establish threshold levels. This approach would be valid if the sound correctly reflects what is experienced by people exposed to wind turbine noise. Such is the nature of the pulsations that electronic systems employing loudspeakers cannot reproduce them accurately. This all begs the question as to why not carry out this study in the field and measure some hard endpoints?

As the authors point out: "Realistically, it is not even possible to answer the posed question to all parties' satisfaction with practical research. For examples, a direct link to adverse health effects from yesterday's tobacco and today's excess sugar can be denied forever, because any research that could actually prove a link to all parties would take longer than forever and would be totally impractical." Surely there is ample evidence that sugar consumption, as it is a rich source of calories, is associated with obesity? This, although arguably not a disease in itself, is a powerful marker for a range of diseases. In this sense obesity represents a strong "intermediate phenotype" lying on the physio-pathological pathway between health and disease. Similarly, in relation to tobacco, there are biomarkers which are elevated in people who smoke and which indicate an increased risk of lung and other associated cancers [83].

So, does Infrasound and low frequency noise emitted by wind turbines make people sick? The authors comment [70] that, "It is abundantly obvious that intense adverse response occurs at certain sites" but stop short of admitting that it does make people sick, despite their having investigated complaints reported to them by adversely affected citizens. The authors support wind energy: "Likewise, wind farm opponents must accept reasonable sound limits or buffer distance to the nearest turbine—not pie-in-the-sky limits to destroy the industry." This all depends on what is considered "reasonable."

It is abundantly clear that sound levels involve a similar, continuous increase in risk, in a similar way that the amount of tobacco smoked determines [81] the risk of lung cancer. That is why cut-points for the levels of sound permitted were established in an attempt to protect receivers. What we have learned about cut-points in the past, for example from the asbestos scandal, is that, from the outset, cut-points are invariably placed too high and constantly need to be reduced [30].

In the late 18th century, the great Scottish Anatomist, John Hunter, wrote to his protégé, Edward Jenner, asking him: "Why think? Why not do the experiment?" [87]. He was exhorting Jenner to measure the core temperature of a hibernating hedgehog. We all have remnants of the genes for hibernation but we don't express them [88]. Similarly, in common with some animals, we possibly all have the genes for reacting to Infrasound, but only some of us express them.

It would be perfectly feasible to mount an experiment, a randomized cross-over trial, in which persons impacted by wind farm noise have their biomarker levels [25] [89] measured after standardized periods of exposure and non-exposure to wind turbine noise. In this way, each person would act as his or her own control. A well-devised trial could be of modest size, be cheap to conduct and deliver results relatively quickly. Assessment of the blood transcriptome [26] would increase the scope of such a trial, as would cortisol assessment [78]. This study could be augmented with the 'Simulation' study proposed by the authors to identify critical frequencies and sound levels if a test chamber and audio system can be devised which accurately reproduces the pulsations experienced in people's homes. Besides, the comparison of means makes for a more powerful statistical analysis. This sort of study will quickly indicate whether exposure to wind turbine noise is safe or not. It has a huge advantage over prospective studies which will take years to accumulate hard disease endpoints, as was the case with tobacco. For many people exposed to industrial wind turbines the question as to whether they can feel or otherwise sense them has already been answered. Could the reluctance of the wind industry to mount the appropriate studies be due to the worldwide spate of complaints from those exposed to wind turbine noise?

The Salford Report, again written [32] by a group of acousticians without any input from sleep experts, concluded that there is "… some evidence for sleep disturbance which has found fairly wide, though not universal, acceptance." The increasing weight of evidence of sleep deprivation's association with several chronic diseases is totally ignored. The authors of the Report are at pains to deny any "direct" health effects. In terms of prevention, any differentiation between 'direct' and 'indirect' is irrelevant: in 271 BC, the Roman consul Manius Curius Dentatus ordered the construction of a canal (*the Curiano Trench*) to divert the stagnant waters surrounding the River Velino in Umbria over the natural cliff at Marmore, to produce Cascata delle Marmore [90]. Romans had an aversion to drinking stagnant water and went to great lengths to "drain the swamp" because they associated it with illness. In this case the stagnant water was only "indirectly causal" but was vital to the propagation of Malaria, and hence draining the swamp abolished Malaria locally.

Governments pursuing renewable energy targets must adhere to the *Precautionary Principle* (see below). They have a duty to commission appropriate studies to ensure that the health of their rural citizens is adequately protected. It might be assumed that the wind industry would have carried out these studies as part of its "due diligence", but, to date, no such studies have been forthcoming.

3. The Public Health Perspective

3.1. Public Health and Utilitarianism

Public Health developed in different ways in different countries. In Europe, Johann Peter Frank's *System einer vollstädigen medinischen Polizey* was particularly influential [91]. Frank's epic work was published in six volumes between 1779 and 1817 and promoted the concept of "Medical Police". The word 'Police' here connotes public administration. It was taken up by Andrew Duncan (Senior) in the Edinburgh University Medical School, who published a "Memorial" in 1798 presenting an outline of what he saw as a comprehensive course of instruction in Medical Police [92]. The concept spread to Ireland, where Henry Maunsell was appointed as Professor of Political Medicine at the Royal College of Surgeons of Ireland in 1841 [93].

The concept was also adopted in England, where Edwin Chadwick wrote upon Preventive Police in 1829 [94]. Chadwick was a lawyer and "...'the bureaucratic radical'... disciple of the archutilitarian [sic] Jeremy Bentham," who in 1842 was to publish his famous *Report on the Sanitary Conditions of the Labouring Population of Great Britain*, which he wrote in his position as Secretary to The Poor Law Commissioners. As a young man, Chadwick was Bentham's assistant and he afterwards applied Bentham's Utilitarian principles to Public Health [95]. Chadwick's *Report* paved the way for the establishment of the General Board of Health in 1848, under the great Public Health Act [96]. Chadwick's work heading the Board strongly influenced the thinking of doctors such as John Simon, and this marks the birth of Public Health in England [96] and the Medical Officers of Health. Thus, in Britain, modern Public Health grew out of the Utilitarian philosophy, developed by Jeremy Bentham, which enshrined the ethos that a morally good action is one that helps the greatest number of people.

However, it now seems that economic growth, particularly during a recession, is such an important goal that other aspects, such as health, are seen as being of secondary importance. It is essential that Public Health should increase its vigilance; to do any less would be to betray its proud past.

3.2. Collateral Damage

In the United Kingdom in1853, a Vaccination Act was passed: it was a *compulsory* act which decreed that all parents had to have their infants vaccinated against Smallpox within three months of birth. It supplanted the *permissive* Vaccination Act of 1840, which simply hadn't worked. Although it was known that a small proportion of children would succumb to the effect of the vaccination, this was trifling in comparison to the number of deaths from Smallpox which would be prevented [97]. In effect, Public Health had accepted the principle of *Collateral Damage*, provided that the overall benefit was large and the damage was small. Eventually, by the 1970s, vaccination was phased out because as the eradication of Smallpox approached, vaccinia was claiming more lives than Smallpox was [98].

3.3. The Precautionary Principle

The problem is just how much *Collateral Damage* is acceptable? When the BSE epidemic emerged in the late 1980s, the Government insisted that, providing simple measures were applied, beef was perfectly safe. The Minister of Agriculture went public and was photographed administering a hamburger to Cordelia, his four-year-old daughter [99]. Instead of applying the *Precautionary Principle* (enabling rapid response in the face of a possible danger to human, animal or plant health) [100], which should have triggered primate feeding experiments, the Government decided to tough it out, apparently for the health of the Farming Industry rather than for the health of its citizens. It compromised by having neural tissue separated from meat, seemingly oblivious of the fact that nerves innervate muscle. In effect, the experiment was being carried out on an unsuspecting populace.

In 1996, the first vCJD cases were identified and epidemiologists predicted thousands of deaths. Public Health was remarkably quiet on the issue but, to date, the disease has only resulted in 177 deaths. The reason that it has not been higher lies in the fact that there is a very specific genetic element as to who will develop the disease. There were no long-term monitoring measures put in place, but *ad hoc* studies indicate that the number of people infected with abnormal prion protein may be in the region of 30,000 [101]. Although representing only a small proportion of the total population, it still lies uneasily with Utilitarian principles in that the level of possible *Collateral Damage* was unacceptably large.

A similar population experiment seems to be underway in terms of environmental noise pollution. Governments, faced with economic recession, have been keen to increase economic activity and meet Green targets. As a result, environmental noise has increased. Public Health must maintain its position as champion of the health of the public and not just slavishly back up government policy. How can it be that environmental noise pollution continues to escalate despite the very real adverse effects it exerts on human health? A recent report from the Royal Society of Public Health has placed stress [102] on the importance of sleep to health. This is all very well, but nowhere in the 30-page document is there a mention of the role of noise in disrupting sleep, in fact the word "noise" is completely omitted. Perhaps the Royal Society was anxious not to open the noise can of worms? In her 'Notes on Nursing' in 1859 [103], Florence Nightingale was not so squeamish, because when she extolled the importance of sleep to health, she was also attuned to the deleterious effects of noise: "Unnecessary noise...is the most cruel absence of care which can be inflicted either on sick or well."

As sleep deprivation is the most important health-damaging effect of environmental noise pollution, Public Health should be treating the matter very seriously. Indeed, the United Nations Committee Against Torture (UN CAT) has explicitly identified "sleep deprivation for prolonged periods" [104] as a method of torture. In 1978, in a case taken to Europe by the Irish Government, the British Government was found guilty of applying five techniques, including subjection to noise and deprivation of sleep [57]. These were used in Ulster to 'encourage' admissions and to elicit information from prisoners and detainees. They amounted to humiliating and degrading treatment, *i.e.* torture. Although the judgment was afterwards overturned on appeal, and downgraded to 'inhuman or degrading treatment', the action is still alive. The case being taken by 'The Hooded Men' is being backed by the Irish Government [105]. This same Government, by its failure to revise the turbine setback guidelines, is imposing noise and sleep deprivation on its rural citizens.

3.4. Public Health's Responsibilities

When Public Health doctors are asked about possible health effects, they tend to dismiss the literature as either non-peer-reviewed, or if it is a review, non-systematic. If they want to read a comprehensive, thorough and systematic review, they should look no further than that by Punch and James [106]. The Public Health Agencies in the UK are now relying on a document published in April 2013 which is also not peer-reviewed [32]. As already mentioned, was written by a group of acousticians at the University of Salford, which begs the question as to why such a group was selected to pronounce on health issues. Since acousticians derive a significant proportion of their income from the wind industry, their scientific objectivity might be open to question. Similarly, if a profession which worked closely with the tobacco industry was asked to report on health, questions would be asked.

Recently, a Vestas PowerPoint presentation from 2004 has surfaced [107] demonstrating that Vestas knew over a decade ago that safer buffers were required to protect neighbors from wind turbine noise. They knew their pre- construction noise models were inaccurate and that "...we know that noise from wind turbines sometimes annoys people even if the noise is below noise limits." Similarly, we are repeatedly told that modern turbines are quieter and produce less Infrasound and low frequency noise, which in reality is the reverse of the case. Denmark has been in the vanguard of wind energy development and there is a Danish initiative entitled "WIND2050" [108]. This appears to seek to promote the interests of the wind industry, particularly through encouraging "Community Ownership" of wind farms. To enable this, the project is "mapping criticism", *i.e.* assembling maps to show where rural citizens have raised any objection to wind farm development. It seems analogous to tobacco companies keeping smoking cessation clinics under surveillance.

There has been a tendency for Public Health to toe the official line that wind farms are entirely safe. This is the message promulgated by the wind industry so Public Health should be evaluating the evidence more critically. If Public Health doctors actually visited the families who have been forced to abandon their homes they might demand to see the necessary studies conducted. They would learn that some of the worst affected are small children who are very often put in the smaller bedrooms which are worst impacted by noise [64]. There is also the intriguing possibility that if Infrasound is conducted through the skin [54], young children will receive a larger dose because their surface area is greater in

relation to their volume in comparison to adults. This is why small children lose heat faster than adults.

To her credit, in 2014, one Irish Public Health doctor, the Deputy Chief Medical Officer, actually stated that while turbines do not represent a threat to Public Health, "there is a consistent cluster of symptoms related to living in close proximity to wind turbines which occurs in a number of people in the vicinity of industrial wind turbines" and that "These people must be treated appropriately and sensitively as these symptoms can be very debilitating" [109]. The Irish Wind Energy Association promptly rounded on her with the accusation of her "having focused on out-of-date information," but she stood her ground admirably.

In view of the foregoing considerations, and because Public Health's apparent official view is that there are no important health effects caused by exposure to wind turbine noise, a reappraisal of the evidence is overdue. Public Health doctors should be conducting focused epidemiological studies, but this is something that they haven't displayed much aptitude for of late. Apart from anything else, Public Health should be rigorously applying the ***Precautionary Principle*** or ***Primum non nocere*** (First, do no harm) ideal, putting monitoring and evaluation in place and then undertaking the appropriate studies. A recent review of peer-reviewed studies published between 2000 and 2015 concluded [110] that the estimated pool prevalence of high subjective annoyance was around 10%. This figure is very close to that found by Kelley [64] and his colleagues cited above, although the true figure may well be higher. The authors observed that epidemiological research on low frequency noise is scarce and suffers from methodological shortcomings. They added that low frequency noise in the everyday environment is an issue which requires more research attention, particularly for people living in the vicinity of relevant sources.

Environmental noise pollution, particularly when it deprives people of sleep, is especially related to the development of CVD, as a recent paper concluded that: "... the public health impact of sufficient sleep duration, in addition to the traditional healthy lifestyle factors, could be substantial" [36]. Public Health must take its responsibilities seriously to protect the Health and Human Rights of all citizens. Despite a desire to meet various Renewable Energy targets, Government must ensure that the appropriate studies are undertaken in order to protect the sizeable minority of the exposed population which suffers adverse effects. In fact, Jeremy Bentham shrewdly anticipated the necessity for Government support for research in both theory and practice [111]. In the 19^{th} century, Public Health acted to protect the health of town dwellers, thrown together by the Industrial Revolution. People had moved from the country into towns where they were exposed to industrial pollution. We are now witnessing the reverse process, a second Industrial Revolution, in which large industrial machines are being imposed on rural dwellers, and Public Health must act to see that sufficient safeguards are put in place so that rural citizens' health is fully protected.

As Bradford Hill observed [112] over half a century ago: "The lessons of the past in general health and safety practices are easy to read. They are characterised by empirical decisions, by eternally persistent reappraisal of public health standards against available knowledge of causation, by consistently giving the public the benefit of the doubt, and by ever striving for improved environmental quality with the accompanying reduction in disease morbidity and mortality". Quite so, it is high time that Public Health gave the public the benefit of the doubt.

4. Conclusion

So has Public Health become too utilitarian? All the available evidence indicates that an important minority of local inhabitants is severely impacted by noise emitted by wind farms sited too close to their homes. This degree of *Collateral Damage* is too large to accept in terms of Utilitarianism. Public Health must exercise the *Precautionary Principle* and retain as much independence from government as possible in assessing the health effects of national policies. The Health and Human Rights of rural-dwelling citizens are every bit as important as those of the rest of society. In fact, in terms of wind energy, the overall benefit is fairly modest [113] [114] and the adverse effect on people's health is far from small. It is essential that separation distances between human habitation and wind turbines are increased. There is an international consensus emerging for a separation distance of 2 km; indeed some countries are opting for 3 km and more. Furthermore, the appropriate, focused studies should be undertaken as soon as possible.

References

[1] Münzel, T., Gori, T., Babisch, W. and Basner, M. (2014) Cardiovascular Effects of Environmental Noise Exposure. *European Heart Journal*, **35**, 829-836. https://doi.org/10.1093/eurheartj/ehu030

[2] Meyer, A.F. (1971) EPA's Noise Abatement Program. United States Environmental Protection Agency, Washington DC.

[3] Basner, M., Babisch, W., Davis, A., *et al.* (2014) Auditory and Non-Auditory Effects of Noise and Health. *The Lancet*, **383**, 1325-1332.

[4] Mead, M.N. (2008) Benefits of Sunlight: A Bright Spot for Human Health. *Environmental Health Perspectives*, **116**, A160-A167.

[5] Leventhall, G. (2003) A Review of Published Research on Low Frequency Noise and Its Effects. Report for DEFRA.

[6] Persinger, M.A. (2014) Infrasound, Human Health, and Adaptation: An Integrative Overview of Recondite Hazards in a Complex Environment. *Natural Hazards*, **70**, 501-525.

[7] Salt, A. and Lichtenhan, J.T. (2014) How Does Wind Turbine Noise Affect People? *Acoustics Today*, Winter, 20-28.

[8] Hubbard, H.H. (1982) Noise Induced House Vibrations and Human Perception. *Noise Control Engineering Journal*, **19**, 49-55. https://doi.org/10.3397/1.2827592

[9] Kelley, M.C. and Garstang, M. (2013) On the Possible Detection of Lightning Storms by Elephants. *Animals*, **3**, 349-355. https://doi.org/10.3390/ani3020349

[10] Ledley, F.D. (1982) Evolution and the Human Tail: A Case Report. *The New England Journal of Medicine*, **306**, 1212-1215. https://doi.org/10.1056/NEJM198205203062006

[11] Nimura, Y. and Nei, M. (2003) Evolution of Olfactory Receptor Genes in the Human Genome. *Proceedings of the National Academy of Sciences of the United States of America*, **100**, 12235-12240. https://doi.org/10.1073/pnas.1635157100

[12] World Health Organisation (2009) Night Noise Guidelines for Europe. WHO Regional Office for Europe, Copenhagen.

[13] Boselli, M., Parrino, L., Smerieri, A. and Terzano, M.G. (1998) Effect of Age on EEG Arousals in Normal Sleep. *Sleep*, **21**, 351-357.

[14] World Health Organisation (2011) Burden of Disease from Environmental Noise: Quantification of Healthy Life Years Lost in Europe. WHO Regional Office for Europe, Copenhagen.

[15] Fields, J.M., De Jong, R.G., Gjestland, T., *et al.* (2001) Standardized General-Purpose Reaction Noise Questions for Community Noise Surveys: Research and a Recommendation. *Journal of Sound and Vibration*, **242**, 641-679.

[16] Ohrstrom, E., Skanberg, A., Svensson, H. and Gidlof-Gunnarsson, A. (2006) Effects of Road Traffic Noise and the Benefit of Access to Quietness. *Journal of Sound and Vibration*, **295**, 40-59.

[17] Hume, K.I., Brink, M. and Basner, M. (2012) Effects of Environmental Noise on Sleep. *Noise & Health*, **14**, 297-302.

[18] He, Q., Zhang, P., Li, G., Dai, H. and Shi, J. (2017) The Association between Insomnia Symptoms and Risk of Cardio-Cerebral Vascular Events: A Meta-Analysis of Prospective Cohort Studies. *European Journal of Preventive Cardiology*. https://doi.org/10.1177/2047487317702043

[19] Chung, S.A., Wolf, T.K. and Shapiro, C.M. (2009) Sleep and Health Consequences of Shift Work in Women. *Journal of Women's Health*, **18**, 965-977. https://doi.org/10.1089/jwh.2007.0742

[20] Carter, P.J., Taylor, B.J., Williams, S.M. and Taylor, R.W. (2011) Longitudinal Analysis of Sleep in Relation to BMI and Body Fat in Children: The FLAME Study. *BMJ*, **342**, d2712. https://doi.org/10.1136/bmj.d2712

[21] Hanlon, E.C., Tasal, E., Leproult, R., *et al.* ((2016) Sleep Restriction Enhances the Daily Rhythm of Circulating Levels of Endocannabinoid 2-Arachidonoglycerol. *Sleep*, **39**, 653-664. https://doi.org/10.5665/sleep.5546

[22] Xie, L., Kang, H., Xu, Q., *et al.* (2013) Sleep Drives Metabolite Clearance from the Adult Brain. *Science*, **342**, 373-377. https://doi.org/10.1126/science.1241224

[23] Yang, G., Lai, C.S.W., Cichon, J., Ma, L., Li, W. and Gan, W.-B. (2014) Sleep Promotes Branch-Specific Formation of Dendritic Spines after Learning. *Science*, **344**, 1173-1178. https://doi.org/10.1126/science.1249098

[24] Sexton, E.S., Storsve, A.B., Walhovd, K.B., Johansen-berg, H. and Fjell, A.M. (2014) Poor Sleep Quality Is Associated with Increased Cortical Atrophy in Community-Dwelling Adults. *Neurology*, **83**, 967-973. https://doi.org/10.1212/WNL.0000000000000774

[25] Irwin, M.R., Olmstead, M.R. and Carroll, J.E. (2016) Sleep Disturbance, Sleep Duration and Inflammation: A Systematic Review and Meta-Analysis of Cohort Studies and Experimental Sleep Deprivation. *Biological Psychiatry*, **80**, 40-52. https://doi.org/10.1016/j.biopsych.2015.05.014

[26] Möller-Levet, C.S., Archer, S.N., Bucca, G., *et al.* (2013) Effects of Insufficient Sleep on Circadian Rhythmicity and Expression Amplitude of the Human Blood Transcriptome. *Proceedings of the National Academy of Sciences of the United States of America*, **110**, E1132-E1141.

[27] Archer, N.A., Laing, E.E., Möller-Levet, C.S., *et al.* (2014) Mistimed Sleep Disrupts Circadian Regulation of the Human Transcriptome. *Proceedings of the National Academy of Sciences of the United States of America*, **111**, E682-E691. https://doi.org/10.1073/pnas.1316335111

[28] Hansell, L.H., Blangiardo, M., Floud, F., *et al.* (2013) Aircraft Noise and Cardiovascular Disease near Heathrow Airport in London: Small Area Study. *BMJ*, **347**, 15432.

[29] Greiser, E. and Glaeske, G. (2013) Social and Economic Consequences of Night-Time Aircraft Noise in the Vicinity of Frankfurt/Main Airport. *Gesundheitswesen*, **75**, 127-133.

[30] Bartrip, P.W. (2004) History of Asbestos Related Disease. *Postgraduate Medical Journal*, **80**, 72-76.

[31] Hanning, C.D. and Evans, A. (2012) Wind Turbine Noise. *BMJ*, **344**, e1527. https://doi.org/10.1136/bmj.e1527

[32] von Hünerbein, S., Moorhouse, A., Fiumicelli, D. and Baguley, D. (2013) Report on Health Impacts of Wind Turbines. Prepared for Scottish Government by Acoustics Research Centre, University of Salford.

[33] Smith, M.G., Ögren, M., Thorsson, P., Pedersen, E. and Waye, K.P. (2016) Physiological Effects of Wind Turbine Noise on Sleep. *Proceedings of the 22nd International Congress on Acoustics*, Buenos Aires, 5-9 September 2016, 440.

[34] Onakpoya, I.J., O'Sullivan, J., Thompson, M.J. and Heneghan, C.J. (2015) The Effect of Wind Turbine Noise on Sleep and Quality of Life: A Systematic Review and Meta-Analysis of Observational Studies. *Environment International*, **82**, 1-9.

[35] Laugsand, L.E., Strand, L.B., Platou, C., Vatten, L.J. and Janszky, I. (2013) Insomnia and the Risk of Incident Heart Failure: A Population Study. *European Heart Journal*, **35**, 1382-1393. https://doi.org/10.1093/eurheartj/eht019

[36] Hoevenaar-Blom, M.P., Spijkerman, A.M.W., Kromhout, D. and Verschuren, W.M.M. (2013) Sufficient Sleep Duration Contributes to Lower Cardiovascular Disease Risk in Addition to Four Traditional Lifestyle Factors: The MORGEN Study. *European Journal of Preventive Cardiology*, **21**, 1367-1375. https://doi.org/10.1177/2047487313493057

[37] Hoevenaar-Blom, M.P., Annemieke, M.W., Spijkerman, A.M.W., Kromhout, D., van den Berg, J.F. and Verschuren, W.M.M. (2011) Sleep Duration and Sleep Quality in Relation to 12-Year Cardiovascular Disease Incidence: The MORGEN Study. *Sleep*, **34**, 1487-1492. https://doi.org/10.5665/sleep.1382

[38] Heidt, T., Sager, H.B., Courties, G., *et al.* (2014) Chronic Variable Stress Activates Hematopoietic Stem Cells. *Nature Medicine*, **20**, 754-758.

[39] Pierpont, N. (2009) Wind Turbine Syndrome: A Report on A Natural Experiment. K Selected Publications, Santa Fe, New Mexico.

[40] Sivertsen, B., Lalluka, T., Salo, P., *et al.* (2014) Insomnia as a Risk Factor for Ill Health: Results from the Large Population-Based Prospective HUNT Study in Norway. *Journal of Sleep Research*, **23**, 124-132. https://doi.org/10.1111/jsr.12102

[41] Salt, A.N. and Lichtenhan, J.T. (2011) Responses of the Inner Ear to Infrasound. *IVth International Meeting on Wind Turbine Noise*, Rome, Italy.

[42] Schomer, P.D., Edreich, J., Boyle, J. and Pamidighantam, P. (2011) A Proposed

Theory to Explain Some Adverse Physiological Effects of the Infrasonic Emissions at Some Wind Farm Sites. *5th International Conference on Wind Turbine Noise*, Denver, 28-30 August 2013.

[43] Ananthaswamy, A. (2013) Like Clockwork: The Cogs and Wheels That Drive Our Thoughts. *New Scientist*, **219**, 32-35.

[44] Danielsson, A. and Landström, U. (1985) Blood Pressure Changes in Man during Infrasonic Exposure. *Acta Medica Scandinavica*, **217**, 531-535. https://doi.org/10.1111/j.0954-6820.1985.tb03258.x

[45] Nussbaum, D.S. and Reinis, S. (1985) Some Individual Differences in Human Response to Infrasound. University of Toronto Institute for Aerospace Report No. 282, CN ISSN 0082-5225.

[46] International Standards Organisation (1996) Mechanical Vibration and Shock—Disturbance to Human Activity and Performance—Classification. 9996, Geneva.

[47] Lawther, A. and Griffin, M.J. (1987) Prediction of the Incidence of Motion Sickness from the Magnitude, Frequency, and Duration of Vertical Oscillation. *The Journal of the Acoustical Society of America*, **82**, 957. https://doi.org/10.1121/1.395295

[48] Castelo Branco, N.A.A., Alves-Pereira, M., Pimenta, A.M. and Ferreira, J.R. (2015) Low Frequency Noise-Induced Pathology: Contributions Provided by the Portuguese Wind Turbine Case. *EuroNoise*, Maastricht, 31 May-3 June 2015, 1-5.

[49] Mulholland, K.A. (1985) Noise Control. In: Tempest, W., Ed., *The Noise Handbook*, Academic Press, London, 281-301.

[50] Swinburn, T.K., Hammer, M.S., Richard, J.D. and Neitze, L.L. (2015) Valuing Quiet: An Economic Assessment of U.S. Environmental Noise as a Cardiovascular Health Hazard. *American Journal of Preventive Medicine*, **49**, 345-353. https://doi.org/10.1016/j.amepre.2015.02.016

[51] Götz, T. and Janik, V.M. (2011) Repeated Elicitation of the Acoustic Startle Reflex Leads to Sensitisation in Subsequent Avoidance Behaviour and Induces fear Conditioning. *BMC Neuroscience*, **12**, 30. http://www.biomedcentral.com/1471-2202/12/30 https://doi.org/10.1186/1471-2202-12-30

[52] Abbassi, M., Zakerian, S.A. and Yousefzadeh, A. (2015) Effect of Wind Turbine Noise on Workers' Sleep Disorder: A Case Study of Manjil Wind Farm in Northern Iran. *Fluctuation and Noise Letters*, **14**, Article ID: 1550020.

[53] Inagaki, T., Li, Y. and Nishi, Y. (2015) Analysis of Aerodynamic Sound Noise Generated by a Large-Scaled Wind Turbine and Its Physiological Evaluation. *International Journal of Environmental Science and Technology*, **12**, 1933-1944. https://doi.org/10.1007/s13762-014-0581-4

[54] Bauer, M., Sander-Thömmes, T., Ihlenfeld, A., Kühn, S., Kühler, R. and Koch, C. (2015) Investigation of Perception at Infrasound Frequencies by Functional Magnetic Resonance Imaging (fMRI) and Magnetoencephalography (MEG). *The 22nd International Congress on Sound and Vibration*, Florence, 12-16 July 2015, 1-6.

[55] Cooper, S. (2015) Personal Communication. Batho, W.J.S., Chair (1990) Noise Review Working Party Report. HMSO, London, 27.

[56] Weichenberger, M., Bauer, M., Kühler, R., *et al.* (2017) Altered Cortical and Subcortical Connectivity due to Infrasound Administered near the Hearing Threshold—Evidence from fMRI. *PLoS ONE*, **12**, e0174420. https://doi.org/10.1371/journal.pone.0174420

[57] Frey, B.J. and Hadden, P.J. (2012) Wind Turbines and Proximity to Homes: The Impact of Wind Turbine Noise on Health: A Review of the Literature & Discussion

of the Issues.
http://www.windturbinesyndrome.com/wp-content/uploads/2012/03/Frey_Hadden_WT_noise_health_01Jan2012.pdf

[58] Noise Review Working Party Report (1990) (Batho, W.J.S., Chair). HMSO, London, 27.

[59] Fletcher, H. and Munson, W.A. (1933) Loudness, Its Definition, Measurement and Calculation. *The Journal of the Acoustical Society of America*, 5, 82-108. https://doi.org/10.1121/1.1915637

[60] James, R.R. (2012) Wind Turbine Infra and Low-Frequency Sound: Warning Signs That Were Not Heard. *Bulletin of Science, Technology & Society*, 32, 108-127. https://doi.org/10.1177/0270467611421845

[61] Brüel, P.V. and Oleson, H.P. (1973) Infrasonic Measurements. *Inter-Noise*, 73, G23z3, Copenhagen, 22-24 August 1973.

[62] Casella Stanger (2001) Report on Low Frequency Noise Technical Research Support for DEFRA Noise Programme. On behalf of DEFRA, Department of the Environment, Northern Ireland, Scottish Executive, National Assembly for Wales.

[63] Kelley, N.D., Hemphill, R.R. and Mckenna, H.E. (1982) A Methodology for Assessment of Wind Turbine Noise Generation. *Transactions on ASME*, 104, 112-120.

[64] Kelley, N.D., McKenna, H.E., Hemphill, R.R., Etter, C.I., Garrelts, R.I. and Linn, N.C. (1985) Acoustic Noise Associated with the MOD-1 Wind Turbine: Its Source, Impact, and Control. Solar Energy Research Institute, A Division of Midwest Research Institute, Golden, Colorado, USA.

[65] Kelley, N.D. (1987) A Proposed Metric for Assessing the Potential of Community Annoyance from Wind Turbine Low-Frequency Noise Emissions. *Presented at the Windpower'87 Conference and Exposition*, San Francisco, 5-8 October 1987. Solar Energy Research Institute, A Division of Midwest Research Institute, Colorado, USA.

[66] Bray, W. and James, R. (2011) Dynamic Measurements of Wind Turbine Acoustic Signals, Employing Sound Quality Engineering Methods Considering the Time and Frequency Sensitivities of Human Perception. *Proceedings of Noise-Con*, Portland, Oregon, 25-27 July 2011.

[67] Kugler, K., Wiegrebe, L., Grothe, B., *et al.* (2014) Low-Frequency Sound Affects Active Micromechanics in the Human Inner Ear. *Royal Society Open Science*, 1, Article ID: 140166. https://doi.org/10.1098/rsos.140166

[68] Department of Trade and Industry (2003) Our Energy Future—Creating a Low Carbon Economy. HMSO, London.

[69] The Working Group on Noise from Wind Farms (1996) The Assessment and Rating of Noise from Windfarms. ETSU-R-97 Final Report, Department of Trade and Industry.

[70] Hessler, G., Leventhall, L.G., Schomer, P. and Walker, B. (2017) Health Effects from Wind Turbine Low Frequency Noise & Infrasound: Do Wind Turbines Make People Sick? That Is the Issue. Sound & Vibration, 34-44.

[71] Schmidt, J.H. and Klokker, M. (2014) Health Effects Related to Wind Turbine Noise Exposure: A Systematic Review. *PLoS ONE*, 9, e114183. https://doi.org/10.1371/journal.pone.0114183

[72] Marshall Day Acoustics (2013) Examination of the Significance of Noise in Relation to Onshore Wind Farms. Commissioned by Sustainable Energy Authority of Ireland (SEAI), 29 November, 29.

[73] Møller, H. and Pedersen, C.S. (2011) Low-Frequency Noise from Large Wind Turbines. *The Journal of the Acoustical Society of America*, 129, 3727-3744. https://doi.org/10.1121/1.3543957

[74] Environment, Community and Local Government (2013) Proposed Revisions to Wind Energy Guidelines 2006: Targeted Review in Relation to Noise, Proximity and Shadow Flicker. 11 December 2013.

[75] Kamperman, G.W. and James, R. (2008) The "How To" Guide to Siting Wind Turbines to Prevent Health Risks from Sound.
http://www.windturbinesyndrome.com/wp-content/uploads/2008/10/kamperman-james-8-26-08-report-43-pp.pdf

[76] Huson, L. (2015) Stationary Wind Turbine Infrasound Emissions and Propagation Loss Measurements (Paper I). *6th International Conference on Wind Turbine Noise*, Glasgow, 20-23 April 2015.

[77] Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). Potential Health Effects of Exposure to Electromagnetic Fields (2015) European Commission, Brussels, Belgium.
http://ec.europa.eu/health/scientific_committees/emerging/docs/scenihr_o_041.pdf

[78] Agnew, R.C.N., Smith, V.J. and Fowhes, R.C. (2016) Wind Turbines Cause Chronic Stress in Badgers (*Meles meles*) in Bitain. *Journal of Wildlife Diseases*, 52, 459-467.

[79] Karwowska, M., Mikolajczak, J., Dolatowski, Z.J. and Borowski, S. (2015) The Effect of Varying Distances from the Wind Turbine on Meat Quality of Growing-Finishing Pigs. *Annals of Animal Science*, 15, 1043-1054. https://doi.org/10.1515/aoas-2015-0051

[80] Pine, M.K., Jeffs, A.G. and Radford, C.A. (2012) Turbine Sound May Influence the Metamorphosis Behaviour of Estuarine Crab Megalopae. *PLoS ONE*, 7, e51790. https://doi.org/10.1371/journal.pone.0051790

[81] Hassanien, R.H.E., Hou, T., Li, Y. and Li, B. (2013) Advances in Effects of Sound Waves in Plants. *Journal of Integrative Agriculture*, 13, 335-348.

[82] Carruthers, B.M., van de Sande, M.I., De Meirleir, K.L., *et al.* (2011) Myalgic Encephalomyelitis: International Consensus Criteria. *Journal of Internal Medicine*, 270, 327-338. https://doi.org/10.1111/j.1365-2796.2011.02428.x

[83] Surgeon General (2010) How Tobacco Smoke Causes Disease: The Biology and Behavioral Basis for Smoking-Attributable Disease: A Report of the Surgeon General (3. Chemistry and Toxicology of Cigarette Smoke and Biomarkers of Exposure and Harm). Centers for Disease Control and Prevention (US), National Center for Chronic Disease Prevention and Health Promotion (US), Office on Smoking and Health (US), Atlanta (GA).

[84] Department of Energy and Climate Change (2016) Wind Turbine AM Review: Phase 2 Report. WSP/Parsons Brinckerhoff, Bristol.

[85] Miller, L.M., Brunsell, N.A., Mechem, D.B., *et al.* (2016) Two Methods for Estimating Limits to Large-Scale Wind Power Generation. *Proceedings of the National Academy of Sciences of the United States of America*, 112, 11169-11174. https://doi.org/10.1073/pnas.1408251112

[86] Swinbanks, M.A. (2015) Direct Experience of Low Frequency Noise and Infrasound within a Windfarm Community. *6th International Meeting on Wind Turbine Noise*, Glasgow, 20-23 April 2015.

[87] Underwood, E.A. (1949) Edward Jenner: The Man and His Work. *BMJ*, 1, 881-884.

[88] Seldin, M.M., Byerly, M.S., Petersen, P.S., *et al.* (2014) Seasonal Oscillation of Liver-Derived Hibernation Protein Complex in the Central Nervous System of Non-Hibernating Mammals. *Journal of Experimental Biology*, 217, 2667-2679.

[89] Dalgard, C., Eidelman, O., Jozwik, C., *et al.* (2017) The MCP-4/MCP-1 Ratio in Plasma Is a Candidate Circadian Biomarker for Chronic Post-Traumatic Stress Disorder. *Translational Psychiatry*, 7, e0125. https://doi.org/10.1038/tp.2016.285

[90] Mapei, C. (MDCCCLVI) Italy, Classical, Historical and Picturesque. Blackie, Glasgow and London, 59-60.

[91] Rosen, G. (1953) Cameralism and the Concept of Medical Police. *Bulletin of the History of Medicine*, 27, 21-42.

[92] Crew, F.A.E. (1949) Social Medicine as an Academic Discipline. In Massey, A., Ed., *Modern Trends in Public Health*, Butterworth, London, 46-79.

[93] Blaney, R. (1984) Henry Maunsell (1806-1879): An Early Community Physician. *Irish Journal of Medical Science*, 153, 42-43. https://doi.org/10.1007/bf02940522

[94] Chadwick, E. (1829) Preventive Police. London Review I, 252-308.

[95] Hamlin, C. (1998) Public Health and Social Justice in the Age of Chadwick: Britain 1800-1854. Cambridge University Press, Cambridge, 1-15.

[96] Coughlin, S.S., Beauchamp, T.L. and Weed, D.L. (2009) Ethics and Epidemiology. Oxford University Press, Oxford, 5-6. https://doi.org/10.1093/acprof:oso/9780195322934.001.0001

[97] Evans, A. (2001) Benjamin Guy Babington: Founding President of the London Epidemiological Society. *International Journal of Epidemiology*, 30, 226-230. https://doi.org/10.1093/ije/30.2.226

[98] Belongia, E.A. and Naleway, A.L. (2003) Smallpox Vaccine: The Good, the Bad, and the Ugly. *Clinical Medicine & Research*, 1, 87-92. https://doi.org/10.3121/cmr.1.2.87

[99] Jasanoff, S. (2012) The Politics of Public Reason. In: Rubio, F.D. and Baert, P., Eds., *The Politics of Knowledge*, Routledge, Oxford, 11-32.

[100] Zander, J. (2010) The Precautionary Principle in EU Law. In: *The Application of the Precautionary Principle in Practice: Comparative Dimensions*, Cambridge University Press, Cambridge, 76-151. https://doi.org/10.1017/CBO9780511779862.006

[101] Gill, N., Spencer, Y., Richard-Loendt, A., *et al.* (2013) Prevalent Abnormal Prion Protein in Human Appendices after Bovine Spongiform Encephalopathy Epizootic Large Scale Survey. *BMJ*, 347, 15675.

[102] Royal Society of Public Health (2016) Waking up to the Health Benefits of Sleep. University of Oxford, Oxford.

[103] Nightingale F. (1859) Notes on Nursing: What It Is, and What It Is Not. Harrison, London, 27.

[104] Garcia, M.J. (2009) U.N. Convention against Torture (CAT): Overview and Application to Interrogation Techniques. CRS Report for Congress, 26 March 2009, 21.

[105] Ferriter, D. (2014) The Hooded Men. *The Irish Times*, 6 December 2014.

[106] Punch, J.L. and James, R.R. (2016) Wind Turbine Noise and Human Health: A Four-Decade History of Evidence That Wind Turbines Pose Risks. https://docs.wind-watch.org/Punch-James-Wind-Turbine-Noise-16-10-21.pdf

[107] http://aefweb.info/data/AUSWEA-2004conference.pdf

[108] https://qmail.qub.ac.uk/owa/redir.aspx?C=ypzjvMYSs8dqquKCSrN5vb_3wZ6Bkxxkz1VRQh9Eog32ntjUe2vUCA..&URL=http%3a%2f%2fwind2050.dk

[109] O'Sullivan, C. (2014) Senior Doctor Defends Wind Turbine Syndrome Conclusions. *The Irish Examiner*, 6 March 2014.

[110] Baliatsas, C., van Kamp, I., van Poll, R. and Yzermans, J. (2016) Health Effects from Low-Frequency Noise and Infrasound in the General Population: Is It Time to Listen? A Systematic Review of Observational Studies. *Science of the Total Environment*, 557-558, 163-169.

[111] Spector, B. (1963) Jeremy Bentham 1748-1832: His Influence upon Medical Thought and Legislation. *Bulletin of the History of Medicine*, 33, 25-42.

[112] U.S. Environmental Protection Agency (1974) Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety. Washington DC, 550/9-74-004.

[113] Hughes, G. (2012) The Performance of Wind Farms in United Kingdom and Denmark. Renewable Energy Foundation, London.

[114] Hughes, G. (2012) Why Is Wind Power So Expensive? An Economic Analysis. The Global Warming Policy Foundation, GWPF Report 7.

JOURNAL OF THE AMERICAN COLLEGE OF CARDIOLOGY
© 2019 PUBLISHED BY ELSEVIER ON BEHALF OF THE
AMERICAN COLLEGE OF CARDIOLOGY FOUNDATION

VOL. 73, NO. 2, 2019

Association of Sleep Duration and Quality With Subclinical Atherosclerosis

Fernando Domínguez, MD, PhD,[a,b,c] Valentín Fuster, MD, PhD,[a,d] Juan Miguel Fernández-Alvira, PhD,[a]
Leticia Fernández-Friera, MD, PhD,[a,c,e] Beatriz López-Melgar, MD, PhD,[a,c,e] Ruth Blanco-Rojo, PhD,[f]
Antonio Fernández-Ortiz, MD, PhD,[a,c,g,h] Pablo García-Pavía, MD, PhD,[b,c,i] Javier Sanz, MD,[a,d] José M. Mendiguren, MD,[j]
Borja Ibañez, MD, PhD,[a,c,k] Héctor Bueno, MD, PhD,[a,l,m] Enrique Lara-Pezzi, PhD,[a,c] José M. Ordovás, PhD[a,f,n]

ABSTRACT

BACKGROUND Sleep duration and quality have been associated with increased cardiovascular risk. However, large studies linking objectively measured sleep and subclinical atherosclerosis assessed in multiple vascular sites are lacking.

OBJECTIVES The purpose of this study was to evaluate the association of actigraphy-measured sleep parameters with subclinical atherosclerosis in an asymptomatic middle-aged population, and investigate interactions among sleep, conventional risk factors, psychosocial factors, dietary habits, and inflammation.

METHODS Seven-day actigraphic recording was performed in 3,974 participants (age 45.8 ± 4.3 years; 62.6% men) from the PESA (Progression of Early Subclinical Atherosclerosis) study. Four groups were defined: very short sleep duration <6 h, short sleep duration 6 to 7 h, reference sleep duration 7 to 8 h, and long sleep duration >8 h. Sleep fragmentation index was defined as the sum of the movement index and fragmentation index. Carotid and femoral 3-dimensional vascular ultrasound and cardiac computed tomography were performed to quantify noncoronary atherosclerosis and coronary calcification.

RESULTS When adjusted for conventional risk factors, very short sleep duration was independently associated with a higher atherosclerotic burden with 3-dimensional vascular ultrasound compared to the reference group (odds ratio: 1.27; 95% confidence interval: 1.06 to 1.52; p = 0.008). Participants within the highest quintile of sleep fragmentation presented a higher prevalence of multiple affected noncoronary territories (odds ratio: 1.34; 95% confidence interval: 1.09 to 1.64; p = 0.006). No differences were observed regarding coronary artery calcification score in the different sleep groups.

CONCLUSIONS Lower sleeping times and fragmented sleep are independently associated with an increased risk of subclinical multiterritory atherosclerosis. These results highlight the importance of healthy sleep habits for the prevention of cardiovascular disease. (J Am Coll Cardiol 2019;73:134–44) © 2019 Published by Elsevier on behalf of the American College of Cardiology Foundation.

Listen to this manuscript's audio summary by Editor-in-Chief Dr. Valentin Fuster on JACC.org.

From the [a]Centro Nacional de Investigaciones Cardiovasculares Carlos III (CNIC), Madrid, Spain; [b]Heart Failure and Inherited Cardiac Diseases Unit, Department of Cardiology, Hospital Universitario Puerta de Hierro, Madrid, Spain; [c]Centro de Investigacion Biomedica en Red en Enfermedades Cardiovasculares (CIBERCV), Madrid, Spain; [d]Zena and Michael A. Wiener Cardiovascular Institute/Marie-Josée and Henry R. Kravis Center for Cardiovascular Health, Icahn School of Medicine at Mount Sinai, New York, New York; [e]HM Hospitales-Centro Integral de Enfermedades Cardiovasculares HM-CIEC, Madrid, Spain; [f]IMDEA Food Institute, CEI UAM + CSIC, Madrid, Spain; [g]Universidad Complutense, Madrid, Spain; [h]Cardiovascular Institute, IDSSC, Hospital Clínico San Carlos, Madrid, Spain; [i]Faculty of Health Sciences, University Francisco de Vitoria (UFV), Pozuelo de Alarcon, Madrid, Spain; [j]Banco de Santander, Madrid, Spain; [k]IIS-Fundación Jiménez Díaz Hospital, Madrid, Spain; [l]Cardiology Department, Hospital Universitario 12 de Octubre, and Instituto de Investigación Sanitaria Hospital 12 de Octubre, Madrid, Spain; [m]Facultad de Medicina, Universidad Complutense de Madrid, Madrid, Spain; and the [n]U.S. Department of Agriculture Human Nutrition Research Center on Aging, Tufts University, Boston, Massachusetts. The PESA study is cofunded equally by the CNIC and Banco Santander. The study also receives funding from the Institute of Health Carlos III (PI15/02019) and the European Regional Development Fund. The CNIC is supported by the Ministry of Economy, Industry and Competitiveness (MEIC) and the Pro CNIC Foundation, and is a Severo Ochoa Center of Excellence (MEIC award SEV-2015-0505). Dr. Bueno has received consulting fees from AstraZeneca, Bayer, Bristol-Myers Squibb-Pfizer, and Novartis; has received speaking fees or support for attending scientific meetings from AstraZeneca, Bayer, Bristol-Myers Squibb-Pfizer, Ferrer, Novartis, and MEDSCAPE-the heart.org; and has received

ISSN 0735-1097/$36.00 https://doi.org/10.1016/j.jacc.2018.10.060

Sleep is an essential physiological process that protects our physical and mental health. Sleep deficiency is highly prevalent in Western societies, and epidemiological studies suggest that not only short but also long sleep duration (LSD) is related to an increased cardiovascular risk (1,2).

SEE PAGE 145

Several studies and meta-analyses have reported associations between short sleep duration (SSD) and hypertension (3,4), with some showing a relationship with incident hypertension in subjects <65 years of age (4,5). No such association has been found with LSD (5). Recent meta-analyses have shown a 30% increased risk of diabetes mellitus among subjects sleeping <5 to 6 h/day, as well as in those who sleep >8 h/day (6). In addition, SSD has been reported to influence food intake and obesity (7).

Although sleep quality and duration have been associated with the risk of coronary heart disease, stroke (1), and subclinical atherosclerosis (8), most studies rely on self-reported questionnaires of sleep evaluation (8,9). The value of previous actigraphy-based studies evaluating atherosclerotic burden is limited because these were mostly small studies (10-12), and they focused on patients with sleep disorders, such as obstructive sleep apnea (OSA) (13,14). Previous studies relying on objectively-assessed sleep have shown that shorter sleep duration is associated with greater carotid intima-media thickness in men (15), and longer sleep duration is associated with a lower coronary calcification incidence, which is related to subclinical atherosclerosis (16). However, studies using newer and more reliable imaging techniques for measuring atherosclerosis are lacking. Moreover, the association of multiterritory atherosclerosis and sleep has not been yet assessed.

The aim of this study was to evaluate the association between actigraphy-measured sleep parameters and subclinical atherosclerosis, investigating possible interactions between sleep parameters, risk factors, dietary habits, and inflammatory markers.

METHODS

STUDY POPULATION. PESA-CNIC (Progression of Early Subclinical Atherosclerosis-Centro Nacional de Investigaciones Cardiovasculares)-Santander is an observational prospective cohort study that recruited 4,184 male and female employees of Santander Bank in Madrid from 40 to 54 years of age (17). All participants were free of known cardiovascular disease (CVD). The baseline visit included a fasting blood test, urine sample, and a 12-lead electrocardiogram. Patients with a history of OSA at baseline (n = 77) and those without actigraphic recording (n = 133) were excluded from the study. The final sample available for this analysis consisted of 3,974 participants. Of those, 3,804 were examined at baseline by 3-dimensional (3D) vascular ultrasound (VUS) (170 were excluded due to incomplete 3D VUS studies and incomplete clinical data necessary for the adjusted models) and 3,899 with noncontrast cardiac computed tomography (CT) (75 were excluded because of incomplete clinical data necessary for the adjusted models).

ABBREVIATIONS AND ACRONYMS

3D = 3-dimensional

CT = computed tomography

LSD = long sleep duration

RSD = reference sleep duration

SFI = sleep fragmentation index

SSD = short sleep duration

VSSD = very short sleep duration

VUS = vascular ultrasound

ASSESSMENT OF CVD RISK FACTORS, METABOLIC SYNDROME, AND DIETARY INTAKE. The participants' medical history, traditional CVD risk factors, lifestyle features (18), and physical examination including anthropometric characteristics were recorded. Obesity was defined as a body mass index (BMI) ≥30 kg/m^2. Metabolic syndrome was defined according to the National Cholesterol Education Program Adult Treatment Panel III criteria (19), which require 3 or more of the following characteristics: 1) abdominal obesity, defined as a waist circumference in men ≥102 cm and women ≥88 cm; 2) serum triglycerides ≥150 mg/dl or drug treatment for elevated triglycerides; 3) serum high-density lipoprotein (HDL) cholesterol <40 mg/dl in men and <50 mg/dl in women or drug treatment for low HDL cholesterol; 4) blood pressure ≥130/85 mm Hg or drug treatment for elevated blood pressure; and 5) fasting plasma glucose (FPG) ≥100 mg/dl or drug treatment for high blood glucose. The Framingham 10-year and 30-year scores, as well as the Fuster-BEWAT (20) score, were calculated in all study participants. Additionally, to avoid the potential confounding factor of underdiagnosed OSA, a modified STOP-BANG (Snoring, Tired, Observed apnea, high blood Pressure, BMI >35 kg/m^2, Age >50, Neck circumference >43 cm in males and >41 cm in

research funding from the Instituto de Salud Carlos III, Spain (PIE16/00021 and PI17/01799), AstraZeneca, Bristol-Myers Squibb, Janssen, and Novartis. All other authors have reported that they have no relationships relevant to the contents of this paper to disclose.

Manuscript received July 17, 2018; revised manuscript received October 9, 2018, accepted October 12, 2018.

females, and male Gender) questionnaire score (mSTOP-BANG) was calculated and results were adjusted for this variable. The STOP-BANG questionnaire evaluates the risk of sleep apnea and has been proved to be a practical tool to screen for OSA (21). The clinical data from the PESA study included all of the necessary parameters to calculate the STOP-BANG score except for the neck circumference, and therefore the results of an mSTOP-BANG score were incorporated into our study.

All participants underwent a survey to complete the computerized dietary history adapted to the Spanish population, which was initially developed and validated in the EPIC-Spain study (22,23). The survey is based on a computer application and is structured according to the episodes of intake throughout the day (breakfast, midmorning, lunch, snack, dinner, and ingestion between meals) (24,25). Once the survey was completed, the software provided information on foods consumed, caloric intake, macronutrient and micronutrient intake, and different forms of food preparation, as well as specific eating habits. Regarding caffeinated drinks, participants were asked to report their daily intake in grams including coffee, tea, cola drinks, and energy drinks. Assuming an approximate density of 1 g/cm^3, results were converted to milliliters.

ASSESSMENT OF QUANTITY AND QUALITY OF SLEEP. Actigraphic and self-reported sleep durations were first analyzed as continuous variables and then divided into multiple categories to achieve groups of adequate sample sizes to reflect the possible nonlinear (U- or J-shaped) associations between sleep duration and risk outcomes. The quantity of sleep was assessed by triaxial accelerometry, using Acti Trainers accelerometers (Actigraph, Pensacola, Florida) placed on the participant's waist for 7 days. Based on the last scientific statement from the American Heart Association regarding the impact of sleep duration on cardiometabolic health, a sleep duration of 7 to 8 h was considered normal and participants within that range were considered as the reference sleep duration (RSD) group (26). The remaining groups included participants with very short sleep duration (VSSD) (<6 h), short sleep duration (SSD) (6 to 7 h), and long sleep duration (LSD) (>8 h).

Sleep quality was assessed by the total sleep Fragmentation Index (SFI), which is defined as the sum of the movement index (MI) and the fragmentation index (FI). MI is the percentage of epochs with y-axis counts >0 in the sleep period. FI is the percentage of 1-min periods of sleep versus all periods of sleep during the sleep period (27). Study participants were divided into quintiles according to sleep fragmentation and those with less fragmented sleep (first quintile) were considered to be the reference group. Additionally, participants completed the Sleep Habits Questionnaire, which was developed and validated by the Sleep Heart Health Study (28).

PSYCHOSOCIAL EVALUATION. The presence of depressive symptoms was evaluated by the Center for Epidemiological Studies-Depression (CES-D) scale. It has been translated and validated in the Spanish population (29), and has demonstrated high sensitivity and specificity for the identification of depressive symptoms in epidemiological studies. Participants also completed the Perceived Stress Scale (PSS) (30), which is widely used for measuring nonspecific perceived stress.

ASSESSMENT OF SUBCLINICAL ATHEROSCLEROSIS. PESA participants underwent 3D VUS studies using a volumetric-linear array transducer to evaluate plaque burden in the bilateral carotid and femoral arteries. As there is currently no standard definition for plaque presence using 3D VUS, noncoronary atherosclerosis was defined as plaque presence using the Manheim criteria for 2-dimensional VUS (31), and the number of affected territories (1 to 4) was also recorded. Cumulative plaque volume (burden, in mm^3) was quantified and divided into tertiles to classify atherosclerosis as mild, moderate, or severe (32). This 3D VUS method has already proven to be accurate measuring plaque volumes in vitro and in vivo (33). Moreover, atherosclerosis assessed by 3D VUS in the PESA cohort correlates with classic cardiovascular risk factors, especially for femoral arteries (32). A 16-slice CT scan was used to quantify the Agatston coronary calcium score (CACS), which was categorized as 0, <1, 1 to 100, 101 to 400, and >400 (34).

All performed imaging tests were blind, and the Centro Nacional de Investigaciones Cardiovasculares conducted the analysis.

ASSESSMENT OF INFLAMMATORY BIOMARKERS. The assessed inflammatory biomarkers included neutrophil count, P selectin, high-sensitivity C-reactive protein (hs-CRP), and vascular cell adhesion molecule (VCAM).

STATISTICAL ANALYSIS. Statistical analyses were performed with SPSS software version 21.0 (IBM, Armonk, New York). The population baseline characteristics of the study are presented as percentages for categorical variables and as the mean and SD for continuous variables. Bonferroni (analysis of variance with multiple testing correction) was used for continuous variables, including p for trend values for the general comparison of groups and specific

TABLE 1 Baseline Characteristics and Sleep Duration Measured by Actigraph

Total Sleep Time (Actigraph)	Total	VSSD <6 h	SSD 6 to <7 h	RSD 7 to <8 h (Ref)	LSD ≥8 h	p Value*
Number of participants	3,974 (100.0)	1,071 (27.0)	1,521 (38.3)	1,222 (30.7)	160 (4.0)	
Age, yrs	45.8 ± 4.3	46.6 ± 4.3†	45.8 ± 4.4†	45.1 ± 4.0	44.5 ± 4.0	**<0.001**
Men	62.6	74.0	65.2	52.0	43.1	**<0.001**
Smoking status						**0.02**
Never	39.4	33.9	41.2	41.7	41.5	
Former	32.4	35.1	30.8	32.9	26.4	
Social	7.5	7.3	7.4	7.4	10.1	
Current	20.7	23.7	20.6	18.0	22.0	
Alcohol intake, g/day	5.8 (1.5–12.6)	7.2 (1.7–14.1)	6.3 (1.8–13.2)	4.7 (1.0–11.0)	4.1 (0.9–10.4)	**<0.001**
MVPA, min/day	46.8 ± 20.7	47.9 ± 22.0	47.2 ± 20.8	46.3 ± 19.6	40.6 ± 17.0†	0.13
Married	75.9	74.6	76.4	77.0	71.1	0.06
BMI, kg/m^2	26.1 ± 3.79	26.9 ± 3.9†	26.2 ± 3.9†	25.5 ± 3.8	24.5 ± 3.6†	**<0.001**
Systolic BP, mm Hg	116.2 ± 12.5	117.9 ± 12.3†	116.6 ± 12.2†	114.3 ± 12.6	114.0 ± 13.7	**<0.001**
Diastolic BP, mm Hg	72.4 ± 9.4	73.6 ± 9.5†	72.5 ± 9.4†	71.4 ± 9.1	71.7 ± 9.6	**<0.001**
Hypertension	12.1	13.9	12.5	10.0	10.0	**0.03**
Antihypertensive drugs	7.3	9.2	7.2	6.0	5.0	**0.02**
Fasting glucose, mg/dl	90.4 ± 13.7	92.1 ± 13.1†	90.6 ± 15.7†	88.9 ± 10.2	89.3 ± 17.3	**<0.001**
Diabetes mellitus	1.7	2.5	1.5	1.2	1.3	0.1
Antidiabetic drugs	1.5	2.1	1.2	1.2	1.2	0.31
Total cholesterol, mg/dl	200.0 ± 34.3	202.0 ± 34.3	200.0 ± 32.6	200.0 ± 33.3	203.0 ± 33.0	0.443
HDL cholesterol, mg/dl	49.2 ± 12.2	47.2 ± 11.8†	49.0 ± 11.7†	50.9 ± 12.8	50.8 ± 13.4	**<0.001**
LDL cholesterol, mg/dl	132.0 ± 29.8	134.0 ± 30.6	132.0 ± 28.8	131.0 ± 29.9	133.0 ± 31.9	0.135
Triglycerides, mg/dl	94.5 ± 57.3	100.7 ± 61.1†	94.4 ± 55.0	89.1 ± 50.7	95.5 ± 88.3	**<0.001**
Lipid-lowering drugs	6.9	8.3	8.0	4.7	4.4	**0.001**
Metabolic syndrome‡	9.5	12.6	8.8	8.0	6.9	**<0.001**
STOP-BANG score§	1.3 ± 1.1	1.6 ± 1.1†	1.3 ± 1.02†	1.1 ± 0.9	1.0 ± 1.0	**<0.001**
STOP-BANG score ≥3§	13.2	18.9	13.2	9.0	6.2	**<0.001**
CRP, mg/dl	0.10 (0.05–0.19)	0.11 (0.05–0.20)	0.09 (0.05–0.18)	0.09 (0.05–0.19)	0.09 (0.05–0.17)	0.07
VCAM, ng/ml	617 (490–765)	593 (476–747)	621 (494–769)	627 (498–772)	630 (488–774)	**0.006**
P-selectin, ng/ml	129 (104–154)	133 (108–157)	129 (104–154)	127 (102–151)	122 (96–140)	**0.002**
Neutrophil, %	57.6 (52.5–62.8)	57.8 (52.8–63.4)	57.3 (52.4–62.2)	57.6 (52.3–62.8)	58.3 (52.2–64.1)	0.23
Use of benzodiazepine and its derivatives	6.8	6.2	6.8	6.5	13.8	**0.012**

Values are n (%), mean ± SD, %, or median (quartile 1, quartile 3). Bold indicates statistical significance. *p values for continuous variables in this column reflect p for trend. †p<0.05 vs. RSD (reference group). ‡National Cholesterol Education Program Adult Treatment Panel III (NCEP-ATP III) criteria. §Modified score. Neck circumference not available.

BMI = body mass index; BP = blood pressure; CRP = C-reactive protein; HDL = high-density lipoprotein; LDL = low-density lipoprotein; LSD = long sleep duration; MVPA = moderate to vigorous physical activity; RSD = reference sleep duration; STOP-BANG = Snoring, Tired, Observed apnea, high blood Pressure, BMI >35 kg/m^2, Age >50, Neck circumference >43 cm in males and >41 cm in females, and male Gender; SSD = short sleep duration; VCAM = vascular cell adhesion molecule; VSSD = very short sleep duration.

p values when compared with the reference group. The chi-square test was used for categorical variables.

The degree of agreement between actigraphic and self-reported sleep duration was quantified by computing a concordance correlation coefficient. Associations between actigraphic sleep parameters (fragmentation index and sleep duration) and cardiometabolic risk outcomes or inflammation markers were evaluated by multivariable ordinal regression models adjusted for age, sex, physical activity, BMI, smoking status, alcohol consumption, systolic blood pressure, education level, fasting glucose, total cholesterol, total kcal per day, marital status, CES-D/PSS, and mSTOP-BANG questionnaire scores. Moreover, to obtain p values for the overall adjusted association between sleep parameters and atherosclerosis variables, we performed a likelihood-ratio test comparing the final models and the model including all variables other than the predictive variable in each analysis.

As sex has been reported to modify the association between sleep and cardiometabolic parameters (35), associations were additionally explored separately in men and women when a test for significance of effect modification by sex showed a p value <0.05.

RESULTS

A total of 2,488 men (62.6%) and 1,486 women (37.4%) underwent actigraphic analysis to evaluate

JACC VOL. 73, NO. 2, 2019
JANUARY 22, 2019:134-44

TABLE 2 Cardiovascular Risk Scales According to Sleep Duration and Fragmentation

Total Sleep Time (Actigraph)	Total	VSSD <6 h	SSD 6 to <7 h	RSD 7 to <8 h (Ref)	LSD >8 h	p Value*
CVD risk scales						
FRS 10%	5.9 ± 4.4	6.9 ± 4.8†	5.9 ± 4.3†	5.0 ± 3.8	5.1 ± 4.6	**<0.001**
FRS 30%	17.7 ± 11.8	20.9 ± 12.7†	17.7 ± 11.4†	15.2 ± 10.6	15.6 ± 12.3	**<0.001**
Fuster-BEWAT score						**<0.001**
Poor	6.5	9.3	5.6	5.5	4.4	
Intermediate	60.1	63.4	62.2	55.6	51.6	
Ideal	33.4	27.3	32.2	38.9	44.0	
Sleep Fragmentation Index (Actigraph)	**Quintile 1 (Ref) 0.23–2.88**	**Quintile 2 2.88–4.04**	**Quintile 3 4.04–5.29**	**Quintile 4 5.29–7.38**	**Quintile 5 7.39–43.43**	
CVD risk scales						
FRS 10%	5.0 ± 3.8	5.4 ± 3.9	5.9 ± 4.4†	6.3 ± 4.9†	6.8 ± 4.7†	**<0.001**
FRS 30%	15.2 ± 10.3	16.6 ± 10.9	17.5 ± 11.4†	18.8 ± 12.6†	20.4 ± 12.8†	**<0.001**
Fuster-BEWAT score						**<0.001**
Poor	4.5	5.8	6.2	7.2	9.0	
Intermediate	57.8	59.8	59.7	58.3	64.8	
Ideal	37.7	34.4	34.1	34.5	26.2	

Values are mean ± SD or %. Post hoc Bonferroni analysis. Bold indicates statistical significance. *p values for continuous variables in this column reflect p for trend. †p < 0.05 compared with reference group.
FRS = Framingham risk score; Ref = reference.

sleep duration and quality. The proportion of participants with RSD was 30.7%, whereas SSD or VSSD accounted for 65.3% of cases. Only 4% of participants presented LSD (Table 1). Regarding sleep fragmentation, each of the quintiles comprised 774 to 786 participants (Online Table 1).

There was a significant but weak correlation between actigraphic and self-reported sleep duration among the study participants (Pearson correlation coefficient: 0.35; $p < 0.001$). Moreover, the 3,899 subjects who answered the questionnaires overestimated their sleep duration as compared with the accelerometer results (Online Figure 1).

CLINICAL PROFILE AND SLEEP PARAMETERS. Baseline characteristics according to actigraphy-measured sleep duration are presented in Table 1. Increased age, higher systolic and diastolic blood pressure hypertension, BMI, lower HDL cholesterol, and metabolic syndrome were significantly more prevalent in participants with VSSD or SSD compared to RSD (7 to 8 h) (Table 1). Similar to VSSD and SSD, participants in the higher quintile for SFI were significantly older and had an increased prevalence of smoking and hypertension (Online Table 1).

The Framingham risk score for 10 and 30 years estimated a significantly higher cardiovascular risk in participants with VSSD or SSD compared with RSD as well as in those included in the 3 higher quintiles of sleep fragmentation. The same findings were observed with the recently described Fuster-BEWAT score (20) (Table 2). No differences were found regarding psychosocial characteristics according to sleep duration and fragmentation (Online Table 2).

ASSOCIATION OF SLEEP DURATION AND QUALITY WITH SUBCLINICAL ATHEROSCLEROSIS. Three-dimensional VUS in carotid and femoral territories was available for analysis in 3,804 participants (Online Table 3). When adjusted for age, sex, moderate to vigorous physical activity (MVPA), BMI, smoking status, alcohol consumption, systolic blood pressure, education level, fasting glucose, total cholesterol, total kcal per day, marital status, CES-D, PSS, and mSTOP-BANG questionnaire scores, VSSD was independently associated with an increased plaque burden compared with the reference group (sleep duration 7 to 8 h) (odds ratio [OR] of being in the highest tertile of plaque burden: 1.27; 95% confidence interval [CI]: 1.06 to 1.52; $p = 0.008$) (Table 3, Central Illustration). The ordinal regression analysis considering tertiles for 3D plaque burden and number of diseased territories also showed that participants who slept <6 h presented a trend toward a more extensive atherosclerosis with a higher number of affected vascular territories, but the differences were not significant (OR of presenting more affected territories: 1.21; 95% CI: 1.02 to 1.45; $p = 0.03$, but overall test p value = 0.18). The association between subclinical atherosclerosis and sleep duration was also investigated using the Sleep Habits Questionnaire. In this case, no statistically significant differences in plaque burden or CAC score were observed between the different sleep groups in the overall association tests

JACC VOL. 73, NO. 2, 2019
JANUARY 22, 2019:134-44

TABLE 3 Atherosclerotic Plaque Burden and Number of Affected Territories Measured by 3D Echocardiography and Sleep Duration: Comparison Between Self-Reported Sleep and Actigraphy

	Actigraph						Sleep Habits Questionnaire					
	Noncoronary Plaque Burden			Number of Territories Affected (1–4)			Noncoronary Plaque Burden (mm³)			Number of Territories Affected (1–4)		
	OR	95% CI	p Value	OR	95% CI	p Value	OR	95% CI	p Value	OR	95% CI	p Value
Total sleep duration, h			0.045*			0.18*			0.33*			0.20*
<6	1.27	1.06–1.52	0.008	1.21	1.02–1.45	0.03	0.99	0.79–1.24	0.92	0.92	0.74–1.16	0.50
6–7	1.10	0.94–1.30	0.25	1.07	0.90–1.26	0.40	1.13	0.98–1.31	0.10	1.13	0.98–1.31	0.09
7–8	1.00	Reference		1.00	Reference		1.00	Reference		1.00	Reference	
>8	1.31	0.92–1.85	0.13	1.13	0.79–1.13	0.50	0.91	0.78–1.34	0.50	1.03	0.78–1.34	0.86
Men sleep duration, h			0.32*			0.41*			0.27*			0.22*
<6	1.21	0.98–1.49	0.08	1.14	0.93–1.41	0.21	1.15	0.88–1.50	0.32	1.06	0.81–1.39	0.69
6–7	1.13	0.93–1.38	0.23	1.04	0.85–1.27	0.71	1.23	1.03–1.46	0.02	1.21	1.02–1.44	0.03
7–8	1.00	Reference		1.00	Reference		1.00	Reference		1.00	Reference	
>8	0.96	0.59–1.56	0.87	1.13	0.79–1.13	0.44	0.99	0.69–1.43	0.96	1.08	0.75–1.55	0.68
Women sleep duration, h			0.02*			0.11*			0.37*			0.33*
<6	1.48	1.06–2.07	0.02	1.38	1.00–1.93	0.053	0.69	0.44–1.07	0.10	0.68	0.44–1.05	0.08
6–7	1.01	0.76–1.36	0.90	1.04	0.85–1.27	0.44	0.94	0.72–1.23	0.66	0.97	0.74–1.26	0.81
7–8	1.00	Reference		1.00	Reference		1.00	Reference		1.00	Reference	
>8	1.83	1.12–3.01	0.02	1.65	1.01–2.72	0.05	0.77	0.51–1.18	0.23	0.89	0.59–1.35	0.59

Odds ratios (ORs) and 95% confidence intervals (CIs) of total plaque burden measured by 3-dimensional echocardiography (carotid and femoral territories) and affected territories in the different groups according to sleep duration compared with the reference group (7 to 8 h of sleep). Ordinal regression model adjusted for age, sex, moderate to vigorous physical activity, body mass index, smoking status, alcohol consumption, systolic blood pressure, education level, fasting glucose, total cholesterol, total kcal/day, marital status, Center for Epidemiological Studies-Depression, Perceived Stress Scale, and mSTOP-BANG questionnaire scores. Total plaque burden was divided into no plaque and tertiles (men: 0, 1.09 to 31.98, 31.99 to 105.62, and 106.53 to 1,241.98 mm³; women: 0, 1.19 to 14.83, 15.02 to 38.89, and 40.69 to 536.34 mm³). *p values for the overall adjusted associations for each analysis (likelihood-ratio test). The other p values correspond to pairwise comparisons with the reference group.
Abbreviations as in Table 1.

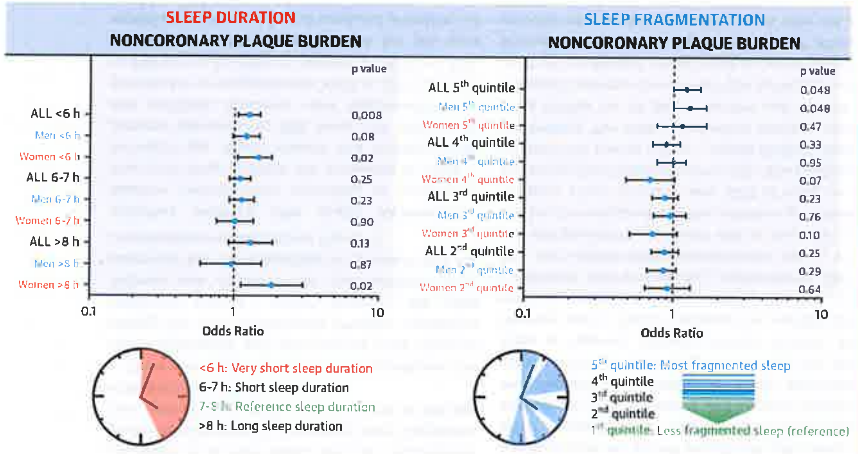
(Table 3), further highlighting the importance of objective sleep data for these kinds of studies. The same analysis was performed to evaluate the impact of sleep fragmentation on plaque burden. We found that the whole cohort and more specifically male participants with a more fragmented sleep (fifth quintile) presented a higher number of affected territories compared to the reference group (first quintile) (Central Illustration). A subanalysis excluding subjects with an mSTOP-BANG score ≥3 (n = 450; 11.8% of study participants with available 3D VUS) was conducted and showed similar results regarding VSSD and noncoronary atherosclerosis (Online Table 4). Moreover, in this case, participants with LSD showed a higher noncoronary plaque burden, although this difference was specifically observed in women (OR: 1.95; 95% CI: 1.20 to 3.19; $p = 0.007$ vs. OR: 1.07; 95% CI: 0.64 to 1.80; $p = 0.80$ in men).

Next, we investigated the relationship between sleep patterns and CACS. Coronary CT was available for analysis in 3,899 participants. Patients in the VSSD and SSD groups, as well as those with more disrupted sleep (fifth quintile), were associated with a higher CACS (Online Table 5). Adjusting for the aforementioned confounding factors, CACS was not significantly higher in SSD, VSSD, or LSD participants regardless of the method used for the evaluation of sleep habits (Online Table 4). Similarly, no significant association was observed between sleep quality and CACS in the variable-adjusted analysis or after excluding subjects with an mSTOP-BANG score ≥3 (Figure 1, Online Table 6).

ASSOCIATION OF DIETARY INTAKE AND INFLAMMATION WITH SLEEP PARAMETERS. No differences were observed between the different sleep duration groups when the quantity of nutrients was adjusted to grams in 2,000 kcal/day (Online Table 7). However, participants in the VSSD group presented a higher daily intake of alcohol, and those included in the VSSD and SSD groups presented a higher intake of caffeine compared with participants in the RSD group (Online Table 7). Similarly, participants in the higher quintile of SFI presented a higher intake of alcohol and caffeine compared with the reference group, and also an increased total energy intake (Online Table 8).

We next investigated the association between inflammation markers and sleep patterns. P-selectin and hs-CRP were significantly higher in VSSD participants (Table 1) and hs-CRP values were significantly higher in the higher quintile of FI compared with the lower quintile (Online Table 1). However, neither VSSD nor SSD were associated with a higher level

CENTRAL ILLUSTRATION Sleep Duration and Quality Versus Subclinical Atherosclerotic Burden



Domínguez, F. et al. J Am Coll Cardiol. 2019;73(2):134–44.

Forest plots showing the odds ratios (ORs) and confidence intervals (CIs) of total plaque burden measured by 3D echocardiography (carotid and femoral territories) in the different groups according to actigraphic sleep duration and fragmentation compared with the reference group (7 to 8 h of sleep, quintile 1). Ordinal regression model adjusted for age, sex, moderate to vigorous physical activity, body mass index, smoking status, alcohol consumption, systolic blood pressure, education level, fasting glucose, total cholesterol, total kcal/day, marital status, Center for Epidemiological Studies-Depression scale, Perceived Stress Scale, and mSTOP-BANG (modified Snoring, Tired, Observed apnea, high blood Pressure, BMI >35 kg/m², Age >50, Neck circumference >43 cm in males and >41 cm in females, and male Gender) questionnaire scores. The p values (**bold** indicates statistical significance) for the overall adjusted association between sleep parameters and atherosclerosis variables correspond to: sleep duration versus noncoronary plaque burden: **p = 0.045** (men: p = 0.32; women: **p = 0.02**); sleep fragmentation versus noncoronary plaque burden: **p = 0.004** (men: **p = 0.02**; women: p = 0.09). Total plaque burden divided in no plaque and tertiles (men: 0, 1.09 to 31.98, 31.99 to 105.62, and 106.53 to 1241.98 mm³; women: 0, 1.19 to 14.83, 15.02 to 38.89, and 40.69 to 536.34 mm³). Sleep fragmentation index values fifth quintile: 7.39 to 43.43; fourth quintile: 5.29 to 7.38; third quintile: 4.04 to 5.29; second quintile: 2.88 to 4.04; first quintile (reference group): 0.23 to 2.88. 3D = 3-dimensional; CT = computed tomography; LSD = long sleep duration; RSD = reference sleep duration; SFI = sleep fragmentation index; SSD = short sleep duration; VSSD = very short sleep duration; VUS = vascular ultrasound.

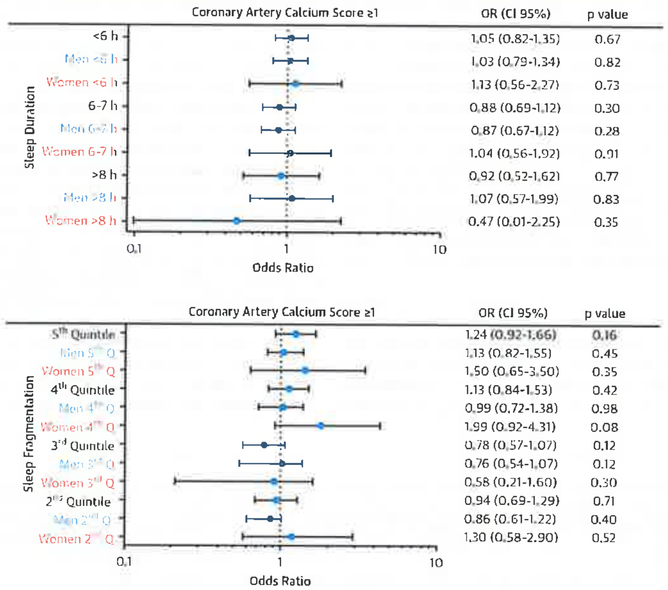
of inflammatory markers in the adjusted model (Online Table 9).

DISCUSSION

Our study shows that objectively assessed sleep duration and sleep fragmentation are independently associated with subclinical atherosclerosis after adjusting for cardiovascular risk factors and OSA risk. Unlike previous studies, the atherosclerotic plaque burden was accurately assessed by 2 imaging techniques including 3D VUS and coronary CT. Because various vascular territories were evaluated, this is the first study to report the impact of actigraphic sleep parameters on multiterritorial atherosclerosis, and is the biggest cohort with objectively measured sleep in this regard published to date. Furthermore, subjects diagnosed with obstructive sleep OSA were excluded, and the results were adjusted for the potential presence of OSA based on an mSTOP-BANG questionnaire score, thereby avoiding the confounding effect of this sleep disorder on our analysis.

We observed that participants sleeping <6 h/night (VSSD group) present a higher burden of noncoronary atherosclerosis and those with most fragmented sleep (fifth FI quintile) show in addition a higher number of affected territories measured by 3D VUS, independently of the presence of conventional CVD risk factors. Furthermore, LSD was related to a higher atherosclerotic burden specifically in women.

FIGURE 1 Coronary Artery Calcium Score Versus Actigraphic Sleep Duration and Fragmentation Index



Forest plot showing the odds ratios and confidence intervals of coronary artery calcium (CAC) scores in the different groups according to sleep duration fragmentation compared to the reference groups (7 to 8 h and first quintile, respectively). CAC score was divided into the following groups according to Agatston score: <1, 1 to 100, 100 to 400, >400. Ordinal regression model adjusted for age, sex, moderate to vigorous physical activity, body mass index (BMI), smoking status, alcohol consumption, systolic blood pressure, education level, fasting glucose, total cholesterol, total kcal/day, marital status, Center for Epidemiological Studies-Depression, Perceived Stress Scale, and mSTOP-BANG (modified Snoring, Tired, Observed apnea, high blood Pressure, BMI >35 kg/m², Age >50, Neck circumference >43 cm in males and >41 cm in females, and male Gender) questionnaire scores. The p values for the overall adjusted association between sleep parameters and CAC score correspond to (**bold** indicates statistical significance): sleep duration versus CAC score ≥1: p = 0.44 (men: p = 0.47; women: p = 0.70); sleep fragmentation versus CAC score ≥1: **p = 0.02** (men: p = 0.12; women: p = 0.08). Total plaque burden divided in no plaque and tertiles (men: 0, 1.09 to 33.70, 33.71 to 107.69, 108.03 to 1,241.98, and >1,241.98 mm³; women: 0, 1.19 to 16.32, 16.56 to 45.24, 45.49 to 536.34, and >536.34 mm³). Sleep fragmentation index values fifth quintile: 7.39 to 43.43; fourth quintile: 5.29 to 7.38; third quintile: 4.04 to 5.29; second quintile: 2.88 to 4.04; and first quintile (reference group): 0.23 to 2.88. CI = confidence interval; OR = odds ratio.

However, we did not find that sleep duration and quality had an effect on CACS or inflammation biomarkers in our study population.

In our study, participants with SSD or VSSD presented a higher prevalence of classical cardiovascular risk factors, which is consistent with previously published data (3,6,36–38). Consequently, individuals with poorer sleep presented higher scores in various cardiovascular risk scales (Table 2). Moreover, participants with VSSD, SSD, and a more fragmented sleep (fourth and fifth quintiles) were more overweight (>26 kg/m²) and those with LSD and nonfragmented sleep presented with lower BMI values (Table 1, Online Table 1).

The link between short sleep duration and higher energy intake has already been suggested (39), but the most extensive related study published to date relied on self-reported sleep measurements (40) and the only available actigraphy-based study was restricted to women (41). In our study, only subjects with the most disrupted sleep (quintile 5) presented a higher energy intake, but the fats, carbohydrates, or proteins did not differ significantly between sleep groups. Only alcohol and caffeine consumption were higher in participants with short and disrupted sleep (Online Tables 5 and 6). Lately, coffee intake has been associated with better cardiovascular outcomes and lower mortality (42), but in our study, a higher caffeine intake seems to be related to unhealthier sleep patterns in groups with more cardiovascular risk factors.

These results support that subjects with poor sleep hygiene are clustered into groups apparently less engaged in healthy cardiovascular behaviors. However, apart from confirming the direct association of sleep duration and quality with cardiovascular risk factors and dietary habits, the current study is the first to show that objectively measured sleep is independently associated with subclinical multi-territory atherosclerosis. The fact that sleep duration and quality was objectively measured is relevant, as we have observed that self-reported sleep duration may not be reliable. In our study, while 27.1% of participants slept <6 h/day according to the accelerometer, only 10.7% reported <6 h sleep in the Sleep Habits Questionnaire. Consequently, the association of self-reported sleep with noncoronary atherosclerosis in our study is different from that seen with actigraphy, and only the subgroup of men who slept 6 to 7 h showed a trend toward a higher risk of noncoronary atherosclerosis (Table 3). This could be explained by the fact that these participants actually present with VSSD rather than SSD.

The largest study to date that analyzed the impact of sleep on atherosclerosis with objectively measured sleep parameters (n = 1,844) included subjects with OSA, and the clinical endpoint was peripheral artery disease measured with ankle-brachial index (14). Another study with 1,465 participants showed that poorer sleep was associated with greater coronary artery calcification (13). However, the effect of sleep patterns on subclinical atherosclerosis in a population without sleep-related disorders has not been adequately studied until now. In the present study, roughly 3,800 participants underwent coronary CT and 3D VUS in different territories. An association with CACS was discarded after adjusting for confounders, but the association with higher noncoronary atherosclerotic burden was significant. This may be explained by the fact that 3D VUS is a more sensitive technique than CACS to measure early atherosclerosis (32).

Regarding LSD, despite the result of a previous meta-analysis that found a correlation with cardiovascular outcomes (1), its effect on subclinical atherosclerosis remains unresolved due to variable results in previous studies (8). We have observed that LSD is not associated with plaque burden or CACs in the general cohort. However, the subgroup of women who slept >8 h presented with a higher burden of subclinical atherosclerosis, and similar results were observed in the general cohort after excluding participants with an mSTOP-BANG score ≥3 (Online Table 4). As the number of patients with LSD was limited, these results need validation in a bigger cohort. In any case, these findings suggest that too-long sleep duration may not be healthy either, and recommendations should be restricted to 7 to 8 h of sleep.

Overall, our findings support the potential role of healthy sleeping in protecting against atherosclerosis. Thus, recommending a good sleep hygiene should be part of the lifestyle modifications provided in our daily clinical practice.

STUDY LIMITATIONS. The PESA study cohort is relatively homogeneous and may not be representative of the general population, as it includes only middle-aged subjects with generally low cardiovascular risk and a characteristic occupation and lifestyle. Although subjects with an established OSA diagnosis were excluded, this condition is usually underdiagnosed in the general population. Thus, the results were adjusted for an mSTOP-BANG questionnaire score with the available clinical data in the PESA study. The original STOP-BANG questionnaire could not be used due to the lack of neck circumference data. A definite OSA evaluation would need a polysomnography study in all study participants, which was not available. In addition, whereas wrist actigraphy might be the preferred method for sleep evaluation, in this study we used waist actigraphy. However, previous studies have shown a good correlation between polysomnography and waist actigraphy data (43).

Furthermore, the LSD group represents only 4% of the total cohort, and results are not as generalizable as in the other groups. Finally, as follow-up data is not included in the study, the effects of sleep patterns on subclinical atherosclerosis over time are not addressed.

However, the proportion of women participants is higher than in other studies, and sleep and clinical data are well characterized in this cohort, which are both strengths of this study.

CONCLUSIONS

Sleep is an important factor influencing cardiovascular health and could have a role as a marker of subclinical atherosclerosis. Objectively measured short sleeping times and fragmented sleep are associated with an increased risk of subclinical atherosclerosis. These results highlight the importance of healthy sleep habits for the prevention of CVD.

ADDRESS FOR CORRESPONDENCE: Dr. José M. Ordovás, Nutrition and Genomics, Nutrition and Genetics, JM-USDA-HNRCA at Tufts University, 711 Washington Street, Boston, Massachusetts 02111. E-mail: jose.ordovas@tufts.edu. Twitter: @jordovas56. OR Dr. Valentin Fuster, Zena and Michael A. Wiener Cardiovascular Institute, The Mount Sinai Hospital, 1190 5th Avenue, New York, New York 10029. E-mail: vfuster@cnic.es. Twitter: @CNIC_Cardio, @MountSinaiNYC.

PERSPECTIVES

COMPETENCY IN MEDICAL KNOWLEDGE: Metabolic syndrome is associated with abnormal sleep patterns. Short and fragmented sleep patterns are independently associated with increased atherosclerotic plaque burden in middle-aged individuals.

TRANSLATIONAL OUTLOOK: Prospective studies are needed to assess the impact of specific interventions that improve sleep hygiene on clinical ischemic events.

REFERENCES

1. Cappuccio FP, Cooper D, Delia L, Strazzullo P, Miller MA. Sleep duration predicts cardiovascular outcomes: a systematic review and meta-analysis of prospective studies. Eur Heart J 2011;32:1484–92.

2. Sabanayagam C, Shankar A. Sleep duration and cardiovascular disease: results from the National Health Interview Survey. Sleep 2010;33:1037–42.

3. Gangwisch JE, Heymsfield SB, Boden-Albala B, et al. Short sleep duration as a risk factor for hypertension: analyses of the first National Health and Nutrition Examination Survey. Hypertension 2006;47:833–9.

4. Guo X, Zheng L, Li Y, et al. Association between sleep duration and hypertension among Chinese children and adolescents. Clin Cardiol 2011;34:774–81.

5. Wang Q, Xi B, Liu M, Zhang Y, Fu M. Short sleep duration is associated with hypertension risk among adults: a systematic review and meta-analysis. Hypertens Res 2012;35:1012–8.

6. Cappuccio FP, D'Elia L, Strazzullo P, Miller MA. Quantity and quality of sleep and incidence of type 2 diabetes: a systematic review and meta-analysis. Diabetes Care 2010;33:414–20.

7. Watanabe M, Kikuchi H, Tanaka K, Takahashi M. Association of short sleep duration with weight gain and obesity at 1-year follow-up: a large-scale prospective study. Sleep 2010;33:161–7.

8. Aziz M, Ali SS, Das S, et al. Association of subjective and objective sleep duration as well as sleep quality with non-invasive markers of subclinical cardiovascular disease (CVD): a systematic review. J Atheroscler Thromb 2017;24:208–26.

9. Meisinger C, Heier M, Löwel H, Schneider A, Döring A. Sleep duration and sleep complaints and risk of myocardial infarction in middle-aged men and women from the general population: the MONICA/KORA Augsburg cohort study. Sleep 2007;30:1121–7.

10. Matthews KA, Strollo PJ Jr., Hall M, et al. Associations of Framingham risk score profile and coronary artery calcification with sleep characteristics in middle-aged men and women: Pittsburgh SleepSCORE study. Sleep 2011;34:711–6.

11. Nakazaki C, Noda A, Koike Y, Yamada S, Murohara T, Ozaki N. Association of insomnia and short sleep duration with atherosclerosis risk in the elderly. Am J Hypertens 2012;25:1149–55.

12. Schwartz J. Sleep and markers of cardiovascular disease risk in elderly Alzheimer's caregivers. Diss Abstr Int Sect B Sci Eng 2013;73.

13. Lutsey PL, McClelland RL, Duprez D, et al. Objectively measured sleep characteristics and prevalence of coronary artery calcification: the Multi-Ethnic Study of Atherosclerosis Sleep study. Thorax 2015:880–7.

14. Nagayoshi M, Lutsey PL, Benkeser D, et al. Association of sleep apnea and sleep duration with peripheral artery disease: The Multi-Ethnic Study of Atherosclerosis (MESA). Atherosclerosis 2016;251:467–75.

15. Sands MR, Lauderdale DS, Liu K, et al. Short sleep duration is associated with carotid intima-media thickness among men in the coronary artery risk development in young adults (CARDIA) study. Stroke 2012;43:2858–64.

16. King CR, Knutson KL, Rathouz PJ, Sidney S, Liu K, Lauderdale DS. Short sleep duration and incident coronary artery calcification. JAMA 2008;300:2859–66.

17. Fernández-Ortiz A, Jiménez-Borreguero LJ, Peñalvo JL, et al. The progression and early detection of subclinical atherosclerosis (PESA) study: rationale and design. Am Heart J 2013;166:990–8.

18. Fernández-Friera L, Peñalvo JL, Fernández-Ortiz A, et al. Prevalence, vascular distribution, and multiterritorial extent of subclinical atherosclerosis in a middle-aged cohort the PESA (Progression of Early Subclinical Atherosclerosis) study. Circulation 2015;131:2104–13.

19. Alberti KG, Eckel RH, Grundy SM, et al. Harmonizing the metabolic syndrome: a joint interim statement of the International Diabetes Federation Task Force On Epidemiology And Prevention; National Heart, Lung, And Blood Institute; American Heart Association; World Heart Federation; International Atherosclerosis Society; and International Association for the Study of Obesity. Circulation 2009;120:1640–5.

20. Fernández-Alvira JM, Fuster V, Pocock S, et al. Predicting subclinical atherosclerosis in low-risk individuals. J Am Coll Cardiol 2017;70:2463–73.

21. Chung F, Abdullah HR, Liao P. STOP-BANG questionnaire: a practical approach to screen for obstructive sleep apnea. Chest 2016;149:631–8.

22. EPIC Group of Spain. Relative validity and reproducibility of a diet history questionnaire in Spain. II. Nutrients. European Prospective Investigation into Cancer and Nutrition. Int J Epidemiol 1997;26 Suppl 1:S100–9.

23. Gonzalez-Svatetz CA. Relative validity and reproducibility of a diet history questionnaire in Spain. I. Foods. Int J Epidemiol 1997;26:S91–9.

24. Peñalvo JL, Fernández-Friera L, López-Melgar B, et al. Association between a social-business eating pattern and early asymptomatic atherosclerosis. J Am Coll Cardiol 2016;68:805–14.

25. Uzhova I, Fuster V, Fernández-Ortiz A, et al. The importance of breakfast in atherosclerosis disease: insights from the PESA Study. J Am Coll Cardiol 2017;70:1833–42.

26. St-Onge M-P, Grandner MA, Brown D, et al. Sleep duration and quality: impact on lifestyle behaviors and cardiometabolic health: a scientific statement from the American Heart Association. Circulation 2016;134:e367–86.

27. Actigraph. Sleep fragmentation index validation. Available at: https://actigraph.desk.com/customer/en/portal/articles/2515583-sleep-fragmentation-index—validation-reference. Accessed July 3, 2018.

28. Unruh ML, Redline S, An MW, et al. Subjective and objective sleep quality and aging in the sleep heart health study. J Am Geriatr Soc 2008;56:1218–27.

29. Soler J, Pérez-Sola V, Puigdemont D, Pérez-Blanco J, Figueres M, Alvarez E. [Validation study of the Center for Epidemiological Studies-Depression of a Spanish population of patients

with affective disorders]. Actas Luso Esp Neurol Psiquiatr Cienc Afines 1997;25:243–9.

30. Remor E. Psychometric properties of a European Spanish version of the perceived stress scale (PSS). Span J Psychol 2006;9:86–93.

31. Touboul PJ, Hennerici MG, Meairs S, et al. Mannheim intima-media thickness consensus. Cerebrovasc Dis 2004;18:346–9.

32. López-Melgar B, Fernández-Friera L, Oliva B, et al. Subclinical atherosclerosis burden by 3d ultrasound in mid-life. J Am Coll Cardiol 2017;70:301–13.

33. López-Melgar B, Fernández-Friera L, Sánchez-González J, et al. Accurate quantification of atherosclerotic plaque volume by 3D vascular ultrasound using the volumetric linear array method. Atherosclerosis 2016;248:230–7.

34. Greenland P, Bonow RO, Brundage BH, et al. ACCF/AHA 2007 clinical expert consensus document on coronary artery calcium scoring by computed tomography in global cardiovascular risk assessment and in evaluation of patients with chest pain. J Am Coll Cardiol 2007;49:378–402.

35. Cappuccio FP, Stranges S, Kandala N-B, et al. Gender-specific associations of short sleep duration with prevalent and incident hypertension: the Whitehall II Study. Hypertension 2007;50:693–700.

36. Meng L, Zheng Y, Hui R. The relationship of sleep duration and insomnia to risk of hypertension incidence: a meta-analysis of prospective cohort studies. Hypertens Res 2013;36:985–95.

37. Holliday EG, Magee CA, Kritharides L, Banks E, Attia J. Short sleep duration is associated with risk of future diabetes but not cardiovascular disease: a prospective study and meta-analysis. PLoS One 2013;8:e82305.

38. Kaneita Y, Uchiyama M, Yoshiike N, Ohida T. Associations of usual sleep duration with serum lipid and lipoprotein levels. Sleep 2008;31:645–52.

39. Dashti HS, Zuurbier LA, de Jonge E, et al. Actigraphic sleep fragmentation, efficiency and duration associate with dietary intake in the Rotterdam Study. J Sleep Res 2016;25:404–11.

40. Grandner MA, Jackson N, Gerstner JR, Knutson KL. Dietary nutrients associated with short and long sleep duration. Data from a nationally representative sample. Appetite 2013;64:71–80.

41. Grandner MA, Kripke DF, Naidoo N, Langer RD. Relationships among dietary nutrients and subjective sleep, objective sleep, and napping in women. Sleep Med 2010;11:180–4.

42. Gunter MJ, Murphy N, Cross AJ, et al. Coffee drinking and mortality in 10 European countries: a multinational cohort study. Ann Intern Med 2017;167:236–47.

43. Enomoto M, Endo T, Suenaga K, et al. Newly developed waist actigraphy and its sleep/wake scoring algorithm. Sleep Biol Rhythms 2009;7:17–22.

KEY WORDS 3D vascular ultrasound, actigraph, cardiac computed tomography, sleep, subclinical atherosclerosis

APPENDIX For supplemental tables and a figure, please see the online version of this paper.

Wind Turbine Syndrome:

The Impact of Wind Farms on Suicide*

Eric Zou

October 2017

Abstract

Current technology uses wind turbines' blade aerodynamics to convert wind energy to electricity. This process generates significant low-frequency noise that reportedly results in residents' sleep disruptions, among other annoyance symptoms. However, the existence and the importance of wind farms' health effects on a population scale remain unknown. Exploiting over 800 utility-scale wind turbine installation events in the United States from 2001-2013, I show robust evidence that wind farms lead to significant increases in suicide. I explore three indirect tests of the role of low-frequency noise exposure. First, the suicide effect concentrates among individuals who are vulnerable to noise-induced illnesses, such as the elderly. Second, the suicide effect is driven by days when wind blows in directions that would raise residents' exposure to low-frequency noise radiation. Third, data from a large-scale health survey suggest increased sleep insufficiency as new turbines began operating. These findings point to the value of noise abatement in future wind technology innovations.

* Department of Economics, University of Illinois at Urbana-Champaign. Email: yzou9@illinois.edu. I am extremely grateful to Dan Bernhardt, Tatyana Deryugina, Don Fullerton, Nolan Miller, and David Molitor for invaluable guidance and support. This paper has also benefited from comments and suggestions by David Albouy, Max Auffhammer, Mark Borgschulte, Karen Brandon, Marcus Dillender, Steve Errede, Julian Reif, and all participants at the University of Illinois Applied Microeconomics Research Lunch, the University of Illinois Program in Environmental and Resource Economics, and the Midwest Health Economics Conference. I thank the Alliance for Audited Media for generously providing access to their database. All errors are mine.

1. Introduction

The rising use of large machinery in industrial operation brings about significant noise pollution. A common feature of machinery noise is that it contains significant amounts of energy in the low-frequency (< 100 Hz) range. With a low pitch, these sounds are less attenuated by barriers, travel longer distances, and their "rumbling" nature appears to be particularly annoying to many.[1] Over the past decade, the rapid growth of the wind energy industry has triggered an increase in the public and academic interest of the health risks of low-frequency noise. By current technology, energy in wind flow is captured using large wind turbines that, with three giant and properly curved blades, convert air motions to rotational energy which is in turn used to generate electricity. As a byproduct of blade aerodynamics, wind turbines emit substantial low-frequency sound. Around the world, communities near some wind farms have made complaints, and on occasion have filed lawsuits, about health effects reportedly due to wind farms' low-frequency noise. Complainants contend that the noise causes headache, nausea, dizziness, and, most predominantly, sleep disruptions.

The phenomenon, usually referred to as "wind turbine syndrome" (Pierpont, 2009), has generated great academic and policy controversy. The debate can be summarized into three pairs of conflicting facts and views. First, industry groups deny the relevance of wind farms noise beyond certain distances, usually 500 meters. In contrast, independent measurements from the physics literature show that wind farms' low-frequency noise can be measured in homes kilometers away from the source (e.g. van den Berg, 2004; Moller and Pedersen, 2011; Ambrose, Rand, and Krogh, 2012). Second, wind turbines' noise contains a significant component at extremely low frequencies (< 20 Hz). Sound in this frequency region is typically inaudible to humans ("infrasound"), and so it should have no health effects through auditory channels (e.g. Basner et al., 2014). However, recent medical research suggests, although not yet conclusively, that exposure to infrasound can cause non-auditory responses such as the excitement of neural pathways responsible for attention and alerting, which might contribute to sleep loss (Weedman and Ryugo, 1996; Danzer, 2012; Salt, Lichtenhan, Gill, and Hartscok, 2013). Finally, while anecdotal evidence of wind turbine syndrome exists in almost every country that has wind farms, the epidemiology literature, which predominantly focuses on survey reports of various annoyance symptoms, has reached little consensus regarding the existence and the importance of wind farms' health impacts on a population

[1] Atmospheric attenuation of sound energy increases at the rate of the square of the sound's frequency. Barriers' ability to absorb sound also decreases at lower frequencies. As a consequence, low-frequency noise exposure may appear stronger in indoor environments where walls block higher-frequency sounds (Ambrose, Rand, and Krogh, 2012; Moller and Pedersen, 2011). For a review, see Leventhall (2004).

scale (Bakker et al., 2012; McCunney et al, 2014; Schmidt and Klokker, 2014). Against this backdrop of uncertainty over whether and how wind turbines may affect health, the use of wind energy is growing. Better understanding of any potential health risks associated with wind farms is crucial in informing future policies that relate to a growing source of electricity generation.

This paper presents a new step toward greater understanding of wind turbine syndrome. There are two main innovations. First, to characterize wind turbine syndrome and to learn about its external costs, I study wind farms' impact on suicide, which can be consistently measured across the population using death records data. While suicide is an extreme situation, representing individuals who have reach the depths of despair (e.g., Case and Deaton, 2015; Case and Deaton, 2017), it is likely to be an enveloping measure of the many, disparate annoyance symptoms associated with wind turbine syndrome. In particular, suicide is closely related to sleep loss -- the signature symptom among wind turbine syndrome sufferers -- which has long been understood as a significant risk factor for suicidal ideation (Choquet and Menke, 1990; Roberts, Roberts, and Chen, 2001), suicide attempts (Tishler, McKenry, and Morgan, 1981), and suicide deaths (Farberow and MacKinnon, 1974; Fawcett, et al., 1990; Rod, et al., 2011). Suicide also merits study because of its high social costs, especially given the fact that suicides often occur as a result of impulsive behavior, sometimes independent of any accompanying medical conditions (see e.g., Simon et al., 2001) – thereby cutting short lives for people who might otherwise have been expected to reach normal life expectancies. While the analysis focuses on suicide, I also use the death records data to consider potential responses of other major causes of death, as I describe in more detail below.

The second innovation of this paper is the use of a quasi-experimental estimation framework that delivers causal estimates on wind farms' adverse health effects. The basis of my research design is over 800 events of utility-scale wind turbines installation across the United States from 2001 to 2013, including both openings of new wind farms as well as major additions of turbines to existing farms. These events allow me to explore quasi-experimental variations in exposure to wind farms along three dimensions: (1) the abrupt change in exposure before and after the new turbines began operation, (2) the geographic variation in residents' exposure by their proximity to the wind farms, and (3) the year-to-year variation in whether installation events occur during a given time of year. Each of these variations - alone *and* in combination - produce effect estimates that are based on alternative natural comparison groups. Taken together, this rules out a range of potential confounding factors. Notably, I show that using the most saturated triple-difference method that exploits all three dimensions of variations yields very similar results to ones obtained using simpler designs, such as a pure before-versus-after event study style

approach. This lends confidence to the identifying assumption that the installation of wind turbines can serve as a valid source of exogenous shocks for the purposes of this study.

My empirical analysis yields robust evidence that wind farms increase suicide. I find no significant changes in the suicide rate over the two years (which likely covers the entire construction period) before the turbines' installation, followed by a prompt increase by about 2 percent in the month when new turbines began generating power. This effect stays relatively stable for the following year. The suicide impact appears to be geographically widespread; effects can be detected at least within 25 km, but no farther than 100 km, to the wind farm. I find that wind farms have fairly precise zero effects on other major causes of deaths, except for some suggestive evidence of increases in deaths related to mental and nervous system disorders. These later estimates, however, are not precise enough to be conclusive. Importantly, the finding on suicide effect is robust to overrejection adjustments when the hypothesized effects of wind farms on other major causes of deaths are simultaneously tested for (Anderson, 2008).

I explore three tests to shed light on the role of low-frequency noise exposure. I begin by documenting an age profile for suicide, which shows that the most concentrated increase in suicide occurs among the elderly population. This is consistent with the view that individuals are increasingly sensitive to noise exposure at older ages (e.g., Miedema and Vos, 2003; Kujawa and Liberman, 2006; Muzet, 2007).

Second, exploiting changes in wind patterns, I find evidence of an agreement between wind farms' low-frequency noise radiation profile and suicide effects heterogeneity with respect to wind directions. Specifically, I find that the suicide effect is explained mainly by days when residents spend downwind or upwind wind farms, while crosswind days are not predictive of the suicide effects. This is consistent with the "acoustic dipole" property that low-frequency noise typically exhibits: measured noise levels are higher at upwind and downwind locations while suppressed at crosswind locations (e.g., Hubbard and Shepherd, 1990; Oerlemands and Schepers, 2009).

Finally, the paper documents evidence of sleep responses to wind farms. I analyze self-reports of sleep in a sample of respondents from a large-scale health survey. I find a significant increase in reported number of nights of insufficient sleep following wind turbine installation. This effect appears to be explained by an increase in reports of sustained (more than seven nights per month) sleep insufficiency.

This paper contributes to the literature by delivering the first national-scale causal evidence on wind farms' adverse health effects. Results of this paper imply that the costs of wind farms are significant even if one considers solely the consequences of suicides. My calculation suggests that wind farms installed between 2001 and 2013 resulted in a total of 34,000 life years lost (LYL) due to increased suicides within a year after installation. To put this number in perspective, during the same one-year time window, the new wind capacity generated roughly 150 million megawatt hours (mwh) of clean energy; by comparison, based on existing estimates of the per mwh health cost of coal-generated electricity (Epstein et al., 2011), generating the same amount of electricity with coal would have resulted in around 53,000 life years lost due to air pollution.

More broadly, this paper is related to the economic literature for developing empirically grounded cost-benefit analysis of wind energy. Existing literature has documented wind farms' negative externality on nearby residents through evidence of lower levels of life satisfaction (Krekel and Zerrahn, 2017) and, more predominantly, reduced property values (e.g., Ladenburg and Dubgaard, 2007; Gibbons, 2015; Dröes and Koster, 2016). Importantly, wind farms' impact on property value is found to be highly local (usually within few kilometers), and there is evidence that housing price effects are largely explained by whether wind farms are visible from the location of the house (Gibbons, 2015). My estimates show that the health effects of wind farms can occur far beyond "sightline" properties where declining property values have been observed. On the benefit side, wind industry operations may benefit local economies (e.g., Kahn, 2013); wind energy production also displaces electricity generation from fossil fuel sources (Cullen, 2013; Novan, 2015), and therefore may have both short-term air quality benefits and also longer-term climate benefits. Together, these cost-benefit parameters have a broad range of policy and regulatory implications such as wind farm siting decisions, the determination of subsidy levels to existing wind farms, and the social return to the development of quieter wind technologies.[2]

This paper's findings also contribute to the understanding of the external determinants of suicide, a leading causes of death that claims around 0.8 million lives per year globally. While suicide is widely recognized as a consequence of the interplay between multiple medical and social determinants, existing evidence predominantly focuses on internal risk factors such as psychiatric illnesses (e.g., Mann, et al., 2005; Hawton and Heeringen, 2009; Zalsman, et al., 2016). However, external determinants of suicide are also important, especially from a suicide prevention viewpoint (e.g., Carleton, 2017). My results suggest that exposure to wind farms is a significant stressor, which may be relevant for at-risk individuals' location choice. Moreover, in subsequent analysis I show that wind farms' suicide effects are strongly correlated

[2] For example, wind turbines can use vorticity, an aerodynamic effect that produces a pattern of vortices, to produce energy rather than using blades <http://www.wired.com/2015/05/future-wind-turbines-no-blades/>; coating wind turbine blades may scatter turbulence when air passes the blades, mimicking the wing structure of owls <www.cnbc.com/id/102777259>; floating wind turbines are able to capture high wind speed in higher altitudes, therefore increasing wind energy generation efficiency <http://www.altaerosenergies.com/bat.html>.

with higher local access to firearms, which provides suggestive evidence on the scope for firearm restriction policies to mitigate increased propensity for suicide.

The remainder of the paper is organized as follows. Section 2 provides background. Section 3 describes primary data sources. Section 4 presents the identification strategy and main results. Section 5 presents evidence on the role of noise pollution. Section 6 reports the suicide effects heterogeneity by local gun access. Section 7 discusses the interpretation and the limitations of the results, and offers conclusions.

2. Background

2.1 Wind Turbine Noise

Noise from modern wind turbines (Figure 1, panel A) is a consequence of blade aerodynamics. Noise is first created upon contact between air flow and the leading edge of the blade. Next, turbulence is produced as air flows over the blade surface. The turbulence is reinforced when it passes the sharp edge of the blade, creating what is known as trailing edge noise. Finally, as air leaves the blade, the tail turbulence (or "wake") interacts with the wind turbine tower as blades pass by, generating impulsive noises (Howe, 1978; Blake, 1986; Wagner, Bareib, and Guidati, 1996; Oerlemans, Sijtsma, and Mendez Lopez, 2007). See Figure 1, panel B for an illustration.

Two unique features of wind turbine noise are relevant to this study. First, acoustic impulses resulting from blade aerodynamics are usually of low frequency, which occurs at the blade-passage frequency (i.e., the product of rotational frequency and the number of blades, typically three) along with its higher harmonics. Measurement using modern wind turbines show peak energy at frequencies typically below 20 Hz (see e.g., Hubbard and Shepherd, 1990; Doolan, Moreau, and Brooks, 2011). While sound in this frequency region is generally inaudible to human ears (i.e., "infrasonic"), exposure may nevertheless create adverse impacts (explained in further detail below). Moreover, low-frequency sound can travel much farther than sound in the audible range due to slower energy loss in propagation. Effective monitoring of the noise profile of wind turbines requires simultaneous measurements from a sound recorder array which is difficult to implement far away from the wind turbine. As a consequence, current understanding of wind turbine's noise distance gradient is restricted to areas in the vicinity of wind farms. However, recent measurements show that receivers up to two kilometers to wind farm can detect low-frequency noise with the pressure level high enough to be perceived by human ear (van den Berg, 2004; Moller and Pedersen, 2011; Ambrose, Rand, and Krogh, 2012).

Second, Wind turbine's low-frequency noise radiation exhibits "acoustic dipole," that is, sound does not radiate in all directions equally, with exposure being stronger in the upwind and the downwind directions while weaker in the crosswind directions (see e.g., Hubbard and Shepherd, 1990; Oerlemands and Schepers, 2009). Figure 1, panel C provides a graphical illustration. In section 5, I exploit this unique acoustic property of low-frequency noise to shed light on the mechanism underlying the impact of wind farms.

2.2 Health Effects of Low-Frequency Noise Exposure

Noise pollution has long been understood as a health hazard. Most directly, noise leads to the loss of auditory cells in the ear, causing hearing problems such as hearing loss (e.g., Vos et al., 2012). Noise exposure is also linked to a range of non-auditory responses such as annoyance, sleep disruptions, reduced cognitive functions, and cardiovascular diseases (for a review, see Basner et al., 2013). One puzzle of wind turbine syndrome centers around the debate over whether noise in the low-frequency range can also cause these health effects.

Human hearing is insensitive to sound at low frequencies, especially in the infrasonic domain (below 20 Hz). Biomechanically, this is due to the fact that *inner hair cells* of the cochlea, the primary sensory cells responsible for conscious hearing, exhibit decreasing sensitivity at lower frequencies (Dallos, 1973). However, recent research has discovered a new micromechanism of the ear's low-frequency sound processing. Experiments with guinea pigs (Salt, Lichtenhan, Gill, and Hartscok, 2013) and with humans (Kugler, et al., 2014), have shown that the *outer hair cells* of the ear are strongly activated when exposed to low-frequency sound. Serving as the main acoustical pre-amplifier, the outer hair cells do not directly contact auditory nerves in the brain. Rather, they are responsible for detecting and amplifying incoming sound through fast oscillation of the cell body (von Bekesy, 1960). Exposure to low-frequency sound triggers this amplification process, causing strong stimulation of cochlea. Whereas it remains unknown why the cochlea appears to process low-frequency sound before discarding it altogether, this mechanism underlies two potential health consequences of exposure to low-frequency sound. First, excessive activation of the cochlea can make the ear more prone to permanent shifts in auditory thresholds, leading to hearing loss. Second, because outer hair cells are connected to neural pathways related to orientation,

attention and alerting (Weedman and Ryugo, 1996; Danzer, 2012), exposure to low-frequency sound may explain annoyance responses, such as sleep disturbance, commonly reported by residents near wind farms.

While complaints about wind farms' noise pollution parallel the growth of wind industry worldwide, research evidence is inconclusive regarding whether or to what extent low-frequency noise exposure from wind farms poses significant health risks. On one side, a large peer-reviewed literature exists on the association between wind turbine operation and a broad set of annoyance responses such as headache, dizziness, nausea, tinnitus, and hearing loss. The most robust association is the link between the turbines' presence and sleep disturbance, which was found in numerous cases to respond to wind turbine noise exposure in a dosage manner (Bakker et al., 2012; Schmidt and Klokker, 2014). The other side of the debate points out that some of the observed annoyance responses can be attributed to subjective factors such as attitudes toward wind energy rather than noise exposure (Knopper and Ollson, 2011). Also, many survey-based studies may suffer from biases related to study design, such as self-selection of survey volunteers and errors in measurement based on recall (McCunney et al, 2014).

3. Data and Summary Statistics

3.1 Primary Data Sources

Wind farm data are obtained from the U.S. Energy Information Administration's form 860 (EIA-860). EIA-860 provides annual census of existing power generators larger than one megawatt (MW) in generation capacity, and it contains information on plant location, nameplate capacity, and month and year in which the new capacity came online. I define wind turbine installation events as entries of new capacities whose primary energy source is specified as wind. My baseline event study estimation includes a total of 828 installation events spanning 39 states in the United States from 2001 to 2013.

My primary outcome variable is the suicide rate at the county × month level from 2001 to 2013. This data come from the National Center for Health Statistics' Vital Statistics Multiple Cause of Death Data File. Suicide rate is defined as the fraction of individuals in the county who died due to suicide (ICD 10 = X60-X84, Y87.0) relative to the county's total population in the year. I also construct age-specific suicide rates using Vital Statistics data's information on descendants' age of death. Population estimates at both the county × year level and the county × year × age level are obtained from the National Cancer Institute's Surveillance, Epidemiology, and End Results Program (SEER).

I derive wind data from the North American Regional Reanalysis (NARR) produced by the National Centers for Environmental Prediction, which contains information on wind conditions at a spatial resolution of 32km × 32 km grid cell. For each grid cell × day, NARR reports the horizontal (u-wind) and vertical (v-wind) components of the wind vector. I link each wind farm to the corresponding grid cell, and convert u- and v-wind into wind vectors (direction and speed) using trigonometry.

3.2 Summary Statistics

Figure 2 illustrates the rapid expansion of the U.S. wind power industry since late 1990s. While utility-scale wind farms were almost non-existent until the turn of the 21st century, by the end of 2013, total generation capacity had reached 60,000 MW. That year, electricity generated from wind farms amounted to 167 million MWh, sufficient to meet electricity consumption for more than 15 million U.S. households. Figure 2 also shows that the geographic span of wind farms expanded rapidly: in the 1990s, an average American lived more than 800 kilometers from the nearest wind farm. By 2013, this number had fallen to about 200 kilometers, and to about 100 kilometers for individuals living in states with wind farms.[3]

Figure 3 plots the location of wind farms throughout the study period. My preferred estimation sample contains a group of "close" counties that are within 25 km of wind farms. This selection criterion is motivated by the 32 km × 32 km spatial resolution of the wind measurement, which allows me to confidently infer wind conditions within a 25-kilometer radius of a given wind farm. In the appendix, I show that the main findings of the paper are not sensitive to this selection rule. I also construct a sample of "distant" counties located 25 to 100 kilometers from the wind farms. I use this "distant" location sample in specifications that exploit spatial differences.

While all empirical specifications in this paper ultimately control for some form of county fixed effects, in Table 1 I examine levels of observable characteristics across counties that are close to wind farms versus those that are far away; I take this step to shed light on external validity of the research design. Column 1 reports characteristics of close (0-25 km) counties in the primary estimation sample. Column 2 represents distant (25-100 km) counties that are used in subsequent analysis for spatial comparison. Column 3 summarizes the same statistics for all other counties (> 100 km from wind farms)

[3] The distance calculations are based on latitude and longitude of wind farms and the Census 2010 county population centers.

that are not examined in this study. Finally, column 4 reports national averages. The suicide rate in the close counties is on average 8.56 per million population per month, slightly lower than the rest of the country, e.g., column 4 shows that national average suicide rate is 9.76. Table 1 also reports suicide statistics for five separate age groups (< 20, 20-39, 40-59, 60-79, and > 80). The different in the average suicide rate does not appear to be driven by any particular age groups. Economic and weather characteristics in counties close to wind farms are generally similar to other counties. One exception is precipitation, which is substantially lower in close counties; this distinction is likely driven by the absence of wind farms in the southeastern region, where precipitation happens to be mostly concentrated. Overall, these statistics suggest no particular concerns over non-representativeness of the study population.

4. Suicide Responses to Wind Turbine Installation Events

4.1 Raw Trends

To motivate the empirical strategy, I begin with a simple trend plot of suicide rates around the 828 wind turbine installation events from 2001 to 2013. Figure 4 plots the average suicide rate from 24 months before (i.e., about one year before wind farm *construction* began) to 12 months after the new wind turbines began generating power. Changes in the suicide rate is measured relative to the level observed one month before the installation event (even month = -1). To remove secular trends in suicide, I condition the regression on 12 month-of-year dummies, and no other controls are included.

Figure 4 shows that the suicide rate stays flat during the two years leading up to the installation event, followed by a prompt increase in the month when the new wind turbines began generating power.[4] The graphical pattern provides three key insights for the empirical strategy and interpretation. First, the fact that the suicide rate is flat in years before installation events provides evidence that the pre-"treatment" period serves as a plausible "control" for what would have occurred regarding suicide rates in the absence of new wind turbine installation. Second, in addition to a flat pre-treatment suicide trend, the evolution of suicide rate is also roughly flat *after* installation events happen. This evidence motivates a simple empirical specification that estimates the causal impact of wind farms by comparing changes in suicide rates before and after installation events. Third, the fact that suicide responses are not experienced even in the months shortly before power generation actually begins suggests that the impact

[4] In the Appendix, I use power generation data to confirm that wind power production increases sharply starting the event month.

is unlikely due to factors related to the *presence* of the wind farm itself (e.g., facility construction, which typically lasts for months) but rather due to factors associated with the *operation* of the wind farm (e.g., noise emission). I provide further discussion of potential mechanisms in section 5.

4.2 Empirical Strategy

Figure 4 motivates a straightforward event study style empirical design that estimates the impact of wind farms by comparing suicide rates in county *c* at time *t* shortly before and after the installation event. Note that, because wind farms can be close to each other, the same county can be linked to (i.e. within 25km to) different installation events, and therefore can appear multiple times in the regression sample. Hence, in subsequent analysis the subscript *c* is understood as a county linked to a nearby wind farm. I estimate the following baseline specification

$$Suicide_{ct} = \beta \cdot Post_{ct} + \underbrace{F_{ct}\eta}_{\substack{fixed\ effects \\ ctrls}} + \overbrace{X_{ct}\gamma}^{\substack{time-variant \\ ctrls}} + \varepsilon_{ct} \quad (1)$$

The key treatment variable is $Post_{ct}$ that indicates periods after the installation event. Fixed effects controls F_{ct} include county fixed effects, month-of-year fixed effects and year fixed effects. In the analysis I also report specifications with increasingly stringent controls, such as ones that include county × month-of-year fix effects or wind farm × year fixed effects. More discussions on fixed effects controls are provided as I describe the results. Besides fixed effects controls, time-variant controls X_{ct} include 10-degree F daily temperature bins and quadratic monthly precipitation. I report standard errors clustered at the wind farm level. In the Appendix, I report specification checks which vary the sample restrictions and other elements of the baseline specification.

Simple before-versus-after comparison, as outlined in equation (1), may confound wind farms' effects with other factors that correlate with installation events in both observable and unobservable ways. Next, I augment the baseline specification in three ways by introducing "control" counties.

First, I compare pre- and post- suicide differences for counties in the baseline sample to distant counties that are farther away from wind farms, forming a spatial difference-in-difference (DD) design.

This design controls for potential geographic patterns in suicide and separates out the component that is specific to counties close to wind farms. The estimation equation is

$$Suicide_{ct} = \beta \cdot Post_{ct} \times Close_c + F_{ct}\eta + X_{ct}\gamma + \varepsilon_{ct} \quad (2)$$

where $Close_c$ indicates counties near wind farms. The rest of the specification is identical to equation (1) except that a) the fixed effects are allowed to vary by close and distant county groups whenever feasible, and b) X_{ct} is understood to include main effects of the interaction terms.[5]

Second, I implement a temporal difference-in-difference design. I compare pre- and post- suicide differences within the event window in the year when wind farm is installed ("event year") to differences within the *same* event window but in other years when wind farm is not installed ("placebo year"). This specification helps tease out the pre- and post- difference in suicide that is specific to the event window within which an installation event actually occur. I estimate

$$Suicide_{ct} = \beta \cdot Post_{ct} \times EventYear_t + F_{ct}\eta + X_{ct}\gamma + \varepsilon_{ct} \quad (3)$$

where $EventYear_t$ indicates whether the event window contains an actual installation event. As before, I allow the fixed effects controls to vary by event year whenever feasible.

Finally, I combine specifications (2) and (3) into a triple-difference (DDD) design, which separates out the part of suicide increase that is specific to counties close to wind farms *and* specific to the year installation occurred. The following equation is fitted

$$Suicide_{ct} = \beta \cdot Post_{ct} \times Close_c \times EventYear_t + F_{ct}\eta + X_{ct}\gamma + \varepsilon_{ct} \quad (4)$$

[5] For example, while the year and the month-of-year fixed effects can vary by $Close_c$, the county fixed effects cannot. Similar reasoning applies to other double- and triple-difference methods described in subsequent analysis. My conclusions are unchanged if fixed effects controls are not allowed to be conditional on the interaction variables.

Again, whenever feasible I allow fixed effects to vary both by $Close_c$ and by $EventYear_t$. X_{ct} is understood to contain all main effects and two-way interaction terms.

4.3 Main Results

Table 2 reports the primary results. Each panel represents a different comparison strategy as outlined by equations (1) to (4). Within each panel, columns 1 through 3 report specifications with increasingly stringent fixed effects controls. I first focus on panel A, which reports the simple pre- versus post- difference estimates corresponding to equation (1). Column 1 shows that, relative to the year before wind turbine installation, the suicide rate increases by a significant 0.183 per million population in the year after installation. Relative to the monthly mean suicide rate of 8.54 per million, the effect size represents a 2.1 percent increase. Column 2 uses more stringent controls by interacting the county fixed effects and the month-of-year fixed effects. Conceptually, this specification makes the suicide comparison between the two observations for the same county on the same month-of-year, but one before installation and one after installation. This specification yields a similar estimate of 0.212 per million. In column 3, I further tight up the specification by allowing year fixed effects to vary by each wind farm, absorbing common variations among all counties linked to the same wind farm in a given year. This specification yields a slightly larger effect estimate of 0.251 suicides per million, although the estimate becomes less precise and the 95 percent confidence interval of the estimate overlap with that of the estimates in column 1 and 2.[6]

Panels B through D of Table 2 report estimates from the augmented designs that use richer sources of variation. These include spatial DD (equation 2), temporal DD (equation 3), and triple D (equation 4) approach. Reassuringly, these alternative comparison strategies produce results that are broadly consistent with the primary specification in panel A, which lends strong support to the causal interpretation of the estimates. Notably, magnitudes of these estimates are also consistent with what we have seen in Figure 4. Thus, in subsequent analysis I use the simple pre- versus post- differences in suicide rates as the preferred estimation method.

4.4 Other Causes of Death

[6] In the Appendix, I examine the robustness of the results to a range of additional specification changes along the lines of (1) sample selection, (2) control variable selection, and (3) standard error clustering.

While this study focuses on suicide responses, I can also use the primary cause of death information contained in the vital statistics data to explore deaths due to other causes. These additional tests help the analysis in at least two ways. First, they may shed light on the underlying mechanisms by which wind farms affect health. For example, while cardiovascular and nervous system responses are linked to high levels of noise exposure (e.g., Basner et al., 2014), changes in neoplasms and infectious diseases likely reflect shifts in population health due to reasons unrelated to noise. Second, the exercise provides a chance to examine the robustness of the main suicide findings with respect to multiple inference, as other causes of death could have been examined in addition to suicide.

To execute these tests, I construct mortality rates for a group of leading causes of death from 2001 to 2013. These include (in rank order) circulatory system, neoplasms, respiratory system, nervous system, accident, metabolic diseases, mental disorders, digestive system, and infectious diseases, all defined using ICD-10's major disease blocks classification.[7] Together with suicide, these 10 causes of death account for more than 90 percent of total deaths. I then estimate the effects of wind farms on these cause-specific mortality rates using estimation equation (1). I present false discovery rate adjusted significance levels, or "q-values", that take into account the fact that 10 hypotheses are being tested simultaneously (Anderson, 2008).

Table 3 summarizes the results. For reference, I repeat the suicide effect estimate in column 1, which corresponds to the estimate in panel A, column 1 of Table 2. There are two main findings. First, the key result on suicide continues to hold at the conventional significance level post multiple inference adjustment (q-value = 0.050). Second, coefficient estimates for causes other than suicide are generally positive, but there is little evidence for statistically significant impacts. Interestingly, the only two individually significant effects emerge in deaths due to nervous system and mental disorders which are intuitively related to noise exposure, although neither survives multiple hypothesis adjustment. Overall, the point estimates are small in magnitude, and in some cases small effects can be ruled out based on the estimates. For instance, in column 2, the 95 percent confidence interval of the circulatory death estimate implies that a 1 percent effect can be ruled out. Mortality rates from other plausibly "placebo" causes such as neoplasms and infections also show rather precise zero responses.

[7] The exact ICD-10 codes used are: suicide (X60-X84, Y870), circulatory (I00-I99), neoplasm (C00-D48), respiratory (J00-J99), nervous (G00-G99), accident (V01-X59), metabolic (E00-E90), mental (F00-F99), digest (K00-K93), and infection (A00-B99).

5. Evidence on the Noise Mechanism

In this section, I explore wind farms' noise pollution as a potential mechanism underlying the suicide effects. Section 5.1 explores age profile of the suicide effects. Section 5.2 exploits an acoustic property of wind farm noise radiation and leverages changes in wind direction to decompose the suicide effect into days with potentially high versus low noise exposure. Section 5.3 documents responses of insufficient sleep using self-reports data from a large-scale survey.

5.1 Age Profile of the Suicide Effect

The elderly are understood to be a particularly at-risk group for noise-induced illnesses (e.g., Miedema and Vos, 2003; Kujawa and Liberman, 2006; Muzet, 2007). Here, I estimate an age profile of wind farms' suicide effect by allowing the effect estimates to vary by age groups. Specifically, I estimate the following equation

$$Suicide_{act} = (Post_{ct} \times AgeGroup_a) \cdot \beta_a + F_{cta}\eta + X_{ct}\gamma + \varepsilon_{cta} \qquad (5)$$

where the unit of observation now is suicide rate in county *c* at time *t* for age group *a* (< 20 years old, 20-39, 40-59, 60-79, and above 80 years old). $AgeGroup_a$ is a set of dummies indicating each age group. Fixed effects F_{cta} are primary fixed effects interacted with age group dummies. Hence, equation (5) allows the impact of wind farm installations on suicide to vary flexibly by age groups, yielding an age profile β_a.

Figure 5 graphically summarizes the results. I find that, while suicide effect estimates are positive for every age group examined, the largest and the most precise effect is observed for the population over 80 years old. Suicide among this group increases about 0.72 per million post wind turbine installation. This effect also represents the largest relative change of 5.33 percent out of the age group's mean rate of suicide. The second largest relative increase in suicide occurs among the population below age 20 years (4.53 percent). By contrast, effects on the population between ages 20 and 80 are more modest and less statistically precise.

5.2 The Role of Wind Direction

In the second test for the noise mechanism, I exploit the unique acoustic property of low-frequency noise radiation in which the level of exposure is higher at upwind/downwind locations while impeded in locations in the crosswind direction, as is discussed in Section 2. Moreover, due to wind refraction, downwind noise is expected to be stronger than upwind noise.

I exploit plausibly exogenous variations in wind directions to decompose the suicide effect by days when counties are upwind, downwind, and crosswind the wind farm. Specifically, I augment equation (1) by allowing the $Post_{ct}$ dummy to vary by the number of days that county *c* is located upwind, downwind, and crosswind of the wind farm in month *t*. The estimation equation is

$$Suicide_{ct} = \left(Post_{ct} \times Direction^{d}_{ct}\right) \cdot \beta_d + F_{ct}\eta + X_{ct}\gamma + \varepsilon_{ct} \qquad (6)$$

Consider the angle between the wind direction at the wind farm and the county *c*'s centroid. Let 0 degree (equivalently, -0 degree) denote the county being exactly downwind, and let 180 degree (or -180 degree) denote the county being exactly upwind. On any given day, a county's downwind-ness can therefore be expressed as a number between -180 and 180. In equation (6), $Direction^{d}_{ct}$ counts the number of days the angle is within four different degree bins *d* where *d* = {0 to 45 and 0 to -45, 45 to 89 and -45 to -89, 90 to 134 and -90 to -134, 135 to180 and -135 to -180}. Hence, β_d identifies the impact of spending one more day in relative direction bin *d* on suicide. As a concise example, β_d where *d* = {0 to 45 and 0 to -45} identifies the marginal suicide effect if a county has one more day of the month when it locates within a 90-degree cone downwind a wind farm.

Consistent with the acoustic dipole property of noise radiation, Figure 6 presents evidence that the suicide effects are mostly explained by days when counties are downwind (*d* = 0 to 45 and 0 to -45) and upwind (*d* = 135 to180 and -135 to -180) to wind farms. In contrast, days when counties are crosswind of wind farms have low explanatory power on suicide. My estimates do not provide suggestive evidence consistent with wind refraction: in fact, I find upwind days are slightly more explanatory than downwind days, although the two are not statistically distinguishable.

Table 4, panel A presents a more parsimonious version of equation (6) where the suicide effects are allowed to vary only by upwind/downwind and crosswind days. Across different econometric specifications, results confirm that the effects are largely explained by upwind/downwind days. Panel B and panel C provide further supportive evidence of the noise channel, showing that the upwind/downwind versus crosswind heterogeneity is stronger when wind speed is higher at the wind farm (panel B) and for larger wind farms as measured by generation capacity (panel C).

5.3 Sleep Responses

In the final test, I turn to survey data to directly examine the effect of wind farms on sleep loss. I use data from the annual Behavioral Risk Factor Surveillance System (BRFSS), a monthly cross-sectional telephone-based health survey of individuals aged 18 years and older, that is maintained by the U.S. Centers for Disease Control and Prevention. My sleep measure is based on a question that asks the respondents the number of days, if any, in the past month that they "did not get enough sleep or rest" (for an application of the same dataset in sleep medicine literature, see Strine and Chapman, 2005). The question is posed among a total of 706,099 respondents for whom their county of residence can be identified in year 2002 and then from 2004 to 2010. In my analysis, I restrict to a subset of 104,519 respondents who lived in counties within 25 kilometers of wind turbine installations, and who were interviewed within the one year before/after installation window. On average, the respondent in my sample reports 8.35 nights of insufficient sleep per month, with 69.9 percent / 39.1 percent / 26.9 percent report at least 1 / 7 / 14 days of insufficient sleep. Using additional information provided by the BRFSS on the survey interview dates and each respondent's individual level survey weight, I construct the average number of nights of insufficient sleep at the county × month level. I also construct three additional measures for the fraction of respondents who report at least *k* days of insufficient sleep in the past month, where *k* can take the values from 1, 7, or 14.[8]

As before, I begin by a simple event study that documents the trends for insufficient sleep before and after wind turbine installation. Analogous to Figure 4, Figure 7 plots changes in the number of nights with insufficient sleep before and after wind turbine installation events. The plot is again conditional on 12 month-of-year dummies and no other controls. While the individual month-by-month event study estimates appear noisy, a break in trend is evident around the time new wind turbines came online.[9] Table 5, column 1 reports that the before-and-after difference in sleep insufficiency is statistically significant at the 5 percent level. Relative to the year before wind turbine installations, respondents report on average 0.2 more nights of insufficient sleep in the year after. Based on a mean report of 8.35 nights, this effect represents a roughly 2.4 percent increase. Columns 2 to 4 suggest that the finding on the increased number of nights of insufficient sleep is likely explained by disproportionate increases in reports of sustained sleep insufficiency rather than increased reports of having *any* sleep insufficiency.

Of course, as in most survey settings, the sleep measures used in this analysis are based on respondents' recall and subjective judgement of sleep quality. Nevertheless, using BRFSS sleep measures provides at least two improvements over previous survey studies of wind farm-related sleep loss. First, BRFSS simply contains a much larger sample, both in terms of the number of respondents and the geographic span, than data used by previous studies that are typically based on hundreds of respondents living in the immediate vicinity of a particular wind farm. Notably, the BRFSS sample selection is based on random-digit telephone dialing, and the sample is constructed to be representative of the U.S. population along many respects, such as age, sex, race, and education levels (CDC, 2012). Second, information on insufficient sleep is elicited as one of the many questions contained in the entire BRFSS survey. This alleviates the concern that many small-scale surveys administered to residents in wind farms' neighborhood tend to frame sleep loss as a consequence of noise or, sometimes explicitly, wind farm noise. To the extent that the BRFSS does not at all instruct respondents to incorporate perceptions of wind farms in sleep reports, it provides a more independent outcome measure for the purpose of this study.

6. Suicide Effects of Wind Farms and Local Gun Access

More than a half of suicides in the United States involve firearms, and a cross-sectional association between gun ownership and suicide has been well documented; nevertheless, the extent to which access to guns influence suicide decisions remains an open question (e.g., Miller and Hemenway, 2008). The context of this paper's study provides an opportunity to expand the current understanding of the issue. This section considers wind farms' suicide effects heterogeneity by local area's gun access.

[8] BRFSS also provides information on a range of individual characteristics. I have confirmed that the conclusions are unchanged if the average sleep measure is adjusted for observable heterogeneity using an auxiliary regression approach that first extracts the county × month fixed effects component of the sleep insufficiency variable when the correlations of individual characteristics (including age, sex, marital status, reported health condition, health insurance coverage, survey interview day, and survey interviewer fixed effects) are parsed out, and then second, uses the fixed effects coefficients as the independent variable in estimation equation (1).

[9] In Figure 7 I choose to normalize sleep insufficiency data in the *second* month prior to installation to zero. This is because the event study coefficients appear to show an increase in reported sleep insufficiency one month before installation. This pattern may be explained by measurement errors in the reference period for which sleep insufficiency is reported, although it may also arise due to noise in the month-by-month coefficient estimates.

I examine whether places with easier access to guns experienced stronger suicide effects when exposed to wind farms. I employ two complementary measures of county-level gun access. The first measure is based on the number of Federal Firearm Licensees (FFLs) in the county. These data are obtained from the Bureau of Alcohol, Tobacco, Firearms and Explosives which provides street address of the universe of FFLs by the end of year 2012. To capture gun shops, I restrict to FFLs listed as "dealers in firearms other than destructive devices," and I compute the number of gun stores per capita for each county.[10] My second measure follows Duggan (2001) who proxies for gun ownership by circulation of the magazine *Guns & Ammo*, the most popular magazine dedicated to firearms, competitive shooting, and hunting. From the Alliance for Audited Media, I obtain county-level counts of print and digital circulation for the August 2005 issue of the magazine. I then convert these counts to per capita scale. The two measures turn out to be highly correlated (raw correlation = 0.84). The geographic patterns are also generally consistent with survey-based measures of residential gun ownership, e.g. Kalesan, Villarreal, Keyes, and Galea (2015).

Table 6 reports estimations of heterogeneous suicide effects by gun access. For both gun measures, I report two types of specifications. First, in columns 1 and 3, I allow suicide effects to vary flexibly by bottom, middle and top terciles of gun access. Second, in columns 2 and 4, I interact the $Post_{ct}$ dummy with continuous measures of gun access. Both types of specifications suggest significantly larger suicide impacts in areas with higher gun access. For example, I find that among counties in the top tercile for gun access, suicide following wind farm installation increases by 1.1 to 1.5 per million population.

7. Discussion and Conclusion

I conclude the paper with a back-of-envelop calculation of the external costs of wind farms as the result of suicides. Given the findings on the age profile of suicide effects, life years lost (LYL) are computed as the summation of age-specific effects across age groups:

$$LYL = \sum_a \sum_c \beta_a \times Population_{ca} \times LifeExp_a$$

[10] This category comprises more than 70% of all the FFLs. Other major categories reported in the data are manufacturers of firearms and ammunition (13%) and pawnbrokers (11%).

where β_a is the age group specific effect of a wind farm on the suicide rate obtained from equation (5). This is multiplied by population in county *c* of age group *a* ($Population_{ca}$) and expected remaining years of life ($LifeExp_a$) to obtain excessive life years lost in the county. $LifeExp_a$ is computed as the difference between average Social Security Administration life expectancy and average age at suicide for individuals in age group *a*.[11] This calculation concludes that, from 2001-2013, new wind farms are responsible for 997 excessive suicides in the first year following their installation. This amounts to 33,939 life years lost.[12]

I now contrast this number with life years that would have been lost in the one-year window had the energy instead been generated by coal. I use the estimate of the social cost of coal-generated electricity at $178 per megawatt hour (MWh) from Epstein et al (2011).[13] Applying their adopted value of statistical life (VSL) of $7.66 million and an average remaining life years of 15.2 years per death, this number is converted to 0.00035321 LYL per MWh coal electricity. New wind farms generated a total of 148.7 million MWh wind power within the first year of operation, which implies a total of 52,523 avoided life years lost had the power been generated entirely from coal. Of course, these numbers do not immediately inform welfare; however, they do suggest that wind farm-related suicides potentially reduce the overall value, even though the technology offers a renewable source of energy, providing an alternative to fossil fuel-based sources, which contribute to greenhouse gas emissions and detrimentally affect air quality.

This study has important limitations that bear mention. First, estimates of this paper reflect the effect of exposure to *wind farms*. While I have shown a number of tests that support the view that noise exposure plays a role in wind farms' effect on suicides, more direct evidence is needed to establish the causal effect of *noise*. Ambient noise monitoring data would be particularly useful. Such data could be used to better measure the noise profile of wind farms, and, in combination with medical data, could enhance understanding of any potential effects on those living in proximity to turbines. In addition, such data could be used to test for a potential dosage relationship, to determine a possible threshold at which noise exposure is likely to affect health. Second, this paper's analysis relies upon county-level suicide data. The growing availability of administrative data on health outcomes may provide more granular information regarding location of related health outcomes. This may benefit the study of wind turbine

[11] Expected remaining years of life among individuals committed suicide are: 63.7 (age < 20), 49.4 (age 20-39), 30.9 (age 40-59),15 (age 60-79), and 4.6 (age > 80). The average expected remaining years of life is 34.3. This is similar to SEER's estimates https://seer.cancer.gov/archive/csr/1975_2012/results_merged/topic_year_lost.pdf

[12] Assuming homogeneous treatment effects across age groups yields a similar estimate of 33,270 life years lost.

[13] The estimate reflects health and environmental cost of coal during its entire life cycle from extraction, transport, processing, and combustion.

syndrome in multiple ways. For example, finer geographical data would help identify effects on individuals who live in the immediate vicinity of wind farms - the situation that provided the initial motivation for this literature's area of inquiry. Greater geographic detail would also be particularly useful for studies that use changes in wind directions as quasi-experiments to pinpoint the effects of noise. Third, while the analysis focuses on suicide as the key outcome of interest, it likely captures only the most severe consequence of wind farm exposure. Other health outcomes, such as emergency room visits and hospitalization, may also be important to provide a richer characterization of the health effects that may stem from living or working in close proximity to wind turbines, and to shed light on the full related costs.

Finally, it is perhaps most important to emphasize that this study estimates wind turbine syndrome clearly as a result of the way wind energy is captured with today's *technology.* It is clear that wind energy, together with other renewable sources, will play a significant role in combating climate change. As noted earlier, this research may bring a new perspective to the value of noise abatement in wind technology innovations.

References

Anderson, Michael L. "Multiple inference and gender differences in the effects of early intervention: A reevaluation of the Abecedarian, Perry Preschool, and Early Training Projects." *Journal of the American statistical Association* 103, no. 484 (2008): 1481-1495.

Basner, Mathias, Wolfgang Babisch, Adrian Davis, Mark Brink, Charlotte Clark, Sabine Janssen, and Stephen Stansfeld. "Auditory and non-auditory effects of noise on health." *The Lancet* 383, no. 9925 (2014): 1325-1332.

Blake, William. 1986. *Mechanics of flow-induced sound and vibration*, vol 2. Academic Press, New York.

Carleton, Tamma A. "Crop-damaging temperatures increase suicide rates in India." *Proceedings of the National Academy of Sciences* (2017): 201701354.

Case, Anne, and Angus Deaton. Suicide, age, and wellbeing: An empirical investigation. No. w21279. National Bureau of Economic Research, 2015.

Case, Anne, and Angus Deaton. "Mortality and morbidity in the 21st century." *Brookings Papers on Economic Activity* (2017): 23-24.

Centers for Disease Control and Prevention (CDC. "Methodologic changes in the Behavioral Risk Factor Surveillance System in 2011 and potential effects on prevalence estimates." MMWR. Morbidity and mortality weekly report 61, no. 22 (2012): 410.

Cullen, Joseph. "Measuring the environmental benefits of wind-generated electricity." *American Economic Journal: Economic Policy* 5, no. 4 (2013): 107-133.

Dallos, Peter. 1973. *The auditory periphery: Biophysics and physiology*. Academic, New York.

Danzer, Steve. 2012. Depression, stress, epilepsy and adult neurogenesis. *Experimental Neurology*, 233: 22-32.

Doolan, Con, Danielle Moreau, and Laura Brooks. 2012. Wind turbine noise mechanisms and some concepts for its control. *Acoustics Australia*, 40 (1): 7-13.

Dröes, Martijn I., and Hans RA Koster. "Renewable energy and negative externalities: The effect of wind turbines on house prices." *Journal of Urban Economics* 96 (2016): 121-141.

Gibbons, Stephen. "Gone with the wind: Valuing the visual impacts of wind turbines through house prices." *Journal of Environmental Economics and Management* 72 (2015): 177-196.

Hawton, Keith et al. "Suicide." *The Lancet*, Volume 373, Issue 9672 , 1372 - 1381

Howe, Michael. 1978. A review of the theory of trailing edge noise. *Journal of Sound and Vibration*, 61: 437-465

Hubbard, Harvey, and Kevin Shepherd. 1990. Wind turbine acoustics. NASA Technical Paper 3057 DOE/NASA/20320-77.

Kahn, Matthew E. "Local non-market quality of life dynamics in new wind farms communities." *Energy Policy* 59 (2013): 800-807.

Knopper, Loren, and Christopher Ollson. 2011. Health effects and wind turbines: A review of the literature. *Environmental Health*, 10: 78.

Krekel, Christian, and Alexander Zerrahn. "Does the presence of wind turbines have negative externalities for people in their surroundings? Evidence from well-being data." *Journal of Environmental Economics and Management* 82 (2017): 221-238.

Kujawa, Sharon G., and M. Charles Liberman. "Acceleration of age-related hearing loss by early noise exposure: evidence of a misspent youth." *Journal of Neuroscience* 26, no. 7 (2006): 2115-2123.

Ladenburg, Jacob, and Alex Dubgaard. "Willingness to pay for reduced visual disamenities from offshore wind farms in Denmark." Energy Policy 35, no. 8 (2007): 4059-4071.

Leventhall, H. G. "Low frequency noise and annoyance." Noise and Health 6, no. 23 (2004): 59.

Mann, J. John, Alan Apter, Jose Bertolote, Annette Beautrais, Dianne Currier, Ann Haas, Ulrich Hegerl et al. "Suicide prevention strategies: a systematic review." *JAMA* 294, no. 16 (2005): 2064-2074.

Miedema, Henk, and Henk Vos. 2003. Noise sensitivity and reactions to noise and other environmental conditions. The Journal of the Acoustical Society of America, 113: 1492-1504.

Muzet, Alain. "Environmental noise, sleep and health." *Sleep medicine reviews* 11, no. 2 (2007): 135-142.

Novan, Kevin. "Valuing the wind: renewable energy policies and air pollution avoided." American *Economic Journal: Economic Policy* 7, no. 3 (2015): 291-326.

Oerlemans, Stefan, Pieter Sijtsma, and Bianchi Mendez Lopez. 2007. Location and quantification of noise sources on a wind turbine. *Journal of Sound and Vibration*, 299: 869-883.

Oerlemans, Stefan, and J. Gerard Schepers. 2009. Prediction of wind turbine noise and validation against experiment. International Journal of Aeroacoustics, 8: 555-584.

Pierpont, Nina. *Wind turbine syndrome: A report on a natural experiment*. Santa Fe, NM: K-Selected Books, 2009.

Rod, Naja Hulvej, Jussi Vahtera, Hugo Westerlund, Mika Kivimaki, Marie Zins, Marcel Goldberg, and Theis Lange. "Sleep disturbances and cause-specific mortality: results from the GAZEL cohort study." *American Journal of Epidemiology* 173, no. 3 (2010): 300-309.

Simon, Thomas R., Alan C. Swann, Kenneth E. Powell, Lloyd B. Potter, Marcie-jo Kresnow, and Patrick W. O'Carroll. "Characteristics of impulsive suicide attempts and attempters." *Suicide and Life-Threatening* Behavior 32, no. Supplement to Issue 1 (2001): 49-59.

Strine, T.W. and Chapman, D.P., 2005. Associations of frequent sleep insufficiency with health-related quality of life and health behaviors. *Sleep medicine*, 6(1), pp.23-27.

Van den Berg, Godefridus Petrus. 1994. Effects of the wind profile at night on wind turbine sound. Journal of Sound and *Vibration*, 227: 955-970.

von Bekesy, Georg. 1960. *Experiments in hearing*. McGraw-Hill, New York.

Vos, Theo, Abraham D. Flaxman, Mohsen Naghavi, Rafael Lozano, Catherine Michaud, Majid Ezzati, Kenji Shibuya et al. "Years lived with disability (YLDs) for 1160 sequelae of 289 diseases and injuries 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010." *The lancet* 380, no. 9859 (2012): 2163-2196.

Wagner, Siegfried, Rainer Bareib, and Gianfranco Guidati. 1996. *Wind turbine noise*. Springer Verlag, 1996.

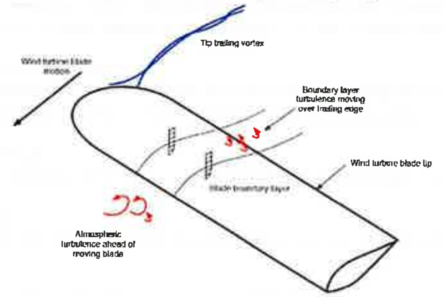
Weedman, Diana, and David Ryugo. 1996. Projections from auditory cortex to the cochlear nucleus in rats: Synapses on granule cell dendrites. *The Journal of Comparative Neurology*, 371: 311-324.

Zalsman, Gil, Keith Hawton, Danuta Wasserman, Kees van Heeringen, Ella Arensman, Marco Sarchiapone, Vladimir Carli et al. "Suicide prevention strategies revisited: 10-year systematic review." *The Lancet Psychiatry* 3, no. 7 (2016): 646-659.

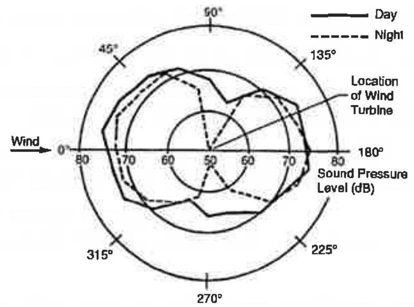
Figure 1: Distribution of Wind Resources and Wind Farms

Panel A. Wind turbine (horizontal axis design)

Panel B. Air flow over a wind turbine blade

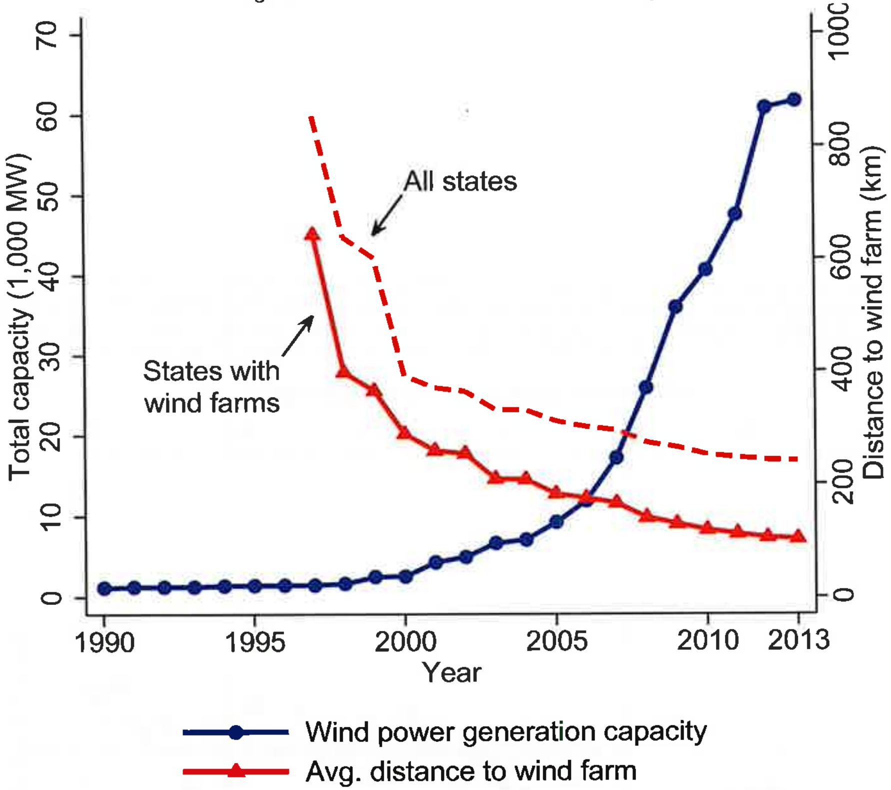


Panel C. "Acoustic Dipole": Wind turbine's low-frequency noise radiation patterns



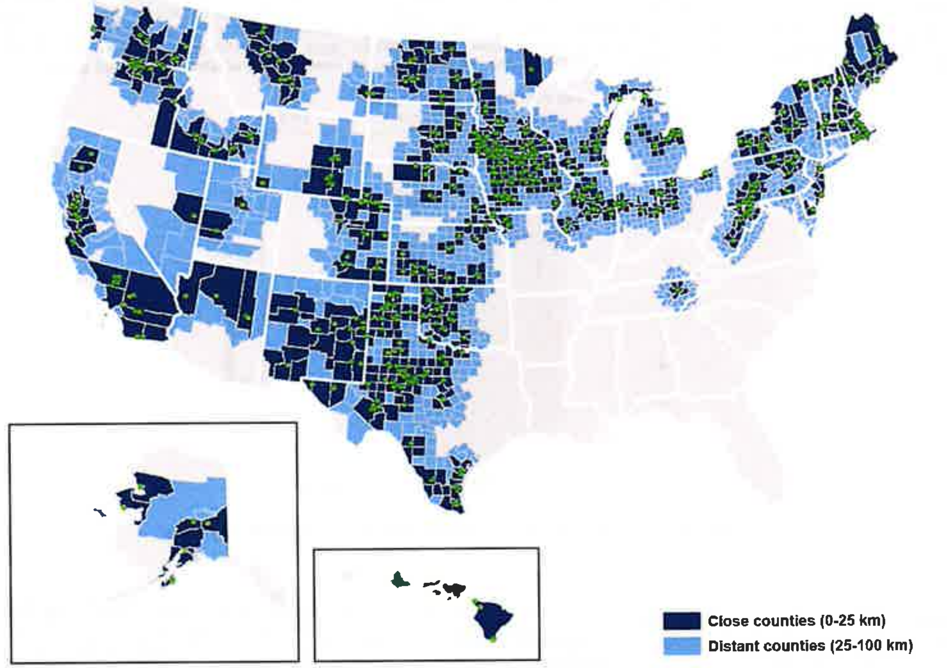
Notes: Panel A is sourced from McCunney et al (2014). Panel B is sourced from Doolan (2011). Panel C is sourced from Hubbard and Shepherd (1990), which shows measured noise level 200 meters from a utility-scale wind turbine when wind speed is 7.2 m/s. Measured frequency of the sound is 8 Hz.

Figure 2: Growth of the U.S. Wind Power Industry



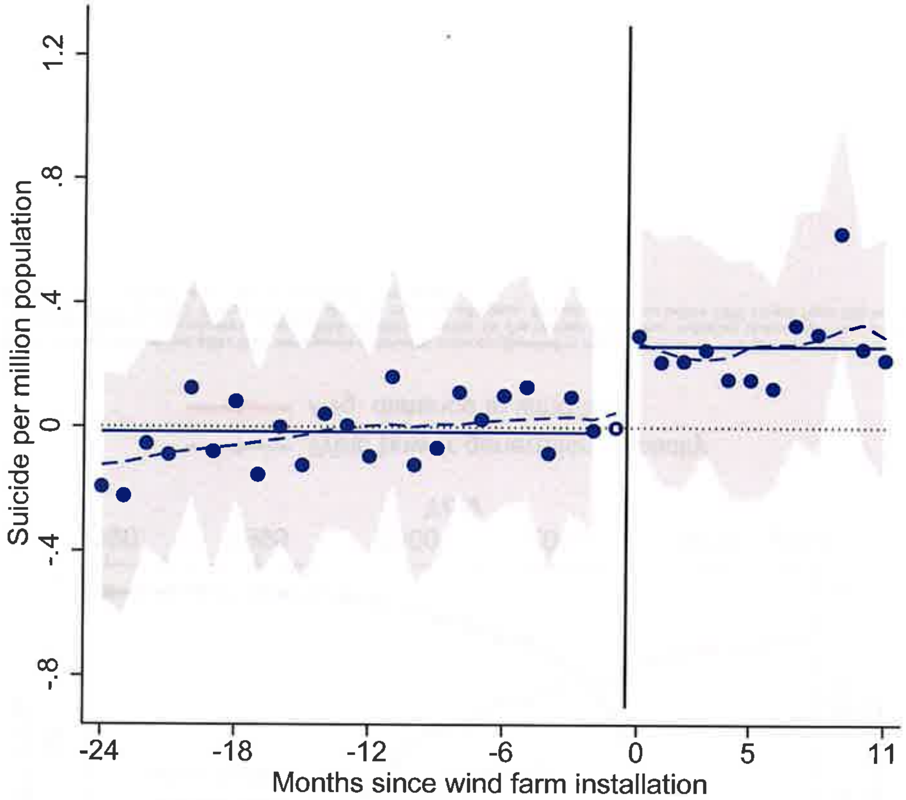
Notes: Circle-connected line plots total wind power generation capacity observed in the EIA-860 form. Triangle-connected lines compute the average distance from county's Census 2010 population center to the nearest wind farm, including states that have wind power capacity by the end of 2013. Dashed line plots distance including all states. Distance statistics before 1997 ranges from 680 km to 1400 km which are not plotted for the sake of readability of the graph.

Figure 3: Distribution of Wind Farms and Sample Counties



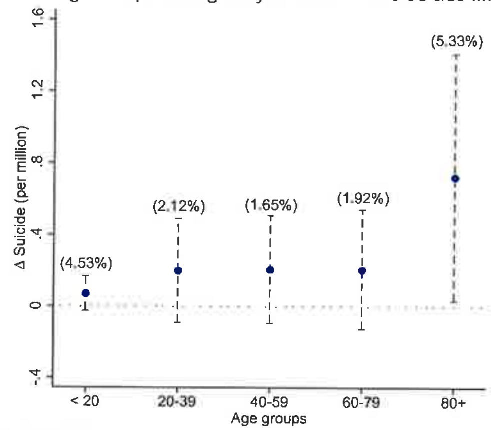
Notes: Map plots location of wind farms and the associated sample counties. Dark color counties are 0-25 km to wind farms. Lighter color counties are 25-100 km of wind farms.

Figure 4: Event Study: Suicide



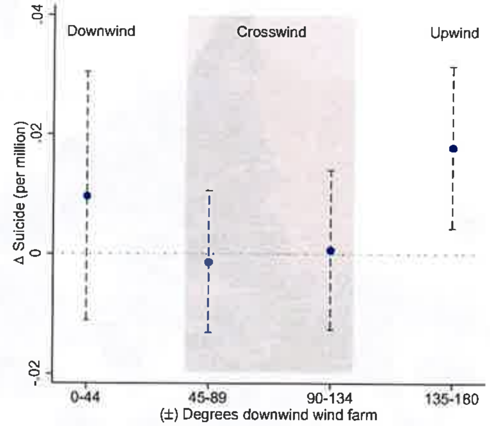
Notes: Graph plots suicide rate (per million population) by months relative to wind farm installation month, using all installation events from 2001-2013. The month immediately before the installation is the omitted category. The regression is weighted by county×year population and is conditional on 12 month-of-year dummies. Dots show monthly point estimates. Solid lines show before vs. after averages of the point estimates. Dashed lines show lowess smooth of monthly point estimates. Shades show 95% confidence interval constructed using standard errors clustered at the wind farm level.

Figure 5: Age Group Heterogeneity in Wind Farm's Suicide Impacts



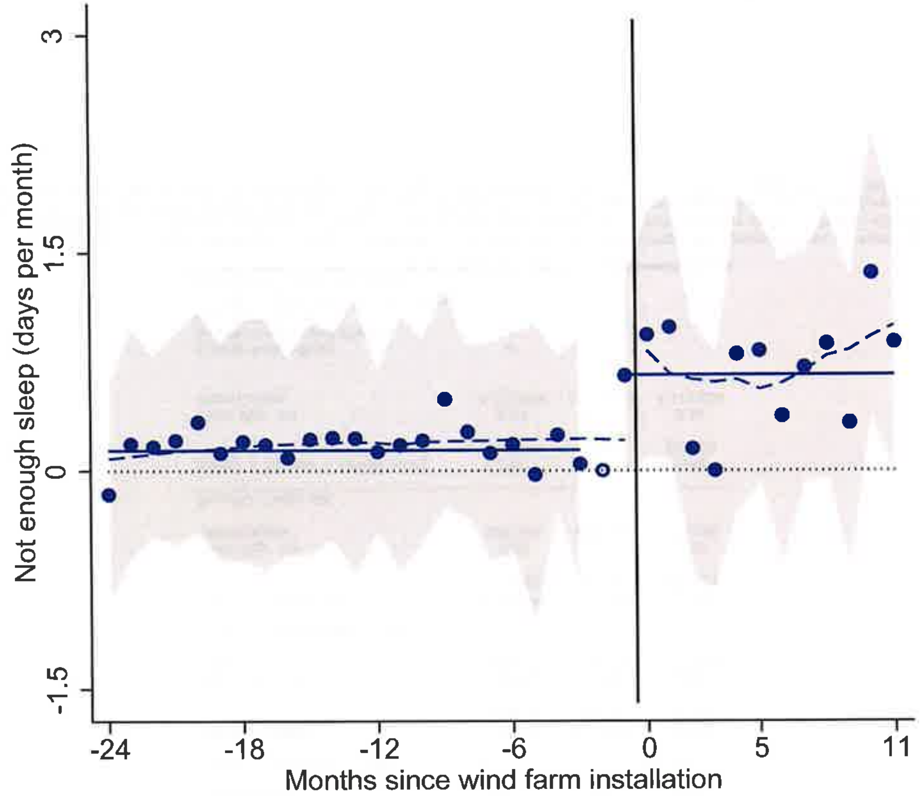
Notes: Graph plots the interaction term between post-event window dummy (Post) and age group category. Percentage numbers in parentheses show coefficient as a fraction of mean suicide rate within each age group. Estimation uses a balanced sample of counties from to 12 months before to 12 months after wind turbine installations. Regressions include county, month-of-year and year fixed effects fully interacted with age categories. All regressions control for daily temperature bins and quadratic monthly precipitation. Dashed bars show 95% confidence interval constructed using standard errors clustered at the wind farm level.

Figure 6: Wind Direction Heterogeneity in Wind Farm's Suicide Impacts



Notes: Graph plots the interaction term between post-event window dummy (Post) and monthly number of days in four relative wind direction bins, as indicated by x-axis. The "0-44" category is days when a county is within (plus/minus) 0-44 degree of the downwind direction, etc. Estimation uses a balanced sample of counties from to 12 months before to 12 months after wind turbine installations. Regressions include county, month-of-year and year fixed effects. All regressions control for daily temperature bins and quadratic monthly precipitation. Dashed bars show 95% confidence interval constructed using standard errors clustered at the wind farm level.

Figure 7: Event Study: Days "Not Get Enough Sleep" (BRFSS Sample)



Notes: Graph plots monthly average number of days that BRFSS respondents report "did not get enough sleep", by months relative to wind farm installation month, using all installation events in 2002 and 2004-2010. The sample includes all respondents living in counties where the sleep measure is available. The omitted category is two months before the wind farm installation. The regression is weighted by county×year population and is conditional on 12 month-of-year dummies. Dots show monthly point estimates. Solid lines show before vs. after averages of the point estimates. Dashed lines show lowess smooth of monthly point estimates. Shades show 95% confidence interval constructed using standard errors clustered at the wind farm level.

Table 1: Summary Statistics

	(1) Sample: < 25 km counties	(2) Sample: 25-100 km counties	(3) Sample: Other counties	(4) Sample: All counties
Suicide (per million)	8.56	9.51	10.92	9.76
	[3.14]	[3.10]	[3.11]	[3.26]
... age < 20	1.75	1.98	1.98	1.91
	[1.29]	[1.31]	[1.32]	[1.31]
... age 20-39	9.79	11.23	12.58	11.31
	[4.54]	[4.47]	[4.32]	[4.58]
... age 40-59	12.67	14.02	15.99	14.37
	[4.59]	[4.51]	[5.01]	[4.92]
... age 60-79	10.31	10.99	13.34	11.73
	[3.40]	[4.19]	[3.99]	[4.27]
... age 80+	13.02	13.22	17.46	14.72
	[7.58]	[7.63]	[8.69]	[8.29]
Population (thousands)	114.4	107.5	68.7	90.4
	[436.8]	[302.7]	[180.8]	[294.6]
... fraction age < 20	0.289	0.287	0.283	0.286
... fraction age 80+	0.033	0.032	0.033	0.033
Poverty rate	0.130	0.106	0.135	0.124
Per cap. income (2000$)	21,756	23,017	20,117	21,578
	[5,629]	[5,377]	[4,585]	[5,320]
Median home value	171,256	141,884	105,279	137,174
	[136,273]	[73,237]	[39,937]	[92,854]
Gun store (per 100,000)	14.4	16.3	19.1	16.8
	[19.1]	[17.5]	[17.5]	[18.1]
Guns & Ammo circulation (per 100,000)	129	153	154	146
	[90]	[82]	[84]	[86]
Wind speed (m/s)	3.78	3.64	3.37	3.54
	[0.48]	[0.49]	[0.44]	[0.49]
Temperature (degree F)	51.5	51.6	58.8	55.1
	[7.1]	[6.6]	[7.1]	[7.8]
Precipitation (millimeter)	66.7	71.5	98.9	83.6
	[26.8]	[27.3]	[26.3]	[30.6]
N (county)	723	870	1,488	3,081

Notes: All statistics are computed at the county level. Standard deviations in brackets. Suicide, wind speed, temperature, and precipitation statistics are computed as monthly average from 2001-2013. Population, poverty, income, and home values are from Census 2000, extracted from Minnesota Population Center National Historical Geographic Information System (NHGIS) Version 11.0. Gun store is measured by per capita number of Federal Firearms Licensees in December 2012. *Guns & Ammo* magazine circulation is measured at August 2005. Statistics are weighted by 2001-2013 average annual population (suicide, gun access) and average age-group specific population (age-specific suicide), and census 2000 population (poverty, income, home values). See the text for more details.

Table 2: Wind Farms' Impact on Suicide

Dep. var. = Suicide per million population	(1)	(2)	(3)
Panel A: Simple diff.			
(Post)	0.183***	0.212***	0.251*
	(0.064)	(0.072)	(0.139)
Mean dep. var	8.54	8.54	8.54
Observations	63,075	63,075	63,075
Panel B: Spatial diff. in diff.			
(Post) × (Close)	0.177**	0.184**	0.244*
	(0.073)	(0.078)	(0.134)
Mean dep. var	8.91	8.91	8.91
Observations	320,918	320,918	320,918
Panel C: Temporal diff. in diff.			
(Post) × (Event year)	0.198***	0.217***	0.248*
	(0.069)	(0.071)	(0.132)
Mean dep. var	8.16	8.16	8.16
Observations	820,166	820,166	820,166
Panel D: Triple diff.			
(Post) × (Close) × (Event year)	0.189**	0.197**	0.246*
	(0.078)	(0.080)	(0.132)
Mean dep. var	8.54	8.54	8.54
Observations	4,173,664	4,173,664	4,173,664
County fixed effects	✓		
Month-of-year fixed effects	✓		
Year fixed effects	✓	✓	
County × month-of-year fixed effects		✓	✓
Wind farm × year fixed effects			✓

Notes: Each column × panel cell reports a separate regression. Estimation uses a balanced sample of counties from to 12 months before to 12 months after wind turbine installations. (Post) indicates months after installation. (Close) indicates counties close to wind farms. (Event year) indicates event windows that contain the actual installation event. All regressions control for daily temperature bins and quadratic monthly precipitation. Standard errors are clustered at the wind farm level. *: $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$.

Table 3: Wind Farms' Impact on Other Causes of Death

Dep. var. = Deaths per million population Cause of death:	(1) Suicide	(2) Circ	(3) Neop	(4) Resp	(5) Nervous	(6) Accident	(7) Metabolic	(8) Mental	(9) Digest	(10) Infect
(Post)	0.183	0.314	0.070	0.528	0.408	0.098	-0.004	0.307	0.103	0.087
	(0.064)	(0.449)	(0.256)	(0.322)	(0.163)	(0.151)	(0.130)	(0.164)	(0.107)	(0.089)
p-value	0.005***	0.476	0.786	0.102	0.012**	0.514	0.975	0.063*	0.338	0.332
q-value	0.050**	0.643	0.874	0.255	0.060*	0.643	0.975	0.210	0.564	0.564
Mean dep. var	8.54	200.4	140.9	58.64	34.65	25.21	25.34	25.59	23.17	13.12
Observations	63,075	63,075	63,075	63,075	63,075	63,075	63,075	63,075	63,075	63,075

Notes: Each column reports a separate regression in which the dependent variable is mortality rate by cause of death, indicated by column name. Causes are defined using the 10th revision of the International Statistical Classification of Diseases and Related Health Problems (ICD-10) codes: suicide (X60-X84, Y870), circulatory (I00-I99), neoplasm (C00-D48), respiratory (J00-J99), nervous (G00-G99), accident (V01-X59), metabolic (E00-E90), mental (F00-F99), digest (K00-K93), and infection (A00-B99). Estimation uses a balanced sample of counties from to 12 months before to 12 months after wind turbine installations. (Post) indicates months after installation. Regressions control for county fixed effects, month-of-year fixed effects, and year fixed effects. All regressions control for daily temperature bins and quadratic monthly precipitation. Standard errors are clustered at the wind farm level. p–value is the unadjusted significance level. q–value is false discovery rate adjusted significance level based on Anderson (2008). See the text for more details. *: significant at the 10% level; **: significant at the 5% level; ***: significant at the 1% level.

Table 4: Wind Farms' Impact on Suicide, by Wind Directions

Dep. var. = Suicide per million population	(1)	(2)	(3)
Panel A: By wind directions			
(Post) × Up/downwind	0.0148***	0.0155***	0.0108
	(0.0054)	(0.0059)	(0.0086)
(Post) × Crosswind	-0.0004	0.0011	0.0064
	(0.0036)	(0.0039)	(0.0062)
Panel B: By wind directions and wind speed			
(Post) × (Up/downwind - Crosswind) × (Bot. tercile wind speed)	-0.0087	-0.0060	-0.0208
	(0.0143)	(0.0163)	(0.0179)
(Post) × (Up/downwind - Crosswind) × (Mid. tercile wind speed)	0.0116	0.0103	-0.0009
	(0.0153)	(0.0158)	(0.0166)
(Post) × (Up/downwind - Crosswind) × (Top tercile wind speed)	0.0254**	0.0249**	0.0197
	(0.0106)	(0.0118)	(0.0144)
Panel C: By wind directions and wind farm size			
(Post) × (Up/downwind - Crosswind) × (Bot. tercile wind farm)	0.0018	0.0013	-0.0177
	(0.0189)	(0.0204)	(0.0192)
(Post) × (Up/downwind - Crosswind) × (Mid. tercile wind farm)	-0.0120	-0.0084	-0.0113
	(0.0166)	(0.0183)	(0.0220)
(Post) × (Up/downwind - Crosswind) × (Top tercile wind farm)	0.0250*	0.0233	0.0305*
	(0.0149)	(0.0155)	(0.0181)
County fixed effects	✓		
Month-of-year fixed effects	✓		
Year fixed effects	✓	✓	
County × month-of-year fixed effects		✓	✓
Wind farm × year fixed effects			✓
Observations	63,075	63,075	63,075

Notes: Each column × panel cell reports a separate regression. Estimation uses a balanced sample of counties from to 12 months before to 12 months after wind turbine installations. (Post) indicates months after installation. "Up/downwind" ("crosswind") counts number of days in a month that the county spend downwind (crosswind) a wind farm. "Bot./Mid/.Top tercile wind speed" ("Bot./Mid/.Top tercile wind speed") is a categorical variable for terciles of monthly wind speed at the wind farm (MW size of the wind farm). All regressions control for daily temperature bins and quadratic monthly precipitation. Standard errors are clustered at the wind farm level. *: $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$.

Table 5: Wind Farms' Impact on Sleep Insufficiency (BRFSS Sample)

	(1)	(2)	(3)	(4)
Sleep loss measure:	Days of insuff. sleep	Any days of insuff. sleep?	$\geq$ 7 days of insuff. sleep?	$\geq$ 14 days of insuff. sleep?
(Post)	0.201**	0.0039	0.0077**	0.0075**
	(0.091)	(0.0053)	(0.0036)	(0.0036)
Mean dep. var	8.35	0.699	0.391	0.269
Observations	2,172	2,172	2,172	2,172

Notes: Each column reports a separate regression. Dependent variables are monthly measures of insufficient sleep, as indicated by column names. Estimation uses a balanced sample of counties from to 12 months before to 12 months after wind turbine installations. (Post) indicates months after installation. All regressions include county fixed effects, month-of-year fixed effects, and year fixed effects. Regressions also control for daily temperature bins and quadratic monthly precipitation. Standard errors are clustered at the wind farm level. *: $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$.

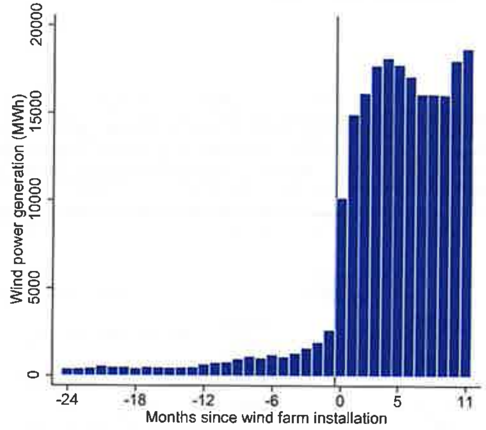
Table 6: Wind Farms' Impact on Suicide, by Firearm Access

Dep. var. = Suicide per million population	(1)	(2)	(3)	(4)
Gun access measure:	Gun shop		*Guns & Ammo* circulation	
(Post) × (Bot. tercile gun access)	0.126*		0.106*	
	(0.066)		(0.062)	
(Post) × (Mid tercile gun access)	0.304		0.434	
	(0.263)		(0.290)	
(Post) × (Top tercile gun access)	1.505***		1.117***	
	(0.438)		(0.382)	
(Post) × log(Gun aceess)		0.205***		0.367**
		(0.074)		(0.144)
Observations	63,075	61,755	63,003	62,931

Notes: Each column reports a separate regression. Estimation uses a balanced sample of counties from to 12 months before to 12 months after wind turbine installations. (Post) indicates months after installation. "Bot./Mid./Top gun access" is a categorical variable for terciles of gun access. Gun access measure is county level Federal Firearms Licensees per 100,000 residents (column 1 and 2) and county level *Guns & Ammo* circulation per 100,000 residents (column 3 and 4). All regressions include county fixed effects, month-of-year fixed effects, and year fixed effects. Regressions also control for daily temperature bins and quadratic monthly precipitation. Standard errors are clustered at the wind farm level. *: $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$.

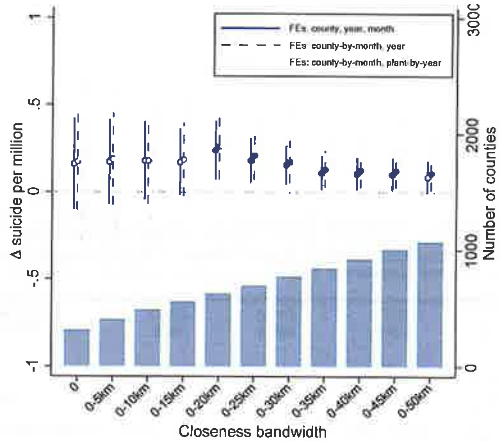
Appendix Figures and Tables

Figure A.1: Event Study: Wind Power Generation



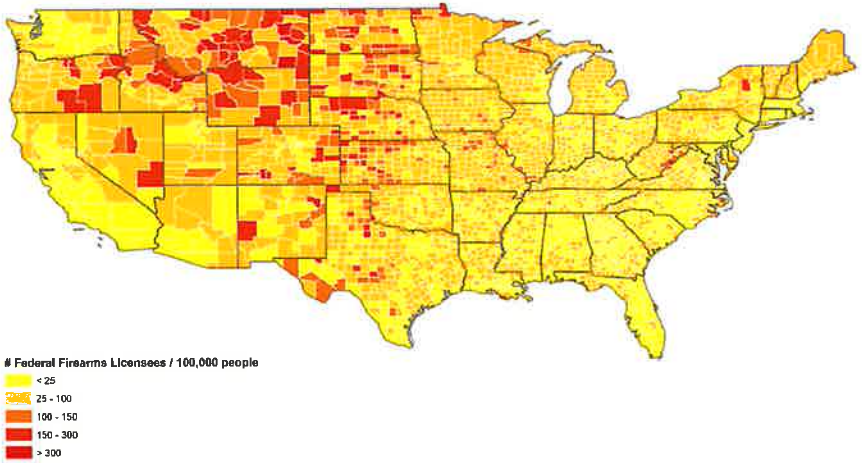
Notes: Graph plots wind power generation (MWh) by months relative to wind farm installation month, using all installation events from 2001-2013. In cases where installations are capacity additions to existing wind farms, positive generation are observed before the installation event.

Figure A.2: Robustness Checks: Closeness Bandwidth



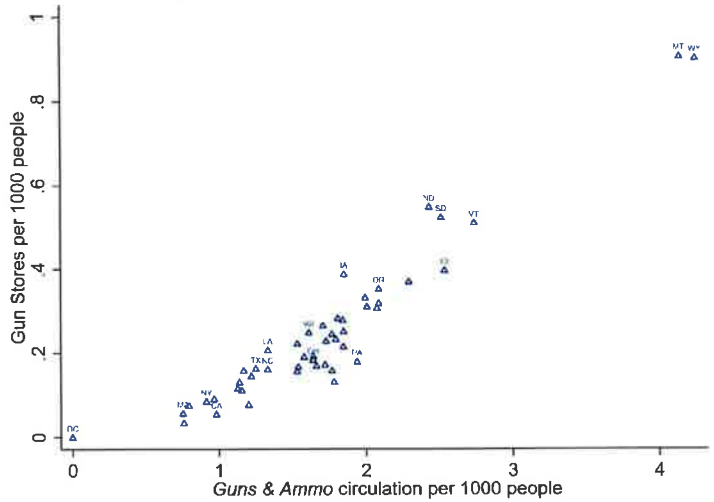
Notes: Each group of range plot items use the same estimation sample, including counties within certain distance to the wind farm as indicated by the x-axis. Bar plots number of counties included in each estimation sample. Within each group, each range plot item shows a separate regression with different fixed effects controls as indicated by the legend. Range bar represents 95% confidence interval constructed using standard errors clustered at the wind farm level. Solid dots highlight coefficients that are individually significant at the 5% level.

Figure A.3: Gun Access by County, December 2012



Notes: Map plots county level number of gun shops per 100,000 population in December 2012. Gun shops are defined as Federal Firearms Licensees listed as "dealers in firearms other than destructive devices".

Figure A.4: Correlation of Gun Access Measures



Notes: Graph plots state level gun access measured by per capita number of gun shops (December 2012) vs. per capita circulation of the magazine *Guns & Ammo* (August 2005).

Table A.1: Robustness Checks: Wind Farms' Impact on Suicide

Dep. var. = Suicide per million population	(1)	(2)	(3)
Alternative SE clusters	0.183	0.212	0.251
... county level	(0.096)*	(0.097)**	(0.142)*
... state level	(0.101)*	(0.109)*	(0.110)**
... wind farm & month (2-way)	(0.076)**	(0.107)*	(0.251)**
Unbalanced sample	0.198***	0.221***	0.315**
	(0.063)	(0.069)	(0.138)
First installation only	0.135**	0.167**	0.329***
	(0.062)	(0.071)	(0.127)
Drop December installations	0.150**	0.177**	0.137
	(0.069)	(0.077)	(0.148)
PTC driven installations only	0.365**	-	-
	(0.158)	-	-
No weather controls	0.198***	0.213***	0.240*
	(0.066)	(0.071)	(0.137)
Weather controls vary by Census Regions	0.157**	0.156**	0.140
	(0.064)	(0.066)	(0.128)
Temperature bins interact precipitation	0.156**	0.153**	0.223*
	(0.065)	(0.071)	(0.123)
County fixed effects	✓		
Month-of-year fixed effects	✓		
Year fixed effects	✓	✓	
County × month-of-year fixed effects		✓	✓
Wind farm × year fixed effects			✓

Notes: Each cell reports a separate regression. Unless noted, estimation uses a balanced sample of counties from to 12 months before to 12 months after wind turbine installations. "PTC driven installations" refer to installations which occurred on months when the Federal Production Tax Credit expired. As all expirations are all on December, the specifications in column 2 and 3 cannot be estimated as they exploit within month-of-year variations. Unless noted, regressions control for daily temperature bins and quadratic monthly precipitation. Unless noted, standard errors are clustered at the wind farm level. *: $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$.

Original Article

The effect of sleep deprivation and disruption on DNA damage and health of doctors

V. Cheung,[1] **V. M. Yuen,**[2] **G. T. C. Wong**[3] and **S. W. Choi**[4†]

1 Resident, Department of Anaesthesia, Pamela Youde Nethersole Eastern Hospital, Hong Kong, Hong Kong SAR
2 Consultant, Department of Anaesthesiology, Queen Mary Hospital, Hong Kong, Hong Kong SAR
3 Associate Professor, Department of Anaesthesiology, 4 Assistant Research Officer, Department of Anaesthesiology, Faculty of Medicine, The University of Hong Kong, Hong Kong SAR

Summary
Observational studies have highlighted the detrimental health effects of shift work. The mechanisms through which acute sleep deprivation may lead to chronic disease have not been elucidated, but it is thought that increased DNA damage or decreased repair can lead to disease. The objective of this study was to examine the effects of acute sleep deprivation on DNA damage. This was a cross-sectional observational study on 49 healthy, full-time doctors. Baseline blood was sampled from each participant after three consecutive days of adequate sleep. Participants ($n = 24$) who were required to work overnight on-site had additional blood sampled on a morning after acute sleep deprivation. DNA damage and expression of DNA repair genes were quantified. Information on health, working patterns and sleep diaries were collected. Independent t-tests were used to compare differences between groups and standardised mean differences expressed as Cohen's d. Overnight on-site call participants had lower baseline DNA repair gene expression and more DNA breaks than participants who did not work overnight ($d = 1.47$, $p = 0.0001$; and 1.48, $p = 0.0001$, respectively). In overnight on-site call participants, after acute sleep deprivation, DNA repair gene expression was decreased ($d = 0.90$, $p = 0.0001$) and DNA breaks were increased ($d = 0.87$, $p = 0.0018$). Sleep deprivation in shift workers is associated with adverse health consequences. Increased DNA damage has been linked to the development of chronic disease. This study demonstrates that disrupted sleep is associated with DNA damage. Furthermore, larger prospective studies looking at relationships between DNA damage and chronic disease development are warranted, and methods to relieve, or repair, DNA damage linked to sleep deprivation should be investigated.

Correspondence to: S. W. Choi
Email: htswchoi@hku.hk
Accepted: 12 November 2018
Keywords: antioxidants; clinician on call; DNA damage; sleep deprivation
Twitter: @affinit79203597
This article is accompanied by an editorial by Fuller and Eikermann, *Anaesthesia* 2019; **74**: 417–419.

Introduction
DNA damage and repair are dynamic processes that may be affected by various conditions and cellular events. Animal studies have shown that sleep loss can induce genetic damage in different organs [1–4]. Sleep deprivation is known to induce oxidative stress, and there is increasing interest in genomic changes related to sleep deprivation [5, 6]. In a study involving participants aged over 60 years, one night of partial sleep deprivation increased gene expression indicative of DNA damage and gene expression consistent with biological ageing [7]. Studies in older adults may not be applicable to a younger, working population, but sleep deprivation is not uncommon in this group, and studies of sleep deprivation and its effect on DNA damage in younger people are lacking. Chronic sleep deprivation can lead to respiratory disease, and experimental studies using urinary 8-hydroxydeoxyguanosine as an indirect marker of DNA damage suggest night-shift workers might display impaired functioning of DNA repair [8]. However, urinary 8-hydroxydeoxyguanosine concentrations are dependent on levels of DNA damage and DNA repair activity, so interpretation can be complicated.

Direct quantification of DNA strand breaks or oxidised bases would be helpful in understanding the effect of sleep deprivation on DNA damage and repair. Both the alkaline comet assay and formamidopyrimidine DNA glycosylase (FPG)-assisted comet assay are widely applied, highly sensitive tests for the most common DNA lesions, including single- or double-strand breaks and alkali-labile sites (e.g. base and phosphate alkylation), and oxidised purines (specifically 8-oxoguanine) and alkylation damage, respectively [9]. By employing both versions of the comet assay, we aimed to detect the presence of DNA damage as a result of different damage mechanisms in an occupationally sleep-deprived population.

†[Correction added on 30 January 2019, after first online publication: The affiliation of the last author has been amended in this current version.]

Methods
We obtained ethical approval from the Hong Kong East and Hong Kong West Cluster Research Ethics Committees, and recruited 51 subjects from two hospitals. Written informed consent was obtained from all participants. Participants were assigned into two groups according to their occupational requirement to work on call overnight on-site.

The on-site call group were full-time clinicians required to work regular overnight on-site calls no less than three times per month. The control group were full-time clinicians who were not required to work overnight on-site calls. Exclusion criteria were as follows: all chronic and acute illnesses; the consumption of any medications or dietary supplements, including vitamins and fish liver oil; all smokers, those consuming alcohol outside of UK Chief Medical Officer guidelines; habitual over-consumption of alcohol; those with a BMI of greater than 27.5; self-reported insomnia; and those who had undergone general anaesthesia in the past month.

We conducted the study over a four-month period. Baseline blood samples were taken on a morning after three consecutive days of self-reported adequate, undisturbed sleep from both groups of participants. Additional blood was sampled from the on-site call group participants on the morning after acute sleep deprivation, which was defined as after an overnight call with participants sleeping less than two sleep cycles (3 h) during their call. All blood samples were taken in the morning, kept at 4°C and used within 3 h of sampling. Data on health status, lifestyle, working patterns and a sleep diary were collected from all participants.

The outcomes of interest were oxidation-induced lesions in DNA and 8-oxoguanine DNA glycosylase (OGG1) activity, measured using two versions of the comet assay performed on lymphocytes harvested from venous blood, and the expression in lymphocytes of several DNA repair genes. Lymphocytes were harvested from venous blood. DNA damage and OGG1 activity were measured using the FPG-assisted comet assay. The comet assay measures strand breaks, and FPG (a microbial analogue of OGG1) creates breaks at sites of oxidation-induced lesions in DNA. The extent of damage was measured as a percentage of DNA in the comet tail of examined cells. Cells treated with a buffer in place of FPG revealed the amount of pre-existing DNA damage (as strand breaks) in lymphocytes, and cells treated with buffered FPG solution revealed the pre-existing strand breaks plus those created by the action of the enzyme on oxidation-induced lesions.

For the detailed protocol, please refer to [9]. For each sample, 50 nucleoids at random were scored in each of two gels treated with FPG, and in each of two gels treated, in parallel, with buffer. The difference between the average DNA score (as a percentage of DNA in comet tail) of (1) the 100 buffer-treated nucleoids (a measure of pre-existing single strand breaks) and (2) the 100 FPG -treated nucleoids (a measure of pre-existing plus single strand breaks created by the action of FPG at oxidation-induced lesions) of each sample was taken as the measure of oxidation-induced DNA damage.

We extracted total RNA within 2 h of collection from blood samples using commercial equipment (Roche, Basel, Switzerland). The mRNA extracted was converted immediately after extraction to cDNA using commercial equipment (RevertAid First Strand cDNA Synthesis Kit, Thermo Scientific). We aliquoted and stored cDNA at −80°C. One aliquot was used for the simultaneous testing in triplicate of the expression of the three genes of interest, namely *XRCC1*, *OGG1* and *ERCC1*, and the housekeeping gene, *HPRT1*, by real-time polymerase chain reaction (PCR). Details of the primers used are available upon request.

Plasma total antioxidant capacity was determined using the ferric reducing ability of plasma (FRAP) assay [10].

Based on data from a pilot study (conducted by the same investigators at Queen Mary Hospital), 23 participants were required in each group to detect a true difference in oxidation-induced DNA lesions (using the FPG-assisted comet assay) of at least ± 1.60% at 80% power and $p < 0.01$

Table 1 Characteristics of on-site call participants and control participants. Values are number (proportion) and mean (SD).

	On-site call n = 24	Control n = 25
Men	9 (38%)	15 (60%)
Women	15 (63%)	10 (40%)
Age; yrs	28.04 (2.42)	33.88 (7.78)
Hours of sleep before baseline blood taken	7.02 (0.74)	6.94 (0.68)
Hours of sleep 2 days before baseline blood taken	7.06 (1.24)	7.48 (1.24)
Hours of sleep 3 days before baseline blood taken	7.60 (2.44)	6.90 (1.14)
Specialties		
Anaesthesia	10 (42%)	4 (16%)
Ear, nose and throat		3 (12%)
Intensive Care Unit	5 (21%)	
Internal medicine	8 (33%)	1 (4%)
Neurosurgery		2 (8%)
Nuclear medicine		1 (4%)
Ophthalmology		2 (8%)
Orthopaedics		1 (4%)
Pathology		2 (8%)
Paediatrics	1 (4%)	
Radiology		8 (32%)
Urology		1 (4%)

with a mean (SD) of 4.5 (1.58)%. We used the paired t-test to compare differences between baseline and postacute sleep deprivation results of on-site call group participants. We used the unpaired t-test to compare results between the on-site call group and no on-site call group. Results were analysed cautiously, using a smaller p value ($p < 0.005$) as a threshold for statistical significance [11]. Effect-size differences between groups and between baseline and postcall values are given as Cohen's *d*.

Results

We analysed data from 24 on-site call group participants and 25 control group participants (Table 1). The on-site call participants had been working these overnight shifts for between one and ten years. Most on-site call group participants were required to work five to six overnight on-site calls per month and achieved between 2 h and 4 h of sleep during calls. Only three out of 24 on-site call group participants habitually napped for between 1-2 h before starting their overnight call shift. Control group participants included those clinicians who were not required to work overnight on-site calls, and also those with no call duties. A majority of control group participants had been exempt from on-site call duties for between 3–5 years, and the time ranged from < 1 to > 10 years. Most control group participants reported having to travel back to hospital for work after midnight once to twice per month during off-site calls. The mean number of hours slept during the three consecutive days before baseline blood sampling was 7.60 h and 6.90 h for on-site call group and control group participants, respectively.

Gene expression data are given as the ratio to the housekeeping gene *HPRT1*. The on-site call group participants demonstrated statistically significantly lower *OGG1* and *ERCC1* gene expression at baseline compared with the control group (Table 2). The on-site call group exhibited lower baseline *XRCC1* expression, although this did not reach statistical significance. On-site call group participants demonstrated more DNA breaks and alkali-labile sites at baseline. There were no differences in baseline oxidised purines and antioxidant capacity between groups.

After acute sleep deprivation in on-site call group participants, DNA repair gene expression (Fig. 1) and plasma antioxidant capacity were decreased. DNA breaks/alkaline-labile sites and oxidised purines were increased after sleep deprivation (Fig. 2 and Table 2).

Two on-site call group participants were subsequently found to be regular consumers of dietary supplement pills. The results from these two participants have been removed from the data presented in this manuscript, but it is to be noted that the overall results with these participants included, and subsequently with them excluded, did not differ.

Sub-group analysis of on-site call group participants (n = 24) comparing anaesthetists (n = 10) with doctors working outside operating theatres (n = 14) showed no difference in DNA damage and antioxidant capacity at baseline and after acute sleep deprivation.

Discussion

This study is the first to quantify DNA damage directly in young adults who are required to work overnight shifts. The results demonstrate that acute sleep deprivation and a frequently disrupted sleep cycle are associated with DNA damage, which is concordant with findings of genotoxicity in sleep-deprived animals and elderly adults [4]. This present study shows that DNA repair gene expression is lower at baseline among night workers and further

Table 2 Gene expression, DNA damage and repair and plasma antioxidant capacity of on-site call and control group participants. Values are mean (SD).

	On-site call n = 24 baseline	Control n = 25 baseline	p value (on-site call vs. Control)	Cohen's d (on-site call vs. control)	on-site call n = 24 post-call	p value (baseline vs. post-call)	Cohen's d (baseline vs. post-call)
XRCC1	0.68 (0.015)	0.75 (0.014)	0.0025*	0.83	0.65 (0.054)	0.0061*	0.49
OGG1	0.84 (0.011)	0.93 (0.011)	0.0001*	1.47	0.79 (0.056)	0.0001*	0.90
ERCC1	0.88 (0.011)	0.94 (0.005)	0.0001*	1.27	0.83 (0.013)	0.0001*	0.87
DNA breaks;	1.79 (0.37)	1.37 (0.15)	0.0001*	1.48	2.23 (0.63)	0.0012*	0.87
Oxidised purines;	8.17 (1.31)	9.06 (1.54)	0.0303	0.64	11.14 (1.39)	0.0001*	2.25
Antioxidant capacity; µM	945.3 (232.5)	936.9 (204.4)	0.8912	0.04	830.2 (171.4)	0.0015*	0.50

*Statistically significant.

decreases after acute sleep deprivation, which supports the postulation that night workers demonstrate impaired DNA repair [12, 13].

DNA damage is a change in the basic structure of DNA that is not repaired when the DNA is replicated. Double-strand breaks are particularly hazardous, as repair failure causes genomic instability and cell death, whereas disrepair can lead to inappropriate end-joining events that commonly underlie oncogenic transformation. This study has shown that doctors who are required to work overnight on-site calls demonstrate 30% higher DNA breaks and alkali-labile sites as compared with those doctors not required to work overnight, and this DNA damage is further increased by over 25% after a night of acute sleep deprivation.

The DNA repair genes, *ERCC1*, *OGG1* and *XRCC1*, examined in this study are involved in nucleotide excision repair, base excision repair and recombinational repair. Decreased or absent expression of these genes is associated with accumulation of DNA damage, increased rates of mutation and tumorigenesis [14, 15]. Significantly lower baseline *OGG1* and *ERCC1* expression, and decreases in expression of all three genes investigated after acute sleep deprivation, suggest impairment of DNA repair activity in sleep-deprived people. It is important to note that overnight on-site call participants in this study were young and healthy, and people from this age group are generally known to demonstrate better tolerance of sleep disturbance [7, 16]. It should be noted that participants in the on-site call group appeared to be younger than those in control group; this is because younger residents are required to work overnight on-site calls, and this may be a limitation of the current study.

Given the paucity of relevant human literature, we should question how these findings should be interpreted and applied clinically. However, sleep deprivation and shift work have been implicated as risk factors for the development and progression of various chronic diseases. A meta-analysis of sixteen prospective cohort studies involving more than 2,000,000 participants suggested a dose–effect relationship between night-shift work and the incidence of breast tumours (risk ratio 1.057) [12]. The findings with respect to cancer at other sites are inconsistent [17]. Two studies suggested that shift workers are at increased risk of prostate cancer, contrary to findings from a large prospective cohort [17, 18]. With regard to colorectal cancer, nurses on rotating night shifts for 15 years or more were found to be at increased risk, whereas a prospective study on the general population and telegraph operators showed no significant association between night shifts and colorectal cancer [19, 20].

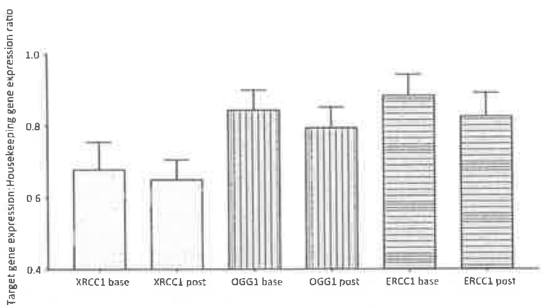


Figure 1 Baseline (base) vs. post-call (post) gene expression in 24 subjects. Values are mean (SD). The paired t-test was used to detect differences between the two time-points. Data are expressed as the ratio of gene expression between the gene of interest compared with expression of housekeeping gene.

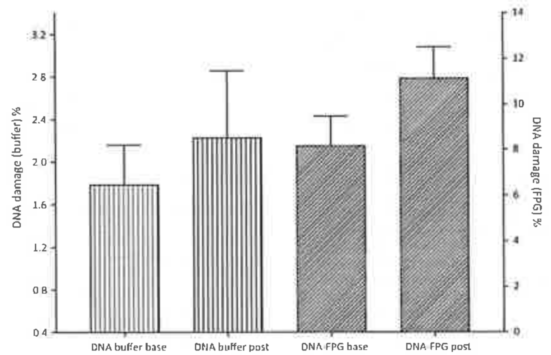


Figure 2 Baseline vs. post-call DNA damage in cells treated with buffer (buffer) and cells treated with FPG. The paired t-test was used to detect differences between the two time-points. Data are expressed as proportion of DNA damage. FPG, formamidopyrimidine DNA glycosylase.

Short sleep duration (< 6.5 h) is associated with mortality in advanced cancer patients in a curvilinear manner [21]. Meta-analyses have shown that shift work is associated with increased risk of myocardial infarction, coronary events and ischaemic stroke [22]. Short sleep duration (< 5 h or 6 h) is associated with a significant increase in the risk of the metabolic syndrome [23]. Meta-analysis of 12 studies involving > 226,000 participants showed that shift work may increase the risk of diabetes [24]. Sleep disruption may be implicated in neurodegeneration. In a prospective actigraphy study of > 1200 healthy elderly women, decreased circadian rhythm amplitude and robustness was associated with an increased risk for mild cognitive impairment or dementia over the next 5 years [25]. In a mouse model, chronic mild sleep restriction has been associated with impairments in contextual and cued memory, and an increase in amyloid-β and insoluble tau, hallmarks of the development of Alzheimer's disease [26]. Whether sleep disturbance is an early symptom or a contributor to the pathophysiology of neurodegenerative disease is still unknown.

Multiple mechanisms to explain the predisposition of shift workers to chronic diseases have been postulated. Disrupted circadian rhythm and suppression of nocturnal

melatonin causes altered endogenous sex hormone balance, desynchrony of clock genes and the expression of genes implicated in cancer development. Heightened neuroendocrine stress responses, higher glucocorticoid and catecholamine levels, disrupted appetite control, pro-inflammatory responses, immunosuppression and changes in lifestyle, including diet and physical activity, are possible contributing factors to increased chronic disease susceptibility during periods of disrupted sleep [27–29].

Our study presents evidence of genetic damage and impairment of DNA repair associated with occupational sleep deprivation in young people. This biomolecular evidence may serve as another basis for the increased risk for malignancies and cardiovascular, metabolic and neurodegenerative diseases. However, further mechanistic studies evaluating the relationship between DNA damage and development of these chronic diseases is required.

We undertook sub-group analysis of on-site call group participants dividing this group into anaesthetists and clinicians who worked outside the operating theatre. No significant differences in DNA damage and antioxidant capacity at baseline and after acute sleep deprivation were found (data not shown), suggesting that chronic occupational exposure to volatile gases used in operating theatres is not associated with genotoxicity [30].

This study has a number of strengths. Participants were all healthy and did not suffer from any chronic disease. Secondly, we used the alkaline comet assay, the current gold standard for evaluation of DNA damage, rather than using surrogate biomarkers of DNA damage. This study is the first to employ the comet assay to investigate the effect of sleep deprivation and sleep cycle disturbance on DNA damage in humans. The successful application of these techniques represents a novel approach to evaluating sleep deprivation and disruption on human genotoxicity. Thirdly, we used a stringent p value for statistical significance, increasing the reproducibility of the results.

DNA damage results obtained using the comet assay have not been investigated in prospective cohort studies, and therefore its predictive value for chronic disease development and the clinical significance of the laboratory findings are unclear. In addition, higher baseline DNA damage in on-site call clinicians could possibly be linked with a frequently disrupted sleep cycle, but it could also be confounded by other factors, including greater work stress in specialties with on-site calls, different occupational risk exposure (e.g. to radiation) between specialties, and other personal factors which are difficult to quantify. We attempted to recruit clinicians from as many different specialties as possible in each group to balance out the confounding effect of the different nature of various specialties.

Although data on the number of sleeping hours on the preceding three consecutive days before baseline blood sampling was collected, sleep adequacy was self-defined. Similarly, acute sleep deprivation was self-reported, and it was not possible to monitor this. Nevertheless, the data as presented reflect the real-life situation of clinicians who are required to perform shift duties. Sleep demand and habits can vary greatly between individuals, and in addition to the number of hours slept, sleep quality is also an important factor determining sleep adequacy. It was beyond the scope of this study to perform psychosocial and behavioural tests after sleep deprivation, and therefore it was not possible to ascertain the extent that one night of sleep deprivation would have on the mental performance of clinicians.

Finally, participants were mostly young Chinese doctors, and therefore the results of this study can only be applied to this population. The genomic consequence of sleep deprivation and disruption may vary as a function of ethnicity, locality and age groups. Another limitation to this study was that sleep scale questionnaires were not collected from the participants. This is because the sleep scales, although validated, are nevertheless subjective and sleep diaries were considered adequate for our current study.

In conclusion, this current study has clearly demonstrated that oxidatively damaged DNA is increased after only one night of acute sleep deprivation. The significance of this DNA damage requires verification in larger, prospective studies. The theory that oxidative stress leading to impaired DNA repair is the 'common soil' of pathogenic mechanisms underlying chronic disease development was first proposed over two decades ago [31]. Future studies should be conducted to evaluate if this DNA damage can be attenuated by the use of antioxidants or agents to promote recovery sleep after acute sleep deprivation.

Acknowledgements

Special thanks to Dr. D. LAM Ming-hon, Department of Anaesthesiology, Queen Mary Hospital for his assistance in data collection and blood-taking. SWC is statistical advisor for *Anaesthesia*, and therefore the manuscript has undergone external independent review. The other authors have no competing interests to declare. This study was funded by the Department of Anaesthesiology, University of Hong Kong.

References

1. Andersen ML, Ribeiro DA, Bergamaschi CT, et al. Distinct effects of acute and chronic sleep loss on DNA damage in rats. *Progress in Neuro-Psychopharmacology and Biological Psychiatry* 2009; **33**: 562–7.
2. Bellesi M, Bushey D, Chini M, Tononi G, Cirelli C. Contribution of sleep to the repair of neuronal DNA double-strand breaks: evidence from flies and mice. *Scientific Reports* 2016; **6**: 36804.
3. Everson CA, Henchen CJ, Szabo A, Hogg N. Cell injury and repair resulting from sleep loss and sleep recovery in laboratory rats. *Sleep* 2014; **37**: 1929–40.
4. Tenorio NM, Ribeiro DA, Alvarenga TA, et al. The influence of sleep deprivation and obesity on DNA damage in female Zucker rats. *Clinics (Sao Paulo)* 2013; **68**: 385–9
5. Arnardottir ES, Nikonova EV, Shockley KR, et al. Blood-gene expression reveals reduced circadian rhythmicity in individuals resistant to sleep deprivation. *Sleep* 2014; **37**: 1589–600.
6. da Costa Souza A, Ribeiro S. Sleep deprivation and gene expression. *Current Topics in Behavioral Neurosciences* 2015; **25**: 65–90
7. Carroll JE, Cole SW, Seeman TE, et al. Partial sleep deprivation activates the DNA damage response (DDR) and the senescence-associated secretory phenotype (SASP) in aged adult humans. *Brain, Behavior, Immunity* 2016, **51**: 223–9.
8. Prather AA, Leung CW. Association of insufficient sleep with respiratory infection among adults in the united states. *Journal of the American Medical Association Internal Medicine* 2016; **176**: 850–2.
9. Collins AR. The comet assay: a heavenly method!. *Mutagenesis* 2015; **30**: 1–4.
10. Benzie IF, Strain JJ. The ferric reducing ability of plasma (FRAP) as a measure of "antioxidant power": the FRAP assay. *Analytical Biochemistry* 1996; **239**: 70–6.
11. Benjamin DJ, Berger JO, Johannesson M, et al. Redefine statistical significance. *Nature Human Behaviour* 2017; **1**: 6.
12. Lin X, Chen W, Wei F, Ying M, Wei W, Xie X. Night-shift work increases morbidity of breast cancer and all-cause mortality: a meta-analysis of 16 prospective cohort studies. *Sleep Medicine* 2015, **16**: 1381–7.
13. Manzella N, Bracci M, Strafella E, et al. Circadian modulation of 8-Oxoguanine DNA damage repair. *Scientific Reports* 2015; **5**: 13752.
14. Bernstein C, Bernstein H. Epigenetic reduction of DNA repair in progression to gastrointestinal cancer. *World Journal of Gastrointestinal Oncology* 2015; **7**: 30–46.
15. Hung RJ, Hall J, Brennan P, Boffetta P. Genetic polymorphisms in the base excision repair pathway and cancer risk: a HuGE review. *American Journal of Epidemiology* 2005; **162**: 925–42.
16. Vgontzas AN, Zoumakis M, Bixler EO, et al. Impaired nighttime sleep in healthy old versus young adults is associated with elevated plasma interleukin-6 and cortisol levels: physiologic and therapeutic implications. *Journal of Clinical Endocrinology and Metabolism* 2003; **88**: 2087–95.
17. Wang XS, Armstrong ME, Cairns BJ, Key TJ, Travis RC. Shift work and chronic disease: the epidemiological evidence. *Occupational Medicine* 2011; **61**: 78–89
18. Kubo T, Ozasa K, Mikami K, et al. Prospective cohort study of the risk of prostate cancer among rotating-shift workers: findings from the Japan collaborative cohort study. *American Journal of Epidemiology* 2006; **164**: 549–55.
19. Schernhammer ES, Laden F, Speizer FE, et al. Night-shift work and risk of colorectal cancer in the nurses' health study. *Journal of the National Cancer Institute* 2003; **95**: 825–8.
20. Tynes T, Hannevik M, Andersen A, Vistnes AI, Haldorsen T. Incidence of breast cancer in Norwegian female radio and telegraph operators. *Cancer Causes and Control* 1996; **7**: 197–204.
21. Collins KP, Geller DA, Antoni M, et al. Sleep duration is associated with survival in advanced cancer patients. *Sleep Medicine* 2017, **32**: 208–12
22. Vyas MV, Garg AX, Iansavichus AV, et al. Shift work and vascular events: systematic review and meta-analysis. *British Medical Journal* 2012; **345**: e4800.
23. Ju SY, Choi WS. Sleep duration and metabolic syndrome in adult populations: a meta-analysis of observational studies. *Nutrition and Diabetes* 2013; **3**: e65.
24. Gan Y, Yang C, Tong X, et al. Shift work and diabetes mellitus: a meta-analysis of observational studies. *Occupational and Environmental Medicine* 2015; **72**: 72–8.
25. Tranah GJ, Blackwell T, Stone KL, et al. Circadian activity rhythms and risk of incident dementia and mild cognitive impairment in older women. *Annals of Neurology* 2011; **70**: 722–32.
26. Rothman SM, Herdener N, Frankola KA, Mughal MR, Mattson MP. Chronic mild sleep restriction accentuates contextual memory impairments, and accumulations of cortical Abeta and pTau in a mouse model of Alzheimer's disease. *Brain Research* 2013; **1529**: 200–8.
27. Bryant PA, Trinder J, Curtis N. Sick and tired: does sleep have a vital role in the immune system? *Nature Reviews Immulogy* 2004; **4**: 457–67
28. Hirotsu C, Tufik S, Andersen ML. Interactions between sleep, stress, and metabolism: from physiological to pathological conditions. *Sleep Science* 2015; **8**: 143–52.
29. Prinz P. Sleep, appetite, and obesity – what is the link? *PLoS Medicine* 2004; **1**: e61.
30. Molina Aragones JM, Ayora Ayora A, Barbara Ribalta A, et al. Occupational exposure to volatile anaesthetics: a systematic review. *Occupational Medicine* 2016; **66**: 202–7.
31. Stern MP. Diabetes and cardiovascular disease. The "common soil" hypothesis. *Diabetes* 1995; **44**: 369–74.

Thorac cardiovasc Surg 2018; 66(S 01): S1-S110
DOI: 10.1055/s-0038-1628066
Georg Thieme Verlag KG Stuttgart · New York

Are There Harmful Effects Caused by the Silent Noise of Infrasound Produced by Windparks? An Experimental Approach

C. F. Vahl
Universitätsmedizin Mainz, Mainz, Germany
,
A. Ghazy
Universitätsmedizin Mainz, Mainz, Germany
,
R. Chaban
Universitätsmedizin Mainz, Mainz, Germany

Publikationsdatum:
22.Januar 2018 (online)

Introduction: The increased number of wind parks raised the question, whether infrasound waves produced by wind turbines are harmful on human-beings, or not. Infrasound is a low frequency sound (< 20 Hz), undetectable with human ears. However, some people live near windparks describe unspecific symptoms i.e., palpitations, dizziness, headache, etc. This study analyses the infrasound effects on isolated atrial human myocardium and measures the contractile performance in human trabeculae using different frequencies and amplitudes of infrasound generated by a loudspeaker.

Methods: Human atrial trabeculae were resected from 8 patients undergoing aorto coronary bypass surgery, then demembranized using Triton X 100 and small fibers were generated with diameter < 0.3 mm and length 4–6 mm. The fibers were attached between force transducer and loudspeaker while activated at optimal length and room temperature in an organ bath using supramaximal calcium concentrations. Then infrasound was imposed using frequencies of 10 Hz or 20 Hz. Sound amplitudes (SA) were either 5% or 10% of tissue length (TL). Sound was applied for 1 minute. Force was measured before and after 1 minute of infrasound.

Results: Imposed infrasound on isolated human myocardium caused a direct force inhibition of the completely activated myocardial preparation. At 10 Hz and 5% TL (SA) force inhibition was 18.8+2% while at 10% TL (SA) up to 23.3+2% ($p < 0.05$). At 20 Hz; force inhibition was 23+2% at 5% TL and 32+4% at 10% TL ($p < 0.01$). After stopping infrasound; force was recovered but not to the initial value. No sound was heard during the experiments. Passive resting force was minimally affected (n.s.).

Conclusion: Infrasound can induce direct effects on human myocardium in the given experimental setting. Although mono-frequency sounds are not present in nature, our experimental data indicate, that direct effects on myocardial tissue are present. The infrasound influence on human tissue requires further investigation because the increasing number of a) wind turbines and b) human beings exposed by the neighborhood of windparks. Humans have no chance to protect themselves from the silent noise of infrasound, as long as no scientific data are present.

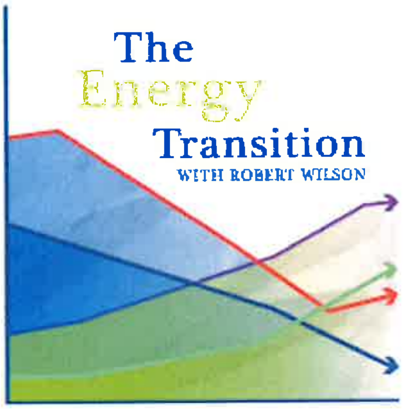
ANNEX 7

POST

Can You Make a Wind Turbine Without Fossil Fuels?

Share Like Comment (117)

February 25, 2014 2260 views



Wind Turbine and Energy Use

Various scenarios have been put forward showing that 100% renewable energy is achievable. Some of them even claim that we can move completely away from fossil fuels in only couple of decades. A world entirely without fossils might be desirable, but is it achievable?

The current feasibility of 100% renewable energy is easily tested by asking a simple question. Can you build a wind turbine without fossil fuels? If the machines that will deliver 100% renewable energy cannot be made without fossil fuels, then quite obviously we cannot get 100% renewable energy.

This is what a typical wind turbine looks like:

What is it made of? Lots of steel, concrete and advanced plastic. Material requirements of a modern wind turbine have been reviewed by the United States Geological Survey. On average 1 MW of wind capacity requires 103 tonnes of stainless steel, 402 tonnes of concrete, 6.8 tonnes of fiberglass, 3 tonnes of copper and 20 tonnes of cast iron. The elegant blades are made of fiberglass, the skyscraper sized tower of steel, and the base of concrete.

These requirements can be placed in context by considering how much we would need if we were to rapidly transition to 100% wind electricity over a 20 year period. Average global electricity demand is approximately 2.6 TW, therefore we need a total of around 10 TW of wind capacity to provide this electricity. So we would need about

50 million tonnes of steel, 200 million tonnes of concrete and 1.5 million tonnes of copper each year. These numbers sound high, but current global production of these materials is more than an order of magnitude higher than these requirements.

Fossil fuel requirements of cement and steel production

For the sake of brevity I will only consider whether this steel can be produced without fossil fuels, and whether the concrete can be made without the production of carbon dioxide. However I will note at the outset that the requirement for fiberglass means that a wind turbine cannot currently be made without the extraction of oil and natural gas, because fiberglass is without exception produced from petrochemicals.

Let's begin with steel. How do we make most of our steel globally?

There are two methods: recycle old steel, or make steel from iron ore. The vast majority of steel is made using the latter method for the simple reason that there is nowhere near enough old steel lying around to be re-melted to meet global demand.

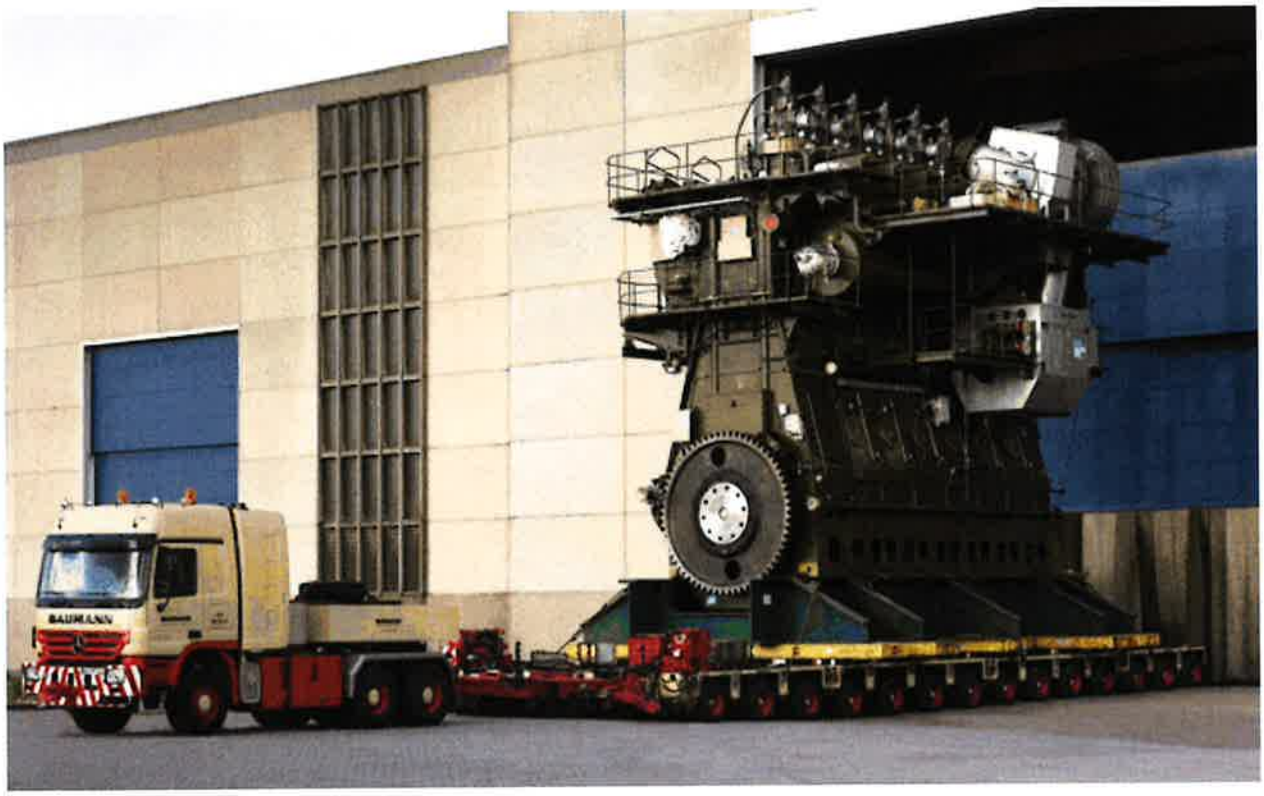
Here then is a quick summary of how we make steel. First we take iron ore out of the ground, leaving a landscape looking like this:

This is done using powerful machines that need high energy density fuels, i.e. diesel:

And the machines that do all of this work are almost made entirely of steel:

After mining, the iron ore will need to be transported to a steel mill. If the iron ore comes from Australia or Brazil then it most likely will have to be put on a large bulk carrier and transported to another country.

What powers these ships? A diesel engine. And they are big:



Simple engineering realities mean that shipping requires high energy dense fuels, universally diesel. Because of wind and solar energy's intrinsic low power density putting solar panels, or perhaps a kite, on to one of these ships will not come close to meeting their energy requirements. We are likely stuck with diesel engines for generations.

We then convert this iron ore into steel. How is this done? There are only two widely used methods. The blast furnace or direct reduction routes, and these processes are fundamentally dependent on the provision of large amounts of coal or natural gas.

A modern blast furnace

The blast furnace route is used for the majority of steel production globally. Here coal is key. Iron ore is unusable, largely because it is mostly iron oxide. This must be purified by removing the oxygen, and we do this by reacting the iron ore with carbon monoxide produced using coke:

$$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$$

Production of carbon dioxide therefore is not simply a result of the energy requirements of steel production, but of the chemical requirements of iron ore smelting.

This steel can then be used to produce the tower for a wind turbine, but as you can see, each major step of the production chain for what we call primary steel is dependent on fossil fuels.

By weight cement is the most widely used material globally. We now produce over 3.5 billion tonnes of the stuff each year, with the majority of it being produced and consumed in China. And one of the most important uses of cement is in concrete production.

Cement only makes up between 10 and 20% of concrete's mass, depending on the specific concrete. However from an embodied energy and emissions point of view it makes up more than 80%. So, if we want to make emissions-free concrete we really need to figure out how to make emissions-free cement.

We make cement in a cement kiln, using a kiln fuel such as coal, natural gas, or quite often used tires. Provision of heat in cement production is an obvious source of greenhouse gases, and providing this heat with low carbon sources will face multiple challenges.

A modern cement kiln

These challenges may or may not be overcome, but here is a more challenging one. Approximately 50% of emissions from cement production come not from energy provision, but from chemical reactions in its production.

The key chemical reaction in cement production is the conversion of calcium carbonate (limestone) into calcium oxide (lime). The removal of carbon from calcium carbonate inevitably leads to the emission of carbon dioxide:

$$CaCO_3 \rightarrow CaO + CO_2$$

These chemical realities will make total de-carbonisation of cement production extremely difficult.

Total cement production currently represents about 5% of global carbon dioxide emissions, to go with the almost 7% from iron and steel production. Not loose change.

In conclusion we obviously cannot build wind turbines on a large scale without fossil fuels.

Now, none of this is to argue against wind turbines, it is simply arguing against over-promising what can be achieved. It also should be pointed out that we cannot build a nuclear power plant, or any piece of large infrastrtucture for that matter, without concrete or steel. A future entirely without fossil fuels may be desirable, but currently it is not achievable. Expectations must be set accordingly.

Recommended Reading

Sustainable Materials With Both Eyes Open – Allwood and Cullen

Making the Modern World: Materials and Dematerialization – Vaclav Smil

#fossil-fuels #renewables-growth #the-energy-transition

Thank Robert for the Post!

Energy Central contributors share their experience and insights for the benefit of other Members (like you). Please show them your appreciation by leaving a comment, 'liking' this post, or following this Member.

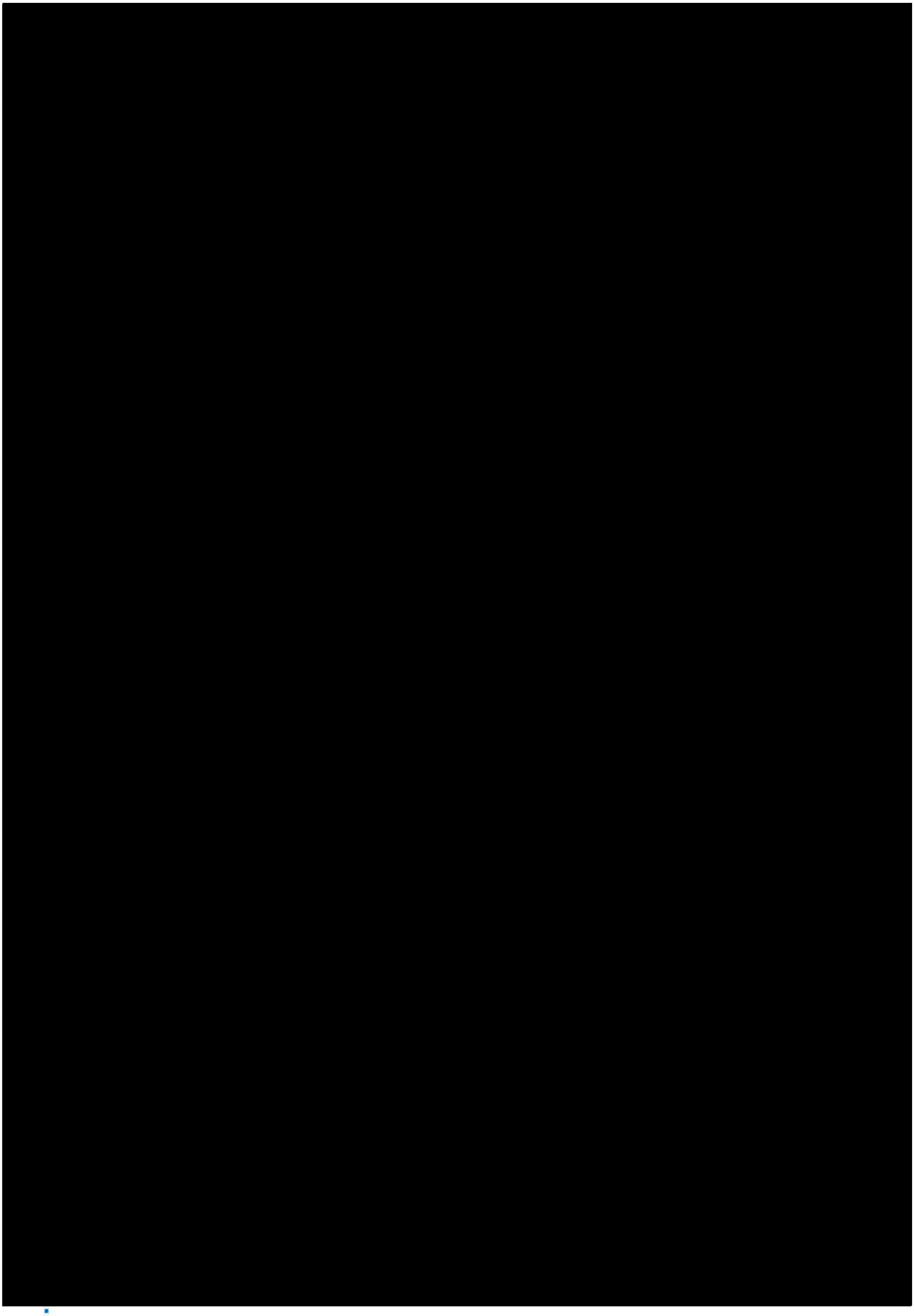
Like this post **Follow Robert**

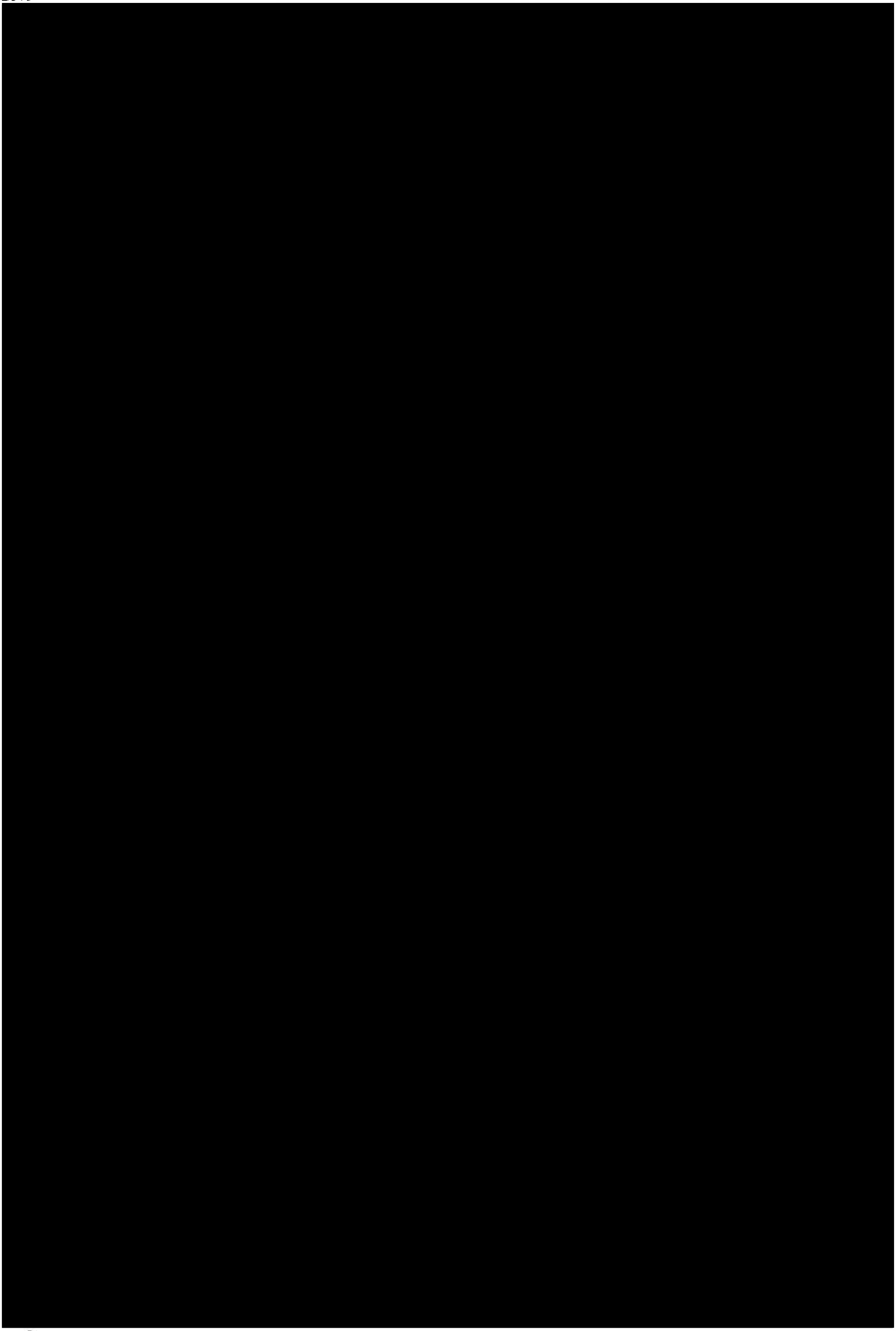
DISCUSSIONS

Keith Pickering on February 25, 2014

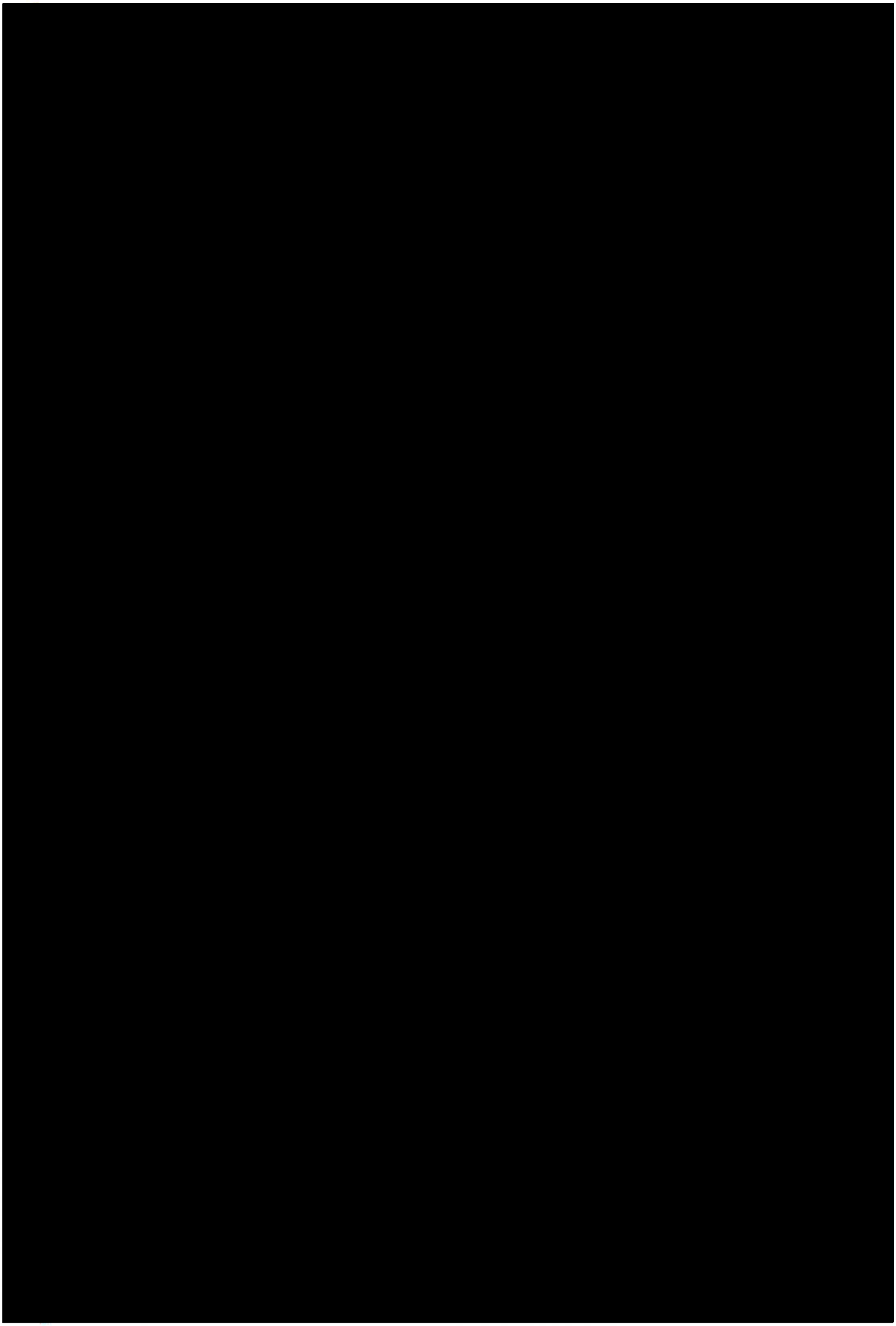
[redacted]

[redacted]





[redacted]

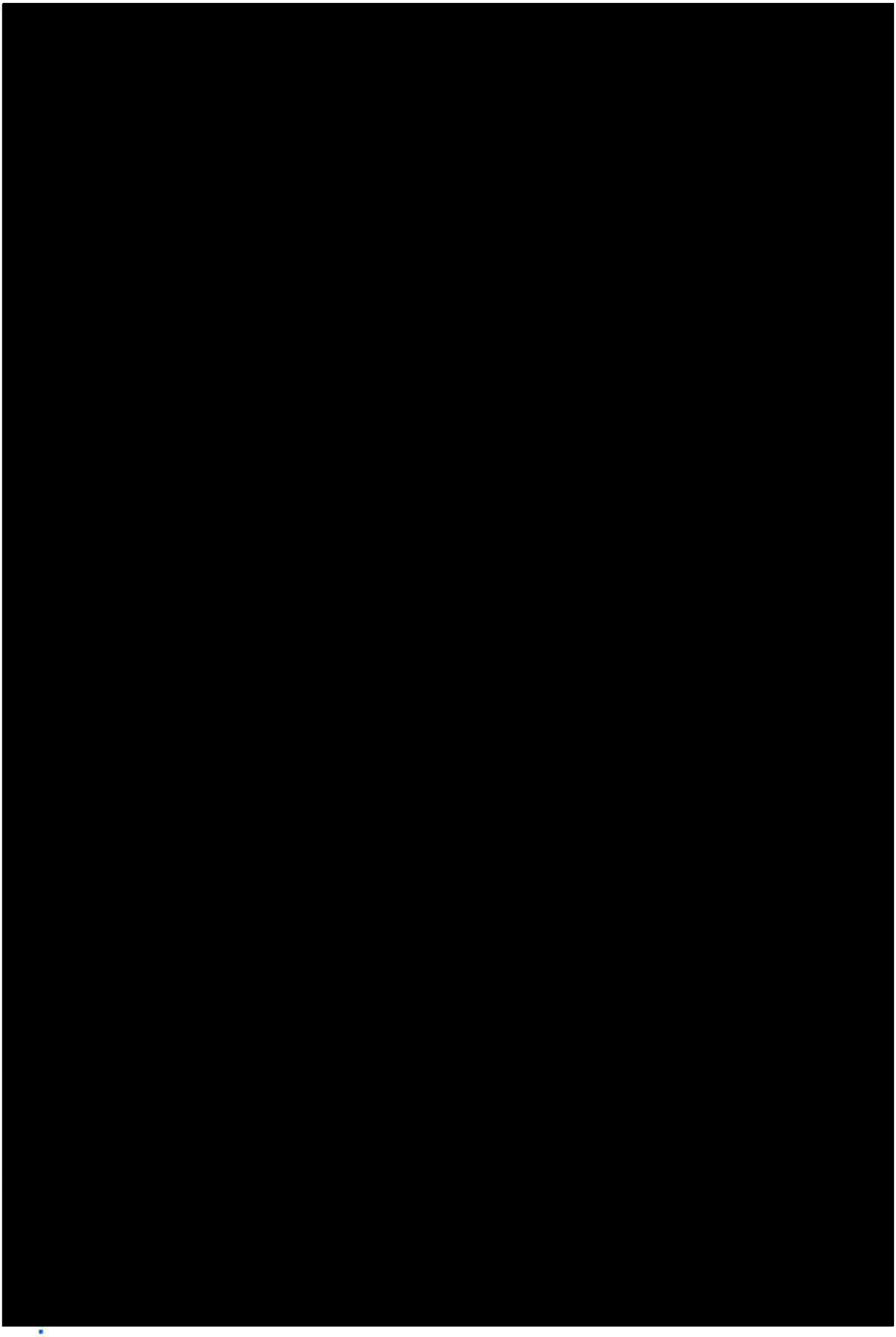


[redacted]

[redacted]

[redacted]

[redacted]



[redacted]

[redacted]

[redacted]

1 2 3 next › last »

Sign in to Participate

MORE POSTS

Big coal wants you to pay to fix its problem

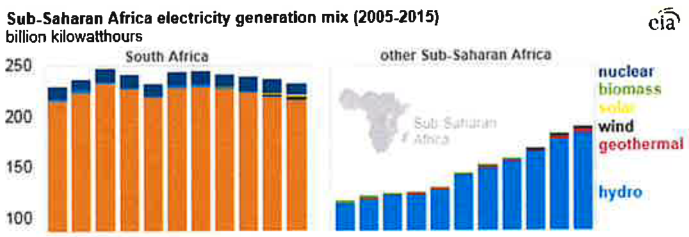
Some of the world's biggest fossil-fuel producers are calling on taxpayers to help them kick their pollution habit.The world's biggest oil, natural gas and mining companies are stepping up their campaign to deploy carbon capture and storage, or..

Limiting fossil fuel production as the next big step in climate policy

The next big step for climate policy might be almost too obvious: Stop producing oil and gas.A study published today in the journal Nature Climate Change lays out the rationale for limiting production of fossil fuels, rather than..

America's energy dominance is a remarkable achievement

Huge news for the fossil fuel industry, but what does this mean for America's focus on alternative energy sources now that the country has found energy independence through crude oil production? And what will potential Democratic leadership do in..



Hydro and fossil fuels power electricity growth in Sub-Saharan Africa - Today in Energy - U.S. Energy Information Administration (EIA)

According to EIA's international electricity statistics, hydroelectric and fossil fuel-powered generation were the top sources of growth between 2005 and 2015 in Sub-Saharan Africa (SSA), defined as the 49 countries fully or partially south of..

Get Published - Build a Following

The Energy Central Power Industry Network is based on one core idea - power industry professionals helping each other and advancing the industry by sharing and learning from each other.

If you have an experience or insight to share or have learned something from a conference or seminar, your peers and colleagues on Energy Central want to hear about it. It's also easy to share a link to an article you've liked or an industry resource that you think would be helpful.

Start a Post » **Learn more about posting on Energy Central »**

Related Content

Big coal wants you to pay to fix its

[redacted]

Sponsors

Dossier on the financial situation, (insolvency) of Irish Wind farms June 2019. (Revised August 2019)

Part 1.

Summary of findings in easy to read form.

1) This report deals only on the financial outlook of Irish wind farms. We say nothing about the environmental, health, noise shadow flicker or property value impacts here because they are already well flagged. It is not a question of if the wind industry either collapses or receives a bail out from the taxpayer, but a question of when. There is currently at least 3,400 Mega Watts (MW) of wind capacity installed valued at about 6.5 billion Euros in their accounts. They are losing an average of 65,000 Euros per MW or 221 million Euros per year. If the government target of 4,000 MW is maintained over the life span of an average wind farm the losses will amount to 884 billion Euros. Still, new installations are continuing, where is the money coming from?

2) Eirgrid promised wind farm electricity generating companies they could generate an average of 32.4% of their capacity from prevailing wind speeds over one year. (Generation Adequacy Report 2010 – 2016). They had no reason whatsoever to make such a claim. Now Eirgrid admit that wind farms are only generating 20% to 26%. (20% in 2018).

Here are the exact words from Eirgrid on the 27th February 2019 in response to a question from Val Martin to clarify comments in one of their reports published in 2019 showing 27% capacity factors in 2018.

"Val

In response to the query you have raised. the Estimated Capacity Factor for the period was 20% and this is based on actuals, while the "27%" is the forecast figure. Therefore what the report is saying is; the actual estimated capacity factor value of 20% was lower than the forecast capacity factor value of 27%.

Kind regards
Customer Relations "

Where wind farms are built using loans, there is enough income to pay the expenses and the loan interest, but not enough to pay the principle within the life span of the wind farm. Where a wind farm is built with share capital, there is enough to pay running expenses and part of the capital, but it will take much

more than the life span of the wind farm to repay the full capital investment. These wind turbines will be long gone for most of the repayment period of the capital cost, whether it's loans, shares or a combination of both.

3) All Irish wind farms we examined are technically insolvent right now. They are not a going concern and have little value being permanent loss makers. Every possible accounting trick is used to hide the true position, including **fair value adjustments,** debt forgiveness from parent companies and paying dividends to existing shareholders from money raised from new shareholders. Fair value adjustments was made legal immediately before the Celtic tiger building/banking collapse of 2008. This trend is spread across the entire fleet of wind farms where profits are rare and losses common. They can never repay their capital costs.

4) The material here has been condensed as much as possible and all of it may not be understood by some readers. Readers should not let this put them off as the message will become clear towards the end. We recommend it be given to the wind industry, to Greencoat Renewables, the ESB, SSE, the Director of Corporate Enforcement, The Dail Committee on Public Accounts, to civil servants with accounting training and their response demanded. Irish renewable energy ventures are a copy of the Celtic Tiger builder/banker boom into which the Patrick Nyberg inquiry investigated and made recommendations which are now being ignored. He noted the herd instinct of all the yes men with responsibility to act which is now being repeated by all but one of the 158 T.D. sitting in the Dail.

5) The Director of Corporate Enforcement was contacted with a specific instance of non compliance, but says he will only become involved if a crime is committed. We show here that in some cases wind farm companies are not complying with the law.

6) We say those holding political office in Ireland have a duty to get to understand what is happening and seek a proper investigation. We will cooperate. We compiled this dossier in the hope that at least one of our **158** members of Dail Eireann will take an interest and act on it.

7) This has implications not only for wind farms, but for their lenders and investors some of whom are likely to be pension funds. These pension funds cannot deliver pensions from the wind farm portfolios when claimants expect a pension. This makes it an ideal case for the Dail Committee on Public Accounts to study.

8) The companies Act is being broken, risky accounting practices are taking place. The checks and balances of the Aarhus Convention and SEA Directive on the environment is by passed as part of a pathological drive to promote this industry which can only end in tears.

Should the reader find part 1 to 5 laborious turn to part 6 for the account details.

Foreword in easy to read

Having repeatedly extended the REFIT subsidy schemes time limits, the Minister announced in early 2019 that it will end for new entrants in March 2020. It is not known what brought about such a decision or if there will be another extension of time. We anticipate government will install all the wind farms it possibly can and we therefore draw attention to the economic implications of that policy.

There is (among all our objections) one single feature of Ireland's renewable energy policy which no one can ignore. It is one which can only be escaped by bringing the whole industry under public control at a huge financial cost to taxpayers and consumers. We accept that generally governments want to do good and sometimes they succeed, but sometimes they fail. We witnessed the Beef tribunal, the investigations into clerical child abuse, the Donegal Garda Inquiry, the Maurice McCabe Judicial inquiry and the most important of all the inquiry into the building and banking collapse of 2008. We know from these inquiries that mistakes were made and we try here to fend off one on energy.

There were 11 forms of renewable energy in the 2009 Renewable Energy Directive, but government decided wind should be to the forefront. It raised the proportion of renewable energy for electricity generation from 16% to 40%. The 40% figure has been reached long ago, we now have wind capacity equal to average electricity demand or 100%.

Wind speeds vary year on year. It takes an output of about 18.2% to pay for the annual operating costs of an average wind farm. A good wind speed year will give a 24% output, which leaves 5.8% to provide interest and capital repayments. There is usually enough to pay interest and a little principle on the capital loan, but not enough to pay all the capital cost within the lifetime of the wind farm. The accounts show that where a 24% output is achieved, 76% of revenue is required to pay all the operating cost. Irish an British wind

speeds are very closely related, best speeds are in the north west declining in the south east midlands.

About the authors.

Val Martin is a native of Kingscourt, Co Cavan. Served 32 years as a member of An Garda Siochana, 16 of it as a Detective Sergeant investigating crime. After retirement he worked as a project manager for Kingscourt community development Council for two years when he entered into ostensible retirement as a suckler cow farmer on his traditional family holding at Drumsallagh, Kingscourt.

He obtained an honours Bachelor of Business Studies degree at the Institute of Public Administration Dublin taking the financial accounting stream in 2003. The course included a financial management module and company law. He conducted a number of successful investigations into various types of fraud and a pyramid selling schemes which led to court convictions.

His hobby (apart from farming) is model mechanical engineering and scientific experimentation. He built a model electrical grid and made electronic components which worked. He is Irish Spokesperson for the European Platform Against Wind farms which has over 1,200 member groups throughout Europe and is affiliated with its counterpart in North America. He took two Judicial Reviews on planning applications as a lay litigant for energy projects. He won one and lost the other. He has a number of videos on the internet You Tube channel entitled valmartinireland You Tube and three of these demonstrate practical working models.

John Joe Dooley is a retired engineer living in Dublin. He worked in the USA and Ireland specialising in installation of production machinery. His education/experience includes assessing the economic contribution of additional machines to an existing system and he is proficient in financial accounting methods. He looks at wind turbines as he would any other machine. Computers are also machines. The cost of a machine must be repaid as profit over its useful life and the depreciation charge to the accounts must reflect this. The depreciation charge for wind farms is too low. The higher the depreciation charge the lower the profits will be.

Owen Martin has a degree in economics and accountancy and researches energy and economic topics in his spare time.

None of the authors ever received, are receiving or are likely to receive any remuneration for their efforts, they do it out of a sense of public duty and to prevent environmental damage. Val Martin has spent a lot of his own money campaigning and helping communities deal with planning applications. We all have given of our time attending events and making submissions to public consultations. It's also an experiment to see if an unsustainable government policy can be altered before the damage is done.

Part 2. slightly more difficult to comprehend.

Climate change.

Climate change, is the main driver for our renewable energy policy with the objective of reducing dependence on fossil fuel and cutting carbon emissions. Whatever the situation with climate change, we accept that if renewable energy displaced fossil fuel, that would be sufficient reason to support it. We have long being pointing out that no more than **65%** of wind **(non synchronous)** power can be allowed into the electricity grid at any one time and no one has worked out how the remaining **35%** will be powered without fossil fuel. This limit is accepted by Eirgrid in their publications and observable on their on-line Dashboard. In addition to this limit, the output of Ireland's wind farms averages between 20% and 26% and declines with age.

This report in the Telegraph refers to a study showing that wind farms do not reduce greenhouse gasses. We cannot see how the co2 released in their construction can ever be recouped.
https://www.telegraph.co.uk/news/earth/energy/windpower/9889882/Wind-farms-will-create-more-carbon-dioxide-say-scientists.html?fbclid=IwAR3GZePBX4gJPDPp72J9pbV5oQ4J9o4QOrjGQMYc5kbLCXvTcxv8gdkKDgU
Note: When opening links, place cursor over it and follow instructions. It may be necessary to press control and left click.

The EU Court of Auditors report 2019, demands countries such as the Netherlands and Ireland increase their capacity of wind and solar generation to help meet Emissions targets. We say that in the absence of the legally required SEA it does not appear to have occurred to any member government to tell these Auditors the limitations of such wind energy source.
https://www.eca.europa.eu/Lists/ECADocuments/SR19_08/SR_PHOTOVOLTAIC_EN.pdf

The economic model in rural Ireland.

It is government policy to help farmers augment their income by other non farming enterprises, renewable wind energy becomes an obvious option. In theory, all the farmer has to do is sign the leases, collect the rent and continue to farm. If only life were this simple, we would not oppose it, but instead would concentrate of the optimum size of wind turbines and their locations.

In its formative years, we could only attempt to forecast wind's performance in the absence of evidence, but now as it becomes a mature industry we can provide evidence to back up our claims that a huge mistake is being made in regard to wind energy. This is being ignored by government, A problem with the current model to augment farm income with electricity income can be seen as follows:

Grid inertia and frequency stability requires conventional fossil fuel generators be run along side wind. There have been efforts to increase the 65% limit without success. The wind does not blow all the time. Fossil fuel and the generating stations to burn it must be kept hot and running continuously. The traditional large condensing steam plant needs 9 hours to start from cold and it is augmented by fast acting gas turbines which are less efficient. We now have almost twice the amount of fuel capacity we need. Irrespective of the fuel saving from wind, the land area where electricity is generated increases radically and the number of companies generating electricity is radically increased.

Traditional capacity. Republic of Ireland.

Maximum power required (winter peak demand)	= 5,000 MW.
Average demand	= 3,400MW
Summer night-time demand	= 2,200MW

Traditional generating capacity form large continuous plant = 6,000 MW
River Hydro generation = 300 MW

Total	**= 6,300MW**

This provided for a 20% reserve during winter peak demand.

Present capacity (Ireland)

6,000 MW of efficient fossil fuel plant (same as before)
300 MW of river Hydro plant (same as before)
3,400 MW of wind generation
2,200 MW of fast acting gas plant.

Total : **11,900** MW

In Eirgrid's 2010 -2016 adequacy report plans were for 15,000 MW by 2016. If we add 25% to the existing 11,900 MW capacity we can see that it will be equivalent to 15,000 MW when we only need 6,300 MW which increases costs by 2.37 times. Effectively the domestic price of traditional electricity should be in the region of 14.5 cent pet unit (kWh). It is now 26 cents. It is not known where it will end, but the cost in Denmark is 32 cent per unit. Denmark is more advanced than Ireland with wind energy installation. The wind industry used to say wind would bring down the price of electricity. This is untrue, it increases the price and the wind industry generally has stopped making these claims. We believe we played a roll in forcing this change. There have been recent utterances in the media that wind does reduce the price of electricity so it appears to be that they say whatever they can get away with.

Landowner rent is only a minor cost of wind energy. Rent amounts to about 15,000 Euros on average per turbine or 7,000 per MW. (there is about 40% tax deducted). Irish land owners are receiving about 240 million Euros wind rent annually before taxation. This is very close to the actual losses being sustained by wind companies. It can be seen that if wind energy worked as commonly believed, it takes about 20 acres to host one 2 MW turbine. As an extreme example if the current rate or roll out continues it will increase the annual electricity bill as follows. Wholesale price is 7.5, retail bill is 26 cents.

One hundredth of the country = 1,615 Euros wholesale and **5491** actual bill.
One fiftieth of the country = 3,230 Euros wholesale and **10,980** actual bill.

1/64 of the country = 5,047 Euros wholesale and **17,159** actual bill.
1/32 of the country = 10,094 Euros wholesale and **34,300** actual bill.
1/8th of the country = 20,880 Euros wholesale and **71,000** actual bill,

Government set a target of 4,000 MW of wind, but it is an open question as to whether government will promote more than that.

Obviously there has to be an optimum wind capacity, we claim it is zero but accept government believes it should be more. Government has not assessed what the optimum capacity is. In the absence of a government decision, the wind industry is making the decision and that decision is to install as much as they possibly can. This policy is clearly unsustainable because there has to be a **saturation limit** for any commodity.

Part 3. Technical in parts but please read on.

Ways to measure the contribution of wind energy.

The engineers traditional way to measure the contribution of any source of electricity generation was **capacity credit,** viz: the amount of existing generation plant it allows to be shut down without endangering supply. Several studies have shown this to be 4% in Ireland for wind. A study by Dutch scientists Dr. Fred Udo and Keys LaPair found this to be the case, we say it follows the laws of diminishing returns if it does any good at all.

We attach the report of the ESB of 2004 which confirms this. it states at page 24 paragraph 2 the ***as the amount of wind increases, the contribution tends towards zero.*** It follows that as more is added the contribution becomes less tending towards zero. Common sense will tell the reader that if they keep adding more wind capacity which does not displace existing fuel generation and if those wind companies are to survive, the price of electricity must increase. We have the, we now have the 3rd highest prices in the world.

At paragraph 3 it goes on to say with regard to figure 16.

*"The red line represents the capacity for an all thermal system. With increasing amounts of wind capacity the total plant rises significantly but the amount of non-wind plant only falls off by a relatively small amount. In fact the amount of non-wind plant reaches a saturation level. The result is a rising level of 'excess plant'. Stated another way the capacity credit for Wind Power Generation **rises more slowly** with increasing amounts of wind power and tends to saturate."*

Here is the link to this report. https://docs.wind-watch.org/EirGrid-WindImpact-Main.pdf Its heading is "Impact of wind power generation in Ireland on the operation of conventional plant and the economic implications" published by the ESB in 2004. (it may be necessary to press control to open the link).

We take the liberty of underlining and highlighting the ESB's own words. They are the experts, the equivalent of the Central Bank on inflation, the Attorney General on law, the Chief Medical Officer on health and the Garda Commissioner on road safety advice. Yet the ESB is ignored by decision makers.

If wind were assessed using the traditional method of capacity credit, it would immediately become apparent that it is not viable and it would be hard to justify its continuance. However, this was circumvented by measuring the contribution by **Capacity Factor** (also called load factor). Capacity factor is the amount of electricity produced over one year expressed as a percentage of the rated capacity of the plant being measured. There are **8766** hours in a year and wind companies are paid wholesale about 70 cents per Mega Watt hour (MWh) and paid three extra amounts we will not specify here. The total amount paid is close to **75** Euros per (MWh). There are curtailment and capacity payments included which are fixed and not related to wind speed.

Wind turbines start to generate at about 12 MPH wind speed and must be turned off for safety at 32 MPH wind speeds. Between these values, the output increases by the cube of the wind speed so that as the wind speed is doubled, output goes up by a factor of 8.

It can be seen that if the Capacity Factor were 100%, (if the wind blew at 33 MPH every minute of the year) and provided wind generation is kept below 65% of demand. wind could be relied on and would reduce the amount of fossil fuel plant used by allowing the shutting down of fossil plant. However at best, the capacity factor is 24% in a good year and this is intermittent. A guaranteed wholesale price of 75 Euros is very bad value with the average for traditional reliable power being 57 Euros.

In its adequacy report 2010 - 2016 Eirgrid promised average capacity factors of 32.4%. Professor Gordon Hughes of Edinburgh University and Val Martin assessed the likely load factors for the UK and Ireland and found average likely factors of 24%. If wind farm incomes were projected at 32.4% factors, a drop to 24% would be a drop from 100% expectations to 74%. (32.4 - 24 = 8.4) 8.4/32.4 X 100 = 26%. Eirgrid's then CEO was written to and he was not prepared to stand by the 32.4% figure. An expected 100 Euros income would drop to 74 Euros. An examination of wind farm company accounts show capacity factors of between 20 and 27%, with 24% being very common and the higher values being rare. Some are much lower. An enquiry with Eirgrid staff in March 2019 revealed that their figure of 27% for 2018 was only a forecast, the actual figure was 20%. Please note this figure **20%.**

Professor Hughes also found that the output of wind turbines degrade with their age so that a turbine producing a factor of 28% in year 1 will degrade to 21% in year 19. This constraint is acknowledged in some financial accounts, but not in others. The result is an overstatement of the asset value of these companies. This would reduce a 24% output factor to 21.8% and a 20% factor to 17.4% after 19 years. 17.4% is below break even point for operating profit. https://www.ref.org.uk/attachments/article/280/ref.hughes.19.12.12.pdf

The guaranteed price of 75 Euros is only part of the subsidy scheme which includes fixed capacity payments to all generating plant, the most valuable is **priority dispatch**, wind electricity must be bought in priority to all other forms of electricity which is about the best subsidy available to any industry. Waste

to heat which is 50% renewable, totally predicable and allows turning off fossil plant is not afforded priority dispatch and some of its output is being dumped to make way for wind. Asian countries may soon refuse to take this waste so restricting its disposal by conversion to electricity makes no sense. .

When wind generation exceeds 65% of demand, it is constrained down by turning off a portion of turbines. There was a small payment for this which is being phased out. As the amount of wind on the grid increases, curtailment increases which suppresses wind company income as they compete with each other for a market. The business term is **cannibalism.** The size of the cake stays the same. but as the capacity of the generators increases, the slices of the cake get smaller.

Storage. Simple to read.

The standard response of wind proponents to these problems is to cite storage as the answer. Mark O'Malley and engineer with UCD and an advisor to the government stated at the launch of the energy green paper in 2012 that storage was not a viable option. See valmartinireland you tube video No 9 which shows storage is impossible because of the volume required. It has not worked anywhere in the world to date. In an RTE radio interview in 2018, a representative of the Commission for Regulation of Utilities justified increasing wind capacity on the basis that it can be stored. Both cannot be correct and Mr O'Malley is a qualified engineer. .

Electricity demand. Somewhat difficult to comprehend.

Electricity is measured in Watts (W), kilo (1,000) Watts (kW) Mega (million) Watts (MW) and so on. This is the power being used at any instant. In order to measure a working quantity, the word hour (h) is inserted. A standard domestic unit is a kWh but to measure generation capacity a MWh is used (1,000 kWh or 1 million Watts). A one kW electric cooker ring would use one kWh in one hour. A standard family home uses about 5,000 kWh in one year. MWh is used for the wholesale market.

Demand varies from about 2,200 MW on a summer's night to about 5,000 MW of a cold January Friday evening. The maximum demand is called winter peak demand. Average demand is about 3,300 MW. This has not increased since the economic collapse in 2008.

Fossil fuel plant is of two types, slow starting condensing steam turbine plant taking 9 hours to go from cold to hot and fast acting gas turbine plant using jet engines which can be started in 15 minutes. The slow starting plant burns, coal, oil and gas and is much more efficient than the gas turbine plant which burns gas. The faster starting the plant is, the less efficient it is. Combined cycle gas turbines have two generators, the first is powered by a gas turbine (jet engine) and the flue gases are diverted into a steam boiler to generate electricity form the high pressure steam. This makes better use of the fuel than any other design and is the most efficient. The boiler component still takes 9 hours to start from cold. The electricity generating capacity in the Republic of Ireland is now:

Slow traditional condensing steam plant from gas, coal and oil 4,000 MW
Fast acting traditional gas plant 2,000 MW

Hydro 300 MW.

Traditional total capacity	**6,300MW**
Present capacity	
Slow starting condensing steam plant	Nil
Fast acting gas plant	2,200 MW
Wind farms	3,400MW
Total additional capacity	**5,600MW**
Present total	**11,900 MW.**

It can be seen that we have 11,900 MW of plant when all we need is 6,300 MW. Government must ensure that all of this survives with the result that consumers must bear the added cost. It can also be seen that we have over 2,200 MW of extra fast acting fossil fuel plant required to balance wind which would not be needed if we had no wind. With traditional plant, extra plant can be installed on the same site using existing staff and supporting facilities, whereas wind farms are spread out into small entities owned by separate companies all of which must survive financially. This means that on an average week day at 3pm, 8,600 MW will go **idle** and unused = **73%.** Even on the coldest January evening when demand reaches 5,000 MW, **57%** will not actually be exporting electricity.

Negative pricing: Paying to dump a waste product.

Since October 2018, Ireland has experienced a high level of negative pricing. Prices dropped as low as minus €139.44 in February 2019. Negative pricing occurs during periods of very high wind, mostly at night, when it becomes too expensive for power stations to switch off and then back on again should wind subside.

In such circumstances, it becomes cheaper for the power station to pay electricity consumers to take their power. It would be a bit like driving into a filling station and seeing a negative price on petrol: i.e. if they paid customers to fill up. Negative pricing is usually offered to large companies with high electricity consumption.

Negative pricing is a new development in the Irish electricity market, but it is symptomatic of a problem that has been happening for many years in Denmark. If power stations are unable to switch off during periods of high wind then that means the co2 savings attributable to wind are much less than is often claimed.

In effect, it means we are running a duplicate system, with renewables running in parallel. It is in effect another subsidy paid for by consumers a type of double billing.

Part 4

The Market. Simple to read.

The market comprises 1) The generators 2) suppliers 3) consumers. The wholesale price of fossil fuel power bought by suppliers like ESB Electric Ireland, Energia or Bord Gais varies according to time of day between 35 Euros and 120 Euros per MWh. The average is about 57 Euros. (5.7 cent per unit)

The guaranteed wholesale price of wind is 75 Euros. This proves that claims that wind would reduce the price of electricity were false. The domestic retail price converted to MWh (1000 units) is 260 Euros, a mark up of 66%. The difference is made up of the administration and infrastructure costs. This means that if a way is found to use all the planned wind electricity, wind generators will get 75 Euros, but consumers will pay 3.4 times that in other charges. In fact 260 - 75 = 185 Euros that goes elsewhere. What is planned is a giant monolithic monster in a very small country struggling to repay a 200 billion Euros debt it owes to the rest of the world.

The Machinery Directive. Simple to read

Engineer John Dooley has made the point that no Irish wind turbine complies with the Machinery Directive and that there is a major health and safety issue involved. Swedish authorities have reported on the collapse of a Vestas V112 three MW turbine which found it did not to comply and another found these turbines don't comply with Article 4 of the directive. Planning authorities have ignored submissions made by them on breaches. Wind farms are currently valued very high, the lack of compliance with this directive is not considered in such valuations. Should someone be killed as a result, enforcement could follow, this could mean closing down certain turbines reducing their value.

Cash for Ash.

An example was the Northern Ireland Cash for ash debacle. Government gave a subsidy of £1 per therm for wood chip costing 60 pence. Participants were heating empty buildings to make the 40 pence profit. When it was realized that the funding came out of the block grant from the British government and had to be paid for by cutting funding in hospitals schools etc, there was a crisis which brought down the Northern Assembly. We hoped this would provoke a re-think of wind energy on the Island, but it was ignored.

The business model of Ireland's wind farms.

In the Nyberg enquiry into the Celtic Tiger collapse, a number of buccaneer activities were observed which should have been acted on by government to prevent the collapse that resulted in a debt of 64 billion Euros to be carried by taxpayers. It is our assertion that history is repeating itself with renewable energy policy. Very recent reports is that 200 billion Euros is owed by only 400 million people.

The business model for wind farms is to overcome local and planning resistance, obtain planning permission, obtain finance and build the wind farm. Next is to sell on the facility to anyone prepared to buy it. There are several examples too numerous to mention, but the Tierworker wind farm in Co. Meath was bought by National Toll Roads within 4 months of commissioning. In most cases, the buyer is an electricity supplier such as ESB electric Ireland, SSE electricity and other such semi state companies. A common feature is that they all are mostly semi state companies or companies requiring a license to operate in the market they occupy. They were set up as semi state companies, but are entitled to behave as private companies. We cannot find examples of genuine private companies investing. Very recently supplier Energia announced it is to spend 3 billion Euros on green energy investment. If this was all wind energy and they expect consumers to repay the capital sum alone, it will cost the average bill payer (3 billion Euros divided by 2 million) = 1,500 Euros each and Energia is just one supplier out of many.

In an article in the Irish Times on May 14th 2019 by Laura Slatery, the semi state forestry company Coillte gave a glowing account of the reversal of their past poor (debt ridden) performance by building wind farms on their extensive lands and immediately selling them to Greencoat Renewables. Greencoat is

another state backed company which is busy buying winds farm of the type we speak here.

https://www.irishtimes.com/business/energy-and-resources/coillte-profits-more-than-treble-on-wind-farm-gains-1.3877296#.XNIOz-Y9sP4.twitter

This should cause alarm bells to ring. Another company Gaelectric cannot sell half its assets. It differs from others in that it has no parent to bail it out. Eventually loss making wind farms will fail to sell, how will they keep going?
https://www.irishtimes.com/business/energy-and-resources/green-energy-firm-gaelectric-for-sale-as-chinese-investors-withdraw-1.3251532

In the Celtic tiger boom/burst, the buyer of overvalued assets were backed by the licensed banks and when the enormity of their reckless lending became known, the taxpayers was forced to step in and bail them out. Now we see that while the banks are exposed for loss making wind farms, the state backed company Greencoat Renewables is directly involving the taxpayer and those paying into a pension in bailing out distressed wind farms. One Canadian company Brookfield sold out when Greencoat bought them at a hansom profit which begs the question of how Greencoat can buy up wind farms with a life span of under 20 years when it will take at 35 to 55 years (and more) to get their money back?

We have learned that while Greencoat makes no real profit, it has resorted to paying dividends to its long established shareholders out of funds received from new shareholders. The practice of allowing loss making companies pay dividends from new share holder funds was unlawful in Ireland until the law was changed recently to allow it.

While Coilte are busy building new wind farms, Bord Na Mona are doing the same. They will soon have to end their peat harvesting operations and wind farms are an obvious way to use their land resource. It begs the question of whether they intend to be electricity suppliers to the National Grid or whether they intend to sell their wind farms on, will state backed Greencoat take an interest and if they do, where will Greencoat get the money? Why would these semi state companies not run the wind farms themselves?

All of these ventures have to join an already struggling gang of electricity generators of conventional and non conventional types. The non conventional types are confined to about a 65% penetration segment and are already cannibalizing themselves for market share.

Between the 25th May 2018 and the 25th September 2018 there was virtually no wind generation at all. It was too calm for 4 months. April and May sometimes brings consistent east winds but these failed since 2007 and have not materialized in recent years. they increase output significantly.

Basic common sense should indicate at this stage that sometime is wrong. All the consumer in Ireland wants is a socket on the wall from which electricity will flow at a price he can afford. It's the same as water, gas and bin collection. Larger companies have diesel and gas generators as an alternative to the mains supply. Households can switch to gas for cooking and it is obvious the monopoly of electric power supply is not secure. Yet the consumer is expected to bail out wind companies, Coilte, Bord Na Mona and a host of planned battery storage and solar generation in addition to conventional plant.

On the 28th February, 2018 blackouts occurred in two zones. High wind speeds were forecast and duty controllers overestimated demand. Demand remained too low while wind surged into the system forcing frequency chaos. One area blacked out was Templebar in Dublin. This incident proves the 65% limit. While he is not a contributor to this dossier and we don't have authority to quote him, UCD economist Colm McCarthy has been consistently warning of this unsustainable situation due to overcapacity.

Interconnection.

During the period of office of Pat Rabbitt as Minister for Energy, the wind industry persuaded him to build 3,000 MW of wind in the Irish midlands for export to the UK. The British realized something was not adding up following communications from Val Martin and others and they stopped the plans. Such export would mean that Irish consumers would have to pay the cost of that 3,000 MW of wind at the priority dispatch price of 75 Euros equal to 240 Euros extra annually, while British consumers would be supplied with regular grid electricity mostly produced from fossil fuel. Irish consumers would be subsidizing their British counterparts.

Part 5.

Political environment. Technical and difficult to comprehend.

The Paris Climate Accord did not aim to reduce carbon emissions, rather it allowed continued expansion of fossil fuel powered industries in China and India and similar countries while limiting emissions in developed countries. The overall amount of emissions is planned to remain unaffected. The Accord agreed to ration (or cap) emissions of co2 based on the financial ability to bear the curtailment of the use of fuel. Two countries stand out, China and India.

These have large populations and a developing industrial base. The Gross National Product (GDP) is divided by the total population which gives a **low** per capita income. China is allowed to continue with business as usual for twelve years while India is to be permitted to continue unabated for an unspecified period.

In western countries the GDP is divided by the total population to give a **high** income ratio compared with that of China and India. The result is that industrial production is being driven out of developed countries to China and India. Many of the parts of vehicles and machinery such as gearboxes, crank shafts and other parts made using smelting of raw metal are now sourced in China and India. It has been observed that the quality of some of these parts is inferior. The United States has withdrawn from the Paris Accord in 2017.

The viability of wind farms is not dependent on the existence of climate change as they cannot reduce or abate co2 in any event. The minister announced Ireland will not reach its target notwithstanding all this wind generation. This presents the political world with a dilemma. It was the promise of renewables such as wind and solar generated electricity that it provided an easy way to decarbonize the economy. To do that it would have to actually displace the use of fossil fuel. If renewables had been assessed by the capacity credit method (the amount of fossil fuel saved) the savings could have been accurately counted in advance and the result would have matched the real result after the facilities were operational. Instead the contribution of renewables was popularly measured by how much was installed. The industry talked about the total wind capacity as if the wind blew continuously. In the public mind neither the 4% contribution not the 32.4% output measure were flagged. A unit of wind was the same as a unit of coal generated power to them, this is a serious misconception.

They failed to measure the amount of fuel saved and as a result we now see a situation where governments must choose between a reduction in manufacturing, food production, transport and other business ventures and creating jobs in the economy. The harsh reality is now facing the US Democratic Party, Irish established parties, Established parties in the UK and established parties in Europe and Australia. The problem is typified in France where the Yellow Vest movement was the direct result of the imposition of a carbon tax on citizens. The Irish government favours building data centres which will increase electricity demand by 25% while attempting to reduce agricultural emissions. The EU recently announced it will allow more South American food be imported in direct competition to the EU produced product. This may result in the destruction of pristine rain forests to make land to produce the food Europe consumes.

The Irish EU and local elections held on the 24th May 2019 did not result in a green wave as predicted by the media. Clearly the green promise of a bright, clean, cheap future is not believed. However, the progressive Fine Gael party did well which might persuade them to continue. An economic downturn would focus attention on this problem, but for now most people are in support of wind energy. No amount of popular support can cause unprofitable companies to become profitable without paying for it. Instances of fuel poverty are on the rise. In Northern Ireland one in 5 household are in arrears, figures are not available for the Republic.

Commercial rates:

It is common for wind developers to give money to local good causes. Element Power Wind Company tried to give 375,000 Euros to a Meath GAA club in 2013, but this was thwarted by campaigners against the Kells wind farm. Meanwhile the wind industry claims it can't afford to pay commercial rates as reported in the online farming newspaper Agriland:
https://www.agriland.ie/farming-news/wind-energy-sector-rates-could-reach-e60-million-by-2030-iwfa/
In the article Gratten Heally claims the rates are to high and could be more than the subsidies received. Rates and community benefit schemes are eventually paid for by consumers through their electricity bills and these costs would not be there at all in a traditional system.

Electric cars.

It can be seen that as the generating capacity increases demand remains static which squeezes all generators. Another way to increase demand is electric cars. These transfer the co2 emissions from the car exhaust to the power station chimney. In low wind conditions electric cars will be charged with fossil fuel generated electricity. Even in high wind speeds, 35% of the power to charge them must come from fossil fuel. There was no study to find out exactly how they compare with traditional vehicles. There is a huge environmental cost to the production of batteries. It can be seen also that there is nothing stopping a motorist charging his electric car from a diesel generator at home using marked gas oil and thereby avoiding paying the taxes and VAT on road fuel. In any event there is not enough time to solve the problem identified here by electric cars.This insolvency crisis is imminent.

In the Sunday Times (Irish edition) of the 11th August, 2019, Stephen O'Brien reports that Graham Doyle, the Secretary of the Department of Transport believes that to achieve the government's target of 900,000 to 1 million electric vehicles by 2030, a total ban on sales of Petrol and Diesel

cars will have to be introduced. Alternatively 10 billion Euros will have to be spent to encourage motorists to switch over.

The German Experience.

Germany has spent 930 billion Euros on renewable energy infrastructure since 2000 and yet it's government has been forced to admit it will not meet its 2020 co2 emissions targets. Visitors to the country report that it is literally plastered over with wind farms. There are ample reports on-line, this one in the Telegraph newspaper refers:
https://www.dailytelegraph.com.au/news/nsw/germany-will-not-meet-its-carbon-emissions-targets-in-2020-despite-spending-billions-of-euros/news-story/6ecb5e173327c74dd8630b68b5ef872e

A direct search can be made on Google. It will be noted that the contribution of all Germany's wind and solar fleet is given at 16%. We would suggest it is lower, but this proves Ireland can never reduce co2 emissions using wind energy because it does not work as commonly believed.

The Danish experience.

Denmark has been to the forefront of wind farm building for 25 years. It has the highest electricity prices in the world charging households 32 Euro cent equivalent per unit (1kWh). It is often paying neighbours to take its electricity. In 2011, 99% of its primary energy came from fossil fuel. Val Martin's video
https://www.youtube.com/watch?v=_WelXkKRRVM&t=118s relates or search valmartinireland you tube. After a massive investment in renewable energy, Denmark is more reliant on fossil fuels than the United States is.

Before any wind farms were built fossil fuel for primary energy = 18.2 million barrels of oil equivalent per day. After they were built the figure was = 18.1 million barrels of oil equivalent per day.

Wind made no difference at all.

The Raragh Wind Farm, Kingscourt. Read only if you have time or skip for now.

The cost of Raragh wind farm is in the region of 30 million Euros. This would buy over 3,000 acres of land or 55 four bedroomed semi detached homes in a good Dublin Suburb.

The roads alone for access to this wind farm measure approximately 1.3 km long by 8 meters wide. It is excavated and filled with a half meter of high quality stone from quarry suppliers in the area. Rough calculations show there is 1200 X 7 X .5 cubic meters of stone installed = **4,200** cubic meters. This is well over 1,000 lorry loads and it was observed that hauliers have been constantly drawing to it for 3 months.

The volume of concrete per turbine is calculated at 1,971 cubic meters of concrete or 4,730 metric tonnes. The web site "Stop These Things" gives the co2 emissions for a small turbine of 481 m3 of concrete and 45 tonnes of steel to be **241** tonnes of carbon emitted. By that measure this wind farm will have emitted **4,820** tonnes of co2 when installed.

The wind industry claim the contribution of wind is equal to the capacity factor, whereas we claim it is equal to its capacity credit. Mainstream media sometimes claims the contribution is simply the amount installed viz: the more the better.

Wind farms require substantial amounts of grid electricity to run, defrost and light which is not separately given in accounts, but has been estimated in other reports at between 10 and 20% of capacity. At 15% Raragh will consume 8766 X 1.5 Mwh = **13,149** MWh of power in a year. Power suppliers charge for this, which is recorded as a cost of sales in wind farm accounts. Add to this all the transport emissions and the carbon footprint of Raragh wind farm can never be recouped. Financially Raragh will achieve a load factor of about 24% which will yield revenue of 1.73 million of which 1.31 million will be operating costs leaving 416,560 to repay the capital cost. It will take 72 years to repay the capital cost not including any interest or dividend. Despite all the efforts, Ireland will fail to meet its co2 targets. Government's response to this appears to be to install even more wind.

Tax Incentives.

We admit not being experts on tax. However, if US based company has a taxable profit of 100,000 and will pay 40% corporation tax on it **= 40,000**.

If it invests 100,000 in an Irish wind farm it will save 40,000 tax. If it never gets any return of that investment it loses 100,000 – 40,000 = **60,000**. Up until now it recouped its 100,000 by selling the wind farm on. If it cannot get a buyer, it looses 60,000 in total. A tax break is no use if the investment is not recouped, Wind farm investments are being recouped through rapid transfer of ownership, but we argue that this can't continue.

Canton Fitzgerald is seeking investment and uses the words exit for short term investors availing of the 40% tax breaks. Professor Gordon Hughes of Edinburgh University reported recently that retail electricity prices will have to

double to pay for wind farms because the operating expenses are higher than anticipated.

Unattainable hopes of the wind industry.

According to Gratten Heally of the wind energy association, government policy is for 75% of our electricity generation to come from wind by 2030. We say that is only by an accounting trick, by counting the contribution by the amount of capacity installed.

Between the 25th May and 25th September 2018 there was virtually no wind energy produced. We know of no other area of the public finances where such unorthodox ways of counting a commodity or service are permitted.

Another misconception is that wind farms power several hundred thousand homes. No home was ever powered by a wind farm, this claim is based on the counting trick explained above.

The impact on People.

The Irish Wind Energy Association has recently apologised to communities for the suffering their installations has caused. A large compensation payment was paid to seven members of a family in Banteer, Co Cork for the impact of noise on them. There is a legal requirement that potential claims such as these be made a provision in the accounts and that there be a note in the accounts for extraordinary expenses. This is not done. The financial Regulator should have a roll to play but won't. Neither local planners nor An Bord Pleanala will entertain submissions as outlined here, technically they are correct because a public plan or programme should have been assessed under Article 3(2) of the SEA Directive but it never was.

Part 6 Financial Accounts. Here is the evidence in black and white.

The double entry financial reporting system is at the heart of Ireland's financial accounting system which in turn is linked to the British system and that of the wider world. Guidelines are issued from time to time by the accounting bodies on how certain matters are to be dealt with. Not all wind farms publish accounts, some are included as part of group accounts by parent companies such as the ESB or SSE and the accounts for these do not separate out the wind farm component. However, some do publish accounts and these are available from the Companies Records Office. We selected these at random.

Only very basic details are published. Irish law allows companies with over 100 million in assets and losses of tens of millions of Euros to publish abridged accounts in which there is no break down of cost of sales etc.

A set of accounts comprises a profit and loss (P & L) account showing gross income from sales less the cost of sales to give an **operating profit**. The cost of sales is usually the cost of purchases which are then sold. Next is taken the expenses required to run the business and this includes wages, rates, rent, transport and other costs both fixed and variable. This gives a profit or loss for the financial year. The assets of the company are not included in the P & L account, , but the annual depreciation of assets amount is. Depreciation lowers profits Euro for Euro it is a charge to the P & L.

The accounts also include a balance sheet which is a snapshot of the company at year end. It includes the tangible fixed assets, current assets and intangible assets owned by the company. It includes money owed by and owed to the company and provision for bad debt. There are usually notes to the account for added clarification. The value of assets at year end is the value at the start of the year less depreciation. Eventually this value arrives at zero. Tangible assets are real land, building, machines, vehicles etc and readers will easily understand them. Intangible assets include good will and in the case of wind farms it is mainly grid connection offers by Eirgrid.. These have a value because the wind farm cannot operate without them, but they cannot be separated from the wind farm itself and if the wind farm is loss making a grid connection to it will not fetch much at auction.

The balance sheet includes current and accumulated profits or losses from the (P &L) account for current and previous years, land, equipment, buildings and cash in hand. It shows the position of the company if it were sold at year end. Central to this is a judgement of how much the assets would realize if sold. A factor is the involvement of the state company Greencoat Renewables which is involved in buying up wind farms using a mix of public and private cash. At the same time the company Gaelectric Renewables sold half its assets to a Chinese consortium that promised to buy the other half. It backed out of that promise. Wind farms are expensive to decommission. There are already calls in Britain for the state to bear the cost and for taxpayers to pay for the decommissioning and replacement of existing wind farms. Because of this the residual value of a wind farm on decommissioning may be negative.
https://environmentjournal.online/articles/uk-must-repower-wind-turbines-to-hit-carbon-targets/?fbclid=IwAR3_FtteN6OQhuMXlim3P_y8YhO3AvIFekPBqXjxHG1zk4KUcH3D60t0XFo

There are three ways to finance any venture; **1) Borrowing** also called leveraging or debt for which interest must be paid. A company that fails to meet its repayments will be in default and could be placed in receivership. **2) Equity** (ordinary share capital), the shareholders effectively own the company and its assets. Dividends are the equivalent of annual payments on a loan. There is no obligation to pay a dividend or to pay back the principle. **3) Premium share** capital, in this case a contract exists giving priority to premium shareholders and if the lender agrees premium shares can take priority over borrowings. It depends on the contract. Wind farms are normally financed by a combination of equity and debt. We found one example of premium share holdings. Wind farms rarely own the land under the facility, this distinguishes it from agriculture (farming) where the land is usually owned.

As wind farms are not profitable, existing turbines become obsolete and manufacturers are forced to offer something bigger and better. It is our view that these don't work either, but it keeps the show on the road for another while. No new developer would consider installing the type of turbines used 10 years ago. Proof of this is that Gaelectric cannot find a genuine buyer for the remaining half of its fleet. Therefore the depreciation charge to the P & L account of all wind farms is too low. If they were accurately valued the losses reported would be much higher. The financial account overstate asset values.

Responsibility for the accuracy of financial accounts rests with the directors. Auditors certify that the accounts give a true and fair view. Situations have occurred where auditors certified that accounts gave a true and fair view and the company was sold. The new owner discovered the accounts did not give a true and fair view. The courts have stopped short of holding auditors legally accountable. This is one of the most controversial areas of law. We believe the turnover and operating costs in the following accounts are accurate, but we question the valuations of assets. Even if valued correctly, the accounts show unsustainable losses. A receiver cannot turn these companies around to make them profitable.

The legal dictionary defines solvency as: **Solvency** The ability of an individual to pay his or her debts as they mature in the normal and ordinary course of business, or the financial condition of owning property of sufficient value to discharge all of one's debts.

Economic principles.

A super normal profit can only be made if there are barriers to entry creating a monopoly. Over time these tend to dissipate. Many conventional companies make a small profit moving from loss to profit many times over years, but healthy companies will make a normal profit to enable it pay shareholders a dividend. Usually such companies will have assets which can be sold if liquidated. There is usually no defined life span on fixed assets, so that temporary difficulties can be overcome by trading their way out. This is not available for wind farms due to their short life span. Land owners may not renew land leases and planning permission is required to upgrade. Residents who have experienced the effects will be determined to object. They will have evidence to back it up.

Here is an **example** of a limited company without the complication of group involvement. It produces animal feedstuffs and has nothing to do with wind energy. It is well run and famous for the quality of its products and loyalty of its customers. It provides a benchmark against which wind farms can be measured.

Corby Rock Mills. Monaghan. No 51890. Accounts 2018 and 2017

Profit on ordinary activities **after** taxation.	2,7 million -------2.7 million
Fixed assets	5.8 million ---- 4.4 million
Accrued profits in the balance sheet	25 million ------22 million.

Debtors out weigh creditors by 3 million. This is an example of a healthy company.

Examples of groups.

The Kingspan Group is a well known multi national building supplier whose accounts are published on line

https://az750602.vo.msecnd.net/kingspan-live/kingspanglobal/media/results-centre/full-year-results-2018.pdf Net profit for 2018 was **335** million and the balance sheet shows long term liabilities at **1,221** million, four years profit will easily repay the capital sum. Its tangible fixed assets are close to **900** million and are not time limited. Dividends of 42% is being paid.

The Glanbia Food Group. Made a profit of **234 million,** had tangible fixed assets of **453** including property and long term liabilities of ***990*** which is not time limited Dividend is 26%.It is obvious the three sets of accounts immediately preceding comply with the fair value principle. We question if this is also true in the case of the wind industry where dividends are not being paid for generating electricity.

The Director of Corporate Enforcement, a repeat of Patrick Neary?

Anyone who thinks this agency will intervene is making a serious mistake. Here we have a 6 billion Euro wind industry where serious issues are raised and nothing is done. The companies Act 2014 states that financial reports must give a **true and fair** view and comply with financial reporting standards. Section 291 says a P & L and balance sheet must be submitted. Section 352 and 353 of the Companies Act 2014 allows smaller companies to submit abridged financial statements. There must be a balance sheet and readers should note the balance sheet **must** include figures from the P & L showing profit or losses accruing. Certain notes must be included in the return.

Example: The Director's attitude to Mountain Lodge wind farm No 343257, Cootehill.

Years are **2016** and **2015.**

Actual called up share capital is 100 Euros. We repeat **100** Euros. So this large wind farm with dozens of turbines shows equity is only 100 Euros. The cost must be borrowed.

Next is the balance sheet. It is a complete blank. The only entry is the 100 Euros called up shares. There is no P & L account figure, there is no assets figure, there is no creditors figure, no debtors figure and no figure for long term debts. Val Martin wrote to the Director pointing out this with the intention of bringing about greater scrutiny of wind farm accounting practices generally and with the intention that he insist on compliance by all companies. The Director replied in writing that unless Mr Martin could point to the commission of a **crime**, he would not become involved. The upshot of this is that the Director of Corporate Enforcement is neglecting to carry out its functions when serious failures are drawn to its attention.

Irish Law.

Under Irish criminal law there are two degrees of criminal law breaches:

1) A summary offence triable by the District Court without the option of a jury.

2) A felony triable in the higher courts with a jury, but in less serious cases triable without a jury in the District Court with the consent of the accused.

3) Some criminal offences are hybrid, so that the Director of Public Prosecutions can choose to try them summarily in the District Court or on indictment in the Circuit Court.

The common meaning of a crime is an offence triable on indictment. The Director's reply indicates that only **crimes** are investigated and not offences. This interpretation is legally a nonsense. Mountain Lodge failed to comply with Section 290, 352 and 352 of the Act.

Section 291 (9) clearly states that any company which fails to comply or any officer which fails to comply or defaults is guilty of a category 2 offence. This is a hybrid offence carrying maximum penalties of a fine up to 50,000 Euros or 5 years imprisonment of both. The directors of Mountain Lodge have submitted a blank sheet, which can be a felony, (a crime). There are issues of Mens Rea (guilty mind) if a prosecution were taken and the appropriate measure might be a warning.
https://www.pearse-trust.ie/blog/categories-of-offences-under-the-companies-act-2014

It follows from this that complaints from members of the public to the Director of Corporate Enforcement will be ignored. Wind farm Companies could and have provided blank balance sheets and get away with it. We say the regulatory environment is hopelessly inadequate.

Section 12 of the Director of Corporate Enforcement Act 2001 sets out the functions as:

a) To enforce the Companies Act. b) To encourage compliance with the Act. c) To investigate suspected offences under the Act.

We are not saying every little deviation from strict conformity should end up in Court, we want the standard of compliance with the Act which shareholders, lenders, creditors and concerned citizens are entitled to be enforced. This is central to the entire concept of limited companies liability about which over 1,000 lengthy sections are enacted in the Companies Act. They might as well be a pop song.

The implications for Irish financial accounting probity are too obvious to itemize. It simply beggars belief and proves that the Director is failing in his duty to ensure financial statements give a true and fair view. This is precisely what Patrick Nyberg warned against and it's happening again.

We point out that long term debts owed by a company and reported in the balance sheet do not include repaying share capital. A healthy company must pay its borrowings and have enough over to pay shareholder's dividends to pay off all investment before the end of life of the project. Shareholders effectively own the company and if the company is worthless and they get nothing, its their loss. They are entitled to know the accounts are true. It is vital to understand that lenders must be paid interest and the principle.

Shareholders do not have to be paid anything, but if the company is wound up or sold they must be paid from the sale or disposal.

A lot of what we report here could be prevented if the Director did what he is paid to do, they have failed before, The Director should be asked to comment.

Gort/Derrybrien wind farm company number 9843001

Owned by the ESB this is the wind farm that resulted in EU Fines of 1.7 million Euros on Ireland for failing to assess the potential of peat sliding from the site into the local village.

P & L account.	**2017**	**2016**
Turnover	5,506,000	5,013,000
Cost of sales	5,863,000	6,344,000
Impairment charge	**(10,172,000)**	
Gross loss	(10,172,000)	(1,331,000)
Administrative expenses	(883,000)	(889,000)
Operating loss	(11,412,000)	(2,200,000)
Interest payable	(112,000)	(155,000)
Loss on ordinary activities before tax	(11,524,000)	(2,375,000)
Tax rebate on loss	1,388,000	284,000
Loss for financial year	**(10,136,000)**	**(2,091,000)**

Balance Sheet.	2017	and	2016
Tangible fixed assets	19,641.000	and	29,308,000

The cost value of assets on 31st December 2017 was 64,422,000 with an addition of 3,732,000 total cost was **68,154,000** which was reduced through depreciation to 19,631,000. It is depreciating in value by about 10 million per year for 2017.

The impairment charge of **10,172,000** is a recognition that the company cannot overcome this shortfall and declares it in its accounts. For this to accrue, there had to have been losses dating back many years. The wind farm is in a good high westerly location.

Notes to the account describe the debt forgiveness by the ESB as being at an ***"Arms Length Basis"*** in our opinion this effectively means the ESB has written off this debt to the tune of 10.1 million Euros and absorbed it themselves. It is a hidden charge to consumers and an attempt to hide the fact that this company is insolvent. This adversely impacts on the ESB's own financial position and means there is no hope of any saving elsewhere from lower fuel costs, efficiencies or improvements being passed on to consumers.

Comment: Gort wind farm is insolvent, its being carried by the ESB as a charity.

Woodhouse windfarm County Waterford. No 3399998 20 MW began to generate in June 2015. It is owned by the ESB and priced at 33 million euros new.

Accounts are available for	**2017**	and	**2016**
Profit	642,000	--------	222,000
Book value of assets	28,955.000	-------------	30,273.000
It's financed by a loan from the ESB	16,593.000	-------- ----	18,106.---
Called up shares	9,525,000	-----------	9,525,000
No dividend was paid.			
Average profit over each of the two years was		**432,000.** per year	

The loan is being paid off first which will take 16,955,000/432,000 = **38 years.** By this time it will have been decommissioned for 20 years. Shareholders can never be paid.

If we take the better profit year of 2017: 16,955 / 642 = **26.4 years.** It will be gone by then also. Woodhouse wind farm is insolvent. The ESB owns 300MW of wind farms as subsidiaries. Accounts are not available for all, but if this one

is typical, all are insolvent and as their life span expires the ESB will have to write off the capital cost. Woodhouse is a charity and not a going concern.

Geartnanane wind farm Bailieboro Co, Cavan No 338335. is a 15 MW facility built on 2004 by Airtricity. It was bought by SSE. Two turbines were fitted with new gearboxes in January 2019. These would cost several hundred thousand Euros. The notes give the facility a useful life of 20 years (ending in 2024).

Accounts are for **2018** and **2017**

Its revenue averaged 2.3 million and after paying expenses and tax it made a profit as follows each year 783,000 and 393,000

Average profit when all was paid = **588,000** each year over the 2 years. Its one of the better ones.

Total owed to lenders etc at the end of 2018 was **2,692,000** Euros. This does not include the two new gearboxes in 2019. We estimate the cost at at least 345,000 increasing total owed **3 million.** To be paid from an average annual profit of 588,000 will take 5 years and 2 months.

The book value of the assets is given at 9 million, but if this valuation is overstated, it brings into question its solvency. We checked back to 2009 when it made a profit of 744,000 and 2010 when it make a profit of 232,000. It paid interest in 2010 of 783,000. This facility is on an excellent site.
Parent company SSE issued a profit warning in September 2018, its share price fell 8%.
https://www.sharesmagazine.co.uk/news/shares/how-safe-is-sse-dividend-after-weather-blows-hole-in-profits

We have checked the accounts for profits for 2008. 2009, 2015, 2016, 2017 and 2018 = 3,561,000 or an average of 593,000 Euros each year. The life span is 20 years, so 593,000 X 20 = **11,860,000** It cost **17,400,000** million. So how can it ever repay its cost? A note to the accounts states *"The company has net current liabilities and is dependent on on-going financial support* from a fellow group company. The financial statements have *been prepared on a going concern basis which assumes adequate finance will be available for the foreseeable future. A fellow group company has given an undertaking not to demand repayments of monies advanced to the company for the foreseeable future"*

Meentycat Wind Farm Donegal No 338333. 72 Mw capacity built in 2004

Cost of its assets is given at 93 Million. Net book value in 2017 is given at 44 million. Its average profit over the years 2017 and 2016 was 1.3

million per year. 44/1.3 = 33 years to repay its capital cost. Life span is given at 20 years which expires in 2024. It will be the year **2050** when its all repaid. In one year it owes about 1 million more than it is owed. Notes say it was given an undertaking by a fellow group company not to demand repayment of monies owed to it for the foreseeable future. It's in a good location. **It's insolvent.** Run as a charity.

Company number 339206 Teevurcher Wind farm, Kells North County Meath. This facility is located in the village of Tierworker, Kells Co.Meath on the Cavan Meath border. It was granted planning permission by Meath Co. Council and was not appealed to An Bord Pleanala. The turbines are located within the 500 meters set back guidelines, some as close as 370 meters to turbines. There are complaints of the effects of shadow flicker and noise.

It was purchased by National Toll Roads soon after commissioning which proves the business model of build and sell on.

Profit and loss account to year ended 31st March 2018.

Total comprehensive loss for the year **(38,328)**

Balance sheet. The fixed assets are 17 million which is indicative of the cost of this comparatively small 5 turbine wind farm.

Debtors and cash amounts to nearly 2 million.

They owe 7.7 million in one year and 11.6 million after one year giving total debts of 19.3 million Euros. This debt is justified by the fact they own the turbines valued at 17 million and 2 million of other assets. It raised about 400,000 share capital which is low so it has a high borrowings to equity ration. Assuming the facility lasts a generous 22 years it will need to repay 19.3 million Euros 19.3 / 22 = 877,000 per year. Yearly profit/losses figures are not available. The company already admits the noise is above planning limits and nothing can be done to abate it. There is no provision for potential claims by residents as required by law. The law says provision must be made for such extraordinary items as legal claims.

Garva Gleebe wind farm, County Leitrim. No 459034 2017 and 2016

Loss on activities after tax refund. 2017 = **(3.1 Million)** 2016 = **(935.000)**
Balance sheet .
Creditors falling due under one year = 7.2million Creditors falling due after 1 year = 45.2 Million

It can be seen the income can never repay the amount due and the only way is to sell the company on at a profit to an unsuspecting buyer. So why are there buyers prepared to buy such a guaranteed loss maker?

Lisheen Wind Farm Co. Tipperary. Commissioned 2009. Abridged accounts to 31st December 2017.

The assets are valued at **33.6** million at year end.

They have cash and debtors (money owed to them) of 7.4 Million which is normally received later.

In the current year they owe **3.6 million.** They will owe **37 million** after one year and the company made a loss of **(275,000)** in 2017 and **(559,000)** the previous year. The exact nature of the money owed to this company is not known, but it can be seen that with losses totalling over two years of **830,000** only a massive increase in wind speeds or a massive increase in the price of electricity exported can allow it pay back its principal capital.
As future profits are unlikely, this company is insolvent, yet there in nothing in the accounts to reflect this. This is what the Companies Act and Financial reporting standards under it are designed to expose, but its all ignored.

Mainstream Renewable Power.

This large company was founded and still is chaired by former Bord Na Mona chairman Eddie O'Connor. It is in the business of developing wind farms in Ireland, Chilli and South Africa. It submits group accounts as head of its own and subsidiary companies. It was called on by Raragh developments to help build the 10 MW Raragh wind farm.

Accounts are for **2017** and **2016**

Operating losses **(12million)** and **(13million)**

It has large financial interests in play which alter the above as follows. Group loss for the year (5 million) and (22million)

The largest item in its assets is inventories at **139** m and **109** m
It is presumed these are wind farms components, tools use to repair them and perhaps expertise in installing them etc.
Restricted cash (held for a particular purpose) **44 m** and **18m**

Total liabilities (159 m) in 2017 and (138m) in 2016. Itis obvious that their annual losses have been accruing at the rate of about 13 million a year. 159/13 = 12 years. The year 2017 less 12 = 2005. It seems it has lost 159 million euros since it was set up amid great fanfare in 2008.

The company itself holds assets which are mainly investments in subsidiaries of **170** million which in turn raises the question of what the real value of these are. It owes **222** million.

It's part funding Raragh wind farm costing **30** million euros, it is writing cheques and they are being honoured. Where the money is coming from is a mystery. The health of this company is dependent on the real value of its assets. Kingspan and Glanbia have assets In property and equipment, this companies assets are less well defined. The losses bring into question the going concern situation. The accounts claim this company is a going concern without any source of revenue to cover its losses and liabilities. This differs from Gartnaneanne and other companies where accounts explain that the directors file the accounts on a going concern basis because guarantees were given from parent companies not to demand payment of the purchase price. The wind developer Element Power could not continue when there was no prospect of making money due to refusal/delays of planning permission. The exposure for mainstream is much larger than Gartnaneanne.

Greencoat Renewables. Their subsidiary companies performance.

Company number 9954446 Greencoat owned Monaincha wind farm.

Accounts are available for **2016** and **2015** Here are the basics.

P & L account
Loss/profit for financial years **(1,981,720)** loss for 2016 and **555,665** profit for 2016. Over the two years its a net loss was **(1,426,000.)**

The balance sheet shows non current liabilities of **63, 289,985.**

Monaincha Wind Farm is **insolvent.** We surely don't have to go any further.

Greencoat owned Knockacummer, a good example.

Knockacummer wind farm Co. Cork. Built by Bord Gais in 2013, 87 MW believed to be increased to 100 MW per Eirgrid's publication. It was bought by Canadian Company Brookfield and is was in turn bought by Greencoat Renewables at a handsome profit. It was originally owned by Bord Gais and was sold on on directions of the EU as part of the bank bail out.

P & L account

This company made a loss of **3.6** million in **2017**, but it received a debt forgiveness of **6.9** million from an intercompany loan which allowed it to declare a profit of **3.3** million.
It made a loss of **4.4** million in **2016** which when added to its real loss in 2017 gives its average losses = **3.45** million per year. 2018 was a bad wind year so it can be assumed Greencoat is facing a bill for 2018 of 3.45 million euros to accrue forever.

The balance sheet shows debtors owe the company about **10** million Euros.

Liabilities within one year and more than one year are 5.8 + 135.7 = **141.2** million in total. Less creditors of 10 million = **131** million rounded off. It has used 6 of its 20 year lifespan leaving 14 more years at best.

The company is funded by shareholder funds of only 10 million indicating high leverage (borrowing). Actual borrowings are not given, but 6.1 million was paid on interest on borrowings indicating heavy borrowing to equity (share) ratio.
e
It can be seen that the **131** million Euros can never be repaid from recurring losses and this company **is insolvent.**

The company was bought over by Greencoat Renewables recently.

It appears that the debt forgiveness of 6,9 million, was just window dressing for the sale and it was recouped in the generous purchase price.

Greencoat owned Ballybane wind farm No 306647. Is 20 MW facility located at Ballylickey, Co. Cork and connected in 2008.

Accounts for **2017** and **2016**

P & L account : There is no P & L account, but the situation is stated on the balance sheet.

Profit of **144,410** for 2017 and **66,076** for 2016

Therefore the total profit is an average of **105,203** annually.

It owed 9 million in 2018 and 38 million after one year = 47 million Euros.

47,000,000 / 105,203 = 446 years. It will take **446** years to repay the capital cost and this wind farm has a life span of no more than 20 years with 10 already expired.

It can be seen that this is a hopeless case of insolvency. It did make a profit, but the capital cost is so enormous that it will be the year 2465 when it is paid off. This is the worst case so far.

Greencoat owned Killhills Windfarm. 36 MW in Co. Tipperary.

Account for **2016** and **2015**

Loss (285,000) and (456,000)

Total loss over two years = **(741 ,000)** Euros.

The company is owed 1.6 million at year end.

In less then one year and in more than one year it owes 44.6 million Euros less debtors = 40.75 million Euros.

This company is not a going concern and can never repay its capital sum. **It is insolvent.** How is Greencoat going to pay company debtors to the tune of **370,500** for each year of operations? Lenders to the company will have to be paid their money and can sue to wind it up. So Greencoat has acquired another permanent loss maker and will soon have to get its cheque book out.

Cloosh Valley wind farm No 845334 is Part of Galway wind park is flagged as the best performing wind farm on the Island of Ireland. Its capacity is 108 MW. It is 75% owned by Greencoat Renewables. It cost 280 million Euros. It was commissioned in September 2017 and accounts are to March 2018 for 7 months. Full yearly accounts are not yet to hand.

Its current assets are 20.8 million which is money owed to it and cash in hand.

Its current liabilities are about the same at = 20.3 Million Euros. They effectively cancel each other out. It is paying 13.3 million on loans indicating high borrowings. There is 91,000 share capital which is low.

Its long term liability is 173.5 million Euros. In 2017 it made a loss of 502,000 Euros but the situation improved in 2018 with a profit of 5.8 million after tax.

173,500,000 / the profit for 2018 = 5.8 million = 30 years to repay. This wind farm will be gone in 20 years leaving 10 more to pay with no income. Full year accounts will likely have more income. but also more expenses. It is not a good example because the accounts are only for part of a year.

Greencoat owned Glanaruddery Wind Farm is 36 MW capacity which became operational in the last quarter of 2017. Its too early to analyse the accounts.

There is no reason to expect it will return better profit than other mature wind farms.

Greencoat owned Garrabereagh Wind Farm Co Cork is 9.2 MW capacity.

This wind farm was due to commence generation in July 2018. It is too soon to judge its performance. A search of the Companies Record Office did not yield a set of accounts.

Greencoat owned Raheeleagh. 35.2 MW in Wicklow. It became operational in Sept 2016.

The first years accounts should show a healthy outlook as plant is new. The Directors declared the load factor to be 42% in 2017 and 38.8% in 2018. The revenue accurately reflects this claim. To achieve this, the wind at the Wicklow site would have to blow at at least 30 miles per hour in 2017 for 21 weeks in the year and in 2018 for 20 weeks. This factor beats anything every achieved in Ireland or Scotland where the average factor is 24% and such wind would be a newsworthy item.

In 2018, there was virtually no wind and very little wind energy generated between 25th May and the 25th September. Eirgrid's own dashboard showed this and we can vouch that we watched it very closely. There could not possibly be a load factor at Raheelagh wind farm of 38.8%. If this were the case, all the forgoing accounts for the year and for previous years would be wrong and it must be bourne in mind that Eirgrid confirm that the factor for 2018 was only 20%. How can this be?

John Dooley investigated. It transpires that Raheelagh wind farm is of 35 MW capacity, but it is only permitted to dispatch half of this (17MW) into the grid. The reason for this constraint is not known, but we assume it is inadequate cabling or a flaw in the connection contract. In periods of good wind speeds, sales are limited to half capacity (about 17MW). As wind speed drops overall output per turbine drops, but more turbines are allowed export at lower output so that at a certain point 17 MW is maintained.

Notwithstanding this, the amount due to be paid in the long term is 54 million and the profit was 1.7 million. It can be seen that it will take 31 years to pay it back and the wind farm will no longer be operational after 20 years. The output will degrade with age and expenses will increase. This wind farm effectively has 35 MW capacity but has only half the normal market. Its capital costs are double its market. In low wind speeds it can sell more than a standard wind farm, but its costs are twice as high. It can never re-pay its capital cost.

Greencoat owned Tullynamoyle wind farm was commissioned in February 2018

11.2 MW located in County Leitrim.

Accounts are not yet available.

Greencoat owned Lisdowney. No. 490019 Co Kilkenny 9.2 MW capacity built in 2010, bought in 2018 by Greencoat. Accounts before sale:

In 2017 owed it 13.7 million in more than one year. It had accrued losses of 274,279 in that same year. It was hopelessly insolvent and is now owned by Greencoat having paid 22.5 million Euros for it. If a private individual was left this facility in a will he would have to refuse to take it, otherwise it would bankrupt him for life. Yet 22.5 million was paid for it. It's crazy.

Summary of Greencoat's wind farms performance to date.

All these are selected at random based on availability.

Knockacummer: Insolvent, it had 6.9 million of its debt written off by its parent in 2017.

Ballybane: Hopelessly insolvent.

Killhills: Is loosing 370,000 Euros a year and can never repay its 40 million capital cost.

Cloosh Valley: Accounts are only available for part of a year for this new facility. They indicate the capital sum cannot be repaid.

Raheelagh: It is showing a load factor of almost twice the average elsewhere in one of the calmest years ever known and yet it will take 31 years to repay its capital cost by which time it will be gone.

Lisdowney: Hopelessly insolvent

Overview of Greencoat Renewables.

Without this company the Irish wind industry would have already collapsed.

It is in the business of buying wind farms and is actively seeking investment by way of shares from any source. They seek investment from pension funds. Their wind farms can never hope to repay their capital cost. It's our view that investors will lose money on Greencoat. **The Irish Strategic Investment Fund is one of its main shareholders with a 76 million Euro stake, Newton Investment Management 16.7 million, Irish Life 15M, Allied Irish Bank 15. Investec 13.2 m, Close Asset Management 9.8 m, Farington 9.8M** and **M & G Investment Management 9 M.** Total 164.5 million. If our fears are correct there will be a serious deficit in pension funds when they fall due to be paid. It will take 250 years to repay the capital cost of the wind farms we identified which is 10 times the maximum lifespan of any asset.

Wind farm companies with high borrowings are selling to Greencoat in what is effectively a debt for equity swap. Existing lenders are paid using equity from new investors. Its balance sheet is published on its web site http://www.greencoat-renewables.com/~/media/Files/G/Greencoat-Renewables/documents/reports-publications/2019/Greencoat%20Renewables%20Plc%20Report%20%20Accounts%202018.pdf

The value of its assets is worded as follows.

"*Non current assets Investments at fair value through profit or loss* ***757,399.000*** *for 2018 and* ***316,796.000*** *for 2017.*" How can this be repaid? We are dealing in billions here! Their accounts show they have **400,000** Euros in borrowing proving they are avoiding debt in favour of equity which they don't have to repay. Whereas the wind farm they are buying are the opposite.

In turn Greencoat Renewables in their own accounts managed to show income of 56 million Euros through a fair value adjustment of 46.7 million Euros. Fair value adjustments have been used in the banking industry to boost the balance sheet. Greencoat have decided that the value of these wind farms increased by 46.7 million euros which they have recorded as income. They are able to show a large profit when in fact they made a loss. In theory, fair value means assets can be valued at the market price rather than the cost price. If a turbine maker decided to double the price of its product, existing installed turbines could double the values of its turbines.

Wind companies could adjust the value of their fleet upwards based on the new cost. Yet the income from these re-valued wind farms will not change. We say accounts citing such re-valuations do not give a true and fair view as legally required notwithstanding that fair value adjustment is legal under the law.

This was made legal just as the Irish builder/banking boom was developing about 2005. but anyone can see how this loophole allows this industry to record high asset valuations which reflect in increased income when in fact no such real effect took place.

In the book Bean Counters by Richard Brooks published by Boomerang Books ISBN 978178649 0292 published in 2009, the author attributes the fair values accounting as one of the key causes of the world wide credit and banking bubble. In the Irish Times of the 22nd May 2019 Greencoat executives are reported as giving glowing reports of their companies performance. The adjustment of their asset values permits them to report values which have no basis in reality by a practice which was unlawful for most of the history of accounting. The hype and positive news it conveys is fooling investors, governments, communities and consumers into supporting what is actually a **pyramid selling scheme** which is causing extensive damage to the environment.

One already gone under. Gaelectric Limited No 418730, accounts for 2016 -2015.

Operating loss: **(1,595,000)** for 2016 ------ **(6,896,000)** for 2015.

Finance costs **(11,099,000)** for 2016 ------- **(3,387,000)** for 2015

Loss on ordinary activities before tax (**24.8 million)** for 2016 -- (**20.3 million) for 2015**.

It valued its property, plant and equipment at **301** million.
Here is what it owed on loans and borrowings = **333** million for 2016, **193** million for 2015 and **95** million for 2014. There was 24 million in equity with some well known Irish business people named as big losers. The Auditors did not comment on whether they considered the company a going concern in the accounts which the Act required them to do. This is another failure by the regulator. The American lender Star Capital is suing the former CEO Brendan McGrath for about 10 million dollars of personal guaranteed debt. The fact that Mr McGrath left himself exposed for such debt shows he actually believed his ventures were viable. This shows neither he or any other CEO can be trusted to assess the viability of their own ventures and cannot be trusted to manage pension funds from licenced pension fund concerns.
https://www.independent.ie/business/irish/energy-companies-line-up-to-prise-off-gaelectrics-assets-36617776.html

A portion of the National Pension Reserve fund went to Gaelectric. The fund is now gone altogether and has no offices. We say that this is where every wind farm company is heading unless there is a bailout soon.
The only difference with this company is that there is no parent to step in but it is possible Greencoat will do so amid much hype and fanfare. Greencoat is the one to watch.

The United Kingdom.

In 2016 the British government banned all subsidies on new wind farms.
https://www.bbc.com/news/uk-politics-33227489
UK Company No. 3254615 Wind Prospect Limited, has been involved as a partner in developing wind farms in the UK and Ireland, it's name appeared on many planning applications. Its profit and loss account shows a loss of £13 million, its balance sheet shows it owes £13 million.

In the Sunday Telegraph dated the 28th July, 2019 Professor Gordon Hughes says the price of electricity will have to be radically increased because wind companies totally underestimated their operating costs.

https://www.thegwpf.com/electricity-bills-could-double-to-bail-out-new-wind-farms-report-claims/

Part 7: Conclusion:

It can be seen that there is an underlying plan to keep insolvent wind farms out of liquidation by any means possible. Parent companies are carrying them along for charity. Relaxations in the law regarding the financial management and reporting of limited companies are being used to the full by directors. But even where the law is breached, nothing is done by regulators. The first refuge of distressed companies is the parent company such as the ESB National Toll Roads and SSE. Where failing wind companies don't have a parent to carry them on, Greencoat is there to intervene to exchange debt for equity. Greencoat itself is on shaky ground. It has (400,000) Euros borrowing of its own to repay and it will soon face the bill to forgive the accruing debts of Knockacummer, Ballybane, Killhills, Lisdowney, Cloosh Valley, Glenaruddery, Ballerbereagh and Reheelagh. Meanwhile it will be getting approaches from other distressed wind farms to buy them out. We will continue to monitor Greencoat. It has Irish investment of 164 million Euros, but claims total assets of ¾ of a billion. One can only wonder where this came from and consider the possibility that investment managers have access to colossal financial resources. Deutcshe Bank is in trouble with 49 trillion Euros exposure in derivatives.

It cannot continue to revalue its assets upwards indefinitely in order to show a book profit, Investors considering investing would be crazy to do so. Whether it is ethical to take money from private investors is questionable, but if this money is being taken from the pension funds of workers it certainly is not ethical, **it is scandalous.**

Ireland's 6.5 billion wind industry is missing one vital ingredient, adequate wind speeds. Companies measured it at each site before they started, so they knew right well. Their business model didn't need any wind, just hype. We could see at least another 1,000 MW of wind installed and more fossil fuel plant to balance it. Ordinary domestic and business electricity bills are paying for it, but not enough to make them profitable. Companies are insolvent and can never repay their capital costs. Every possible intervention is and will be used to put off the evil day. How long more can parent companies hold out themselves? This will end in grief one way or the other. How will banks cope with a 6.5 billion hole in their loan book. Economist Colm McCarthy predicted NAMA for wind farms. It's just the Celtic tiger reincarnated. Our government learned nothing, determined to ignore those trying to alert it. If it can happen with energy it can happen with anything. It's now over to public representatives to investigate or not and seek responses from the various agencies involved. There are no shortage of accountants in the civil service. We have made our contribution, it over to them.

Since this was written, we learned from an RTE Primetime programme on the 5th June, 2019 that the ESB has been allowing hundreds of thousands or litres oil to leak into the ground and waterways of Dublin for decades, while we see here that they handed 10.1 million Euros to Gort wind farm which itself have environmental issues. This calls into question ESB's priorities. The financial press has in the past few days reported severe problems at the German Deutsche bank and that there are indications of an impending economic slowdown world wide. Questions are being asked about the real value of hedge funds and derivatives which are a major component of the world banking system. The accounts of Mainstream Renewable Power show they rely heavily on derivatives. If the buccaneer financial management approach we have uncovered here extends into other areas of the Irish and international business world, then there is no real value underpinning any of their assets and at the first signs of a financial downturn .the real value will be tested. We won't make predictions and hope it does not come to that extreme. We hope the powers that be will look into this and defer back to us but if an economic down turn dies come about, the waste on useless wind energy may be exposed anyway. Then it will be too late. . There is talk in the financial press of Deutsche bank failing.

Val Martin's

John Dooley

Owen Martin.

References.

https://www.yumpu.com/en/document/read/30216289/generation-adequacy-report-2010-2016-eirgrid

https://www.telegraph.co.uk/news/politics/2910739/Wind-farms-fail-to-deliver-value-for-money-report-claims.html

http://epaw.org/echoes.php?lang=en&article=n612

https://www.youtube.com/watch?v=_WelXkKRRVM&t=248s

https://www.wind-watch.org/news/2014/01/13/german-wind-farm-operator-prokon-warns-of-imminent-insolvency/

Page 24 and 25 of this relates https://docs.wind-watch.org/EirGrid-WindImpact-Main.pdf

This article which is pier reviewed advises investment in the re-conditioning of wind turbines after they wear out. The fact that the previous investors did not recover their investment does not appear to have occurred to the authors.

https://budgeting.thenest.com/can-invest-windmill-energy-farms-23327.html

CLIMATE RESEARCH

PATRICK MOORE: SHOULD WE CELEBRATE CARBON DIOXIDE?

Date: 15/10/15 Patrick Moore PhD, Global Warming Policy Foundation

2015 Annual GWPF Lecture

Institution of Mechanical Engineers, London 14 London

My Lords and Ladies, Ladies and Gentlemen.

Thank you for the opportunity to set out my views on climate change. As I have stated publicly on many occasions, there is no definitive scientific proof, through real-world observation, that carbon dioxide is responsible for any of the slight warming of the global climate that has occurred during the past 300 years, since the peak of the Little Ice Age. If there were such a proof through testing and replication it would have been written down for all to see.

The contention that human emissions are now the dominant influence on climate is simply a hypothesis, rather than a universally accepted scientific theory. It is therefore correct, indeed verging on compulsory in the scientific tradition, to be skeptical of those who express certainty that "the science is settled" and "the debate is over".

But there is certainty beyond any doubt that CO2 is the building block for all life on Earth and that without its presence in the global atmosphere at a sufficient concentration this would be a dead planet. Yet today our children and our publics are taught that CO2 is a toxic pollutant that will destroy life and bring civilization to its knees. Tonight I hope to turn this dangerous human-caused propaganda on its head. Tonight I will demonstrate that human emissions of CO2 have already saved life on our planet from a very untimely end. That in the absence of our emitting some of the carbon back into the atmosphere from whence it came in the first place, most or perhaps all life on Earth would begin to die less than two million years from today.

But first a bit of background.

I was born and raised in the tiny floating village of Winter Harbour on the northwest tip of Vancouver Island, in the rainforest by the Pacific. There was no road to my village so for eight years myself and a few other children were taken by boat each day to a one-room schoolhouse in the nearby fishing village. I didn't realize how lucky I was playing on the tide flats by the salmon-spawning streams in the rainforest, until I was sent off to boarding school in Vancouver where I excelled in science. I did my undergraduate studies at the University of British Columbia, gravitating to the life sciences – biology, biochemistry, genetics, and forestry – the environment and the industry my family has been in for more than 100 years. Then, before the word was known to the general public, I discovered the science of ecology, the science of how all living things are inter-related, and how we are related to them. At the height of the Cold War, the Vietnam War, the threat of all-out nuclear war and the newly emerging consciousness of the environment I was transformed into a radical environmental activist. While doing my PhD in ecology in 1971 I joined a group of activists who had begun to meet in the basement of the Unitarian Church, to plan a protest voyage against US hydrogen bomb testing in Alaska.

We proved that a somewhat rag-tag looking group of activists could sail an old fishing boat across the north Pacific ocean and help change the course of history. We created a focal point for the media to report on public opposition to the tests.

When that H-bomb exploded in November 1971, it was the last hydrogen bomb the United States ever detonated. Even though there were four more tests planned in the series, President Nixon canceled them due to the public opposition we had helped to create. That was the birth of Greenpeace.

Flushed with victory, on our way home from Alaska we were made brothers of the Namgis Nation in their Big House at Alert Bay near my northern Vancouver Island home. For Greenpeace this began the tradition of the Warriors of the Rainbow, after a Cree Indian legend that predicted the coming together of all races and creeds to save the Earth from destruction. We named our ship the Rainbow Warrior and I spent the next fifteen years in the top committee of Greenpeace, on the front lines of the environmental movement as we evolved from that church basement into the world's largest environmental activist organization.

Next we took on French atmospheric nuclear testing in the South Pacific. They proved a bit more difficult than the US nuclear tests. It took years to eventually drive these tests underground at Mururoa Atoll in French Polynesia. In 1985, under direct orders from President Mitterrand, French commandos bombed and sank the Rainbow Warrior in Auckland Harbour, killing our photographer. Those protests continued until long after I left Greenpeace. It wasn't until the mid-1990s that nuclear testing finally ended in the South Pacific, and it most other parts of the world as well.

Going back to 1975, Greenpeace set out to save the whales from extinction at the hands of huge factory whaling fleets. We confronted the Soviet factory whaling fleet in the North Pacific, putting ourselves in front of their harpoons in our little rubber boats to protect the fleeing whales. This was broadcast on television news around the world, bringing the Save the Whales movement into everyone's living rooms for the first time. After four years of voyages, in 1979 factory whaling was finally banned in the North Pacific, and by 1981 in all the world's oceans.

In 1978 I sat on a baby seal off the East Coast of Canada to protect it from the hunter's club. I was arrested and hauled off to jail, the seal was clubbed and skinned, but a photo of me being arrested while sitting on the baby seal appeared in more than 3000 newspapers around the world the next morning. We won the hearts and minds of millions of people who saw the baby seal slaughter as outdated, cruel, and unnecessary.

Why then did I leave Greenpeace after 15 years in the leadership? When Greenpeace began we had a strong humanitarian orientation, to save civilization from destruction by all-out nuclear war. Over the years the "peace" in Greenpeace was gradually lost and my organization, along with much of the environmental movement, drifted into a belief that humans are the enemies of the earth. I believe in a humanitarian environmentalism because we are part of nature, not separate from it. The first principle of ecology is that we are all part of the same ecosystem, as Barbara Ward put it, "One human family on spaceship Earth", and to preach otherwise teaches that the world would be better off without us. As we shall see later in the presentation there is very good reason to see humans as essential to the survival of life on this planet.

In the mid 1980s I found myself the only director of Greenpeace International with a formal education in science. My fellow directors proposed a campaign to "ban chlorine worldwide", naming it "The Devil's Element". I pointed out that chlorine is one of the elements in the Periodic Table, one of the building blocks of the Universe and the 11th most common element in the Earth's crust. I argued the fact that chlorine is the most important element for public health and medicine. Adding chlorine to drinking water was the biggest advance in the history of public health and the majority of our synthetic medicines are based on chlorine chemistry. This fell on deaf ears, and for me this was the final straw. I had to leave.

When I left Greenpeace I vowed to develop an environmental policy that was based on science and logic rather than sensationalism, misinformation, anti-humanism and fear. In a classic example, a recent protest led by Greenpeace in the Philippines used the skull and crossbones to associate Golden Rice with death, when in fact Golden Rice has the potential to help save 2 million children from death due to vitamin A deficiency every year.

The Keeling curve of CO2 concentration in the Earth's atmosphere since 1959 is the supposed smoking gun of catastrophic climate change. We presume CO2 was at 280 ppm at the beginning of the Industrial Revolution, before human activity could have caused a significant impact. I accept that most of the rise from 280 to 400 ppm is caused by human CO2 emissions with the possibility that some of it is due to outgassing from warming of the oceans.

NASA tells us that "Carbon Dioxide Controls Earth's Temperature" in child-like denial of the many other factors involved in climate change. This is reminiscent of NASA's contention that there might be life on Mars. Decades after it was demonstrated that there was no life on Mars, NASA continues to use it as a hook to raise public funding for more expeditions to the Red Planet. The promulgation of fear of Climate Change now serves the same purpose. As Bob Dylan prophetically pointed out, "Money doesn't talk, it swears", even in one of the most admired science organizations in the world.

On the political front the leaders of the G7 plan to "end extreme poverty and hunger" by phasing out 85% of the world's energy supply including 98% of the energy used to transport people and goods, including food. The Emperors of the world appear clothed in the photo taken at the close of the meeting but it was obviously Photo-shopped. They should be required to stand naked for making such a foolish statement.

The world's top climate body, the Intergovernmental Panel on Climate change, is hopelessly conflicted by its makeup and it mandate. The Panel is composed solely of the World Meteorological Organization, weather forecasters, and the United Nations Environment Program, environmentalists. Both these organizations are focused primarily on short-term timescales, days to maybe a century or two. But the most significant conflict is with the Panel's mandate from the United Nations. They are required only to focus on "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the atmosphere, and which is in addition to natural climate variability." So if the IPCC found that climate change was not being affected by human alteration of the atmosphere or that it is not "dangerous" there would be no need for them to exist. They are virtually mandated to find on the side of apocalypse.

Scientific certainty, political pandering, a hopelessly conflicted IPCC, and now the Pope, spiritual leader of the Catholic Church, in a bold move to reinforce the concept of original sin, says the Earth looks like "an immense pile of filth" and we must go back to pre-industrial bliss, or is that squalor?

And then there is the actual immense pile of filth fed to us more than three times daily by the green-media nexus, a seething cauldron of imminent doom, like we are already condemned to Damnation in Hell and there is little chance of Redemption. I fear for the end of the Enlightenment. I fear an intellectual Gulag with Greenpeace as my prison guards.

Let's begin with our knowledge of the long-term history of the Earth's temperature and of CO2 in the Earth's atmosphere. Our best inference from various proxies back indicate that CO2 was higher for the first 4 billion years of Earth's history than it has been since the Cambrian Period until today. I will focus on the past 540 million years since modern life forms evolved. It is glaringly obvious that temperature and CO2 are in an inverse correlation at least as often as they are in any semblance of correlation. Two clear examples of reverse correlation occurred 150 million years and 50 million years ago. At the end of the Jurassic temperature fell dramatically while CO2 spiked. During the Eocene Thermal Maximum, temperature was likely higher than any time in the past 550 million years while CO2 had been on a downward track for 100 million years. This evidence alone sufficient to warrant deep speculation of any claimed lock-step causal relationship between CO2 and temperature.

The Devonian Period beginning 400 million years ago marked the culmination of the invasion of life onto the land. Plants evolved to produce lignin, which in combination with cellulose, created wood which in turn for the first time allowed plants to grow tall, in competition with each other for sunlight. As vast forests spread across the land living biomass increased by orders of magnitude, pulling down carbon as CO2 from the atmosphere to make wood. Lignin is very difficult to break down and no decomposer species possessed the enzymes to digest it. Trees died atop one another until they were 100 metres or more in depth. This was the making of the great coal beds around the world as this huge store of sequestered carbon continued to build for 90 million years. Then, fortunately for the future of life, white rot fungi evolved to produce the enzymes that can digest lignin and coincident with that the coal-making era came to an end.

There was no guarantee that fungi or any other decomposer species would develop the complex of enzymes required to digest lignin. If they had not, CO2, which had already been drawn down for the first time in Earth's history to levels similar to todays, would have continued to decline as trees continued to grow and die. That is until CO2 approached the threshold of 150 ppm below which plants begin first to starve, then stop growing altogether, and then die. Not just woody plants but all plants. This would bring about the extinction of most, if not all, terrestrial species, as animals, insects, and other invertebrates starved for lack of food. And that would be that. The human species would never have existed. This was only the first time that there was a distinct possibility that life would come close to extinguishing itself, due to a shortage of CO2, which is essential for life on Earth.

A well-documented record of global temperature over the past 65 million years shows that we have been in a major cooling period since the Eocene Thermal Maximum 50 million years ago. The Earth was an average 16C warmer then, with most of the increased warmth at the higher latitudes. The entire planet, including the Arctic and Antarctica were ice-free and the land there was covered in forest. The ancestors of every species on Earth today survived through what may have been the warmest time in the history of life. It makes one wonder about dire predictions that even a 2C rise in temperature from pre-industrial times would cause mass extinctions and the destruction of civilization. Glaciers began to form in Antarctica 30 million years ago and in the northern hemisphere 3 million years ago. Today, even in this interglacial period of the Pleistocene Ice Age, we are experiencing one of the coldest climates in the Earth's history.

Coming closer to the present we have learned from Antarctic ice cores that for the past 800,000 years there have been regular periods of major glaciation followed by interglacial periods in 100,000 year-cycles. These cycles coincide with the Milankovitch cycles that are tied to the eccentricity of the Earth's orbit and its axial tilt. It is highly plausible that these cycles are related to solar intensity and the seasonal distribution of solar heat on the Earth's surface. There is a strong correlation between temperature and the level of atmospheric CO2 during these successive glaciations, indicating a possible cause-effect relationship between the two. CO2 lags temperature by an average of 800 years during the most recent 400,000-year period, indicating that temperature is the cause, as the cause never comes after the effect.

Looking at the past 50,000 years of temperature and CO2 we can see that changes in CO2 follow changes in temperature. This is as one could expect, as the Milankovitch cycles are far more likely to cause a change in temperature than a change in CO2. And a change in the temperature is far more likely to cause a change in CO2 due to outgassing of CO2 from the oceans during warmer times and an ingassing (absorption) of CO2 during colder periods. Yet climate alarmists persist in insisting that CO2 is causing the change in temperature, despite the illogical nature of that assertion.

It is sobering to consider the magnitude of climate change during the past 20,000 years, since the peak of the last major glaciation. At that time there were 3.3 kilometres of ice on top of what is today the city of Montreal, a city of more than 3 million people. 95% of Canada was covered in a sheet of ice. Even as far south as Chicago there was nearly a kilometre of ice. If the Milankovitch cycle continues to prevail, and there is little reason aside from our CO2 emissions to think otherwise, this will happen gradually again during the next 80,000 years. Will our CO2 emissions stave off another glaciation as James Lovelock has suggested? There doesn't seem to be much hope of that so far, as despite 1/3 of all our CO2 emissions being released during the past 18 years the UK Met Office contends there has been no statistically significant warming during this century.

At the height of the last glaciation the sea level was about 120 metres lower than it is today. By 7,000 years ago all the low-altitude, mid-latitude glaciers had melted. There is no consensus about the variation in sea level since then although many scientists have concluded that the sea level was higher than today during the Holocene Thermal optimum from 9,000 to 5,000 years ago when the Sahara was green. The sea level may also have been higher than today during the Medieval Warm Period.

Hundred of islands near the Equator in Papua, Indonesia, have been undercut by the sea in a manner that gives credence to the hypothesis that there has been little net change in sea level in the past thousands of years. It takes a long time for so much erosion to occur from gentle wave action in a tropical sea.

Coming back to the relationship between temperature and CO2 in the modern era we can see that temperature has risen at a steady slow rate in Central England since 1700 while human CO2 emissions were not relevant until 1850 and then began an exponential rise after 1950. This is not indicative of a direct causal relationship between the two. After freezing over regularly during the Little Ice Age the River Thames froze for the last time in 1814, as the Earth moved into what might be called the Modern Warm Period.

The IPCC states it is "extremely likely" that human emissions have been the dominant cause of global warming "since the mid-20th century", that is since 1950. They claim that "extremely" means 95% certain, even though the number 95 was simply plucked from the air like an act of magic. And "likely" is not a scientific word but rather indicative of a judgment, another word for an opinion.

There was a 30-year period of warming from 1910-1940, then a cooling from 1940 to 1970, just as CO2 emissions began to rise exponentially, and then a 30-year warming from 1970-2000 that was very similar in duration and temperature rise to the rise from 1910-1940. One may then ask "what caused the increase in temperature from 1910-1940 if it was not human emissions? And if it was natural factors how do we know that the same natural factors were not responsible for the rise between 1970-2000." You don't need to go back millions of years to find the logical fallacy in the IPCC's certainty that we are the villains in the piece.

Water is by far the most important greenhouse gas, and is the only molecule that is present in the atmosphere in all three states, gas, liquid, and solid. As a gas, water vapour is a greenhouse gas, but as a liquid and solid it is not. As a liquid water forms clouds, which send solar radiation back into space during the day and hold heat in at night. There is no possibility that computer models can predict the net effect of atmospheric water in a higher CO2 atmosphere. Yet warmists postulate that higher CO2 will result in positive feedback from water, thus magnifying the effect of CO2 alone by 2-3 times. Other scientists believe that water may have a neutral or negative feedback on CO2. The observational evidence from the early years of this century tends to reinforce the latter hypothesis.

How many politicians or members of the media or the public are aware of this statement about climate change from the IPCC in 2007?

"*we should recognise that we are dealing with a coupled nonlinear chaotic system, and therefore that the long-term prediction of future climate states is not possible.*"

There is a graph showing that the climate models have grossly exaggerated the rate of warming that confirms the IPCC statement. The only trends the computer models seem able to predict accurately are ones that have already occurred.

Coming to the core of my presentation, CO2 is the currency of life and the most important building block for all life on Earth. All life is carbon-based, including our own. Surely the carbon cycle and its central role in the creation of life should be taught to our children rather than the demonization of CO2, that "carbon" is a "pollutant" that threatens the continuation of life. We know for a fact that CO2 is essential for life and that it must be at a certain level in the atmosphere for the survival of plants, which are the primary food for all the other species alive today. Should we not encourage our citizens, students, teachers, politicians, scientists, and other leaders to celebrate CO2 as the giver of life that it is?

It is a proven fact that plants, including trees and all our food crops, are capable of growing much faster at higher levels of CO2 than present in the atmosphere today. Even at the today's concentration of 400 ppm plants are relatively starved for nutrition. The optimum level of CO2 for plant growth is about 5 times higher, 2000 ppm, yet the alarmists warn it is already too high. They must be challenged every day by every person who knows the truth in this matter. CO2 is the giver of life and we should celebrate CO2 rather than denigrate it as is the fashion today.

We are witnessing the "Greening of the Earth" as higher levels of CO2, due to human emissions from the use of fossil fuels, promote increased growth of plants around the world. This has been confirmed by scientists with CSIRO in Australia, in Germany, and in North America. Only half of the CO2 we are emitting from the use of fossil fuels is showing up in the atmosphere. The balance is going somewhere else and the best science says most of it is going into an increase in global plant biomass. And what could be wrong with that, as forests and agricultural crops become more productive?

All the CO2 in the atmosphere has been created by outgassing from the Earth's core during massive volcanic eruptions. This was much more prevalent in the early history of the Earth when the core was hotter than it is today. During the past 150 million years there has not been enough addition of CO2 to the atmosphere to offset the gradual losses due to burial in sediments.

Let's look at where all the carbon is in the world, and how it is moving around.
Today, at just over 400 ppm, there are 850 billion tons of carbon as CO2 in the atmosphere. By comparison, when modern life-forms evolved over 500 million years ago there was nearly 15,000 billion tons of carbon in the atmosphere, 17 times today's level. Plants and soils combined contain more than 2,000 billion tons of carbon, more that twice as much as the entire global atmosphere. The oceans contain 38,000 billion tons of carbon, as dissolved CO2, 45 times as much as in the atmosphere. Fossil fuels, which are made from plants that pulled CO2 from the atmosphere account for 5,000 – 10,000 billion tons of carbon, 6 – 12 times as much carbon as is in the atmosphere.
But the truly stunning number is the amount of carbon that has been sequestered from the atmosphere and turned into carbonaceous rocks. 100,000,000 billion tons, that's one quadrillion tons of carbon, have been turned into stone by marine species that learned to make armour-plating for themselves by combining calcium and carbon into calcium carbonate. Limestone, chalk, and marble are all of life origin and amount to 99.9% of all the carbon ever present in the global atmosphere. The white cliffs of Dover are made of the calcium carbonate skeletons of coccolithophores, tiny marine phytoplankton.

The vast majority of the carbon dioxide that originated in the atmosphere has been sequestered and stored quite permanently in carbonaceous rocks where it cannot be used as food by plants.

Beginning 540 million years ago at the beginning of the Cambrian Period many marine species of invertebrates evolved the ability to control calcification and to build armour plating to protect their soft bodies. Shellfish such as clams and snails, corals, coccolithofores (phytoplankton) and foraminifera (zooplankton) began to combine carbon dioxide with calcium and thus to remove carbon from the life cycle as the shells sank into sediments; 100,000,000 billion tons of carbonaceous sediment. It is ironic that life itself, by devising a protective suit of armour, determined its own eventual demise by continuously removing CO2 from the atmosphere. This is carbon sequestration and storage writ large. These are the carbonaceous sediments that form the shale deposits from which we are fracking gas and oil today. And I add my support to those who say, "OK UK, get fracking".

The past 150 million years has seen a steady drawing down of CO2 from the atmosphere. There are many components to this but what matters is the net effect, a removal on average of 37,000 tons of carbon from the atmosphere every year for 150 million years. The amount of CO2 in the atmosphere was reduced by about 90% during this period. This means that volcanic emissions of CO2 have been outweighed by the loss of carbon to calcium carbonate sediments on a multi-million year basis.

If this trend continues CO2 will inevitably fall to levels that threaten the survival of plants, which require a minimum of 150 ppm to survive. If plants die all the animals, insects, and other invertebrates that depend on plants for their survival will also die.

How long will it be at the present level of CO2 depletion until most or all of life on Earth is threatened with extinction by lack of CO2 in the atmosphere?

During this Pleistocene Ice Age, CO2 tends to reach a minimum level when the successive glaciations reach their peak. During the last glaciation, which peaked 18,000 years ago, CO2 bottomed out at 180 ppm, extremely likely the lowest level CO2 has been in the history of the Earth. This is only 30 ppm above the level that plants begin to die. Paleontological research has demonstrated that even at 180 ppm there was a severe restriction of growth as plants began to starve. With the onset of the warmer interglacial period CO2 rebounded to 280 ppm. But even today, with human emissions causing CO2 to reach 400 ppm plants are still restricted in their growth rate, which would be much higher if CO2 were at 1000-2000 ppm.

Here is the shocking news. If humans had not begun to unlock some of the carbon stored as fossil fuels, all of which had been in the atmosphere as CO2 before sequestration by plants and animals, life on Earth would have soon been starved of this essential nutrient and would begin to die. Given the present trends of glaciations and interglacial periods this would likely have occurred less than 2 million years from today, a blink in nature's eye, 0.05% of the 3.5 billion-year history of life.

No other species could have accomplished the task of putting some of the carbon back into the atmosphere that was taken out and locked in the Earth's crust by plants and animals over the millennia. This is why I honour James Lovelock in my lecture this evening. Jim was for many years of the belief that humans are the one-and-only rogue species on Gaia, destined to cause catastrophic global warming. I enjoy the Gaia hypothesis but I am not religious about it and for me this was too much like original sin. It was as if humans were the only evil species on the Earth.

But James Lovelock has seen the light and realized that humans may be part of Gaia's plan, and he has good reason to do so. And I honour him because it takes courage to change your mind after investing so much of your reputation on the opposite opinion. Rather than seeing humans as the enemies of Gaia, Lovelock now sees that we may be working with Gaia to "stave of another ice age", or major glaciation. This is much more plausible than the climate doom-and gloom scenario because our release of CO2 back into the atmosphere has definitely reversed the steady downward slide of this essential food for life, and hopefully may reduce the chance that the climate will slide into another period of major glaciation. We can be certain that higher levels of CO2 will result in increased plant growth and biomass. We really don't know whether or not higher levels of CO2 will prevent or reduce the eventual slide into another major glaciation. Personally I am not hopeful for this because the long-term history just doesn't support a strong correlation between CO2 and temperature.

It does boggle the mind in the face of our knowledge that the level of CO2 has been steadily falling that human CO2 emissions are not universally acclaimed as a miracle of salvation. From direct observation we already know that the extreme predictions of CO2's impact on global temperature are highly unlikely given that about one-third of all our CO2 emissions have been discharged during the past 18 years and there has been no statistically significant warming. And even if there were some additional warming that would surely be preferable to the extermination of all or most species on the planet.

You heard it here. "Human emissions of carbon dioxide have saved life on Earth from inevitable starvation and extinction due to lack of CO2". To use the analogy of the Atomic Clock, if the Earth were 24 hours old we were at 38 seconds to midnight when we reversed the trend towards the End Times. If that isn't good news I don't know what is. You don't get to stave off Armageddon every day.

I issue a challenge to anyone to provide a compelling argument that counters my analysis of the historical record and the prediction of CO2 starvation based on the 150 million year trend. Ad hominem arguments about "deniers" need not apply. I submit that much of society has been collectively misled into believing that global CO2 and temperature are too high when the opposite is true for both. Does anyone deny that below 150 ppm CO2 that plants will die? Does anyone deny that the Earth has been in a 50 million-year cooling period and that this Pleistocene Ice Age is one of the coldest periods in the history of the planet?

If we assume human emissions have to date added some 200 billion tons of CO2 to the atmosphere, even if we ceased using fossil fuels today we have already bought another 5 million years for life on earth. But we will not stop using fossil fuels to power our civilization so it is likely that we can forestall plant starvation for lack of CO2 by at least 65 million years. Even when the fossil fuels have become scarce we have the quadrillion tons of carbon in carbonaceous rocks, which we can transform into lime and CO2 for the manufacture of cement. And we already know how to do that with solar energy or nuclear energy. This alone, regardless of fossil fuel consumption, will more than offset the loss of CO2 due to calcium carbonate burial in marine sediments. Without a doubt the human species has made it possible to prolong the survival of life on Earth for more than 100 million years. We are not the enemy of nature but its salvation.

As a postscript I would like to make a few comments about the other side of the alleged dangerous climate change coin, our energy policy, in particular the much maligned fossil fuels; coal, oil, and natural gas.

Depending how it's tallied, fossil fuels account for between 85-88% of global energy consumption and more than 95% of energy for the transport of people and goods, including our food.

Earlier this year the leaders of the G7 countries agreed that fossil fuels should be phased out by 2100, a most bizarre development to say the least. Of course no intelligent person really believes this will happen but it is a testament to the power of the elites that have converged around the catastrophic human-caused climate change that so many alleged world leaders must participate in the charade. How might we convince them to celebrate CO2 rather than to denigrate it?

A lot of nasty things are said about fossil fuels even though they are largely responsible for our longevity, our prosperity, and our comfortable lifestyles.

Hydrocarbons, the energy components of fossil fuels, are 100% organic, as in organic chemistry. They were produced by solar energy in ancient seas and forests. When they are burned for energy the main products are water and CO2, the two most essential foods for life. And fossil fuels are by far the largest storage battery of direct solar energy on Earth. Nothing else comes close except nuclear fuel, which is also solar in the sense that it was produced in dying stars.

Today, Greenpeace protests Russian and American oil rigs with 3000 HP diesel-powered ships and uses 200 HP outboard motors to board the rigs and hang anti-oil plastic banners made with fossil fuels. Then they issue a media release telling us we must "end our addiction to oil". I wouldn't mind so much if Greenpeace rode bicycles to their sailing ships and rowed their little boats into the rigs to hang organic cotton banners. We didn't have an H-bomb on board the boat that sailed on the first Greenpeace campaign against nuclear testing.

Some of the world's oil comes from my native country in the Canadian oil sands of northern Alberta. I had never worked with fossil fuel interests until I became incensed with the lies being spread about my country's oil production in the capitals of our allies around the world. I visited the oil sands operations to find out for myself what was happening there.

It is true it's not a pretty sight when the land is stripped bare to get at the sand so the oil can be removed from it. Canada is actually cleaning up the biggest natural oil spill in history, and making a profit from it. The oil was brought to the surface when the Rocky Mountains were thrust up by the colliding Pacific Plate. When the sand is returned back to the land 99% of the so-called "toxic oil" has been removed from it.

Anti-oil activists say the oil-sands operations are destroying the boreal forest of Canada. Canada's boreal forest accounts for 10% of all the world's forests and the oil-sands area is like a pimple on an elephant by comparison. By law, every square inch of land disturbed by oil-sands extraction must be returned to native boreal forest. When will cities like London, Brussels, and New York that have laid waste to the natural environment be returned to their native ecosystems?

The art and science of ecological restoration, or reclamation as it is called in the mining industry, is a well-established practice. The land is re-contoured, the original soil is put back, and native species of plants and trees are established. It is possible, by creating depressions where the land was flat, to increase biodiversity by making ponds and lakes where wetland plants, insects, and waterfowl can become established in the reclaimed landscape.

The tailings ponds where the cleaned sand is returned look ugly for a few years but are eventually reclaimed into grasslands. The Fort McKay First Nation is under contract to manage a herd of bison on a reclaimed tailings pond. Every tailings pond will be reclaimed in a similar manner when operations have been completed.

As an ecologist and environmentalist for more than 45 years this is good enough for me. The land is disturbed for a blink of an eye in geological time and is then returned to a sustainable boreal forest ecosystem with cleaner sand. And as a bonus we get the fuel to power our weed-eaters, scooters, motorcycles, cars, trucks, buses, trains, and aircraft.

To conclude, carbon dioxide from burning fossil fuels is the stuff of life, the staff of life, the currency of life, indeed the backbone of life on Earth.

I am honoured to have been chosen to deliver your annual lecture.

Thank you for listening to me this evening.

I hope you have seen CO2 from a new perspective and will join with me to Celebrate CO2!

Public Consultation on the Draft Statutory Climate Change Adaptation Plan for the Electricity and Gas Networks Sector

By Pat Swords BE CEng FIChemE CEnv MIEMA

April 2019

Biography: Pat Swords is a Fellow of the Institution of Chemical Engineers and a Chartered Environmentalist. He has more than thirty years' of experience in the design and regulatory compliance of industrial projects in Europe, USA, Asia and the Middle East covering such sectors as chemicals, pharmaceuticals, food and energy. Between 2000 and 2016 he was extensively involved as a consultant on EU technical aid projects in Central and Eastern Europe implementing the industrial pollution control and control of major accidents legislation.

Contents

1. Introduction and Summary

1.1 The three key steps to effective problem solving

Successful problem solving is based on the following simple steps:

1. Identify and Quantify the Problem: What are the impacts and their significance?

2. What options are available? Such as reduction at source, alternative energy sources, treatment technologies, etc.?

3. What resources should be allocated? Do nothing? Do something? Do a lot?

As the introduction to the Public Consultation states:

- *Ireland's first statutory National Adaptation Framework (NAF) was published in January 2018. The NAF sets out the national strategy to reduce the vulnerability of the country to the negative effects of climate change and to avail of any positive impacts.*

1.2 Has the problem been correctly identified?

Figure 1.1 overleaf is a line graph of Ireland's mean temperature for the last sixty years. It can be generated in less than 20 seconds from data stored on the website of the Central Statistics Office (CSO), as collected from the fifteen meteorological recording sites Met Eireann operate around the country.[1] What it clearly demonstrates is that the weather is boringly normal, and if any climate change is occurring, it is miniscule and not causing any adverse impacts. Indeed, those who have lived through those decades would concur with the data.

[1] https://www.cso.ie/px/pxeirestat/statire/SelectVarVal/Define.asp?Maintable=MTM02&PLanguage=0

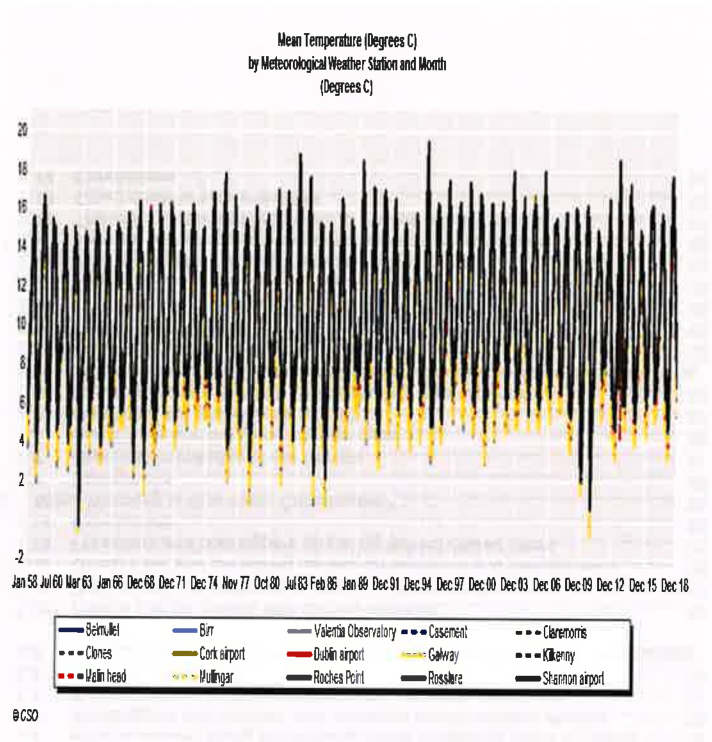


Figure 1.1: Mean temperatures for Republic of Ireland for the Period 1958 to 2019

1.3 The staggering sums of money which are being allocated

Figure 1.2 overleaf graphically shows the investment in renewable energy in Europe over the period 2004 to 2017. It is not difficult from this and other sources to determine that approximately a trillion Euros[2] have been spent on this alleged climate change problem, which has had an enormous impact on the cost of electricity, an essential requirement for a modern society. As Figure 1.3 shows electricity prices in the EU have risen strongly, on average 3.9% per year, while general inflation has been less than half of this. Many commentators have pointed out the simple relationship, as shown in the following Figure 1.4, that the more renewable electricity capacity is installed, so to increases dramatically the cost of electricity to the consumer.

[2] Trillion = thousand billion

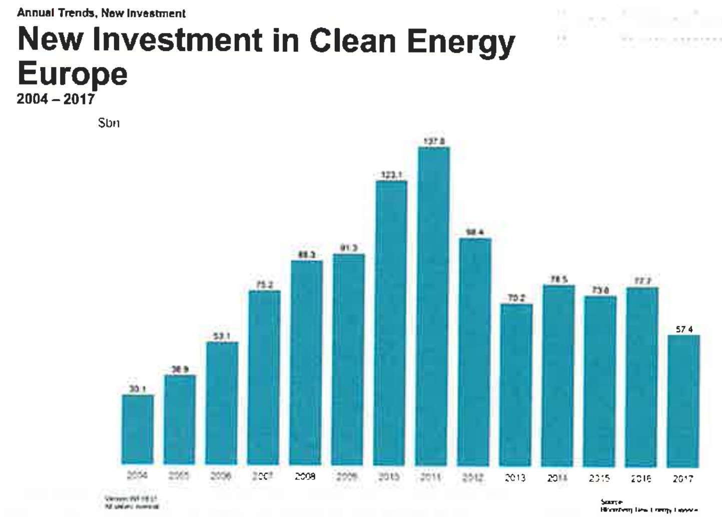
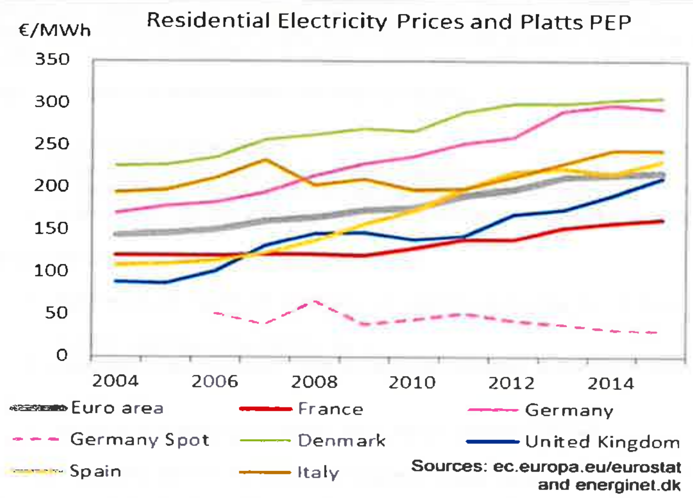


***Figure 1.2:** Investment in Renewable Energy in Europe in $ billions*[3]



[3] https://data.bloomberglp.com/bnef/sites/14/2018/01/BNEF-Clean-Energy-Investment-Investment-Trends-2017.pdf

Figure 1.3: *Residental Electrity Proces in Europe and wholesale electricity price index (PEP)*[4]

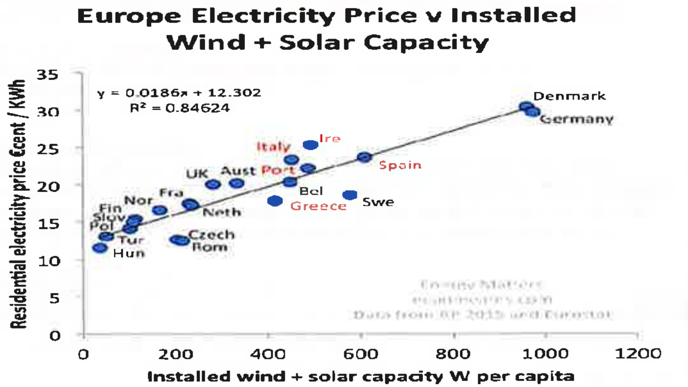


Figure 1.4: *Relationship between soaring electricity price and renewable electricity capacity*[5]

1.4 The unacceptable consequences to society and the environment

The direct financial cost of these renewables is only part of a wider picture, which includes significant social and environmental costs. Figure 1.5 overleaf shows that an estimated 50 to 125 million people – between 10 and 25 percent of the EU's population – are at risk of "energy poverty" a fact which even those avidly promoting 'Green' policies have to acknowledge.[6] This situation is being made worse by rapidly rising electricity prices. The doubling of residential electricity prices in Germany has led in 2017 to some 340,000 households in German having their electricity disconnected, due to their inability to pay bills, a rise of 14,000 on the previous year.[7] In the EU as a whole, poorer households are most affected, as over 10% of their income goes on energy costs.

The same EU data also shows that average industrial prices for electricity and natural gas are twice those in the USA, [8] leading to a serious loss of industrial competitiveness, resulting in job losses particularly in the more traditional energy intensive sectors.[9] This is a loss of competitiveness, which will only widen, as other

[4] http://www.pfbach.dk/firma_pfb/references/pfb_towards_50_pct_wind_in_denmark_2016_03_30.pdf

[5] http://euanmearns.com/green-mythology-and-the-high-price-of-european-electricity/

[6] https://www.boell.de/en/european-energy-atlas-2018

[7] https://www.faz.net/aktuell/finanzen/meine-finanzen/mieten-und-wohnen/verbraucher-zahlen-hunderte-millionen-euro-fuer-ungenutzten-oekostrom-15936120.html

[8] https://ec.europa.eu/energy/en/data-analysis/energy-prices-and-costs

[9] https://www.politico.eu/article/eu-energy-plans-put-jobs-at-risk/

countries are not pursuing the same energy objectives. However, as an increasing political backlash is occurring to these unsustainable rising energy costs, the enormous level of expenditure in renewable investment has had to be curtailed by the reduction in subsidies available, which can be seen in the resulting falloff in the renewable investment trend in Figure 1.2.

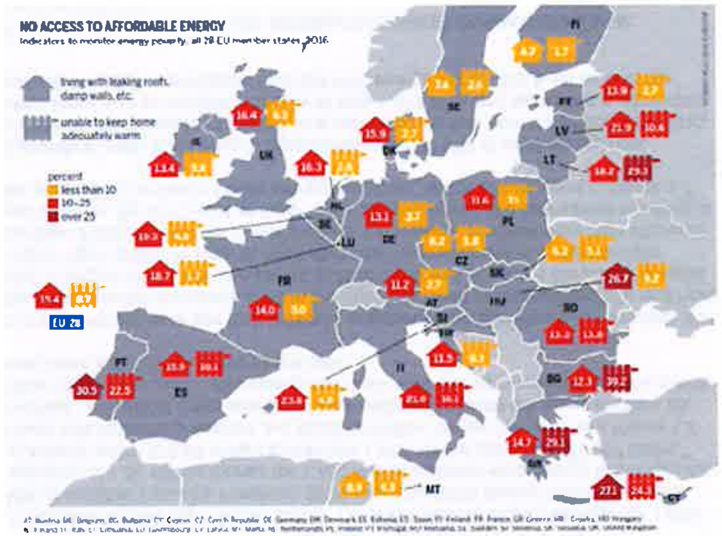


Figure 1.5: *Extent of energy poverty in EU*

As regards the environmental cost, many areas of EU have suffered radical changes in landscapes altered by enormously intrusive wind turbines, Germany for instance having installed more than 30,000 such turbines. As the German wild animal foundation points out with respect to the unacceptable impacts of any further wind turbines being installed in forested areas, some 250,000 bats and 12,000 raptors (birds of prey) are already being killed by wind turbines each year in Germany.[10] After several years of intensive conservation measures in the 80s and 90s, the number of successful raptor breeding pairs, which was increasing, is now once again in decline.

1.5 What is actually being delivered by these staggering sums of money

One could justifiably question as to what is exactly being delivered to justify this huge cost? The answer sadly is little or nothing. For example many commentators point to the enormous 'black hole' that is German's 'Energiewende' or renewable energy transformation.[11] Not least as Figure 1.6 overleaf shows, following reunification there was a decrease in German emissions as East German industry was modernised. But

[10] https://www.deutschewildtierstiftung.de/naturschutz/windenergie-und-artenschutz

[11] https://www.politico.eu/article/germany-climate-change-green-energy-shift-is-more-fizzle-than-sizzle/

in the last decade, despite the hundreds of billions of Euro invested in Energiewende, national emissions have not measurably decreased and Germany will miss its 2020 target climate emissions by a significant percentage.

France, which traditionally generated nearly 80% of its electricity from nuclear energy had in 2016 some 10% of the carbon intensity inherent to German electricity production, while its electricity costs were nearly half those of Germany.[12] However, because France is now pursuing more renewable energy, both the cost of its electricity and the carbon intensity of that electricity are now rising.[13] Indeed, it was the government announcement of a further punitive carbon tax on petrol and diesel, in order to finance more renewables, which led to the massed 'yellow vests' demonstrations. Many of those protesting were, quite rightly, questioned as to if their leaders had lost all sense of reason and logic.

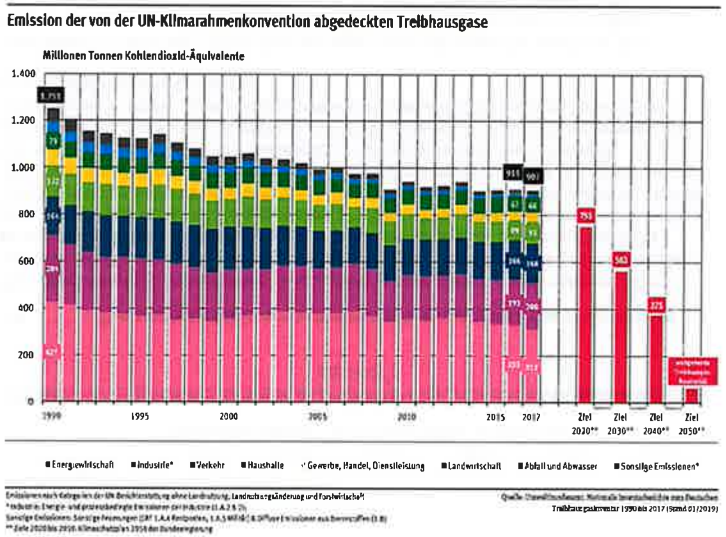


Figure 1.6: *German emissions of greenhouse gases in million tonnes of CO_2 equivalents 1990 -2017; from bottom, energy sector, industry, traffic, households, 'commerce, trade and services', agriculture, waste and wastewater, other emissions. Targets on the right for 2020, 2030, 2040 and 2050: Source German Federal Environment Agency (UBA)*[14]

[12] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Electricity_prices,_First_semester_of_2016-2018_(EUR_per_kWh).png

[13] https://www.forbes.com/sites/michaelshellenberger/2019/02/05/if-saving-the-climate-requires-making-energy-so-expensive-why-is-french-electricity-so-cheap/

[14] https://www.umweltbundesamt.de/daten/klima/treibhausgas-emissionen-in-deutschland/kohlendioxid-emissionen#textpart-1

The situation isn't any better here in Ireland. REFIT is EU State Aid for Environmental Protection and in the application for REFIT I in 2007 to approve 1,450 MW of wind energy[15] the following information was supplied by the Department of Communication, Energy and Natural Resources on projected emission savings based on the fact that wind technology would be the dominant technology:

Emissions	***Annual** savings per 100 MWs installed* *Tonnes of oxide*
Carbon Dioxide	*0.19 ml.*
Sulphur Dioxide	*4k*
Nitrogen Oxides	*1.3k*
	Ml = millions *K = thousands*

In essence a claim that it would deliver 1.9 million tonnes of CO_2 savings per 1,000 MW of installed capacity. However, SEAI report for 2012 claims a CO_2 emissions reduction of 1.51 million tonnes for 1,783 MW of installed wind energy in the Republic of Ireland, which is 0.84 million tonnes per 1,000 MW or only 45% of 2007 claim.[16] Given that Ireland's emissions are about 60 million tonnes per year, see Figure 1.7 overleaf, and global emissions from fossil fuels and industry are approximately 36 billion tonnes per year,[17] this saving from Irish wind energy represented 1.4% of Irish emissions and 0.002% of the global total.

It is also interesting to see from Ireland's emissions trends in Figure 1.7 overleaf, that the energy sector emissions grew in the 2000s, but had decreased by 2010 and have little changed since then. The period 2000 to 2008 was of course the period of rapid 'Celtic Tiger' growth in Ireland, but it also saw the investment in a considerable number of modern thermal power stations, the majority of which were high efficiency gas turbines. By 2010 most of these were commissioned and operational resulting in the decrease in emissions from energy industries, which can be seen in Figure 1.7.

Currently in early 2019 there is approximately 3,500 MW of wind energy now installed in the Republic of Ireland, one would expect that from the period from 2010, when there was an installed capacity of only 1,379 MW, one would see a significant reduction in carbon emissions from the Irish energy sector. Not least as over the

[15] PART III.10 SUPPLEMENTARY INFORMATION SHEET ON ENVIRONMENTAL PROTECTION AID

[16] https://www.seai.ie/resources/publications/Quantifying-Irelands-Fuel-and-CO2-Emissions-Savings-from-Renewable-Electricity-in-2012.pdf
2012 installed capacity in the Republic obtained from NREAP progress report.

[17] See Section 2.3 and: https://www.globalcarbonproject.org/carbonbudget/18/highlights.htm

same timeframe, there was little or no growth in Irish electricity demand.[18] Yet the bottom segment of the bar graph in Figure 1.7, which is attributed to the energy industries, has altered little in that period.

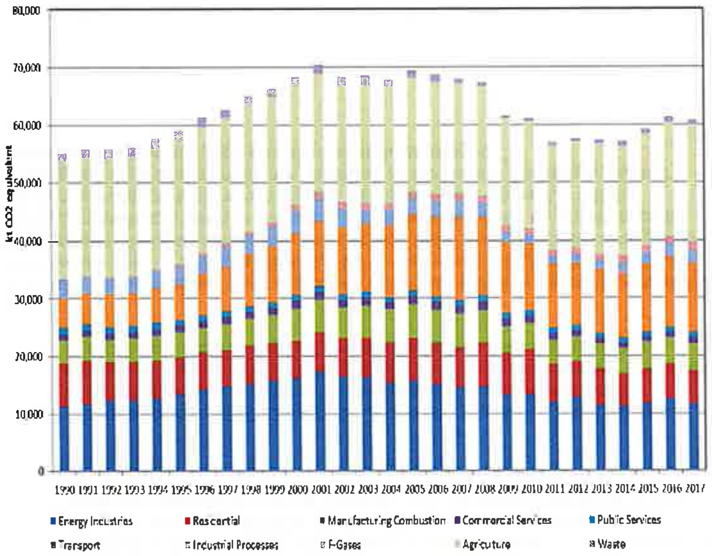


Figure 1.7: *Ireland's greenhouse gas emissions inventory (energy industries bottom blue) – Source EPA*[19]

Despite this massive costs have had to be paid by the electricity consumer. While the Irish State has never prepared any cost benefit data for this renewable programme, it can easily be estimated that it is costing Irish citizens €1.2 billion per year.[20] Indeed, the Irish Academy of Engineering was pointing out in 2014 that the electricity rates were some 50% higher than they would have otherwise been in order to fund the Government mandated renewable investment.[21]

One can only conclude, that simply staggering sums of money are now having to be paid by European and Irish electricity consumers, for a so called 'solution' to a problem, which isn't occurring, and for which even if it was occurring, this so called 'solution' is incapable of delivering anything of merit.

[18] See Section 2.7: https://www.seai.ie/resources/publications/Energy-in-Ireland-2018.pdf

[19] http://www.epa.ie/climate/emissionsinventoriesandprojections/nationalemissionsinventories/

[20] http://en.friends-against-wind.org/doc/Wind_Aware_The_Costs_of_Wind_Energy_in_Ireland.pdf

[21] http://iae.ie/wp-content/uploads/2017/07/Energy_Policy_Green_Paper_-_IAE_Response_31.07.14.pdf

1.6 'Bootleggers and Baptists' and 'evidence based decision making'

Indeed, the whole agenda of climate change is a classic case of what is recognised in economics as 'Bootleggers and Baptists':

- *Theories of regulation offer thought facilitating devices that may help to explain the functioning of government in a political economy. Among formal theories put forward in the 20th century are public interest, capture, special interest, and money for nothing. The Bootlegger and Baptist theory is based on the frequent observation of two distinct and different interest groups pursuing the same regulatory end. The name comes from experiences observed in regions of the US where religious groups oppose the Sunday sale of alcoholic beverages, a positioned welcomed by bootleggers, illicit sellers who welcome a wider market for their services. In the context of regulation generally, the "Baptists" are those who take moral high ground in the efforts to gain regulation, as with environmental groups. The "bootleggers" are those who gain monopoly rents when the Baptists successfully provide an output restriction, as when producers of clean energy see coal operations closed down.*[22]

Yet this concept is nothing new, for example "*Cui bono?*" is a Latin phrase from Cicero meaning 'to whom is it a benefit?' and is an adage still used to suggest a hidden motive or that the party responsible for something may not be who it appears at first to be. Indeed, Shakespeare also articulated the concept that "*politics makes strange bedfellows*".

It is undisputable that there are enormous sums of money to be made in the complete 'wild west' which is the Government sponsored rush to renewable energy. Equally so that those who are behind these projects are solely there for profit, but are facilitated by and supportive to those for whom 'climate change' has become a quasi-religious belief system. A belief system, which is characterised by an inability to rationally evaluate the natural world and is instead dominated by emotionally justified positions. That the "*road to hell is paved with good intentions*" has been articulated for centuries,[23] while the history of mankind is indelibly sculpted by the awful mess, which time and time again ideologies and mass hysteria events have left behind. Despite this as a society we fail to prioritise evidence based decision making and as a result sooner or later we are left to sit down once again to a banquet of consequences.

This 'evidence based decision making' is often defined by the following steps:[24]

1. *Use of the best available scientific findings.*

[22] Bootleggers and Baptists in the Theory of Regulation Bruce Yandle, Clemson University: https://www.researchgate.net/publication/267785761_Bootleggers_and_Baptists_in_the_Theory_of_Regulation

[23] Saint Bernard of Clairvaux (c. 1150), "*L'enfer est plein de bonnes volontés ou désirs" (hell is full of good wishes or desires).*

[24] Rousseau, D. M., & Mccarthy, S. (2007). Educating Managers from an Evidence-Based Perspective. Source: Academy of Management Learning & Education, 6(1), 84–101. Plus: https://www.researchgate.net/publication/313967850_Evidence-Based_Management

2. *Gathering and attending to organisational facts, indicators and metrics in a systematic fashion to increase their reliability and usefulness.*

3. *On-going use of critical, reflective judgment and decision aids in order to reduce bias and improve decision quality.*

4. *Consideration of ethical issues including the short- and long-term impact of decisions on stakeholders.*

The outstanding success we have seen in the last century in the field of medicine can be attributed to its use of evidence based decision making. While over time scientific enquiry helps convert 'unknowns' to 'knowns', such evidence is not always available to offer certainty to policy decisions, which are influenced by multiple stakeholders and their agendas.

1.7 Known knowns, known unknowns and unknown, unknowns

Donald Rumsfeld in 2002 in reply to a question on Iraqi weapons of mass destruction and terrorists put it so succulently with respect to the "*know knowns, known unknowns and unknown, unknowns*'. However, this does not detract from the fact that even before the 2003 invasion of Iraq, there were considerable 'known, knowns', not least as Hans Blix, the UN Chief Weapons Inspector put it:

- *Speaking on the anniversary of the United States' invasion of Iraq, originally declared as a pre-emptive strike against a madman ready to deploy weapons of mass destruction (WMDs), the man first charged with finding those weapons said that the U.S. government has "the same mind frame as the witch hunters of the past" — looking for evidence to support a foregone conclusion.*

- *"There were about 700 inspections, and in no case did we find weapons of mass destruction," said Hans Blix, the Swedish diplomat called out of retirement to serve as the United Nations' chief weapons inspector from 2000 to 2003; from 1981 to 1997 he headed the International Atomic Energy Agency.*[25]

As history shows, that war was pursued with the quasi-religious fervour to establish a 'new world order' – the 'Baptist' agenda. While many paid a high price, in particular the dead and wounded servicemen and civilians, there were also those who greatly profited, as at least $138bn of US taxpayers' money was spent on private security, logistics and reconstruction contractors – the 'Bootlegger' element.[26] Did the 'Bootleggers' fund and promote the 'Baptists', as the classic 'Bootlegger, Baptist' theory would articulate? Well such links have been alleged.[27]

[25] https://www.berkeley.edu/news/media/releases/2004/03/18_blix.shtml

[26] https://www.ft.com/content/7f435f04-8c05-11e2-b001-00144feabdc0

[27] For example: https://www.texasmonthly.com/articles/did-dick-cheney-sink-halliburton-and-will-it-sink-him/

1.8 The 97% consensus

In considering the agenda of 'Catastrophic Anthropogenic (manmade) Climate Change' there are in fact, as is discussed later in Section 2, very considerable 'known, knowns' in that; (i) the planet's weather is normal and; (ii) that carbon dioxide (CO_2) emissions from burning fossil fuels are simply not capable of causing catastrophic warming. Regardless of what consensus may appear to develop, such consensus or beliefs are not evidence and while consensus may well be politics, it is not science, which is inherently evidence based.

Furthermore, claims that 97% of scientists agree in 'Catastrophic Anthropogenic Climate Change' are profoundly absurd, given as to how difficult it is to get 97% of a group of humans to agree to anything. Not least a group of researchers into a highly complex issue related to subtle changes in the inherently highly variable weather.[28] That over time the climate changes in a cyclical manner is an undisputed concept, as is the gradual warming we have experienced in the last two centuries since the 'Little Ice Age'. That CO_2 emissions have the potential to lead to a limited amount of warming is also generally accepted by many in this field, but the general acceptance of these three concepts as being established, does not then in any automatic respects lead to a conclusion that there is an impending environmental catastrophe due to rapidly rising temperatures.

As is explained in Section 2, such a hypothesis was widely speculative from the beginning and with each passing year it is clearer as to how speculative it is. In is therefore a 'known, known' that 'Catastrophic Anthropogenic Climate Change solely exists as a highly speculative hypothesis and for which we have no evidence in our weather data to support it. For one to accept this speculative hypothesis is also to accept that the planet's climatic systems are at a level of severe instability, an instability not supported by the considerable knowledge we have of the past. Furthermore, this highly speculative hypothesis was widely criticised from its inception and with each passing year, as its projections rapidly diverge from the evidence in front of us, the criticisms and concerns in the scientific community grow louder.

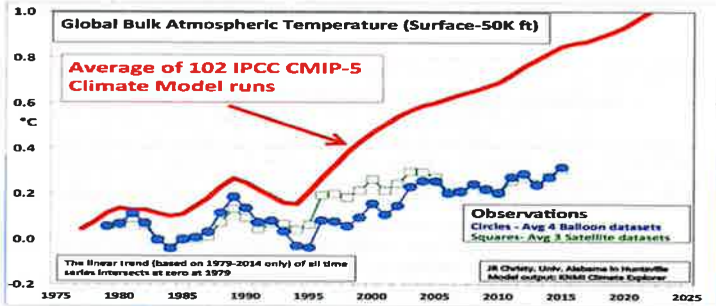


Figure 1.8: *Divergence of predictions of IPCC Climate Models from observations*[29]

[28] For some background as to the political activism behind this 97% claim, see for example: https://www.scientificamerican.com/article/how-to-determine-the-scientific-consensus-on-global-warming/

[29] https://tropical.colostate.edu/media/sites/111/2018/01/Bill-Gray-Climate-Change.pdf

1.9 The political ownership of the IPCC and the failure to address uncertainties

The UN's Intergovernmental Panel on Climate Change (IPCC) was established in 1988 on the basis of 'Catastrophic Anthropogenic Climate Change', i.e. that man's continued use of fossil fuels would lead to an environmental disaster. However, this was solely a political decision, which was taken before the scientific knowledge on the planet's climatic systems was at level of confidence, to either predict such a catastrophe would occur or robustness enough to support major policy decisions in this area. Indeed, at that time, the area of climate studies was very much a niche area with a limited amount of knowledge. However, the IPCC's name as an Intergovernmental Panel highlights as to how it was from the start a political creation.

This political ownership is clearly evident when one compares the 'Summary for Policymakers' in the reports of the IPCC, with the detailed technical analysis within. This analysis, to put it mildly, is characterised by an absence of a detailed understanding of the natural variability and cycles, which occur with the planet's dynamics. Meteorological knowledge can only extent to forecasting the weather eight to ten days ahead, yet the summary for policy makers can make definite predictions about the climate at the end of the century and what we should be doing about it at enormous cost.

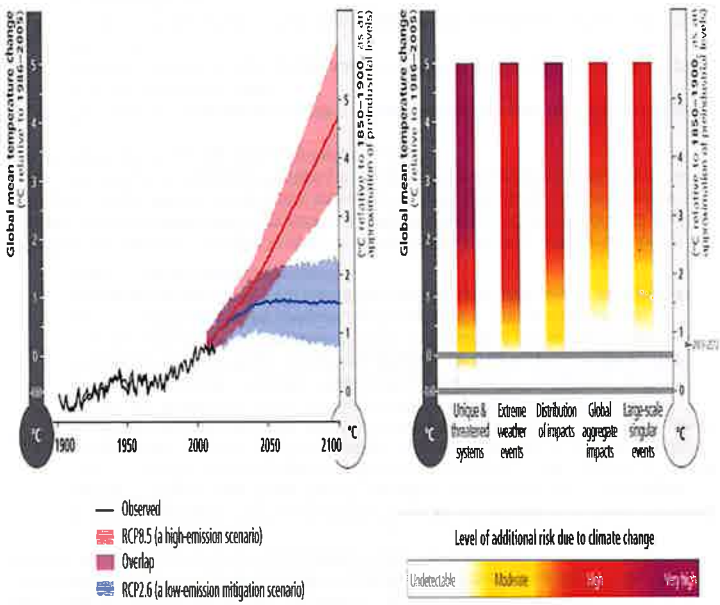


Figure 1.9: *IPCC Fifth Assessment Report (AR.5) Summary for Policy Makers- Climate Change 2014 Impacts, Adaptions and Vulnerability*[30]

[30] https://www.ipcc.ch/site/assets/uploads/2018/02/ar5_wgII_spm_en.pdf

However, the same IPCC Fifth Assessment Report when reviewed in more detail with respect to 'Uncertainties' provides the following:[31]

- *FAQ 1.1 | If Understanding of the Climate System Has Increased, Why Hasn't the Range of Temperature Projections Been Reduced?*

- *The models used to calculate the IPCC's temperature projections agree on the direction of future global change, but the projected size of those changes cannot be precisely predicted. Future greenhouse gas (GHG) emission rates could take any one of many possible trajectories, and some underlying physical processes are not yet completely understood, making them difficult to model. Those uncertainties, combined with natural year-to-year climate variability, produce an 'uncertainty range' in temperature projections*

To reiterate the position previously articulated, it is not disputed that there is a potential for some limited warming due to increased use of fossil fuels, but that does not most certainly lead to an automatic conclusion that that temperatures will rise rapidly leading to a catastrophic situation. Not only is the IPCC not in a position to forecast the projected change in temperatures, the details as to why being documented in the following Section 2, but as Figure 1.8 documents, their models on which their whole output is based are diverging rapidly from 'mother nature', a mother nature whose natural variability and responses they clearly do not understand.

Hans Van Storch a Professor at the Meteorological Institute of the University of Hamburg and a prominent German climate researcher highlighted to the influential Der Spiegel magazine in 2013:[32]

- *SPIEGEL: Just since the turn of the millennium, humanity has emitted another 400 billion metric tons of CO_2 into the atmosphere, yet temperatures haven't risen in nearly 15 years. What can explain this?*

- *Storch: So far, no one has been able to provide a compelling answer to why climate change seems to be taking a break. We're facing a puzzle. Recent CO_2 emissions have actually risen even more steeply than we feared. As a result, according to most climate models, we should have seen temperatures rise by around 0.25 degrees Celsius (0.45 degrees Fahrenheit) over the past 10 years. That hasn't happened. In fact, the increase over the last 15 years was just 0.06 degrees Celsius (0.11 degrees Fahrenheit) -- a value very close to zero. This is a serious scientific problem that the Intergovernmental Panel on Climate Change (IPCC) will have to confront when it presents its next Assessment Report late next year.*

Indeed, an ever increasing number of scientists in such fields as meteorological research, atmospheric physics, energy systems and economic analysis, many of whom at one time worked as technical contributors to the IPCC, have turned into fierce critics pointing out how politicised and inaccurate its outputs are. Yet despite the increasing divergence of the models on which it makes its predictions from actual observations, the IPCC's political rhetoric just gets shriller and shriller.

[31] http://www.climatechange2013.org/images/report/WG1AR5_FAQbrochure_FINAL.pdf

[32] https://www.spiegel.de/international/world/interview-hans-von-storch-on-problems-with-climate-change-models-a-906721.html

1.10 Politics can be diverse with diverse interests

Naturally this is a totally unacceptable situation, given the enormous costs and restrictions on society expected to be thrown at this alleged problem, a conclusion which is actively recognised in many countries. For example, China was calling at the 2011 Durban climate summit for a review of climate change science by 2015, as a precondition for entering any possible negotiated agreement post 2020.[33] As the Chinese Academy of Science was summarising it at that time:[34]

- *In recent decades, there have been a number of debates on climate warming and its driving forces. Based on an extensive literature review, we suggest that (1) climate warming occurs with great uncertainty in the magnitude of the temperature increase; (2) both human activities and natural forces contribute to climate change, but their relative contributions are difficult to quantify; and (3) the dominant role of the increase in the atmospheric concentration of greenhouse gases (including CO_2) in the global warming claimed by the Intergovernmental Panel on Climate Change (IPCC) is questioned by the scientific communities because of large uncertainties in the mechanisms of natural factors and anthropogenic activities and in the sources of the increased atmospheric CO_2 concentration. More efforts should be made in order to clarify these uncertainties.*

The Paris Agreement (Climate Treaty) of 2016[35] solely requires "*all Parties to put forward their best efforts through nationally determined contributions (NDCs) and to strengthen these efforts in the years ahead*". It is both interesting and informative to dip into the NDCs of individual Parties (countries).[36] For example that of China, which can be summarised by the following bullet points:[37]

- *To achieve the peaking of carbon dioxide emissions around 2030 and making best efforts to peak early;*
- *To lower carbon dioxide emissions per unit of GDP by 60% to 65% from the 2005 level;*
- *To increase the share of non-fossil fuels in primary energy consumption to around 20%; and*
- *To increase the forest stock volume by around 4.5 billion cubic meters on the 2005 level.*

Which can be interpreted as; (i) we will continue to increase our use of fossil fuels as our economy continues to grow up to around 2030; (ii) as we modernise and become more efficient we expect this to be reflected in our carbon intensity; (iii) as a major importer of fossil fuels we will continue to strive for diversification, such as in our

[33] https://bellona.org/news/climate-change/international-climate-conferences/2011-12-chinese-delegation-to-durban-lays-out-conditions-under-which-it-will-cut-emissions

[34] http://www.springerlink.com/content/w342k240350n4564/fulltext.pdf and http://scienceandpublicpolicy.org/images/stories/papers/reprint/human_induced.pdf

[35] https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

[36] https://www4.unfccc.int/sites/ndcstaging/Pages/Home.aspx

[37] https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/China%20First/China%27s%20First%20NDC%20Submission.pdf

successful and ambitious nuclear programme[38] and; (iv) we will reverse the currently unacceptable rate of deforestation, which is currently leading to desertification.[39] In essence China ensured it offended nobody by ratifying this Paris Treaty, but China also ensured that in practice it would not have to adopt any measures which would compromise its continued development.

India's NDC has similar objectives as the above in that as India modernises its economy it will become more energy efficient. However, India made it clear in that it is a developing economy and it will continue that essential development:[40]

- *It is clarified that India's INDC do not bind it to any sector specific mitigation obligation or action, including in agriculture sector. India's goal is to reduce overall emission intensity and improve energy efficiency of its economy over time and at the same time protecting the vulnerable sectors of economy and segments of our society.*

That the Trump administration has withdrawn from the Paris Agreement is well known, what is regretfully less discussed is his reasoning for doing so:[41]

- *"..... close to $3 trillion in lost GDP and 6.5 million industrial jobs, while households would have $7,000 less income..."*

- *"Even if the Paris Agreement were implemented in full, with total compliance from all nations, it is estimated it would only produce a two-tenths of one degree — think of that; this much — Celsius reduction in global temperature by the year 2100. Tiny, tiny amount. In fact, 14 days of carbon emissions from China alone would wipe out the gains from America — and this is an incredible statistic — would totally wipe out the gains from America's expected reductions in the year 2030...."*

- *"There are serious legal and constitutional issues as well. Foreign leaders in Europe, Asia, and across the world should not have more to say with respect to the U.S. economy than our own citizens and their elected representatives. Thus, our withdrawal from the agreement represents a reassertion of America's sovereignty".*

For those that rationalise their decision-making rather than default to the emotional attraction of the quasi-religious argument, the above is entirely reasonable and logical. If it could be demonstrated that what was articulated above was widely inaccurate, then its reasoning could be justifiably challenged, but there is no such evidence, as is discussed in the following Section 2, of any inaccuracies in the above. Yet regretfully we have reached a position in many quarters, where attacking the man rather than the logic suffices, which regretfully is the classic trait of the out and out Baptist preacher.

[38] https://www.reuters.com/article/us-china-nuclearpower-hualong/china-goes-all-in-on-home-grown-tech-in-push-for-nuclear-dominance-idUSKCN1RT0C0

[39] http://factsanddetails.com/china/cat10/sub66/item389.html

[40] https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/India%20First/INDIA%20INDC%20TO%20UNFCCC.pdf

[41] https://www.whitehouse.gov/briefings-statements/statement-president-trump-paris-climate-accord/

Furthermore, whether we like it or not, it is indisputable that over 70% of the earth's population has no intention of doing anything about reducing fossil fuel emissions, in fact they very much intend to increase them. Not only is the EU's official position on reducing climate change an increasingly unilateral decision, but it is also one which is generating increasing discontent within the general population of the EU.[42]

1.11 Political activism rather than impartial assessment

Hans Van Storch in the same Der Spiegel interview in 2013 highlighted:

- *Unfortunately, some scientists behave like preachers, delivering sermons to people. What this approach ignores is the fact that there are many threats in our world that must be weighed against one another. If I'm driving my car and find myself speeding toward an obstacle, I can't simple yank the wheel to the side without first checking to see if I'll instead be driving straight into a crowd of people. Climate researchers cannot and should not take this process of weighing different factors out of the hands of politics and society.*

President Trump has also pointed out he does not deny climate change, but when pressed "*about the scientists who say it's worse than ever*". He has answered: "*You'd have to show me the scientists because they have a very big political agenda*".[43]

Again, this simply reflects the position in that what is increasingly promoted as climate science is often barely concealed 'political advocacy'. It is the function of the professional scientist to inform, inclusive of the inherent uncertainties, but decision making is inherently a trade-off between many requirements, some conflicting, and should be left to society at large and to the democratically elected representatives of that society in particular. You cannot simultaneously be a competent impartial advisor and a political campaigner – they are mutually exclusive.

Since 2003 the US has had detailed guidance related to the conduct of Regulatory Impact Analysis, which time and time again stresses the importance of uncertainties and how the strengths of the analysis should be delineated along with any uncertainties about its conclusions. As this guidance goes on to explain:[44]

- *In some cases, the level of scientific uncertainty may be so large that you can only present discrete alternative scenarios without assessing the relative likelihood of each scenario quantitatively. For instance, in assessing the potential outcomes of an environmental effect, there may be a limited number of scientific studies with strongly divergent results. In such cases, you might present results from a range of plausible scenarios, together with any available information that might help in qualitatively determining which scenario is most likely to occur.*

[42] For example the successful campaign of second largest party from the April 2019 Finnish elections – climate change policies are elitist and excessively expensive: https://www.nytimes.com/2019/04/14/world/europe/finland-election-climate.html

[43] https://www.ecowatch.com/trump-climate-scientists-political-agenda-2612537150.html

[44] https://georgewbush-whitehouse.archives.gov/omb/circulars/a004/a-4.html

- *When uncertainty has significant effects on the final conclusion about net benefits, your agency should consider additional research prior to rulemaking. The costs of being wrong may outweigh the benefits of a faster decision.*

Given all of the above, is it in anyway surprising that the Trump Administration in February 2019 announced its intention "*to establish create an ad hoc group of select federal scientists to reassess the government's analysis of climate science and counter its conclusions that the continued burning of fossil fuels is harming the planet*".[45] It is after all entirely reasonable that publically funded climate science, which is inherently characterised by enormous uncertainties and which demands that near unlimited sums of money and resources to be dedicated to it, is subjected to scrutiny by others, who may not necessarily share the same viewpoints. Professional engineers for example are used to their designs being reviewed by others before they go to construction.

Indeed, science fundamentally works on the basis that a hypothesis is presented; this is then challenged as the evidence emerges to either approve or disapprove the hypothesis. Catastrophic Anthropogenic Climate Change is nothing but one of many potentially valid scientific hypotheses related to climate. It is also one for which, as the following Section 2 documents, there is an increasing divergence between outputs of the computer models representing this catastrophic hypothesis, and the evidence of the real world around us. *Nullius in verba* (Latin for "*on the word of no one*" or "*take nobody's word for it*") is the motto of the Royal Society, which was founded in England in 1660 and is the oldest national scientific institution in the world.

We should not forget these core scientific principles and recognise that science may well have questions for which there may not be answers for in our lifetime. Religion on the other hand is one which has all the answers and for which questions are not acceptable. People's emotional outbursts are not accepted as evidence to support the making of judgements in the Court of Law and for good reason. That an ex-President of Ireland and climate change campaigner Mary Robinson would come out in March 2019 with official statement that: *Denial of climate change is not just ignorant, but "malign and evil"*,[46] clearly demonstrates, as to how this climate change agenda is increasingly being dominated by those, who demonstrate characteristics of intolerant Baptist preachers, rather than rather than rational and informed analysis.

1.12 Group think and preaching replace competency and transparency

Warren Buffet is probably the world's most famous and successful investor and is renowned for his witty quotes, such as:

- "*Risk comes from not knowing what you are doing*" and;
- "*When the tide goes out a lot of people are left looking naked*"

The above could quite rightly be applied to 'Official Ireland' and indeed the EU administration, with respect to the chronic mismanagement of fiscal policy and the financial sector, which lead to the financial crash in 2008. Despite the economic

[45] https://www.pressherald.com/2019/02/24/white-house-to-pick-scientists-to-reassess-federal-climate-report/

[46] https://www.theguardian.com/environment/2019/mar/26/climate-change-denial-is-evil-says-mary-robinson

indicators in the build-up to the crash demonstrating a grossly overheated situation, the litany was repeated over and over again by 'Official Ireland', in that we were heading for a 'soft landing'. This was advice that many in the general public accepted in their subsequent decision making and which led to many of these suffering increased hardship as a result.

When Professor Morgan Kelly of University College Dublin, a specialist in economic history, stated in 2006 that the economy was so overheated that a crash with house prices falling by up to 50% was the only possible outcome; it prompted the then Taoiseach (Prime Minister) Bertie Aherne to state that those "*cribbing and moaning*" about spiralling property prices should "*commit suicide*".[47] This demonstrate not only a basic intolerance to others' views that did not suit one's own agenda, but also an ingrained cultural antagonism to accepting an analysis, which did not suit Official Ireland's politics.

It was therefore not surprising when the Finnish economist Nyberg wrote the official report into the financial collapse;[48] he attributed the 'root cause' to institutionalised 'Groupthink' defined as:

- *Groupthink occurs when people adapt to the beliefs and views of others without real intellectual conviction. A consensus forms without serious consideration of consequences or alternatives, often under overt or imaginary social pressure. Recent studies indicate that tendencies to groupthink may be both stronger and more common than previously thought.*

One would think that we have learnt from this, but there is zero indication that either 'Official Ireland' or the EU administration has.

The Environmental Protection Agency (EPA) published a press release in October 2018 entitled: *"Relentless implementation of policy needed to combat effects of climate extremes"*.[49]

- *"We have, by any measure, experienced an extraordinary year where nature reminded us who is in charge. With our changing climate, the confident predictions are that we can expect extreme events at greater frequency into the future", said Laura Burke, Director General of the EPA, speaking at the annual 'Environment Ireland' conference.*

It seems she listed the following at that conference to justify this position of 'Official Ireland':[50]

- *September 2017 – Storm Aileen*
- *October 2017 – Storm Brian & ex-Hurricane Ophelia*
- *December 2017 – Storm Dylan & Storm Caroline*

[47] https://www.irishtimes.com/business/economy/the-day-the-banks-stood-still-counting-the-cost-of-the-crash-a-decade-later-1.3642474

[48] http://www.bankinginquiry.gov.ie/Documents/Misjuding%20Risk%20-%20Causes%20of%20the%20Systemic%20Banking%20Crisis%20in%20Ireland.pdf

[49] http://www.epa.ie/newsandevents/news/pressreleases2018/name,64793,en.html

[50] https://www.irishtimes.com/news/environment/recent-storms-have-cost-billions-and-severely-tested-ireland-says-epa-1.3651507

- *January 2018 – More rain in Malin Head than at any time since 1885*
- *March 2018 – The Big Snow & Storm Emma*
- *April 2018 – Wettest ever in many locations*
- *May, June & July 2018 – Prolonged drought and heatwave*

Are these relevant? Like many of the now 'older' generation in Ireland I resent the naming and hyping of storms and such like as 'media events', where in the past it was simply just a windy or stormy day. However, data doesn't lie and returning to the same CSO meteorological database as used for Figure 1.1, it is very easy to generate the following line graph below in Figure 1.10.

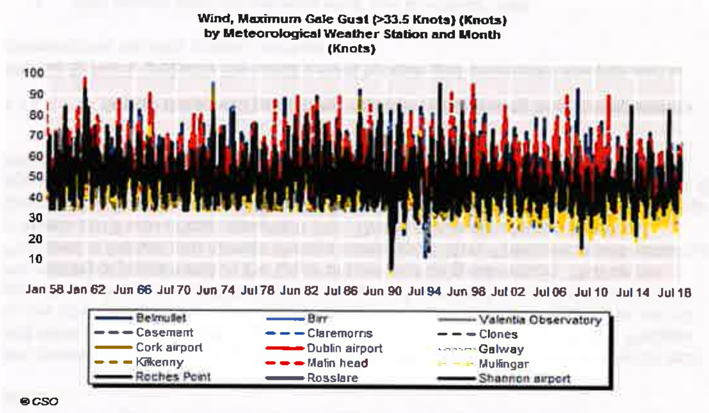


Figure 1.10: *Graph generated from Met Eireann meteorological data (Jan 1958 to March 2019) on the CSO website*[51]

Not only was 2018 nothing special, but if there is a trend, then it is if anything getting somewhat less windy. Furthermore, Met Eireann estimates that on average an 'Ex-tropical storm' will hit Irish shores every three years. Ex-Hurricane Ophelia was quite strong, but it caused far less damage than Ex-Hurricane Charlie in 1986[52] and Ex-Hurricane Debbie in 1961.[53] Indeed, "Oíche na Gaoithe Móire", the night of the big wind in 1839, was the most devastating storm ever to hit Ireland causing enormous damage.[54] One can only conclude that nothing abnormal is currently occurring with respect to the wind conditions Ireland is experiencing.

[51] https://www.cso.ie/px/pxeirestat/Statire/SelectVarVal/Define.asp?maintable=MTM04&PLanguage=0

[52] https://www.irishtimes.com/news/ireland/irish-news/hurricane-charley-storm-that-travelled-from-the-us-to-ireland-1.2910412

[53] https://www.irishtimes.com/news/ireland/irish-news/hurricane-debbie-high-winds-death-and-destruction-in-1961-1.3256985

[54] http://www.irishcultureandcustoms.com/ACalend/BigWind.html

It is also possible with the same CSO website to generate a line graph of rainfall. As can be seen from Figure 1.11 below, it is normally wet in Ireland; while there can be months when it is very wet. This is not surprising in that a number of intense low pressures can move in rapidly one after another from the Atlantic. So again nothing unusual is happening.

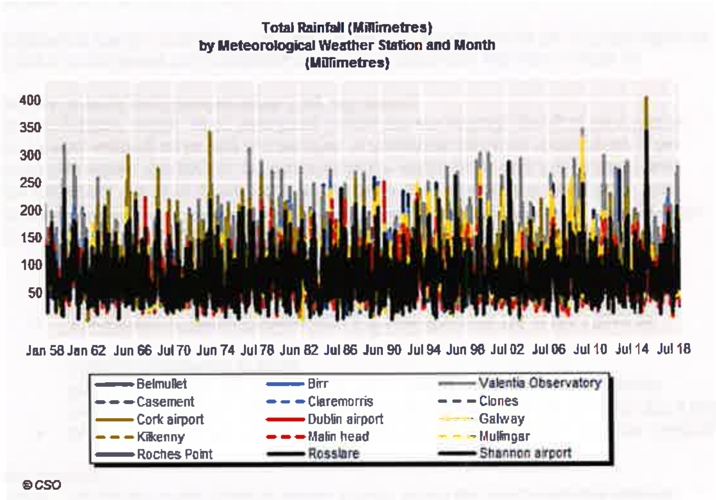


Figure 1.11: *Graph generated from Met Eireann meteorological data (Jan 1958 to March 2019) on the CSO website*[55]

As regards warm summers, once in a while we get lucky, such as those of us able to remember, not only the glorious summer of 2018, but those of 1974 and 1976 as well. We also get cold outbreaks from time to time, as explained further in Section 2 and Section 2.12 in particular. 2018 was one such outbreak, while 2010, 1982, 1963 and 1947 all had very severe conditions, which extended for considerably longer than the cold snap in 2018.

One can only conclude, is this all that 'Official Ireland' can provide to justify the billions of Euro, which we are now required, year on year, to fork out on this agenda, with even more billions of Euro to be added to that bill? It also reflects a position which is increasingly disturbing. This was after all the most senior environmental official in the State, who is expected to provide sound impartial advice to inform political decision making, but is clearly instead engaged in blatant scare mongering and political advocacy.

The United Nations Economic Commission for Europe's (UNECE) Aarhus Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters[56] requires that environmental

[55] https://www.cso.ie/px/pxeirestat/Statire/SelectVarVal/Define.asp?maintable=MTM01&PLanguage=0
[56] https://www.unece.org/env/pp/introduction.html

considerations be taken into Government decision-making. Furthermore, public authorities are required to possess and update environmental information, which is relative to their decision making and ensure that it is transparent. This latter requirement is to be seen transcribed into Directive 2003/4/EC on environmental information and the implementing Irish regulations,[57] namely such environmental information has to be "*up-to-date, accurate and comparable*".

Sadly an abject failure to comply with this has become the norm. The research reports on the EPA's website related to climate change all have a disclaimer in the cover pages. While their content is fundamentally based on the output of the computer models, which as the above and the following Section 2 point out, are so deeply flawed, as to be unable to reflect the conditions, which prevail on the planet. However, these chronic uncertainties are never explained to the public.

Engineering professionals do not put disclaimers on their designs before they go to construction. They are liable if such designs fail or cause an accident; as a result they know they could quickly find themselves in a Court of Law, in which professional competency is assumed as given. This situation is no different for a range of other professions, such as medicine. However, it clearly doesn't seem to apply to those who are responsible for promoting and developing environmental policies and programmes, such policies and programmes which are clearly responsible for huge costs for no obvious gain.

This situation is now rampant in 'Official Ireland' and the EU Administration. In 2012 the Department of the Environment, Community and Local Government conducted in March 2012 a Public Consultation on Climate Policy and Legislation, which hyperlinked to an EU Commission webpage on Climate Action, in relation to a roadmap to a low carbon economy by 2050, which stated:

- *"Science tells us that all developed countries would need to reduce emissions by 80-95% in order to have a fair chance of keeping global warming below 2℃".*

This clearly was the sole justification for the draconian measures being promoted, but what was supporting this statement, where did it come from? The UNECE 'Aarhus Convention: An Implementation Guide'[58] defines that transparency "*means that the public can clearly follow the path of environmental information, understanding its origin, the criteria that govern its collection, holding and dissemination, and how it can be obtained*". As previously highlighted Member States have to ensure that information on the environment is "*up-to-date, accurate and comparable*". An Access to Information on the Environment Request was made by this author and two others related to the above statement and three other aspects of the consultation. There was a point blank refusal to answer it.

It was appealed to the Commissioner for Environmental Information, who subsequently took more than a year to deal with the appeal. The appeal was rejected, on the basis of being "*manifestly unreasonable*".[59] In particular a misuse of rights as the appellant "*was seeking to challenge the Department's reliance on the*

[57] https://www.dccae.gov.ie/en-ie/about-us/compliance/access-to-information-on-the-environment-(aie)/aie-legislation/Pages/AIE-Legislation.aspx

[58] http://www.unece.org/index.php?id=35869

[59] https://www.ocei.ie/decisions/dCEI_12_0005-Mr-Pat-Swords-and-the-/

mandatory greenhouse gas mitigation targets underlying the national climate policy and legislation development programme and to raise questions about the Department's intention to take "due account" of "all" submissions made in the context of the public consultation exercise being carried out at the time his request was made".

Quite an amazing conclusion, as the whole purpose of the access to information pillar of the Aarhus Convention is that the public can gain access to information, which they then may choose to utilise in the third pillar of the Convention, namely access to justice. A conclusion which is also completely at variance with the detailed guidance in the 'Aarhus Convention: An Implementation Guide'. However, a further appeal to the High Court was prohibitively expensive, but as the Commissioner had taken so long to deal with the issue, a similar access to information request was made to the EU Commission addressing the statement above. They replied reasonably promptly, and maybe one should not be too surprised at the answer. Namely they had reached political consensus on it at the Copenhagen and Cancun Climate Summits (2009 and 2010 respectively) and then adopted it at their Council meeting in 2011.[60]

There never was any evidence based documentation available to support this, while year after year the weather continues to be normal. It is also deeply worrying to see the institutionalised lack of competency on the subject matter, which is now so completely ingrained, as all that is occurring is the implementation of arbitrarily agreed political targets. The Chair of the An Bord Pleanala is a political appointee, who has enormous discretionary powers in terms of planning decisions around the State. The current Chair is Dave Walsh and for which the Bord Pleanala website documents:[61]

- *Dave headed up the Department's Environment and Climate Division, leading Ireland's and the EU negotiations on climate change during Ireland's 2013 EU Presidency which ultimately led to the adoption of the Paris UN Climate Change Agreement in 2015.*

- *A graduate of Trinity College with a Single Honours BA in the Classics (Ancient Greek and Latin), Dave also has a Higher Diploma in Education (TCD) and a Ms.C in Economic Policy (TCD/IPA).*

One can quite rightly question, as to if he had any recognisable competency in matters related to the weather and hence climate. While that is not to unfairly belittle the individual, the core of the issue is that there is no evidence that anybody else there had either. Simply put, no documentation exists as to how the problem was quantified, namely as to why our weather is abnormal, because it clearly isn't. No documentation exists, as to how these measures are actually going to be effective and as to what quantified benefits they will deliver.

Others in academia have analysed what these measures will cost in order to implement this EU strategy.[62] The GDP of the EU is expected to be $17,900 billion in

[60] See point 15: https://ec.europa.eu/research/era/docs/en/brussels-european-council-4-february-2011-presidency-conclusions.pdf

[61] http://www.pleanala.ie/about/members.htm

[62] https://www.worldscientific.com/doi/pdf/10.1142/S2010007813400010

2019,[63] which is down from its record high of $19,137 billion in 2008. These climate change measures are estimated by 2050 to lead to a reduction in the order of 5 to 6 % of GDP, which equates to some $1,050 billion per year, which give or take the level of accuracy in the estimation, is about a trillion Euros (thousand billion) per year. Alternatively given that the EU population is 508 million, this equates to an annual contribution by each man, woman and child of €2,000.

You would think for this, which is a decision already made and being relentlessly implementing, that there would be a degree of analysis to justify it and as to how it is being optimised in its implementation. Well you thought wrong.

As for the competent authority for matters related to the weather in this country, namely Met Eireann, they are not pushing this agenda at all. They just provide scientific analysis of the state of the weather, which is summarised each month into a climatic statement, each of which goes to show that the weather is simply normal.[64]

Prof. J. Ray Bates obtained his PhD from the Massachusetts Institute of Technology and has had a distinguished career:[65]

- Adjunct Professor of Meteorology, University College Dublin, 2004-
- Prof. of Meteorology, Niels Bohr Institute, University of Copenhagen, 1995-2004.
- Senior Scientist and Branch Head, Lab. For Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland, 1987-1995.
- Irish Meteorological Service (now Met Éireann), 1963-1987. Positions held: Forecaster, Head of Research Division, Assistant Director.

He has served as an expert reviewer of the IPCC's earlier report, but has like other similar scientists become a major and public critic of its work, such as in his recent publication relating to the inaccuracies of the 2018 IPCC SR1.5 report and its deficiencies.[66] As the introduction to his publication states:

- *The recent special report of the Intergovernmental Panel on Climate Change, known as SR1.5 goes far beyond all its previous publications in raising the level of alarm about climate change and in calling for drastic action to combat it. The report adopts the standpoint that the essential aspects of climate science are settled and then conflates what it sees as a necessary policy response with ethical issues of sustainable development, poverty eradication and reducing inequalities.*

- *The report calls for radical changes in the world's economy to achieve zero carbon emissions by mid-century. Given the extremely costly and highly disruptive changes this course of action would entail, the rigour of the underlying scientific case should be beyond question. Here, some central aspects of SR1.5 are examined to see whether the report exhibits a level of scientific rigour commensurate with the scale of its prescribed course of action. The conclusion, based on the evidence, is that it does not.*

[63] https://tradingeconomics.com/european-union/gdp
[64] For example for March 2019: https://www.met.ie/climate-statement-for-march-2019

[65] http://www.raybates.net/

[66] https://www.thegwpf.org/content/uploads/2019/01/Bates-2018b.pdf

With each passing year, it is clearer in how speculative and alarmist the IPCC's claims are, the reasons why being discussed further in Section 2 of this document. Yet the political rhetoric just gets shriller, as more and more, who should know better, clamber on the soap box of moral superiority and engage in sanctimonious preaching at others.

Despite this, two things are happening and there are no reasons why they will not continue to happen. Namely, (i) the weather continues to be normal, while (ii) more and more countries continue to do nothing about reducing emissions. At the December 2018 COP24 IPCC climate conference in Katowice, Poland this SR1.5 report warned that *"Limiting global warming to 1.5°C would require rapid, far-reaching and unprecedented changes in all aspects of society."*[67]

- *"The United States was willing to note the report and express appreciation to the scientists who developed it, but not to welcome it, as that would denote endorsement of the report," the US State Department said, revealing the underlying issue behind elevating acknowledgement of the IPCC's report. "As we have made clear in the IPCC and other bodies, the United States has not endorsed the findings of the report."*

The US was joined by Russia, Saudi Arabia and Kuwait, as they all had major reservations over the quality of the 'scientific' work presented.

Sadly Prof Ray Bates is both scorned by what considers itself to be an environmental movement in Ireland,[68] which after all is inherently righteous and doesn't have to provide analysis of the weather's systems, and also 'Official Ireland'. History repeats itself as there is an uncanny similarity to the situation back in 2006 with Professor Morgan Kelly of UCD.

1.13 Preachers and bootleggers operating behind closed doors

That the general public have never been informed of what these measures are costing, on what basis they are justified, what alternatives have been considered, what are the impacts and mitigation measures, etc., is because the legal procedures requiring these to be completed, and the participation of the public to be engaged in the decision-making, have been bypassed. Since 2005 Ireland like the USA has a requirement for Regulatory Impact Analysis including detailed cost benefit assessments and public participation, before major regulations are adopted. The latter also referring to reaching agreement on draft EU legislation. Sadly these Regulatory Impact Analyses just don't get done. We also have a legal requirement for Strategic Environmental Assessment of plans and programmes, such that the justifications and alternatives can be assessed, along with the impacts and mitigation measures. These just don't get done either.

The EU simply adopted a political target for 20% renewable energy by 2020. As it had failed to evaluate, what exactly was to be built in each Member State, where it was to be built, what its costs and benefits would be, what were the alternatives to the programme, etc., it therefore reached the position that this 20% renewable

[67] https://cleantechnica.com/2018/12/10/cop24-begins-to-devolve-as-key-countries-block-ipcc-1-5-report/

[68] https://www.thetimes.co.uk/article/retired-ucd-professor-told-to-weather-climate-contrarian-jibe-b6mfmnlw3

energy target had to be implemented in the following manner, as described in Recital 15 of the 2009/28/EC Directive.[69]

- *The starting point, the renewable energy potential and the energy mix of each Member State vary. It is therefore necessary to translate the Community 20 % target into individual targets for each Member State, with due regard to a fair and adequate allocation taking account of Member States' different starting points and potentials, including the existing level of energy from renewable sources and the energy mix. It is appropriate to do this by sharing the required total increase in the use of energy from renewable sources between Member States on the basis of an equal increase in each Member State's share weighted by their GDP, modulated to reflect their starting points, and by accounting in terms of gross final consumption of energy, with account being taken of Member States' past efforts with regard to the use of energy from renewable sources.*

In other words, the 20% renewable energy target was 'dished out' to the Member States based on what level of renewable energy resources they already had and a 'fudge factor' based on GDP. The Irish Republic got a 16% target and the UK 15%, while Austria with considerable hydro resources got double that at 34%. This 2009/28/EC Directive on 20% renewable energy was adopted on the 23rd April 2009, by the 30th June 2009 the Commission had to adopt a template for the National Renewable Energy Action Plans (NREAPs) and these in turn had to be completed, adopted by the Member States and notified to the Commission by the 30th June 2010.

As regards what was actually in the NREAPs and they are an awful disjointed and rambling document to read, the core issue was to be found right at the end of the NREAP template.[70]

5.3. Assessment of the impacts (Optional)
Table 13
Estimated costs and benefits of the renewable energy policy support measures

Measure	*Expected renewable energy use (ktoe)*	*Expected cost (in EUR) — indicate time frame*	*Expected GHG reduction by gas (t/year)*	*Expected job creation*

Nineteen of the Member States left this completely blank, the Irish NREAP going from Section 5.2 direct to Section 5.4. The other Member States provided little or no analysis. So all this renewable Directive does is deliver a politically agreed target, the costs, impacts and benefits of which are completely unknown.

The fact that the whole manner in which this Directive was implemented through the NREAPs was a complete breach of the legal requirements of the UNECE Aarhus Convention led to a legal investigation there by the UNECE Compliance Committee.

[69] http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32009L0028

[70] http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32009D0548

In July 2014 a ruling of non-compliance in International Law was adopted by the Parties to the Convention against the EU.[71] This non-compliance in International law is automatically non-compliance with EU law, as the Convention is an integral part of EU legal order. The Court of Justice of the European Union (CJEU) has already made it clear, in that because the Convention takes precedence in the EU legal structure, if there is a conflict with secondary legislation, such as a Directive, EU and Member State institutions and judiciary would have to apply the provision of the Convention and derogate from the secondary law provision.[72]

However, the EU has refused to comply with this ruling and EU citizens are unable to enforce it, as they have no right of access to the CJEU. This failure to provide the access to justice provisions of the Convention has led to additional findings of the UNECE Compliance Committee, but to the huge annoyance of the other eighteen Parties (countries to the Convention), the EU and its Member States in September 2017 used its blocking votes to prevent a further Decision in non-compliance being taken in International Law against it with respect to these failings in access to justice.

As has been documented in more detail elsewhere, compliance proceedings at UNECE are continuing against the EU, the Compliance Committee issuing a further sharp rebuke to the EU in their February 2019 progress review.[73] This found that not only had the EU failed to make any meaningful progress towards compliance with the implementation of the NREAPs and the lack of access to justice provisions, but that its new Regulation on an Energy Union (adopted in late December 2018) had also failed to comply with the public participation requirements of the Directive.

Further details on these compliance proceedings is summarised elsewhere,[74] but suffice is to say these decisions on both the renewable programme to date and the future renewable programme post 2020 are being taken behind closed doors by a limited number of select officials and 'favoured representatives'. This is occurring in a manner which is non-transparent, bypassing the public's rights for participation and which is downright illegal. For example, the original findings of the UNECE Compliance Committee in relation to the 2010 adoption of the Irish NREAP documented how an initial targeted consultation was carried out with selected entities, but not with the wider public.[75]

[71] https://www.unece.org/fileadmin/DAM/env/pp/mop5/Documents/Post_session_docs/Decision_excerpts_in_English/Decision_V_9g_on_compliance_by_the_European_Union.pdf

[72] See documentation of 21.11.2007: https://www.unece.org/env/pp/compliance/Compliancecommittee/17TableEC.html

[73] https://www.unece.org/fileadmin/DAM/env/pp/compliance/Requests_from_the_MOP/ACCC-M-2017-3_European_Union/Correspondence_with_the_Party_concerned/First_progress_review_on_M3_EU_adopted_22.02.2019.pdf

[74] See for example: https://www.thegwpf.com/un-legal-tribunal-issues-rebuke-of-eu-renewable-energy-programme/ and https://mailchi.mp/30f2915d1ae2/un-censures-eu-on-illegalities-around-renewable-energy-programmes See also page 68 and Section 5: https://www.documents.clientearth.org/wp-content/uploads/library/2019-02-26-access-to-justice-in-european-union-law-a-legal-guide-on-access-to-justice-in-environmental-matters-ce-en.pdf

[75] https://www.unece.org/fileadmin/DAM/env/pp/compliance/C2010-54/Findings/ece_mp.pp_c.1_2012_12_eng.pdf

As the Irish NREAP documents in its Appendix 6, this was with members of the so called 'Renewable Energy Development Group'.[76]

Not surprisingly, this is a list of 33 entities comprising Government departments, agencies, semi-states and companies investing in the renewable sector. It could accurately be described an insider cabal of preachers and bootleggers. The public or even the interests of the public were nowhere to be seen.

1.14 Conclusions

The climate change and renewable policies currently being pursued are environmentally, technically, financially and legally completely flawed. They are being relentless driven by political goal setting, which has never even remotely demonstrated that it could first identify and quantify the problem, which as it stands doesn't exist. It has now developed a momentum that has lost all connection with meteorological circumstances and instead is justified by individuals' moral and political superiority.

As a society we have been there before, just over a hundred years ago a wave of nationalistic fervour gripped Europe. Young men rushed off to the front for King or Kaiser on the basis that it would all be over by Christmas. Gangs of women roamed the streets handing out white feathers to men, who were not in uniform. Sadly the destruction and slaughter that followed was on an unprecedented scale. The twenties were characterised by mass hysteria on the stock market, which led to the terrible crash of 1929 and the subsequent great depression.

The Bolshevik ideology also rose to power in the twenties and wreaked havoc for several subsequent decades. In the thirties the ideology of the National Socialists rose to the fore and it also subsequently wreaked total havoc. The Germans not content with two episodes of mass hysteria in the earlier parts of the 20th Century lost the run of themselves over Waldsterben (dying forests) in the eighties[77], while currently they are immersed in hysteria over shutting down perfectly viable nuclear plants[78] and plastering their countryside at enormous cost with wind turbines and solar panels (Energiewende).

Globally since 1999, we have had the mass hysteria related to Y2K, the 'dotcom' bubble and crash, and further hysteria related to the war on terror and the Weapons of Mass Destruction (WMD) which weren't there. One could also throw in swine flu for good measure and not forget the madness of the build-up to the crash of 2008.

Now the weather is allegedly all out of control, when there is no evidence that it actually is. However, history teaches us all that is required is a scary hypothesis, a promise of some form of better Nirvana, or even better a combination of the two, plus then let the groupthink and exuberance take over. As Mark Twain put it; "*it's a lot easier to fool people then to convince them that they have been fooled*". Pity that

[76] https://www.dccae.gov.ie/documents/The%20National%20Renewable%20Energy%20Action%20Plan%20(PDF).pdf

[77] https://notrickszone.com/2011/05/26/documentary-on-the-german-waldsterben-hysteria-looking-back-30-years/

[78] Plus doing so in a manner which was not fully legal and has as a result meant compensation claims have to be paid: https://phys.org/news/2018-05-berlin-compensate-power-firms-nuclear.html

time and time again an awful mess has to be first left behind before the realisation dawns and the pendulum swings. Sadly it the whole situation wouldn't arise in the first place without the chronically irresponsible behaviour of those placed in a position of trust and authority.

2. MINOR WARMING OR RUN AWAY CATASTROPHE?

2.1 Background

Humans successfully live in regions as diverse as the tropics to the polar North. It is not unusual for many successfully inhabited regions to have an annual temperature range of -20 °C to +40 °C, while over the course of a single day a temperature range of nearly half of this is not uncommon. To some environmental campaigners, any influence of man on the planet is unacceptable, but then we are getting into a level of extremism in which the depopulation of the planet is the objective.

William Nordhaus is an American economist and Professor of Economics at Yale University, who is best known for his work in economic modelling and climate change and was one of the two winners of the 2018 Nobel Prize in Economic Sciences. Figure 2.1 below is an extract from one of his papers.

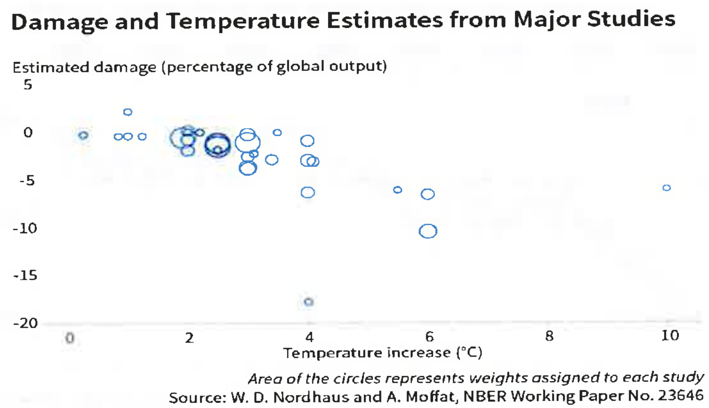


Figure 2.1: *Estimated damage per Degree Celsius of Temperature Increase*[79]

What the above shows is that a mild warming of the order of 2 °C is not detrimental. Indeed, it may even be beneficial, as it is the cold which has the potential to cause more hardship. In practice an increase in temperature of 1 °C is equivalent to a move of some 200 km nearer to the equator, Belfast gets Cork's climate.[80] It is not until significant warming occurs, such as 4 °C or more, that significant damage can be considered to be occurring. In a nutshell, not all global warming is catastrophic or even harmful, it is the extent of the warming which counts.

As this Section goes on to explain, for catastrophic warming to occur requires far more than just CO_2 emissions, it also requires the planet's climatic systems to be in a

[79] https://www.nber.org/reporter/2017number3/nordhaus.html

[80] Belfast mean temperature 8.9 °C while that of Cork is 9.9 °C:
https://en.climate-data.org/europe/united-kingdom/northern-ireland/belfast-6014/
https://www.met.ie/climate-ireland/1981-2010/cork.html

state of complete instability, an instability for which the evidence is simply not there. The future is always unknown, but so too is the fact that as a society we always live with a degree of unknowns. For example, in deciding that a defendant is guilty, the jury have to accept a degree of unknowns, in that they weren't actually there. They are also presented with diametrically conflicting hypotheses during the trial, but in coming to their decision, they will usually apply what is known as Occam's razor:

- *Occam's razor (also Ockham's razor; Latin: lex parsimoniae "law of parsimony") is a problem-solving principle that, when presented with competing hypothetical answers to a problem, one should select the one that makes the fewest assumptions. The idea is attributed to William of Ockham (c. 1287–1347), who was an English Franciscan friar, scholastic philosopher, and theologian.*

In other words, straightforward concepts, which do not require a high degree of complexity and interactions to explain the evidence which is available, are inherently better.

2.2 Historical knowledge of our climate

Any study of climatic systems should start with a review of our knowledge of the past. Armagh Observatory in N. Ireland has one of the longest temperature records on the planet, see Figure 2.2 below. In addition, Armagh has not grown dramatically over the intervening two centuries, so the record is not appreciably affected by the impact of urbanisation, which by its nature tends to create a heat island.

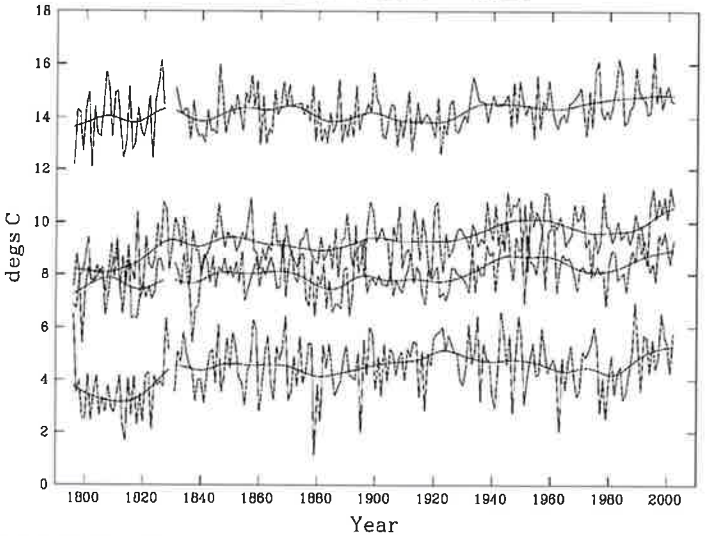


Figure 2.2: *Armagh Observatory temperature record; from the bottom, winter, spring, autumn, summer*[81]

[81] http://artefacts.ceda.ac.uk/badc_datadocs/armagh/445.pdf

What is obvious is that there has been little change in summer temperatures, with the biggest change occurring to winter temperatures in the period 1800 to 1830. Furthermore, there is also an indication of an undulating cycle, of about 30 years of warmer conditions followed by 30 years of somewhat colder (see the 1920s and 1930s versus the 1960s and 1970s). This is a point which will be returned to later in Section 2.8. However, if there is any degree of significant change in the record, then this is clearly that of the period 1800 – 1830. In 1820 the world's population was 1.05 billion, the industrial revolution was in its infancy and the steam train had not been invented. In other words, it wasn't CO_2 which was driving the change.

A global mean surface temperature record is by its nature a problematic concept, as the planet is quite diverse by its nature and subject to significant temperature variations (see Section 2.10), while urban heat impacts have affected many temperature recording sites, which are now located in busy urban areas or airports. However, Figure 2.3 below does provide such a historical global mean surface temperature record. That the temperature has risen since the 1850s is not disputed, but a point of relevance, which will be returned to later, is that the temperature rise in the period 1920 to 1940 is not much different to the rise in the period 1980 to 2000.

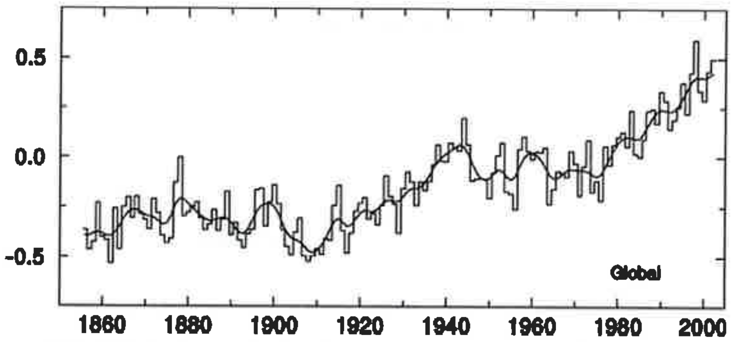


Figure 2.3: *Historical global mean surface temperature record HADCRUT1*[82]

H.H Lamb was a post war meteorologist and founding father of climatic research. While his work predating the founding of the IPCC and the increasing dominance of computer modelling, his book "Climate History and the Modern World" is like a detective novel piecing together from old records mankind's passage through time and how the climate changed. Explaining such as why in Ireland we have the Ceide Fields and bog oak.[83] As can be seen from Figure 2.4 overleaf, the Medieval period was warm, which was then followed by the 'Little Ice Age', before a general rise in temperature to present day circumstances. However, we have not yet reached the same temperatures as expereinced in what is referred to as the 'Medieval Warm Period'.

[82] https://crudata.uea.ac.uk/cru/data/crutem1

[83] https://ens9004-mza.infd.edu.ar/sitio/upload/08-%20LAMB.%20H.H.%20-%20LIBRO%20-%20Climate.%20History%20and%20the.pdf

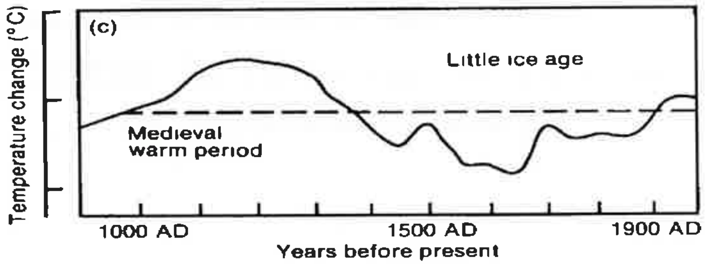


Figure 2.4: *Graph from IPCC first report Chapter 7 "Observed Climate Variations and Change", which was based on H.H Lamb's work*[84]

Indeed, Tim Severin in his recreation of the 'Brendan Voyage' in the 1970s consistently refers in his book as to how climatic conditions would have been more favourable in the time Medieval times of St Brendan, when Irish monks crossed the Atlantic in a leather boat. Figure 2.5 below shows the climatic record of the Greenland ice cores, which puts the above climatic trend into a longer context.

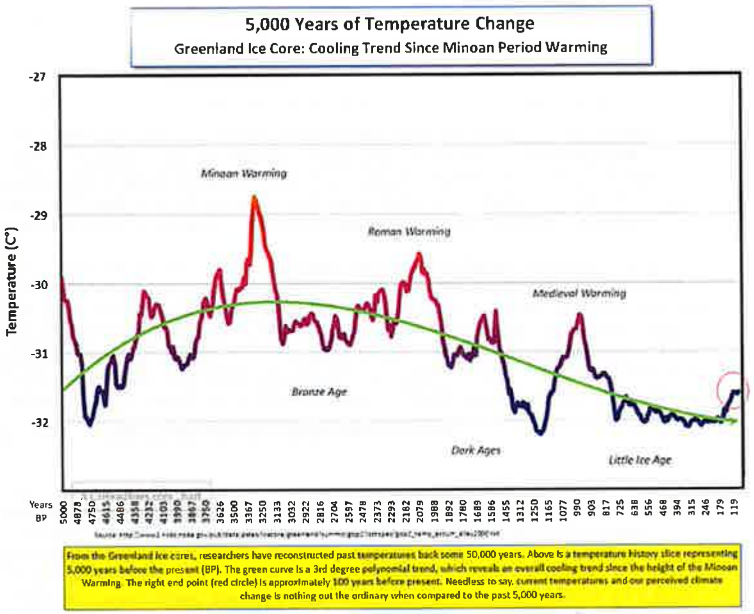


Figure 2.5: *Greenland ice core temperature record*[85]

[84] https://www.ipcc.ch/ipccreports/far/wg_I/ipcc_far_wg_I_chapter_07.pdf

While H.H Lamb's research would have pre-dated access to the above ice core data, his book eloquently describes the major consequences which occurred when the climate shifted from the Medieval Warm Period to the Little Ice Age. Similarly the 'Dark Ages', which followed the Roman Period were a time of great upheaval and difficulties. In general the extended record shows a decreasing trend and in the main, it is quite stable and self correcting.

However, history does have to get rewritten to suit the politics, and this is what happened with the famous 'Hockey Stick' graph, see Figure 2.6 below, which featured strongly in the 2001 Third Assessment Report of the IPCC, in particular its Summary for Policy Makers.[86]

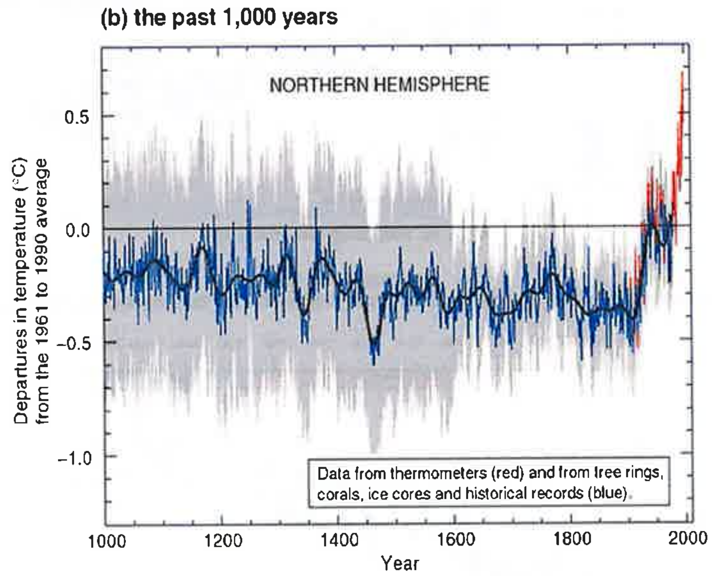


Figure 2.6: *'Hockey Stick' graph from IPPC Third Report of 2001*

This lead to huge controversy, as it sought to effectively 'wipe out' the Medieval Warming Period and what was known and accepted by the research community to that point. There was also a refusal to provide access to the data, which was used to generate this graph, which lead in time to the release of the 'climategate' e-mails. This story is written elsewhere,[87] but effectively the above graph was generated by the use of unsuitable data and biased statistics. Many would rightly consider it as

[85] https://www.c3headlines.com/temperature-charts-historical-proxies.html

[86] https://gridarendal-website-live.s3.amazonaws.com/production/documents/:s_document/287/original/wg1spm.pdf?1488203631

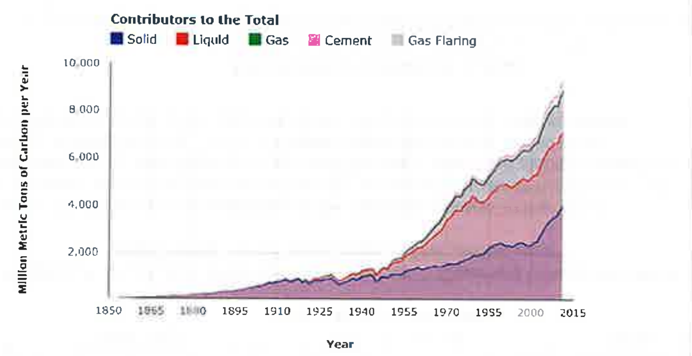
[87] Such as in the "The Hockey Stick Illusion: Climategate and the Corruption of Science" by A.W. Montford

politically motivated fraud and there is considerable evidence to support this position. It also highlights a fundamental principle, in that source data for scientific claims has to be made available, such that it can be replicated by others. Particularly so when such claims are being made to deliberately influence policy makers in areas, which involve enormous public spending and constraints on people's lifestyles. As it turns out this highly publicised graph is no longer used by the IPCC. However, this then 'begs the question', if a number of sceptically minded citizens had not been motivated to chase after the supporting information and the e-mails and other documentation had not come to life documenting the degree of deception occurring, then where would we be now?

2.3 Fossil fuels and the global carbon cycle

Figure 2.7 below shows the historical growth in carbon emissions from fossil fuel usage, which when expressed alternatively in emissions of CO_2, currently equates to about 36 billion tonnes per annum.[88] What is clear, and is generally accepted by the scientific community, is that emissions did not grow significantly until around 1950. That fossil fuel emissions of CO_2 are potentially a driver of climatic change, is really a concept applying to the post 1950 era. Furthermore, the global population in 1950 was 2.53 billion, while it is now 7.3 billion, although this growth is levelling off.[89]

If we refer back to Figure 2.3, as was pointed out, the rise in global temperature, which occurred in in the period 1920 to 1940 is not much different to the rise in the period 1980 to 2000, yet the alleged driver for this, namely CO_2 emissions, was radically different in the two periods. Note: Irish emissions, as was explained previously in Section 1.5, amount to about 60 million tonnes of CO_2 per annum.



Source: Boden, T.A., G. Marland, and R.J. Andres. 2015. Global, Regional, and National Fossil-Fuel CO_2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi 10.3334/CDIAC/00001_V2015.

Figure 2.7: *Historical growth in fossil fuel emissions*[90]

[88] To convert emission in Carbon to CO_2; molecular weight of CO_2 is 44 kg/kmol and carbon 12 kg/kmol. Therefore a conversion factor of 3.67

[89] Global population in 1950 was 2.53 billion, now 7.3 billion

[90] https://cdiac.ess-dive.lbl.gov/trends/emis/glo_2010.html

It is generally accepted that the pre-industrial concentration of CO_2 in the atmosphere was about 280 parts per million (ppm) or 0.028%. As the emissions above rise, there is also an increase in measured concentrations of CO_2 in the atmosphere, but this is a complex relationship, as will be explained later, while as Figure 2.8 below shows, no statistically relevant correlation exists between increasing CO_2 in the atmosphere and global surface temperatures.

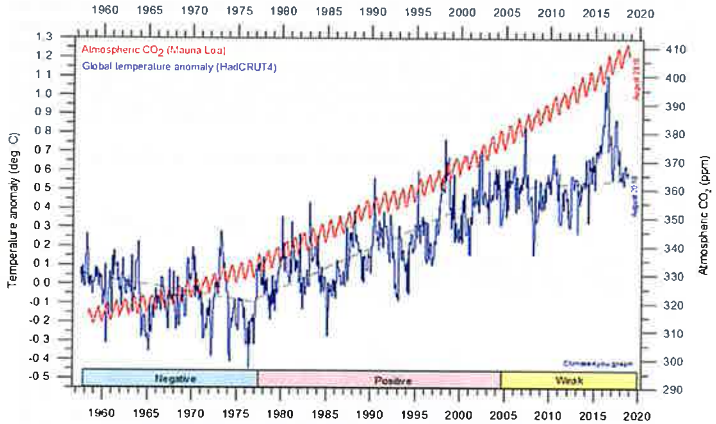


Figure 2.8: *Relationship between global temperature change and rising atmospheric CO_2 concentrations*[91]

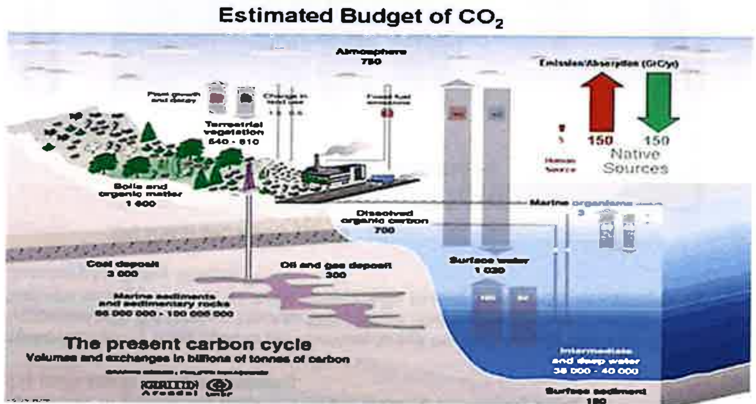


Figure 2.9: *UN's representation of the planet's Carbon Cycle*[92]

[91] https://www.climate4you.com/ Greenhouses Gases

[92] https://www.grida.no/resources/6453

Figure 2.9 above is a representation of the global carbon cycle, showing not only the complexity of the mass flows, but that the natural cycles completely dominate the anthropogenic (manmade) contribution. The tiny red arrow on left (5 Gt/Cyr) is anthropogenic fraction, while the big red and green arrows (150 Gt/Cyr) are the natural carbon exchange, which is primarily driven by the oceans both degassing and reabsorbing CO_2.

Even a minor imbalance between natural sources and sinks can overwhelm the anthropogenic component of CO_2 emission. Neither are we remotely in a position to verify the flows depicted above. As a result there is still some considerable scientific controversy, as to what percentage of the current increase in atmospheric CO_2 concentrations is due to natural degassing of the oceans, which is occurring as we experience a warming cycle following the 'Little Ice Age', versus the contribution from burning of fossil fuels.

2.4 So what is the greenhouse effect?

Chemical engineers attach great importance to the completion of heat and mass balances around the industrial facilities they are designing. These are the detailed assessments of the how heat and mass flows through the process and are the cornerstone of such designs. Figure 2.10 below, on paper at least, appears to be a very fine heat balance of the planet.

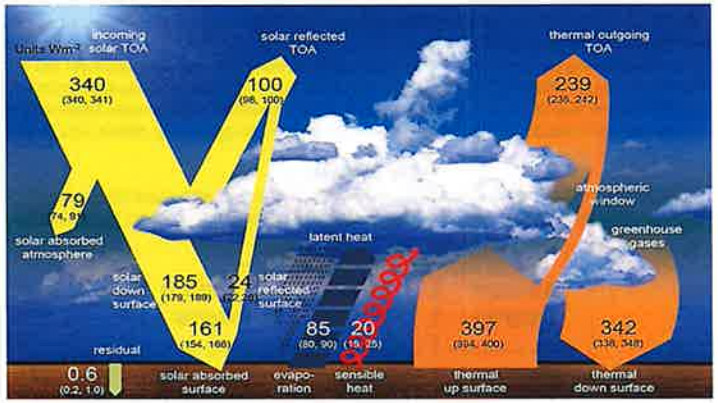


Figure 2.10: *IPCC representation of Global Energy Balance*[93]

However, the section of the IPCC report from which it is derived "2.3.1 Global Mean Radiation Budget" is full of caveats as to how the figures are uncertain. In reality Figure 2.10 is nothing more than a 'pretty picture'. Take for instance what should be easy, the measurement of the incoming solar radiation, the sun after all being the biggest driver of our climate. Do we know this figure to be right?

[93] Figure 2.11 of the IPC AR5 Report:
https://www.ipcc.ch/report/ar5/wg1/observations-atmosphere-and-surface/

The atmosphere prevents us from obtaining a direct measurement of incoming solar radiation at ground level, as is shown above, so it was only with the recent advent of satellites that we have been able to get above the atmosphere to measure it. However, the readings from the satellites that have been utilised have differed and the measurement devices have decayed over time. We also know that the sun's output varies; there is the 'eleven year' sun spot cycle, while there are variations over a longer period. So while a numerical figure above is presented, this may be a snapshot of a short period of time, but is not necessarily an accurate representation of what happens over a longer period.

What is known as the 'greenhouse effect' can also be seen in Figure 2.10, the heat from the incoming solar radiation is partly reflected as longer wave infra-red radiation from the relatively warm surface of the planet. As this long wave infra-red radiation (depicted in orange) passes through the atmosphere, some of it is caught by the molecules there and re-radiated back to the earth's surface, while a fraction continues straight out to space. This re-radiation is the 'greenhouse effect'. However, the numbers assigned to the heat flows above are nothing but pure guesswork. For example as NASA point out:[94]

- *We find that water vapor is the dominant substance — responsible for about 50% of the absorption, with clouds responsible for about 25% — and CO_2 responsible for 20% of the effect (exact numbers disputed and not known) The remainder is made up with the other minor greenhouse gases, ozone and methane for instance, and a small amount from particles in the air (dust and other "aerosols").*

The bottom line is that water vapour is the overwhelming dominant driver of this 'greenhouse effect' and as we all know, it's presence in the atmosphere is highly variable and certainly not something that can be measured on a global scale. Indeed, while the CO_2 concentration is 400 ppm, the average water vapour concentration is estimated to be somewhat in the region of 25,000 ppm, but this is a guess as the ratio of the number of water molecules to CO_2 molecules varies from 1:1 near the poles to circa 97:1 in the tropics.

The reason for this being that cold air cannot hold the level of moisture that warm air does, which is due to the principle of saturation. For example, as warm air cools as it ascends, clouds form and precipitation occurs; the colder air now carrying an excess of water vapour beyond its saturation point at that temperature. There is therefore a complex meteorological relationship between the temperature of the air and its moisture content, e.g. a one percent increase in relative humidity or in low cloud cover decreases the temperature by 0.15 °C and 0.11 °C, respectively.[95] Water vapour is the dominant atmospheric gas contributing to the 'greenhouse effect', but we are simply not in a position to quantify the actual role it plays.

However, this is only part of the complexity, as Figure 2.10 on the left shows, as the solar radiation is incoming, it is partly reflected back to space. This reflection is called 'albedo'; clouds naturally have an albedo, but this is also a variable factor and dependent on parameters such as size, location (upper atmosphere versus lower atmosphere), colour, etc. The earth also has an albedo, dark surfaces will absorb incoming radiation, but if they are covered in ice and snow the albedo will be much

[94] https://www.giss.nasa.gov/research/briefs/schmidt_05/

[95] https://journals.sagepub.com/doi/abs/10.1260/0958-305X.25.2.389?journalCode=eaea

higher as the radiation is reflected. Figure 2.11 below shows therefore in a simple schematic fashion the complexity of the dynamics occurring with various cloud cover.

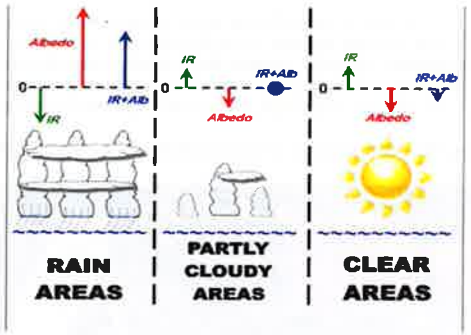


Figure 2.11: *Conceptual model of typical variations of IR, albedo and (IR + albedo) associated with three different areas of rain and cloud for periods of increased precipitation*[96]

In the 'rain areas' the significant cloud cover is directly related to the fact that the air is saturated with a high concentration of water vapour. As a result this water vapour is responsible for a strong 'greenhouse effect' depicted by the green arrow showing the net infrared flow being reflected back to the earth. However, as the clouds are well developed, the albedo is strong with considerable reflection of the incoming solar radiation, which is denoted by the red arrow going to space. The combination of the two is the blue arrow, which in these circumstances shows a net reflection of radiation to space and a cooling effect.

In the partly cloudy areas, the concentration of water vapour is lower and in many cases below saturation. This results in a reduced greenhouse gas effect, such that the infrared radiation from the warm planet below is primarily lost to space. However, the albedo is now not so strong, such that there is net solar radiation flow to the planet below. In combination the two cancel each other out, as shown by the blue dot, as the outgoing infrared radiation (green arrow) and incoming solar radiation (red arrow) are more or less equal.

In the final scenario, the sky is clear as the air is relatively dry and below saturation. There is as a result a limited amount of water vapour such that the greenhouse effect is weak and a strong infrared flow to outer space occurs depicted by the green arrow. The albedo is weak as there are no clouds, so there is also a strong solar radiation inward flow, as depicted by the red arrow. The net result depicted by the blue arrow is that there is an overall inward flow of radiation to the earth and a heating effect.

In practice we know this ourselves, when the weather is dry and the sky clear, the days are warmer and nights colder than those days when the sky is covered with cloud. We also know how thunderstorms can have a welcome cooling effect after 'stifling heat'.

[96] https://tropical.colostate.edu/media/sites/111/2018/01/Bill-Gray-Climate-Change.pdf

The planet is also temperature self-regulating by these means. Sea water temperature in the tropics rarely exceeds 32 °C despite the sun remorselessly beating down on it. As the day progresses the rate of evaporation increases, resulting in a cooling effect for the sea water and the increasing build-up of clouds. By late afternoon huge thunderstorms often develop, which ascend into the upper atmosphere, where the global circulation patterns carry the energy North and South, see Figure 2.16 in Section 2.7. The rain falling from these thunderstorms has a local cooling effect, while the moisture carried aloft North and South on global circulation patterns has the ability to raise the temperature in those regions, which are not exposed to such intense direct sunlight, and hence incoming solar radiation, as the tropics.

This response is what is known as negative feedback, if the morning in the tropics is somewhat warmer, the evaporation and cloud development simply occurs that bit earlier, with the net result that there is simply a slight increase in local precipitation and the amount of moisture carried into the upper atmosphere. The planet most certainly does not spin out of control, getting hot and hotter.

Referring back to Figure 2.10; this does not reflect an accurate representation of the planet's heat balance, but rather the current 'guesswork' of the IPCC. Furthermore, the dynamics of clouds and their heat flows are highly unknown, and until they are known, which could take a long time, all we have is 'guesswork'. So if the IPCC cannot accurately represent the current heat balance of the planet, how then are they in a position to make definite statements related to changes that are occurring? Particularly so, as is now explained in the next section, these changes to the heat balance are extremely limited in the order of their magnitude.

2.5 The limited impact of CO_2 on the planet's heat balance

The content of Figure 2.12 is crucial to any debate on Catastrophic Anthropogenic Global warming, but regretfully is neither known by nor explained to the public.

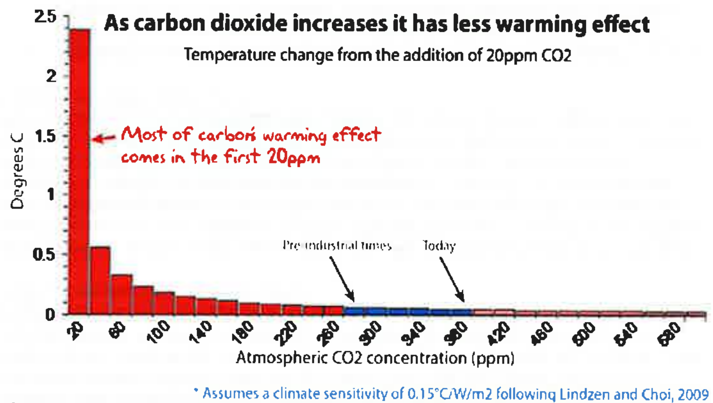


Figure 2.12: *The ability of CO_2 to have a warming effect – due to saturation of the wavelengths responsible for the 'greenhouse effect'*[97]

[97] http://joannenova.com.au/2010/02/4-carbon-dioxide-is-already-absorbing-almost-all-it-can/

The wavelengths over which CO_2 absorbs and re-radiates infrared radiation are already almost completely saturated at low concentrations of CO_2, this radiative effect being logarithmic with respect to concentration. This saturation can be thought of like painting a wall, which was previously a dark colour, with a new white colour. With the first coat the wall is predominately white, but a few dark streaks can be discerned. With a subsequent coat or two, there is very little or any dark colour showing. From that point on adding additional coats don't make any difference, as saturation with white paint has already been reached. Another way of looking at it is suppose you had a wine cellar, but the buzz was only in the first glass and it didn't matter how much wine you drank after that.

At the pre-industrial CO_2 concentration of 280 ppm, the wavelengths over which CO_2 can be absorbed by carbon dioxide are already almost fully saturated, and as the relationship is logarithmic, most of that absorption occurred in the first 0 to 60 ppm. There is therefore limited additional greenhouse gas effect and hence warming occurring as the CO_2 concentration is increased further. Indeed, this greenhouse effect is rapidly tailing off. This is why with respect to the whole agenda of the impact of burning additional fossil fuels, the single most important number, and to which the whole conflicting argument can be distilled to, is the value of the climate sensitivity which is applicable?

This climate sensitivity is the estimated response of the planet to a doubling of the pre-industrial CO_2 concentration of 280 ppm to about 560 ppm. As Figure 2.12 above shows, there is very limited additional warming impact beyond this point. It would also take the combustion of more or less our known reserves of fossil fuel to raise the planet's CO_2 concentration to around 560 ppm, while at the same time a powerful feedback mechanism would be occurring. That the oceans absorb CO_2 is well known, see Figure 2.9, and the quantity of CO_2 in the oceans is some fifty times that in the atmosphere. As the concentration of CO_2 in the atmosphere increases, the rate of absorption into the oceans also increases, this is a well know law of physics called Henry's Law. CO_2 in the oceans is also sequestered into the carbonates in shellfish and similar calcifying organisms, which is how limestone is formed over time.

Many scientists doubt we would actually reach 560 ppm, but if it did it most certainly wouldn't cause any direct harm us. As humans when we respire we release CO_2, the level in exhaled air being about 3.8%, or 38,000ppm. The concentration limit in industry for an eight hour shift is 0.5% or 5,000 ppm, while higher values are often to be found in submarines, where sailors routinely perform complex tasks in a confined and pressurised environment with nuclear reactors and ballistic missiles.

Plants also need CO_2 to grow, so higher CO_2 levels improve growth rates, such that agricultural greenhouses are routinely raised in CO_2 concentration to 1,000 ppm. This improvement in growth is most pronounced in arid regions, as the plants there cannot open their stomata (pores) so wide to allow the necessary gas transfer, as they would then loose too much valuable water vapour. This then restricts their ability to take in the necessary CO_2 through their leaves for growth, a situation which is improved when the CO_2 concentration is higher. Numerous studies have shown that the planet is increasingly greener in the last few decades, with this increased biomass growth being predominately attributed to increased CO_2 concentrations.[98] This is welcome news, not least as it correlates with increasing yields for grains and other foodstuffs.

[98] For example: https://www.nature.com/articles/nclimate3004

Referring back to the analogy of the wine cellar, the climate sensitivity can also be considered as equivalent to whom you feed that first glass of wine to. Is the planet in its response similar to a newly born baby with high sensitivities or is it more akin to a mature adult, who is used to having a drink or two? Surprisingly, there is little dispute or controversy in relation to the simple calculation from doubling the CO_2 concentration and the resulting temperature rise, which is in the order of about 1 °C. This is a point always agreed by the IPCC, see below, where the GCMs are the Global Circulation Models.[99]

- *"In the idealised situation that the climate response to a doubling of atmospheric CO_2 consisted of a uniform temperature change only, with no feedbacks operating (but allowing for the enhanced radiative cooling resulting from the temperature increase), the global warming from GCMs would be around 1.2°C":*

As highlighted in the previous Section 2.1, this is equivalent to everybody moving about 200 km nearer to the equator, namely Belfast gets Cork's temperatures. So where does the environmental disaster come from that is Catastrophic Anthropogenic Climate Change?

2.6 How Catastrophic Anthropogenic Climate Change requires the planet to be unstable

Figure 2.12 summarises the answer to this question, the whole theory of Catastrophic Anthropogenic Climate Change is based on the fact that the planet's climatic systems are inherently unstable. A strong feed forward mechanism occurs, in that a small amount of warming from a rise in CO_2 concentrations occurs, this then leads to an increase in water vapour in the atmosphere, which is the dominant greenhouse gas, which in turn leads to a much larger rise by several orders of magnitude in the overall warming effect. In other words it is solely the postulated increase in water vapour in the atmosphere, which causes the catastrophe.

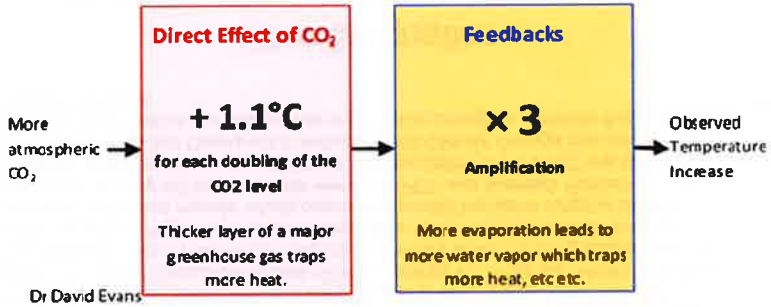


Figure 2.13: *The feed forward mechanisms of an unstable planet which are required for Catastrophic Anthropogenic Climate Change to occur*[100]

[99] AR4 Climate Change 2007: The Physical Science Basis Section 8.6.2.3 page 631: https://www.ipcc.ch/site/assets/uploads/2018/05/ar4_wg1_full_report-1.pdf

[100] http://joannenova.com.au/2012/01/dr-david-evans-the-skeptics-case/

This then is the hypothesis on which the whole Catastrophic Anthropogenic Climate Change agenda was based, which from the onset was always widely disputed. Not least as there was an equally valid, less complex hypothesis, see Figure 2.14 below, which was based on the fact that; (a) the planet's climate has been stable over millennia, demonstrating that negative feedbacks dominate, while (b) the increased warming from doubling the CO_2 concentration is limited to about 2% of the net incoming solar radiation. Therefore, this small increase in temperature from the increasing CO_2 concentration would be effectively lost within the planets natural feedback mechanisms. Indeed, as was previously articulated, such as the rain clouds in the tropics being just a little more active.

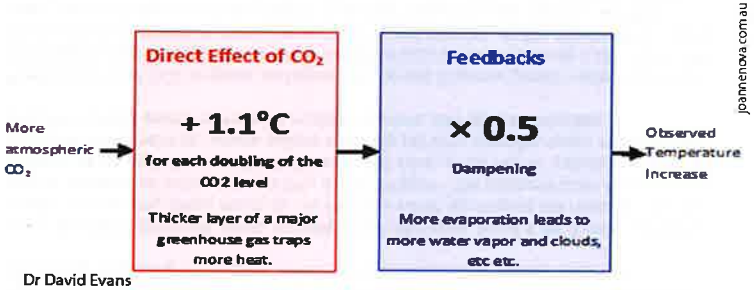


Figure 2.14: *The impacts of a feedback mechanism on the direct warming effects of CO_2*

Richard S. Lindzen was Professor of Meteorology at the Massachusetts Institute of Technology until his retirement in 2013. While he worked on the earlier IPCC reports, he became a major critic of the politicised and alarmist position adopted. As he has often pointed out: Small percentage changes in either water vapour or clouds are fully capable of changing the infrared flux more than the changes induced by increased CO_2.[101] This increased warming from CO_2 is therefore just 'noise' when compared with the natural climatic variations which occur, such as in relation to snow cover, oceanic circulation, volcanic eruptions, etc.

As the American Chemical Society also explains:[102]

- *The addition of the non-condensable gases causes the temperature to increase and this leads to an increase in water vapor that further increases the temperature. This is an example of a positive feedback effect. The warming due to increasing non-condensable gases causes more water vapor to enter the atmosphere, which adds to the effect of the non-condensables.*

- *There is also a possibility that adding more water vapor to the atmosphere could produce a negative feedback effect. This could happen if more water vapor leads to more cloud formation. Clouds reflect sunlight and reduce the amount of energy that reaches the Earth's surface to warm it. If the amount of solar warming decreases, then the temperature of the Earth would decrease. In that case, the effect of adding more water vapor would be cooling rather than warming. But cloud cover does mean more condensed water in the*

[101] https://www.thegwpf.org/content/uploads/2018/10/Lindzen-AnnualGWPF-lecture.pdf

[102] https://www.acs.org/content/acs/en/climatescience/climatesciencenarratives/its-water-vapor-not-the-co2.html

atmosphere, making for a stronger greenhouse effect than non-condensed water vapor alone – it is warmer on a cloudy winter day than on a clear one. Thus the possible positive and negative feedbacks associated with increased water vapor and cloud formation can cancel one another out and complicate matters. The actual balance between them is an active area of climate science research.

That the science was ever settled is preposterous. Until society develops a detailed knowledge of how clouds form and the energy and water vapour balances within them, the Global Circulation Models (GCMs) used by the IPCC will remain as nothing but academic toys, in which their outputs are entirely driven by the guesses used as input figures. As Figure 2.15 below shows, after more than 30 years, we have got nowhere with these models, which continue to predict the same range of climate sensitivity as they did back in 1980s when the IPCC was founded. Furthermore, to reiterate what was previously articulated, the foundation of the IPCC was based on a political decision that Catastrophic Anthropogenic Climate Change was occurring, a decision taken before the science was ever robust enough to conclude that this was actually the case.

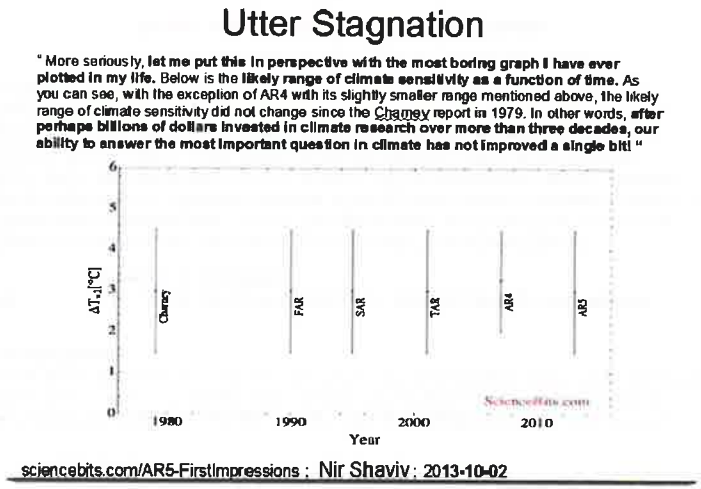


Figure 2.15: *More than thirty years of the range of predictions of climate sensitivity by Global Circulation Models used by the IPCC*

Despite the fact that these models are of such limited use, it is not as if we are entirely in a position of 'known unkowns'. For starters we have now reached a CO_2 concentration of 400 ppm, which given the logarithmic relationship shown in Figure 2.12, is about 45% of the climate sensitivity to be experienced. Not only are there no dramatic changes occurring, but the feed forward mechanism integral to the catastrophic warming shown in Figure 5.13, requires a significant increase in specific humidity to occur in the upper troposphere. Where the troposphere is the lowest region of the atmosphere, which extends from the earth's surface to a height of about 6–10 km, i.e. the region where jet aircraft fly. Yet satellite measurements are simply not showing this increase in water vapour content in the upper troposphere to be occurring. In fact a slight decrease is happening. While this position is being highlighted by a number of scientific papers,[103] it is being ignored by the politicised IPCC.

We also know from extended ice core data now stretching back to the ice age periods, ice ages which were caused by orbital changes in the planet that in these periods both the planet's temperature and CO_2 concentration changed quite dramatically. However, the critical feature is this data is that the CO_2 increase lagged temperature. In simple words the temperature increased and then this was followed in later years by an increase in CO_2. This indicates that as the oceans warmed, they degassed, and disapproves the theory that CO_2 led to the temperature increase.

In summary then to accept the hypothesis of Catastrophic Anthropogenic Climate Change is to accept that the small stubby tail can wag the big dog and that the planet's climatic systems are at a degree of instability, which defies our known knowledge based on the considerable evidence available to us. As a scientific hypothesis, it was widely speculative from the start, and given what we now know from the evidence in front of us, it can only be considered to be a hypothesis which is 'busted'. Simply put, Catastrophic Anthropogenic Climate Change only exists within highly flawed computer models and the minds of those, who want to believe it. There are far more balanced and realistic explanations for the real world around us, which are not obsessed with CO_2. Over the last thousands of years since the last ice age there have been subtle changes in the planet's climate and we would be well advised to concentrate our efforts to understand those first, before we go off making rash predictions.

2.7 The oceans drive the atmosphere and not the other way around

In their section on uncertainties in their AR5 report of 2013 the IPCC stated:[104]

- *"There are fundamental limits to just how precisely annual temperatures can be projected, because of the chaotic nature of the climate system. Furthermore, decadal-scale projections are sensitive to prevailing conditions—such as the temperature of the deep ocean—that are less well known. Some natural variability over decades arises from interactions between the ocean, atmosphere, land, biosphere and cryosphere, and is also linked to phenomena such as the El Niño-Southern Oscillation (ENSO) and the North Atlantic Oscillation".*

Oceans form more than 70% of the planet's surface and go to great depths. The heat absorbing capacity of the oceans is a thousand fold that of the atmosphere, which is not surprising given that water has a very high specific heat capacity. The biggest short term impact on global climate is the El Nino Southern Oscillation (ENSO), while the biggest medium term impacts are the Atlantic Multidecadal Oscillation (AMO) and

[103] For example:
https://www.researchgate.net/publication/274956207_The_potency_of_carbon_dioxide_CO2_as_a_greenhouse_gas

[104] Climate Change 2013 – The Physical Science Basis: Working Group I. See FAQ 1.1 on page 140:
https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_all_final.pdf

the equivalent Pacific Multidecadal Oscillation (PDO). Indeed Met Eireann's own Research on the Irish Climate states:[105]

- *"The Atlantic multidecadal oscillation (AMO) explains over 90% of the pronounced decadal temperature and summer precipitation variation"*

The global circulation patterns are shown in idealised form in Figure 2.16 below.

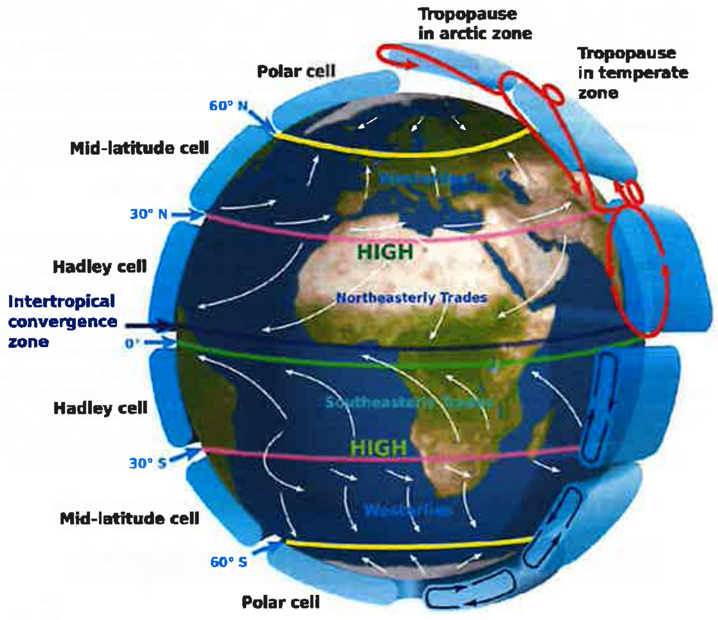
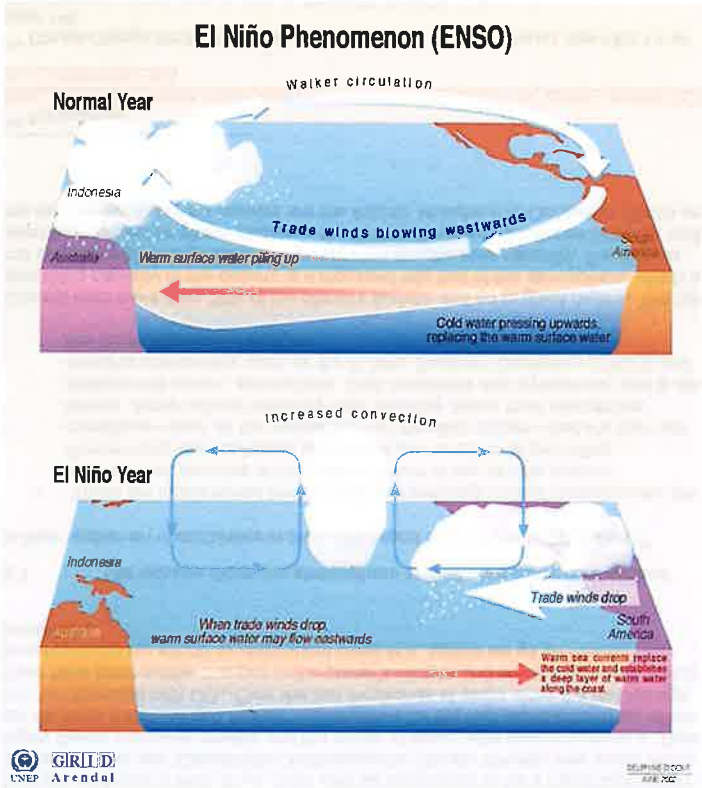


Figure 2.16: *The idealised global circulation pattern*

In simple terms the effect of these weather systems is to shift heat from the tropics to the poles, the poles radiating heat to space, particularly so in the period of winter darkness. However, these weather systems are constantly moving, not only due to seasonal changes, but there are also pattern shifts on a short and long term basis driven by oceanic effects. Figure 2.17 overleaf is a schematic of the El Nino Southern Oscillation (ENSO), which is the biggest short term impact on the planet's climatic systems.

[105] "The influence of ocean variations on the climate of Ireland":
https://rmets.onlinelibrary.wiley.com/doi/full/10.1002/wea.2543



Sources: Climate Prediction Center-NCEP, NOAA

Figure 2.17: *Simple schematic of the El Nino Southern Oscillation (ENSO)*[106]

In a normal year the easterly trades blow across the Pacific leading warm water to pile up in the Western Pacific, where as a result what is known as the tropical convergence occurs, which is a band of active and vigorous thunderstorms. At the same time, cold water rises off the coast of South America and is blown to the West. Neither the intensity nor the timing of an El Nino can be predicted, but when it occurs there is a strong drop off in the Easterly trade winds allowing the warm surface water to 'slosh' back East into the Central Pacific or even as far back as the South American coast. As a result the weather patterns change over the whole Pacific and interrelated regions, as the zone of increased convection moves east into the Central and Eastern Pacific region. Parts of South America experience torrential rainfall, while rainfall is reduced in Australia and Indonesia.

[106] https://grimstad.uia.no/puls/climatechange/nns02/10nns02.htm

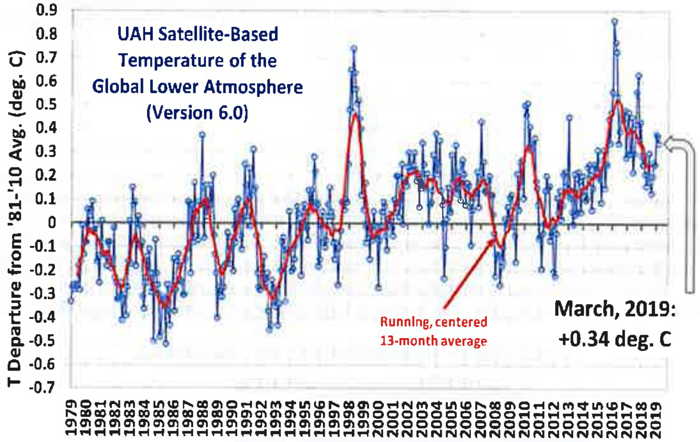


Figure 2.18: *Global satellite record showing peaks due to El Nino years*[107]

US satellites have being measuring global temperatures since 1979. This record is characterised by the El Nino years, 1999 and 2017 being particularly powerful El Nino years, as these El Nino years have acted like a pump, injecting ocean heat into the atmosphere to be dispersed to the poles. The aftermath of the El Nino is followed by La Nina, the cold phase of the El Niño Southern Oscillation, which is associated with cooler than average sea surface temperatures in the Central and Eastern tropical Pacific Ocean, see 'normal year' of previous Figure 2.17. The short term global temperature record is therefore driven by the alternating ENSO phases. Note: 2016 may have seen the biggest spike in global temperatures, due to an exceptionally powerful El Nino, but it was subsequently followed by biggest drop in temperatures every recorded.

2.8 The influence of the Meridional Overturning Current (MOC)

A (geographic) meridian (or line of longitude) runs North South on the planet's surface, as opposed to lines of latitude, which run East West. Figure 2.19 overleaf is a simplified representation of the Meriodional Overturning Current (MOC), which is like an enormous ocean heat conveyor. Every school child in Ireland learns about the Gulf Stream, but this is only the northerly and surface part of the Atlantic Thermohaline Circulation. This circulation is driven by both the prevailing winds and the density differences due to variations in temperature and salinity. Salinity is higher in the tropical regions where there is increased evaporation, while as the water is transported to the more polar regions of the North Atlantic, it cools and sinks. As a subsurface current it then returns to the South, completing the circulation pattern.

This is a complex pattern taking not just years, but centuries for the water exchange to occur. However, on a decadal level (over decades) there are some notable and repeatable changes.

[107] http://www.drroyspencer.com/latest-global-temperatures/

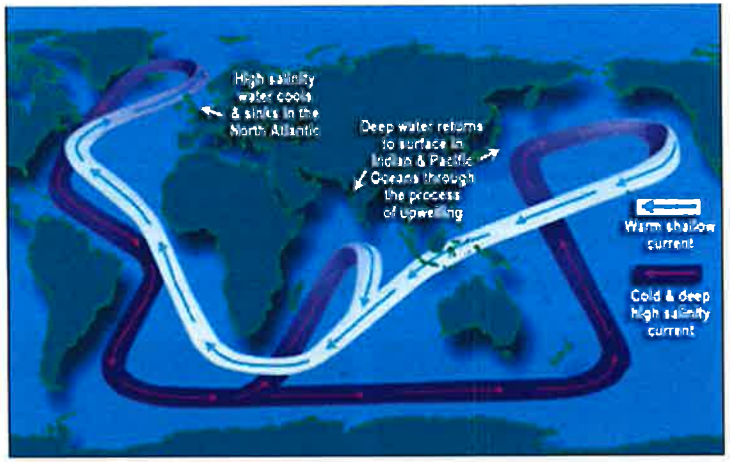


Figure 2.19: *A simplified representation of the Meridional Overturning Current*

As previously mentioned, the Atlantic Multidecadal Oscillation (AMO) is considered by Met Eireann to be responsible for 90% of the decadal variation in Irish summer temperatures and precipitation. When the AMO is in its strong or positive phase, the North Atlantic sea surface temperatures are warmer as the Thermohaline Circulation is strong. During the negative (weak) phase of the AMO, the North Atlantic sea surface temperatures are colder. Both the AMO and equivalent Pacific Decadal Oscillation (PDO)[108] have been known for centuries due to their impacts on fish stocks.

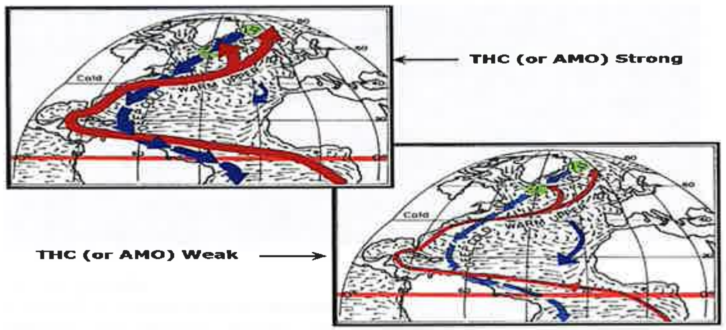


Figure 2.20: *Simplified schematic of the Atlantic Multidecadal Oscillation (AMO) which is due to changes in the Thermohaline Circulation (THC)*[109]

[108] https://www.sciencedirect.com/topics/earth-and-planetary-sciences/pacific-decadal-oscillation
[109] https://tropical.colostate.edu/media/sites/111/2018/01/Bill-Gray-Climate-Change.pdf

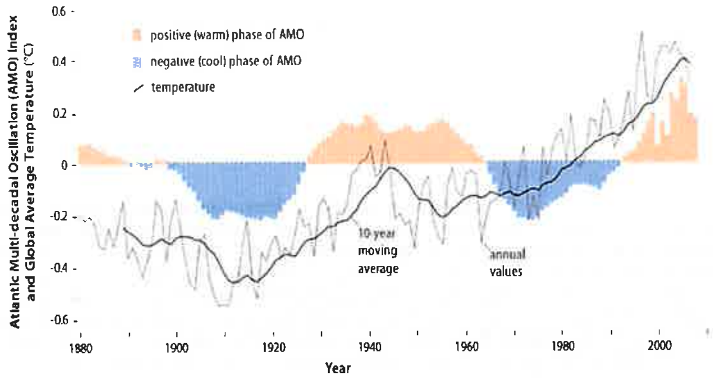


Figure 2.21: *Relationship between phases of the AMO and Global Average temperature (° C)*[110]

The AMO follows an approximately thirty year pattern of a positive warm phase followed by a negative cold phase, which correlates with the undulating cycle to be seen in the Armagh temperature record, see previous Figure 2.2. The above Figure 2.21 shows the relationship between the phases of the AMO and global average temperatures. It is not an exact relationship, but positive phases of the AMO do seem to be leading to an increase in temperatures.

However, one must remember that the Atlantic is but only one of two large oceans. Figure 2.22 below shows what happens when the AMO is represented along with the PDO.

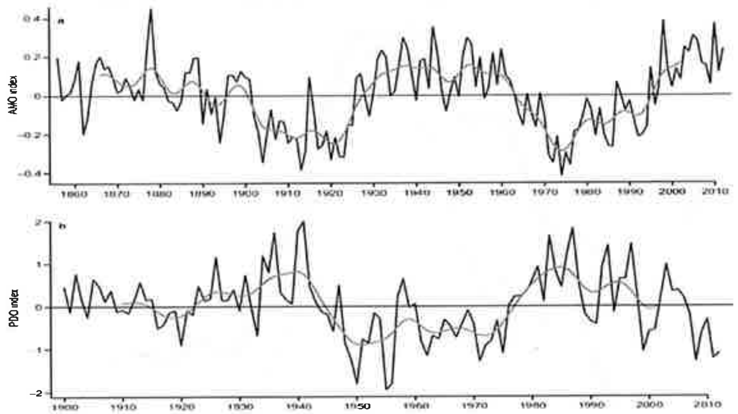


Figure 2.22: *AMO Index top graph and PDO Index bottom graph*[111]

[110] https://www.climate.gov/news-features/features/short-term-cooling-warming-planet

Both the AMO and the PDO have the potential to overlap in both their warm and cold phases, therefore along with the El Nino Southern Oscillation being a major driver of global temperature change.

The North Atlantic Oscillation (NAO) index is the difference in atmospheric pressure between the Icelandic Low and the Azores High.[112] As such it constantly varies on a daily basis, but trends can be seen. It is also the index, which is most important in describing and determining the weather patterns in North Western Europe, see Figure 2.23 below.

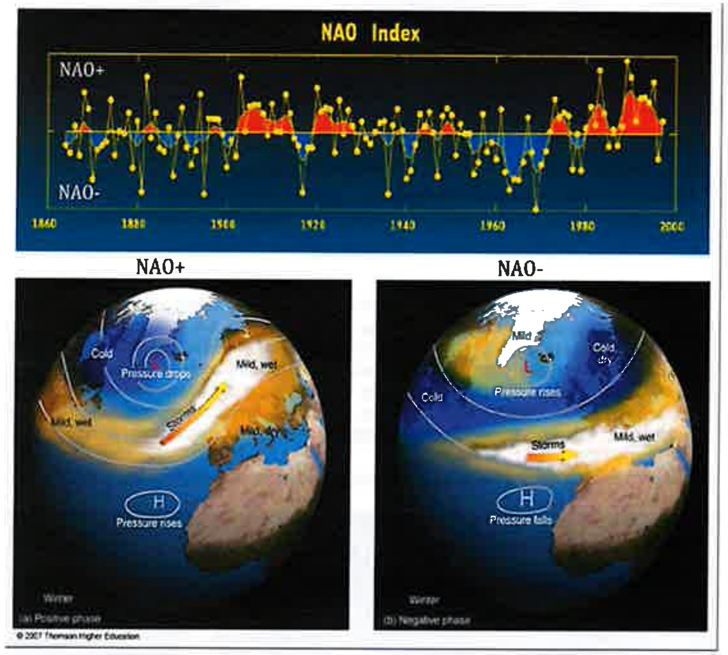


Figure 2.23: *Schematic representation of NAO Index and variations since 1860*

When the NAO is in the positive phase in winter, the jetstream is strong and a succession of low pressures route into North Western Europe resulting in mild, wet and windy weather. When the NAO is in the negative phase in winter, the jetstream is located further south, such that the low pressures tend to move into the Mediterranean, while high pressure builds in North Western Europe leading to cold and dry conditions. The NAO also tends to show a cyclical pattern, which is linked to the phases of the AMO.

[111] https://www.researchgate.net/figure/a-Atlantic-Multi-decadal-Oscillation-AMO-index-defined-as-detrended-North-Atlantic_fig1_282846396

[112] https://www.cpc.ncep.noaa.gov/data/teledoc/nao.shtml

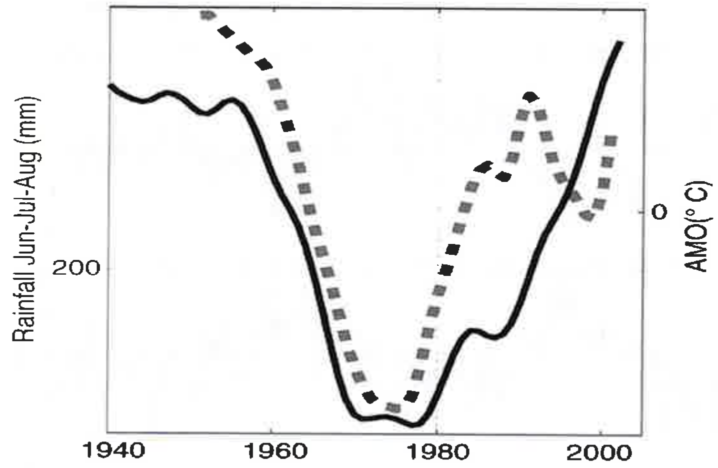


Figure 2.24: *Met Eireann Research Paper – Correlation between Irish summer rainfall and phases of the AMO*[113]

Figure 2.24 is taken from the same Met Eireann research paper on: *"The influence of ocean variations on the climate of Ireland".* As can be seen when the AMO is negative, Irish summer weather is characterised by drier conditions, as the low pressures coming in from the Atlantic are fewer and less active. This can be explained by the cooler sea surface temperatures of the cold negative phase, as opposed to the warmer sea surface temperature of the positive phase, the latter which undoubtedly results in more moisture in the atmosphere.

The Sahel is the sub-Saharan region, which is known to experience drought conditions during the negative phase of the AMO.[114] It is not surpring that Band-Aid in 1984, which was a response to terrible drought conditions in that region and resulting starvation, occurred after several years of the impact of a negative AMO. Since then the scientific literature is full of references to the greening of the Sahel, which is partly due to the fact that we have subsequently been in the positive phase of the AMO. It is also known that the number of tropical storms, which mature into severe hurricanes, is much greater during warm phases of the AMO than during the cooler phases, which is logical given that the increased sea sufrace temperatures in the warm phase provide more energy to cyclonic development.

[113] https://rmets.onlinelibrary.wiley.com/doi/full/10.1002/wea.2543

[114] https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2006GL026267

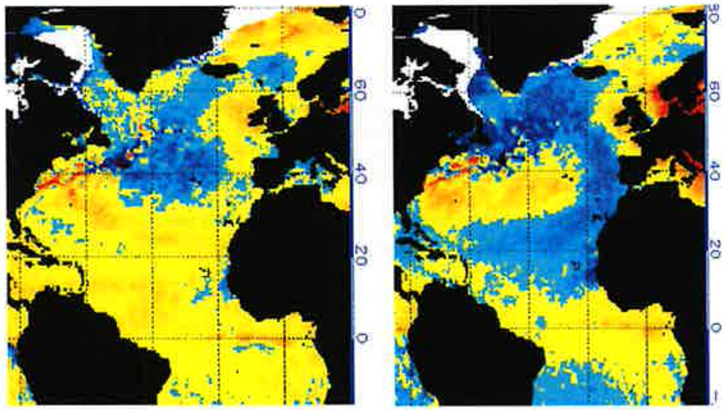


Figure 2.25: *Atlantic sea surface temperature anamolies; June 2016 on the left and June 2018 on the right*[115]

Figure 2.25 shows the change, which occurred in Atlantic sea surface temperatures in the period June 2016 to June 2018. Increasingly it is commented on in the scientific literature that the AMO is now showing indications of turning negative again.[116] Are we to see a greater frequency of warmer and drier summers in Ireland? Certainly 1974 and 1976 were 'stand out' summers, while 2018 didn't disappoint. Did the colder sea surface temperatures play a role? There are many meteorologists who appear to think so.

Clearly there are known oceanic climate cycles, which have major impacts on the weather of North Western Europe and as far south as the Sahel, but this impact also goes further north to the Arctic.

2.9 The Arctic ice is melting – again

The melting of sea ice in the Arctic is the 'poster child' of activists promoting Catastrophic Anthropogenic Climate Change. However, this is worthy of more detailed examination. The sea ice obviously grows during the depth of the Arctic winter when there is little or no sunlight, while in the summer there is a melting phase as sunlight reaches the ice twenty four hours a day. In the more northerly areas, some ice is multi-annual in that it surives the summer melt. It is the extent of this remaining summer ice, which is the clarion call, in that it is frequently projected that because of global warming the Arctic will become ice free. Indeed, as many point out with justification, the Arctic should according to these predictions have been ice free several years ago, but it most certainly isn't.[117] However, new revised predictions can always be made for several years hence, 'as the show must kept on the road'.

[115] https://www.ospo.noaa.gov/Products/ocean/sst/anomaly/

[116] https://www.nature.com/articles/s41598-017-11046-x

[117] https://notrickszone.com/2018/07/21/charlatans-of-the-arctic-laughing-stock-ice-free-arctic-predictions-fake-science-at-its-best/

THE CHANGING ARCTIC.

By George Nicolas Ifft.

[Under date of October 10, 1922, the American consul at Bergen, Norway, submitted the following report to the State Department, Washington, D. C.]

The Arctic seems to be warming up. Reports from fishermen, seal hunters, and explorers who sail the seas about Spitzbergen and the eastern Arctic, all point to a radical change in climatic conditions, and hitherto unheard-of high temperatures in that part of the earth's surface.

Figure 2.26: *Report of American consul in Norway to the U.S. State Department in October 1922 and published in the Monthly Weather Review*[118]

Howver, it is not the first time that the Arctic has warmed up and that this has 'hit the papers'. A warming occurred in the 1920s and 1930s as the above Figure 2.26 documents. This was then followed by a cooling phase particularly so in the 1960s and 1970s, when pack ice increased. An astute observer would notice that the Arctic is barely open to the Pacific, as the Bering Strait is quite narrow, while it is very open to the influence of the North Atlantic. The warming and cooling phases described above clearly match those of the phases of the AMO, while the rate of ice melt is determined by the water temperature below it rather than the air temperature above it.

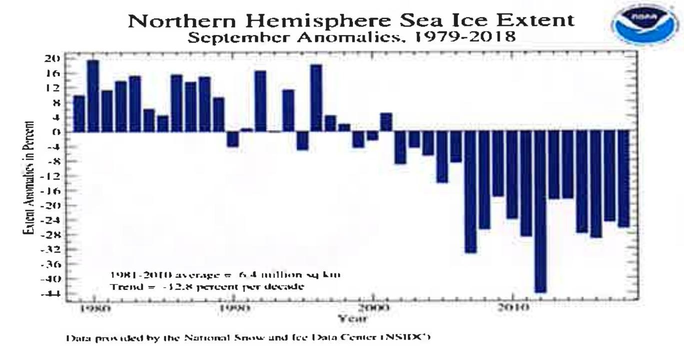


Figure 2.27: *Arctic ice extent for September*

[118] See also: http://www.climate4you.com/ClimateAndHistory%201900-1949.htm

Figure 2.27 above is a graphical representation of the change in Arctic sea ice for the month of September, which is when it is at its minimum following the Summer melt. Early satellites started measuring such sea ice extent in 1975 during the cold AMO, when it was at its maximum, while the reduction in sea ice can be attributed to the warm phase of the AMO. Summer storms, as happened in 2012, break up the ice floes, such that they are not then registered as pack ice by the satellite measurement. In general, while there was an initial decrease in summer sea ice extent, it has leveled off and the expectation is that as we move back into the cold phase of the AMO, it will increase again. It is also noteworthy that over the same period, Antarctic sea ice extent has shown little change.

2.10 Why temperature is a poor indicator of warming

Chemical engineers and others, who do heat transfer calculations, know that the relationship between temperature and energy input is complex, particularly so when one is dealing with air. At -35 ⁰C air is extremely dry and the saturated concentration corresponds to 0.2 g/m^3. However, when air is at a temperature of +35 ⁰C air is moist and humid and the saturated concentration corresponds to 40 g/m^3.[119] This is a difference of a factor of 200, which given that water vapour has a very high specific heat capacity much greater than that of dry air, has a major impact on the resulting energy balance. In fact the energy input to raise 35 ⁰C saturated air by one degree is 6.4 times higher than raising air at -35 ⁰C by one degree. Alternatively one can express this as the fact that if moist air moves up from the South into the polar regions in winter, the temperature will spike.

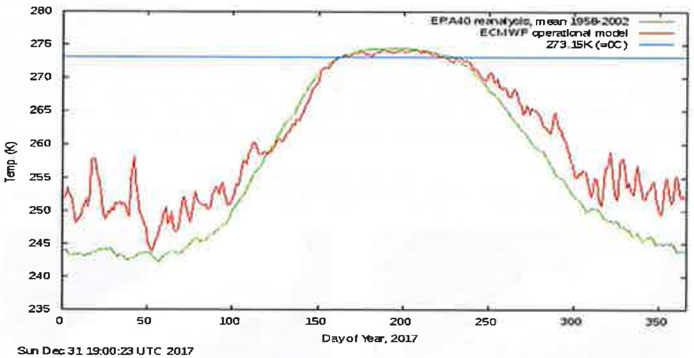


Figure 2.28: *Temperature record of Arctic for 2017 in degress Kelvin (273 ⁰K = 0 ⁰C) in red with long term average (1958-2002) shown in green*[120]

What the above record shows is that during the winter months the average temperature in the Arctic on the long term record has been about 245 ⁰K = -28 ⁰C. However, recent years have shown an increase in temperature in winter months as moisture has moved in from the South, which has also led to significantly increased

[119] http://www.uigi.com/WebPsycH.html

[120] http://ocean.dmi.dk/arctic/meant80n.uk.php

snow over Greenland.[121] In summer there has been little if any change, the air is warmer anyhow, so is capable of carrying the mositure without a temperature spike.

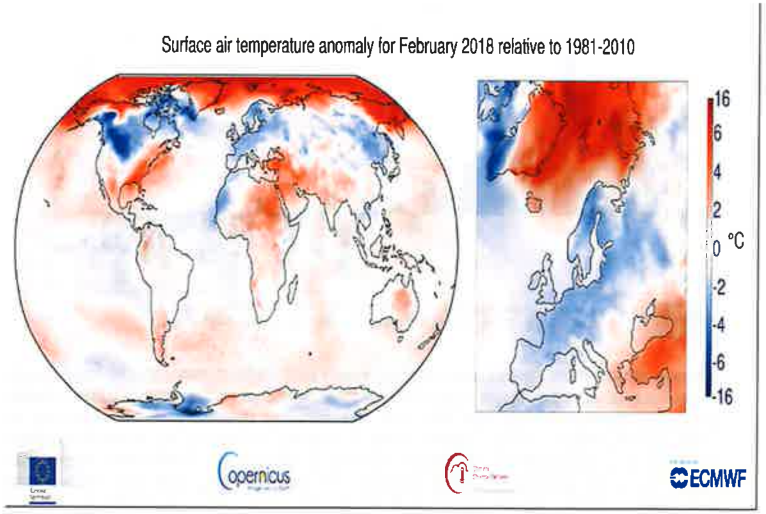


Figure 2.29: *Air temperatures anomaly for February 2018 versus long term record 1981-2010*[122]

This then begs the question, is everywhere else warming up as well. Figure 2.29 is a snaphop of global temperature anomalies for February 2018 (the period of the famous 'Beast from the East'). It is typical of recent winters in the Northern Hemisphere in that it is clearly visible as to how the Artic region was warmer than the period 1981 to 2010. However, the rest of the planet was a bit of a 'mixed bag', some regions somewhat colder while others were somewhat warmer.

Figure 2.30 overleaf is the satellite temperature record on a regional basis for the period 2016 to 2018. As can be clearly seen, the only place which is showing a temperature increase is the winters in the Arctic.

[121] http://polarportal.dk/en/news/news/heavy-snowfall-in-greenland/

[122] https://climate.copernicus.eu/surface-air-temperature-october-2018

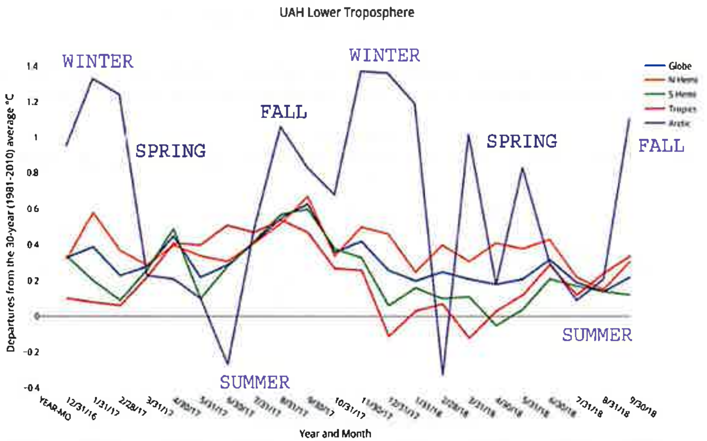


Figure 2.30: *Satellite temperature records which show only increase is for the winter in the Arctic (period 2016 to to 2018)*

This complex relationship means a number of things, first as to how this 'global temperature' value is of limited use in assessing, as to if the planet is warming by any significant amount. Heat flows around the planet, from the oceans to the atmosphere and from the tropics to the poles, the latter both by the weather systems and the oceanic currents. The very act of shifting some atmospheric heat from the tropics to the poles in itself can cause a rise in the global temperature, due to this heat spike in the Arctic, without there even being a net gain in heat energy in the atmosphere. Furthermore, the fact that as we can now see above, that any recent global temperature increase is being predominately driven by the winter situation in the Arctic, means that any net heat gain in the planet is being exaggerated by this effect.

In reality we have seen two powerful El Ninos in recent years, see Figure 2.18, which have pumped moisture into the atmosphere. This has now made its way to the poles, where it is being radiated out. It is also fascinating to see the additional dynamics in this process, in which there has been a trend back to increased winter snow cover in the Northern Hemisphere in recent years.[123] Snow cover has a strong albedo, which is a cooling feedback in winter, while the increased snow melt in spring and summer causes a influx of colder water into the Arctic ocean, which is again a negative feedback.

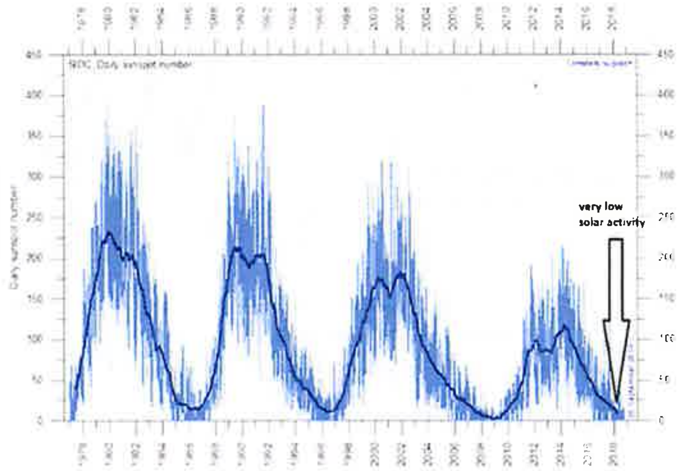
We don't have sufficient data to understand these natural cycles and feedbacks, but the point to be made is that they are feedbacks. Nature tends to be self-correcting, with negative feedbacks. It is like the ball in the middle of the bowl. Roll it up the side and the natural forces will then act to roll it back towards the centre. Nature abhors positive feedbacks where issues run out of control, such as the ball at the top of a slope, which accelerates as it runs downhill.

[123] Northern Hemisphere Snow Cover, 2018-2019: https://globalcryospherewatch.org/assessments/snow/2019/

2.11 The sun is the biggest driver of the climate – and it varies

A constant criticism of the IPCC is that it is 'one trick pony', in which the only game in town is CO_2, while realistically there are a large number of variables, which can all impact to a significant degree on climate. The World Meteorological Organixation listing some sixteen essential climate variables.[124] As Figure 2.10 shows, the sun is the biggest input to the global heat balance and that input varies.

An 'active sun' is when the sunspot count is high, while a 'quiet sun' is when the sunspot count is low. As Figure 2.31 shows, we are currently in a period of transition. There are sunspot cycles of the order of eleven years, while on a longer timeframe the intensity of these sunspot cycles can vary quite dramatically. The 20th Century up to the period of 2005 was characterised by very active sunspot cycles, but we are now rapidly moving into a period of a much quieter sun. Indeed, in early 2019, the sun has been blank without any sunspots for weeks on end.



This plot shows the daily observations of the number of sunspots during the last four solar cycles back to 1 January 1977 according to Solar Influences Data Analysis Center (SIDC). The thin blue line indicates the daily sunspot number, while the dark blue line indicates the running annual average. The current low sunspot activity is indicated by the arrow at the lower right of the plot. Last day shown: 30 Sep 2018. Data source: climate4you.com.

Figure 2.31: *Sunspot cycles for period 1977 to September 2018*

As far as our knowledge goes, and in this case our actual measurements are limited, the Total Solar Irradiance (TSI), which is the total energy reaching the planet's atmosphere, does not vary much between an active sun with significant sunspots

[124] https://public.wmo.int/en/programmes/global-climate-observing-system/essential-climate-variables

and a quiet sun with few sunspots.[125] Indeed, many consider that variance in TSI to be around 0.1%. However, other changes are occurring, in that during the active sun:

- The sun's magnetic field is considerably stronger. This shields the earth from the cosmic radiation, which is bombarding us from deep space. Hence less cosmic radiation enters the earth's atmosphere in an active sun.
- While the TSI varies little, the solar Extreme Ultraviolet (EUV) radiation increases by a factor of ten. This causes the Earth's upper atmosphere to expand.

Conversely during a quiet sun:

- The sun's magnetic field weakens and more cosmic radiation reaches the earth's atmosphere.
- The EUV decreases by a factor of ten, with the result that the upper atmosphere significantly contracts. Indeed, this can be seen by the fact that many satellites, which have little or no fuel, such as the Hubble telescope, are currently still in orbit several years after they were expected to be.[126]

Sunspot cycles can, to a degree, be forecasted from planetary motions, while historical values can be deducted from isotopes.

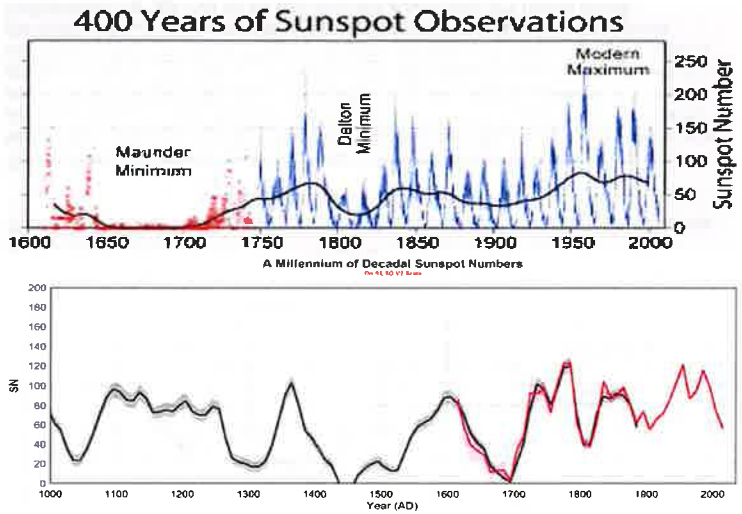


Figure 2.32: *Known record of sunspot numbers, above for 400 years and below for 1,000 years*

The English astronomer William Herschel (1788 – 1822) achieved notoriety for pointing out that "Sunspots correlated with wheat prices". The 'Mauder Minimum'

[125] https://arxiv.org/ftp/arxiv/papers/1601/1601.05397.pdf

[126] https://earthobservatory.nasa.gov/features/OrbitsCatalog/page3.php

above in Figure 2.32 also corresponded with the 'Little Ice Age' in which climatic conditions were tough and food often short due to poor agriculture yields, see H.H. Lambs book previously referenced in Section 2.2 for more details. Increasing sunspot numbers subsequently led to improved climatic conditions and a more bountiful harvest.[127] Indeed, there is no denying that there is a correlation between the climatic shifts discussed previously in Section 2.2 and the sunspot record.

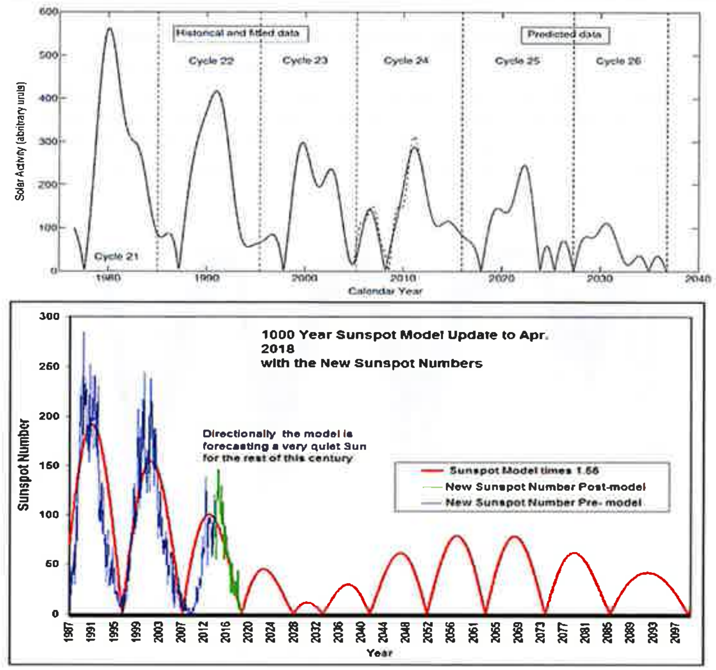


Figure 2.33: *Different predictions for future sunspot cycles; top graph out to 2040 and bottom graph to 2100*[128]

As Figure 2.33 shows the period of an intensely active sun, which was characteristic of the 20th Century, has come to an end and the next decades are going to exhibit a sun with far quieter characteristics. We are, whether we like it or not, in a period of change and transition.

[127] https://www.nature.com/news/2003/031215/full/news031215-12.html

[128] See for example: https://tallbloke.wordpress.com/2018/11/05/valentina-zharkova-incorporates-planetary-theory-into-solar-activity-model/ and https://tallbloke.wordpress.com/2018/06/09/leif-svalgaard-reveals-his-solar-cycle-25-prediction-at-last/

2.12 The polar vortex and outbreaks of intense winter cold

The polar vortex is nothing new, it has been known since 1853, but it has been 'hitting the headlines' in recent Northern Hemisphere winters. See Figure 2.34 below for a description.

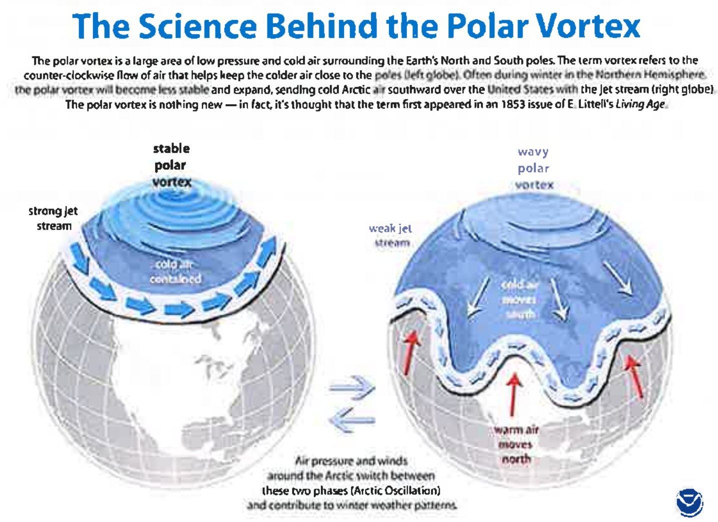


Figure 2.34: *Description of the Polar Vortx, coutesy NOAA*[129]

Winters in the Northern Hemisphere can be 'zonal' see schematic on the left, with a strong jet stream and resulting positive NAO (see figure 2.23). Such winters are in North Western Europe mild, wet and windy. However, the polar vortex can break down and what are known as 'Rossby Waves' form in the jetstream.[130] In other words it kinks, as is shown in the schematic on the right, in that warm air moves North and cold Arctic air can rush South, the consequences of the latter we all know. In many cases with resulting cold to very cold Easterly winds associated with a negative NAO.

The troposhere, as was explained previously, is the layer of the atmosphere from ground level to about 6 to 10 km, i.e. where jet aircraft fly and clouds are to be found. Above it is the stratosphere. Ozone in the stratosphere is what water vapour is to lower down in the troposphere, i.e. the differences in ozone concentration drive the circulation. All of this is very complex, not least as we have only had weather ballons taking measurements in the stratosphere since the 1950s. However, we do know that in the Arctic, changes in the stratosphere can impact on the troposhere below and cause the polar vortex to become weak and even split, see schematic above on the right.

[129] https://www.noaa.gov/multimedia/infographic/science-behind-polar-vortex

[130] https://oceanservice.noaa.gov/facts/rossby-wave.html

Changes in the sun are, as previously highlighted, more pronounced in the UV spectrum. This impacts on the ozone balance in the stratosphere, the degree of which is still being researched,[131] but it is seen to have an impact on the NAO.[132] Furthermore, a Sudden Stratospheric Warming (SSW) is one of the most radical changes of weather that is observed on our planet, as the stratosphere in the winter Arctic rapidly warms up. In most but not all cases this propogates down into the troposphere, causing the winds (polar night jet) holding the polar vortex to break down and an outbreak of very cold air to pour South, such as in 1963, 1982, 2018 and 2019.

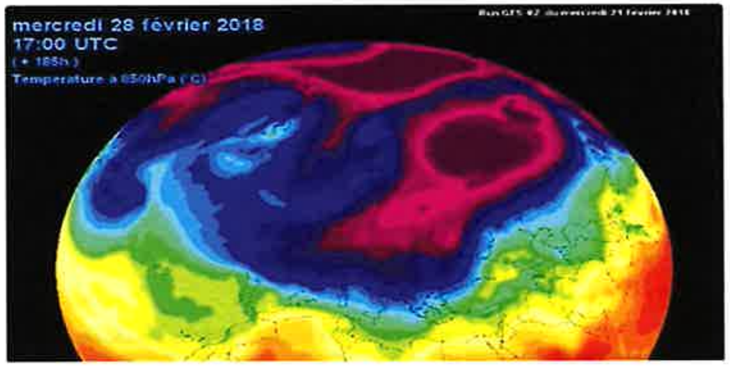


Figure 2.35: *Polar vortex splitting and pouring South following the SSW event in early February 2018*

There is still a lot to be learnt about Sudden Stratospheric Warmings (SSWs), but volcanic activity, El Ninos, warmer sea surface temperatures, low solar activity, etc., can all lead to a weaker polar vortex, which splits, etc.[133] Winters 2017 / 2018 and 2018 / 2019 were both characterised by very low solar conditions. In early February 2018 a SSW happened, which propagated down into the troposphere and led to the renown 'Beast from the East' in North Western Europe at the end of February. Additional cold outbreaks followed in mid-March and the in general it was a cold spring with a late arrival of summer.

In the first week of 2019 another SWW even occurred, which also propagated down into the troposphere. In led to an initial cold snap in North Western and Central Europe at the end of January 2019, while the polar vortex split and poured South into Canada and Central USA. This intense cold in the USA had the consequences of firing up the jetstream across the Atlantic, flipping the NAO back to strongly positive, with the net result that the remaining part of the winter and into spring in North Western Europe was quite mild.

[131] https://www.ethz.ch/content/dam/ethz/special-interest/usys/iac/iac-dam/documents/group/chemie/Impacts%20of%20solar%20variability%20on%20climate.pdf

[132] https://arxiv.org/pdf/1602.06397.pdf

[133] Research is ongoing, but a solar link is being seen: https://www.terrapub.co.jp/onlineproceedings/ste/CAWSES2007/pdf/CAWSES_257.pdf

In is notewothy that if one reviews Samuel Pepys' diary, written in the 1660s during the period of the 'Little Ice Age', while it records as to how intense cold periods occurred with the famous 'frost fairs' on the frozen River Thames, there was also quite a number of mild winters in a row.[134] Indeed, in 1662 the winter was again very warm, "*which do threaten a plague,*" and January 15 was "*a fast day ordered by Parliament to pray for more seasonable weather*". The future is yet to be written, but as we move into a period of low solar activity more reminisicent of that period, will our winter weather be characterised by more Arctic outbreaks than we have been used to? Time will of course tell, but the evidence does point that way. Indeed, as H.H. Lamb's book documents, that period was characterised by wind patterns, which were more Easterly than found in the 20th Century.

2.13 Cloud cover is also a variable

As has been documented in the previous Sections 2.4 to 2.6, the whole output of the IPCCs work is inherently flawed, as they do not understand the dynamics of the water vapour cycle and clouds in particular. Furthermore, we do know that cloud cover varies, see for example Figure 2.36 below:

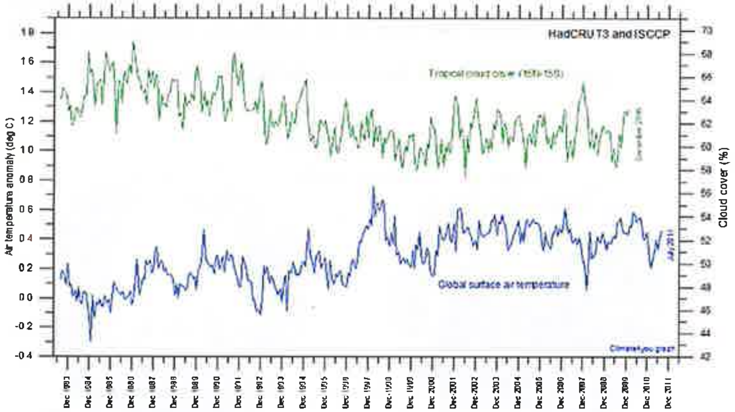


Figure 2.36: *Variation of tropical cloud cover with global surface temperatures (1983 to 2011)*[135]

Tropical cloud cover decreased in the 1980s and 1990s during the period when we saw an equivalent rise in global surface temperatures. It also provides a plausible explanation as to why there were subsequently two very significant El Nino events, as with less tropical cloud cover, the tropical oceans would have warmed more. Henrik Svensmark is a physicist and professor in the Division of Solar System Physics at the Danish National Space Institute (DTU Space) in Copenhagen. The 'Svensmark theory' postulates that during a period of a quieter sun, the increased

[134] ftp://ftp.library.noaa.gov/docs.lib/htdocs/rescue/mwr/049/mwr-049-07-0410b.pdf

[135] https://www.climate4you.com/ (Climate + Clouds)

penetration of cosmic rays into the atmosphere causes additional ionisation and subsequent nucleation for clouds to form.[136]

In simple terms, during a quieter sun, there should be an increase in cloud cover and hence less solar radiation reaching the earth's surface, therefore a cooling effect. While with a more active sun there are less cosmic rays, hence less clouds and therefore a general warming effect. It is a theory backed up by experimental work and one which is gaining acceptance. As previously, time will tell as we move into this period of a quieter sun and additional data is recorded.

2.14 Conclusions

In conclusion on this Section:

- The impact of CO_2 from burning fossil fuels on the global heat balance is minor (≈ 2%). The planet is a complex 'heat engine', for catastrophic warming to occur this would need to be highly unstable – which it isn't, as if it was we would know about it already.

- There is no dramatic change in climate occurring and present conditions are normal; i.e. in line with what one would expect from natural impacts and nothing that hasn't been seen before. The increased greening from the rise in CO_2 concentrations is a welcome benefit, particular so in arid regions.

- Climate models are incapable of replicating the complexities of this 'heat engine' and are totally unfit for making predictions.

- Many decades of careful and interesting observations will be required to improve our knowledge of the complex natural variations.

[136] https://www.nature.com/articles/s41467-017-02082-2

Renewables Threaten German Economy & Energy Supply, McKinsey Warns In New Report

Michael Shellenberger Contributor
Energy
I write about energy and the environment.

To stabilize the electricity grid and avoid becoming too dependent on imported natural gas, Germany expanding coal mining to the Hambach forest, where environmental activists were arrested last September.

A new report by consulting giant McKinsey finds that Germany's *Energiewende,* or energy transition to renewables, poses a significant threat to the nation's economy and energy supply.

One of Germany's largest newspapers, *Die Welt*, summarized the findings of the McKinsey report in a single word: "disastrous."

"Problems are manifesting in all three dimensions of the energy industry triangle: climate protection, the security of supply and economic efficiency," writes McKinsey.

In 2018, Germany produced 866 million metric tons of carbon dioxide, a far cry from its goal of 750 million tonnes by 2020.

Thanks to a slightly warmer winter, emissions in Germany went down slightly in 2018, but not enough to change the overall trend. "If emissions reductions continue at the same pace as they did over the past decade, then CO_2 targets for 2020 will only be reached eight years later, and 2030 targets will not be reached until 2046."

Germany has failed to even come close to reducing its primary energy consumption to levels it hoped. McKinsey says Germany is just 39% toward its goal for primary energy reduction.

Despite much hype, Germany still generates just 35% of its electricity from renewables. And if biomass burning, often dirtier than coal, is excluded, wind, water and solar electricity in Germany accounted for just 27% of electricity generation in 2018.

But McKinsey issues its strongest warning when it comes to Germany's increasingly insecure energy supply due to its heavy reliance on intermittent solar and wind. For three days in June 2019, the electricity grid came close t black-outs.

"Only short-term imports from neighboring countries were able to stabilize the grid," the consultancy notes.

As a result of Germany's energy supply shortage, the highest observed cost o short-term "balancing energy" skyrocketed from €64 in 2017 to €37,856 in 2019.

"It can be assumed that security of supply will continue to worsen in the future," says McKinsey.

Renewables are causing similarly high price shocks in other parts of the world including Texas, Australia, and California.

And Britain and Australia have faced similar energy supply problems in recent years as they have attempted to transition to intermittent renewables

"Wind generation, solar and interconnectors are different to the convention: electricity generation sources," Britain's National Grid said in a report after lightning knocked a wind farm and natural gas plant off the grid in August, causing a black-out in London.

Australia electricity regulators in August sued four wind farm operators for contributing to a huge blackout in 2016.

Bloomberg News, which strongly advocates renewable energy, last week called the supply problems a "warning short to the rest of the world."

"We have to have systems in place to make sure we still have enough generation on the grid -- or else, in the best case, we have a blackout, and in the worst case, we have some kind of grid collapse," Severin Borenstein, a University of California energy economist told Bloomberg.

California's increasingly perilous electricity grid may put pressure on California Governor Gavin Newsom to keep the state's last nuclear plant running.

German utilities too are warning of insecure supply. "By 2023 at the latest, w will be running with eyes wide open into a shortfall in secure capacity," a managing director for the Germany energy industry association BDEW said.

"The ongoing phase-out of nuclear power by the end of 2022 and the planne coal withdrawal will successively shut down further secured capacity," explained McKinsey. "In particular, the industrial regions in western and southern Germany are affected, in which many capacities go off the grid and at the same time, one can not expect high rates of development of renewables."

In June, Germany imported more electricity than it exported, and by 2023, Germany will become a net electricity importer, McKinsey predicted.

The growing insecurity of German energy supply is made worse by the fact that its neighbors Belgium and Netherlands may shut down baseload capacity: coal plants in the Netherlands and nuclear plants in Belgium.

As such, McKinsey worries that Germany may not be able to meet demand with imports. "In the medium term, there is a risk that there will not be enough supply capacity in the entire European network."

That could happen as soon as five years from now. "Without adequate expansion, the first bottlenecks could occur as early as the middle of the nex decade, and they will continue to worsen until 2030."

If Germany continues to phase out both coal and nuclear, Germany will lose "the equivalent of 43% of total secured output in 2018."

To stabilize the electricity grid and avoid becoming too dependent on imported natural gas, Germany is expanding coal mining to the Hambach forest, where environmental activists were arrested last September.

Meanwhile, local communities and environmentalist have successfully blocked the building of transmission lines from the windy north to the industrial south.

"By the first quarter of 2019, just 1,087 kilometers of the planned 3,600 kilometers of power lines were completed." At that rate, McKinsey notes, "th 2020 target will not be reached until 2037. "

German consumers have paid dearly for the energy transition. German electricity prices are 45% above the European average, McKinsey reports. Green taxes account for 54% of household electricity prices.

Electricity prices will continue to rise through 2030, McKinsey predicts, despite promises in recent years by renewable energy advocates and Germar politicians that they would go down.

And higher prices will threaten the German industry's competitiveness. "Even a modest increase of a few euros per megawatt-hour," McKinsey says, "could jeopardize the competitiveness of energy-intensive industries in Germany."

Radical change is required, McKinsey says. "Small changes in direction are no longer sufficient to lead the energy transition back on track. What is required is a fundamental turn in energy policy."

Among the radical changes required include building transmission lines *eigl times faster* than they are currently being built, building new back-up powei plants, and installing instruments to control electricity demand, all of which would drive electricity prices even higher.

"But it is also clear that the consequences of a blackout would be much higher," warns McKinsey.

Alternatively, Germany could abandon its phase-out of nuclear energy, something the consultancy, like many others in the country, does not mention.

Michael Shellenberger

Michael Shellenberger is a Time Magazine "Hero of the Environment" and Green Book Award Winner. He is also a frequent contributor to The New York Times, Washington Post,... **Read More**

£450m lost over failed green power programme

Minister who backed plan now works in sector

Ben Webster, Environment Editor
February 23 2017, 12:01am, The Times

Britain is wasting hundreds of millions of pounds subsidising power stations to burn American wood pellets that do more harm to the climate than the coal they replaced, a study has found.

Chopping down trees and transporting wood across the Atlantic Ocean to feed power stations produces more greenhouse gases than much cheaper coal, according to the report. It blames the rush to meet EU renewable energy targets, which resulted in ministers making the false assumption that burning trees was carbon-neutral.

Green subsidies for wood pellets and other biomass were championed by Chris Huhne when he was Liberal Democrat energy and climate change secretary in the coalition government. Mr Huhne, 62, who was jailed in 2013 for perverting the course of justice, is now European chairman of Zilkha Biomass, a US supplier of wood pellets.

The report was written by Duncan Brack, a former special adviser to Mr Huhne, for Chatham House, the respected international affairs think tank. Britain is by far the biggest importer of wood pellets for heat and power in the EU, shipping in 7.5 million tonnes last year, mostly from the US and Canada.

Drax, Britain's biggest power station, received more than £450 million in subsidies in 2015 for burning biomass, which was mostly American wood pellets. The report says that the government's assessment of the impact on the climate of switching from coal to wood pellets is flawed because it ignores emissions from burning pellets in power stations. The assessment counts only emissions from harvesting, processing and transporting wood pellets.

Wood pellets are claimed to be carbon-neutral partly because the forests from which they come are replanted. New trees would eventually absorb as much carbon as was emitted when mature trees were harvested and burnt. However, the report says that this process could take centuries — too late to contribute to preventing climate change over coming decades.

Mr Brack said: "It is ridiculous for the same kind of subsidies that go to genuine zero-carbon technologies, like solar and wind, to go to biomass use that might be increasing carbon emissions. It's not a good use of money.

"For any biomass facility that is burning wood for energy, unless they are only burning stuff like saw-mill residues or post-consumer waste, their activities will be increasing carbon emissions in the atmosphere for decades or centuries. We shouldn't be subsidising that."

Pellet companies and power stations using them tended to claim that most of their wood was residues, Mr Brack said. In fact, about three quarters of the pellets from the southern US came from whole trees and residues accounted for only a quarter. "Whole trees can sometimes be misclassified as residues," the report said. Mr Brack called on the EU to use its present review of energy policies to restrict subsidies to biomass that actually reduced emissions.

Nina Skorupska, chief executive of the Renewable Energy Association, which represents Drax, in North Yorkshire, said: "This report hangs on the fallacy that it takes decades for a forest to recapture carbon. That isn't true . . . Imagine you have 100 trees, all growing 3 per cent bigger per year. You could remove two trees for timber, with offcuts going to bioenergy, and the forest would still absorb 1 per cent more carbon than the year before. There's no delay involved. This is true whether it's a hundred trees or a hundred million.

"Biomass delivers a massive cut in carbon emissions compared to fossil fuels. The whole supply chain is monitored in detail to ensure we cut greenhouse gas emissions by at least 60 per cent compared to fossil fuels."

Drax said: "The biomass we use is sustainably sourced from working forests where biodiversity is protected, productivity is maintained and growth exceeds what is harvested. We take the low-grade material to make the compressed wood pellets used to generate electricity . . . There is a widespread scientific consensus that this low-value wood is precisely the material which delivers the biggest carbon reductions."

NoTricksZone

"Not here to worship what is known, but to question it" - Jacob Bronowski. Climate and energy news from Germany in English - by Pierre L. Gosselin

Browse: Home / 2018 / July / 09 / Why Are We Doing This? A Trove Of New Research Documents The Folly Of Renewable Energy Promotion

Why Are We Doing This? A Trove Of New Research Documents The Folly Of Renewable Energy Promotion

By Kenneth Richard on 9. July 2018

The advocacy for widespread growth in renewable energy (especially wind, solar, and biomass) usage has increasingly become the clarion call of the anthropogenic global warming (AGW) movement. And yet more and more published research documents the adverse effects of relying on renewables.

Image: Wasili Karbe, cropped from video here.

Over the course of the last year, at least 30 papers have been published in the peer-reviewed scientific literature detailing the fatuity of promoting renewable energy as a long-term "fix" for climate change mitigation. A categorized list of these papers is provided below.

1. "More Renewables Mean Less Stable Grids"

Schäfer et al., 2018 ***"Multiple types of fluctuations impact the collective dynamics of power grids and thus challenge their robust operation."***

(press release) ***"More renewables mean less stable grids, researchers find … [I]ntegrating growing numbers of renewable power installations and microgrids onto the grid can result in larger-than-expected fluctuations in grid frequency."***

2. Increasing Fossil Fuel Use (Natural Gas) Reduces Emissions More Than Increasing Wind/Solar Energy

Anderson et al., 2018 ***"Before consideri… just how far we've already come without … existing power plants) in the U.S. Figure … and natural gas prices from 2005 through 2017 (estimated). During that***

Search

Pages

1. About
1. Contact
1. Cookie Policy
1. Data Privacy /Datenschutz
1. Legal/Impressum
1. Rules For Reposting
100+ Papers – Sun Drives Climate
129 Climate Scandals
285 Papers 70s Cooling 1
285 Papers 70s Cooling 2
285 Papers 70s Cooling 3
2m Higher Holocene Sea Levels
450 Non Warming Graphs (1)
450 Non Warming Graphs (2)
75 Papers: Low Sensitivity
Climate Bet For Charity
Climategate 2.0
Skeptic Papers 2014
Skeptic Papers 2015
Skeptic Papers 2016
Skeptic Papers 2016 (1)
Skeptic Papers 2016 (2)
Skeptic Papers 2016 (3)
Skeptic Papers 2017 (1)
Skeptic Papers 2017 (2)
Skeptic Papers 2017 (3)
Skeptic Papers 2018 (1)
Skeptic Papers 2018 (2)
Skeptic Papers 2018 (3)
Who's Who Guide In Germany?

Recent Comments

spike55 on Sea Ice Model Projections In A Death Spiral! Arctic Ice Volume Holds Steady For A Decade!
spike55 on Sea Ice Model Projections In A Death Spiral! Arctic Ice Volume Holds Steady For A Decade!
Kenneth Richard on Why Are We Doing This? A Trove Of New Research Documents The Folly Of Renewable Energy Promotion
tom0mason on Sea Ice Model Projections In A Death Spiral!
… ly
Kenneth Richard on Why Are We Doing This? A Trove Of

period, emissions have declined from nearly 2.7 billion tons to approximately 1.9 billion tons (~30%), while revealing a strong link to natural gas prices. To be sure, while other factors (such as renewable energy incentives) also had an impact, the clearest means by which to reduce CO2 emissions has been to reduce the cost of generating electricity with less CO2-emitting fuels (i.e., substituting natural gas for coal). So successful have market forces been under the existing regulatory framework to date that estimated 2017 CO2 emission levels are already at the CPP's 2025 target(albeit without accounting for electricity demand growth between 2017 and 2025), well exceeding the AEO's own Reference Case projections for 2025."

Jewell et al., 2018 *"Hopes are high that removing fossil fuel subsidies could help to mitigate climate change by discouraging inefficient energy consumption and leveling the playing field for renewable energy.Here we show that removing fossil fuel subsidies would have an unexpectedly small impact on global energy demand and carbon dioxide emissions and would not increase renewable energy use by 2030. Removing [fossil fuel] subsidies in most regions would deliver smaller emission reductions than the Paris Agreement (2015) climate pledges and in some regions global [fossil fuel] subsidy removal may actually lead to an increase in emissions, owing to either coal replacing subsidized oil and natural gas or natural-gas use shifting from subsidizing, energy-exporting regions to non-subsidizing, importing regions."*

3. Renewables Fail To Deliver: When Demand Is High, Generation Capacity Is Low

Cradden and McDermott, 2018 *"Prolonged cold spells were experienced in Ireland in the winters of 2009–10 and 2010–11, and electricity demand was relatively high at these times, whilst wind generation capacity factors were low. Such situations can cause difficulties for an electricity system with a high dependence on wind energy."*

4. Renewable Energy Becomes More Costly The More It Is Deployed … Renewable Energy Expansion Ensures More Fossil Fuel Installation Is Necessary As Backup

Blazquez et al., 2018 *"However, promoting renewables –in liberalized power markets– creates a paradox in that successful penetration of renewables could fall victim to its own success. With the current market architecture, future deployment of renewable energy will necessarily be more costly and less scalable. Moreover, transition towards a full 100% renewable electricity sector is unattainable. Paradoxically, in order for renewable technologies to continue growing their market share, they need to co-exist with fossil fuel technologies. … The paradox is that the same market design and renewables policies that led to current success become increasingly less successful in the future as the share of renewables in the energy mix grows. … Full decarbonization of a power sector that relies on renewable technologies alone, given the current design of these markets, is not possible as conventional technologies provide important price signals. Markets would collapse if the last unit of fossil fuel technologies was phased out. In the extreme (theoretical) case of 100 percent renewables, prices would be at the renewables marginal cost, equal to zero or even negative for long periods. These prices would not be capturing the system's costs nor would they be useful to signal operation and investment decisions. The result would be a purely administered subsidy, i.e., a non-market outcome. This is already occurring in Germany as Praktiknjo and Erdmann [31] point out and is clearly an unstable outcome. Thus, non-dispatchable technologies need to coexist with fossil fuel technologies. This outcome makes it impossible for renewables policy to reach success, defined as achieving a specified level of deployment at the lowest possible cost. With volatile, low and even negative electricity prices, investors would be discouraged from entering the market and they would require more incentives to continue to operate."*

Marques et al., 2018 *"The installed capacity of wind power preserves fossil fuel dependency. … Electricity consumption intensity and its peaks have been satisfied by burning fossil fuels. … [A]s RES [renewable energy sources] increases, the expected decreasing tendency in the installed capacity of electricity generation from fossil fuels, has not been found. Despite the high share of RES in the electricity mix, RES, namely wind power and solar PV, are characterised by intermittent electricity generation. … The inability of RES-I [intermittent renewable energy sources like wind and solar] to satisfy high fluctuations in electricity consumption on its own constitutes one of the main obstacles to the deployment of renewables. This incapacity is due to both the intermittency of natural resource availability, and the difficulty or even impossibility of storing electricity on a large scale, to defer generation. As a consequence, RES [renewable energy sources] might not fully replace fossil sources … In fact, the characteristics of electricity consumption reinforce the need to burn fossil fuels to satisfy the demand for electricity. Specifically, the ECA results confirm the substitution effe[illegible] solar PV and fossil fuels. In contrast, ins[illegible] required all fossil fuels and hydropower [illegible] long-run equilibrium. The EGA outcomes show that hydropower has been*

New Research Documents The Folly Of Renewable Energy Promotion
Kenneth Richard on Sea Ice Model Projections In A Death Spiral! Arctic Ice Volume Holds Steady For A Decade!
tom0mason on Sea Ice Model Projections In A Death Spiral! Arctic Ice Volume Holds Steady For A Decade!

Videos

- Climategate – English
- Climategate – German
- Those Who Claim Absolute Knowledge
- Dr Werner Kirstein
- Salby On CO2 vs Temp
- Meeresspiegel
- The Boy Who Cried Warming
- Baliunas on Weather Cooking

Climatic Indicators

- ENSO BoM Report
- ENSO 3.4 Chart
- ENSO Outlook 6 Months
- Sea Level – Global
- Sunspot Watch
- Temp Arctic DMI
- Temp Forecast Europe
- Temp Forecast Global
- Temp Surface AMSU Satellite
- Temp UAH Satellite
- Temp Unisys SST
- Temp Forecast US/Canada
- Sunspot Tracking Graph
- Sea Ice Arctic View
- PDO Index
- PDO index graph
- Snow/ice Cover
- Surface Temp Global
- Snow and ice cover
- Global sea level
- Berkeley Earth Data
- German historical data

NoTricks Blogroll

- Changement Climatique
- Climate Depot
- Donna Laframboise
- EIKE
- WUWT
- Wood for Trees
- The Climate Scam
- Climategate.nl
- Science Skeptical
- Nonoy Oplas
- [illegible]
- GWPF – Benny Peiser

substituting electricity generation through NRES [non-renewable energy sources], but that other RES have needed the flexibility of natural gas plants, to back them up. … [D]ue to the intermittency phenomenon, the growth of installed capacity of RES-I [intermittent renewable energy sources – wind power] could maintain or increase electricity generation from fossil fuels. … In short, the results indicate that the EU's domestic electricity production systems have preserved fossil fuel generation, and include several economic inefficiencies and inefficiencies in resource allocation. … [A]n increase of 1% in the installed capacity of wind power provokes an increase of 0.26%, and 0.22% in electricity generation from oil and natural gas, respectively in the long-run."

5. Biofuels – Declared Carbon-Neutral Renewables By The EU – *Increase* Emissions More Than Coal

Sterman et al., 2018 *"[G]overnments around the world are promoting biomass to reduce their greenhouse gas (GHG) emissions. The European Union declared biofuels to be carbon-neutral to help meet its goal of 20% renewable energy by 2020, triggering a surge in use of wood for heat and electricity (European Commission 2003, Leturcq 2014, Stupak et al 2007). … But do biofuels actually reduce GHG emissions? … [A]lthough wood has approximately the same carbon intensity as coal (0.027 vs. 0.025 tC GJ−1 of primary energy […]), combustion efficiency of wood and wood pellets is lower (Netherlands Enterprise Agency; IEA 2016). Estimates also suggest higher processing losses in the wood supply chain (Roder et al 2015). Consequently, wood-fired power plants generate more CO2 per kWh than coal. Burning wood instead of coal therefore creates a carbon debt—an immediate increase in atmospheric CO2 compared to fossil energy—that can be repaid over time only as—and if— NPP [net primary production] rises above the flux of carbon from biomass and soils to the atmosphere on the harvested lands. … Growth in wood supply causes steady growth in atmospheric CO2 because more CO2 is added to the atmosphere every year in initial carbon debt than is paid back by regrowth, worsening global warming and climate change. The qualitative result that growth in bioenergy raises atmospheric CO2 does not depend on the parameters: as long as bioenergy generates an initial carbon debt, increasing harvests mean more is 'borrowed' every year than is paid back. More precisely, atmospheric CO2 rises as long as NPP [net primary production] remains below the initial carbon debt incurred each year plus the fluxes of carbon from biomass and soils to the atmosphere. … [C]ontrary to the policies of the EU and other nations, biomass used to displace fossil fuels injects CO2 into the atmosphere at the point of combustion and during harvest, processing and transport. Reductions in atmospheric CO2 come only later, and only if the harvested land is allowed to regrow."*

Fanous and Moomaw, 2018 *"These nations fail to recognize the intensity of CO2 emissions linked to the burning of biomass. The chemical energy stored in wood is converted into heat or electricity by way of combustion and is sometimes used for combined heat and power cogeneration. At the point of combustion, biomass emits more carbon per unit of heat than most fossil fuels. Due to the inefficiencies of biomass energy, bioenergy power plants emit approximately 65 percent more CO2, per MWH than modern coal plants, and approximately 285 percent more than natural gas combined cycle plants. Furthermore, the Intergovernmental Panel on Climate Change (IPCC) states that combustion of biomass generates gross greenhouse gas (GHG) emissions roughly equivalent to the combustion of fossil fuels. In the case of forest timber turned into wood pellets for bioenergy use, the IPCC further indicates that the process produces higher CO2 emissions than fossil fuels for decades to centuries."*

6. Biofuels "Use More Energy At A Higher Cost" And Produce More Air Pollution Than Fossil Fuels

Richardson and Kumar, 2017 *"A growing human population creates a larger demand for food products and makes conservation of resources and increased efficiency of agricultural production more vital. … These results conclude that feed production systems are more energy efficient and less environmentally costly than corn-based ethanol. … [A]ccording to the findings of this study, biofuels, derived for the purpose of producing energy with little environmental impacts, actually use more energy at a higher environmental cost than the alternative crop use. As technology stands now, in terms of energy and environmental sustainability, the benefits of switching land uses to the production of corn-based transportation biofuels are not as favorable as continuing to produce corn for feed/food consumption."*

Emery et al., 2017 *"Although climate ch… policies are generally expected to be compatible with air pollution and health*

Die kalte Sonne
1000+ papers
Tallbloke's Talkshop
toryaardvark
Judith Curry
Klimazwieback
Kiwi Thinker
Skeptical Science
Pop-Tech Resource
Ice Age Cometh!
Weather Action
38 pause excuses
Climate Common Sense
Climate Dispatch
Warmists' View Of Dissenters
Climate Change Predictions
Wo bleibt
Frojdh Sweden
22 Unangenehme Klimafakten
22 Inconvenient Climate Facts
MWP Map
NIPCC
Energiefrage

Categories

Abnormal Climate Psych
Activism
Agriculture
Alarmism
Alternative Energy
Antarctic
Arctic
Climate Bet For Charity
Climate Politics
Climate Sensitivity
CO2 and GHG
Cooling/Temperature
Data Manipulation
Drought and Deserts
Emissions
Glaciers
Gore
Green Follies
Greenpeace
Hockey Team
Humour
Hurricanes/Tornados
Innovation
IPCC
Lifestyles of the Rich and Alarmist
Little Ice Age
Media / Bias
Medieval Warm Period
Misc.
Models
Monthly summaries
Natural Oceanic Oscillations
Natural Variability
Nuclear energy
Nutrition
Ocean Acidification
Oceans
Ozone 'Hole'
Paleo-climatology
Pollution
Russian Climate Science
Scepticism
Sea Ice
Solar Sciences
Stupid Predictions

cost reductions (McCollum et al., 2013), there is evidence that first-generation alternative fuels such as corn ethanol lead to higher health costs due to air pollution than conventional fuels [gasoline] (Hill et al., 2009). … We find that life-cycle non-GHG air pollutant emissions, particularly NOX [nitrous oxides] and PM [particulates], are higher for corn ethanol and other biofuel blends than conventional petroleum fuels. Emissions of volatile organic compounds (VOCs) and carbon monoxide (CO) increase by 9–50% per 100 km traveled for high-ethanol blends from corn grain and combined grain and stover feedstocks. NOX, PM [particulates], and SOX [sulfur dioxides] increase by 71–124% from corn grain and 56–110% from combined grain and stover, relative to conventional gasoline. Biodiesel blends show an increase of 1–11% (B20) and 4–55% (B100) in air pollution, with the largest increases in VOC [volatile organic compounds] and SOX [sulfur dioxides] emissions. … The total social costs of ethanol blends are higher than that of gasoline, due in part to higher life-cycle emissions of non-GHG pollutants and higher health and mortality costs per unit."

7. Proximity To Wind Turbines Significantly Reduces Quality Of Life, Well-Being For Nearby Residents

Barry et al., 2018 *"The findings indicate that residential proximity to wind turbines is correlated with annoyance and health-related quality of life measures. These associations differ in some respects from associations with noise measurements. Results can be used to support discussions between communities and wind-turbine developers regarding potential health effects of wind turbines."*

Krekel and Zerrahn, 2017 *"We show that the construction of wind turbines close to households exerts significant negative external effects on residential well-being … In fact, beyond unpleasant noise emissions (Bakker et al., 2012; McCunney et al., 2014) and impacts on wildlife (Pearce-Higgins et al., 2012; Schuster et al., 2015), most importantly, wind turbines have been found to have negative impacts on landscape aesthetics (Devine-Wright, 2005; Jobert et al., 2007; Wolsink, 2007). … We show that the construction of a wind turbine within a radius of 4,000 metres has a significant negative and sizeable effect on life satisfaction. For larger radii, no negative externalities can be detected."*

Gortsas et al., 2017 *"Infrasound, low frequency noise and soil vibrations produced by large wind turbines might disturb the comfort of nearby structures and residents. In addition repowering close to urban areas produces some fears to the nearby residents that the level of disturbance may increase. Due to wind loading, the foundation of a wind turbine interacts with the soil and creates micro-seismic surface waves that propagate for long distances and they are able to influence adversely sensitive measurements conducted by laboratories located far from the excitation point."*

8. "Renewable Energy Consumption Has A Negative Effect On Economic Growth"

Lee and Jung, 2018 *"The results of the autoregressive distributed lag bounds test show that renewable energy consumption has a negative effect on economic growth, and the results of a vector error correction mechanism causality tests indicate a unidirectional relationship from economic growth to renewable energy consumption. The empirical results imply that economic growth is a direct driver expanding renewable energy use. In terms of policy implications, it is best for policy makers to focus on overall economic growth rather than expanding renewable energy to drive economic growth. … [O]ur result suggests that renewable energy policy should be implemented when the real GDP is enough large to overcome the negative impact from renewable energy, because the causality from economic growth to renewable energy consumption in the long run as one of our result is caused by both low productivity of renewable energy production and expansion of government-led renewable energy."*

9. Research: 100% Renewable Energy Is "Unattainable" In Reality – Decarbonization Is "Arguably Reckless"

Clack et al., 2017 *"The scenarios of [Jacobson et al., 2015, "Low-cost solution to the grid reliability problem with 100% penetration of intermittent wind, water, and solar for all purposes"]can, at best, be described as a poorly executed exploration of an interesting hypothesis. The study's numerous shortcomings and errors render it unreliable as a guide about the likely cost, technical reliability, or feasibility of a 100% wind, solar, and hydroelectric power system. It is one thing to explore the potential use of technologies in a clearly caveated hypothetical analysis; it is quite another to claim that a model using these technologies at an unp the feasibility and reliability of the mode midcentury. From the information given by [Jacobson et al., 2015], it is clear that both hydroelectric power and flexible load have been modeled in*

Tectonics/Volcanoes
Temperature Bias/Urbanization
Uncategorized
Warming/CO2 Benefiting Earth
We're To Blame
Weather
Wind Power

Archives

2018
2017
2016
2015
2014
2013
2012
2011
2010

Die kalte Sonne – German bestseller!

Meta

Log in
Entries RSS
Comments RSS
WordPress.org

erroneous ways and that these errors alone invalidate the study and its results."

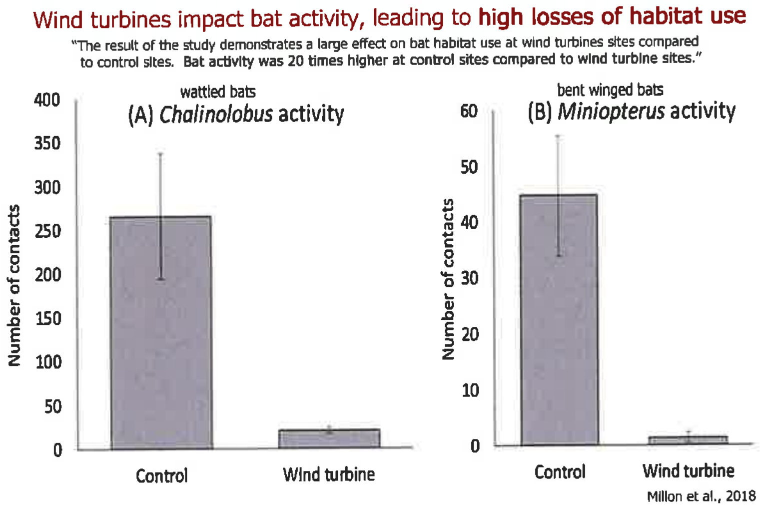
Heard et al., 2017 *"While many modelled scenarios have been published claiming to show that a 100% renewable electricity system is achievable, there is no empirical or historical evidence that demonstrates that such systems are in fact feasible. Of the studies published to date, 24 have forecast regional, national or global energy requirements at sufficient detail to be considered potentially credible. We critically review these studies using four novel feasibility criteria for reliable electricity systems needed to meet electricity demand this century. [N]one of the 24 studies provides convincing evidence that these basic feasibility criteria can be met. Of a maximum possible unweighted feasibility score of seven, the highest score for any one study was four. ... On the basis of this review, efforts to date seem to have substantially underestimated the challenge and delayed the identification and implementation of effective and comprehensive decarbonization pathways. ... To date, efforts to assess the viability of 100% renewable systems, taking into account aspects such as financial cost, social acceptance, pace of roll-out, land use, and materials consumption, have substantially underestimated the challenge of excising fossil fuels from our energy supplies. This desire to push the 100%-renewable ideal without critical evaluation has ironically delayed the identification and implementation of effective and comprehensive decarbonization pathways. We argue that the early exclusion of other forms of technology from plans to decarbonize the global electricity supply is unsupportable, and arguably reckless. ... The realization of 100% renewable electricity (and energy more broadly) appears diametrically opposed to other critical sustainability issues such as eradication of poverty, land conservation and reduced ecological footprints, reduction in air pollution, preservation of biodiversity, and social justice for indigenous people."*

10. Wealthy Countries Foist Social-Environmental Disruption From Wind, Solar Onto Poorer Countries

Shakespear, 2018 *"A trend was found, whereby developing countries tend to suffer the most socio-environmental disruption from material extraction for solar-panels and wind-turbines while exhibiting lower implementation of these technologies, and developed countries show opposite effects. This indicates that EUE [ecologically unequal exchange] effects constitute global solar-panel and wind-turbine systems, and that developed countries displace socio-environmental disruption from energy innovation onto developing countries. ... [I]mplementation of solarpanels and wind-turbines tended to be the most prevalent within countries that suffer the least environmental and socio-economic consequences from the extraction of materials for these technologies. This effectively means that efforts to increase sustainability in relatively powerful countries via renewable energy implementation exacerbates unsustainable practices in the relatively less powerful countries that extract the minerals for these technologies."*

11. Wind Power Harming The Environment, Biosphere – Destroying Habitats, Endangering Rare Species

Millon et al., 2018 (full paper) *"Wind turbines impact bat activity, leading to high losses of habitat use ... Island bats represent 60% of bat species worldwide and the highest proportion of terrestrial mammals on isolated islands, including numerous endemic and threatened species (Fleming and Racey, 2009). ... We present one of the first studies to quantify the indirect impact of wind farms on insectivorous bats in tropical hotspots of biodiversity. Bat activity [New Caledonia, Pacific Islands, which hosts nine species of bat] was compared between wind farm sites and control sites, via ultrasound recordings at stationary points [A bat pass is defined as a single or several echolocation calls during a five second interval.] The activity of bent winged bats (Miniopterus sp.) and wattled bats (Chalinolobus sp.) were both significantly lower at wind turbine sites. The result of the study demonstrates a large effect on bat habitat use at wind turbines sites compared to control sites. Bat activity was 20 times higher at control sites compared to wind turbine sites, which suggests that habitat loss is an important impact to consider in wind farm planning. ... Here, we provide evidence showing that two genera of insectivorous bat species are also threatened by wind farms. ... To our knowledge, this is one of the first studies quantifying the indirect negative impact of wind turbines on bat activity in the tropics. ... The lower attractiveness of the foraging habitat under wind turbines, both in a tropical and in a temperate climate, indicates that the indirect impact of wind turbine is a worldwide phenomenon."*



Lopucki et al., 2018 *"Living in habitats affected by wind turbines may result in an increase in corticosterone levels in ground dwelling animals… Environmental changes and disturbance factors caused by wind turbines may act as potential stressors for natural populations of both flying and ground dwelling animal species. The physiological stress response results in release of glucocorticoid hormones. … The common vole showed a distinct physiological response – the individuals living near the wind turbines had a higher level of corticosterone [physiological stress affecting regulation of energy, immune reactions]. … This is the first study suggesting impact of wind farms on physiological stress reactions in wild rodent populations. Such knowledge may be helpful in making environmental decisions when planning the development of wind energy and may contribute to optimization of conservation actions for wildlife."*

Ferrão da Costa et al., 2018 *"According to a review by Lovich and Ennen (2013), the construction and operation of wind farms have both potential and known impacts on terrestrial vertebrates, such as: (i) increase in direct mortality due to traffic collisions; (ii) destruction and modification of the habitat, including road development, habitat fragmentation and barriers to gene flow; (iii) noise effects, visual impacts, vibration and shadow flicker effects from turbines; (iv) electromagnetic field generation; (v) macro and microclimate change; (vi) predator attraction; and (vii) increase in fire risks. … Helldin et al. (2012) also highlighted that the development of road networks associated with wind farms could promote increased access for traffic related to recreation, forestry, agriculture and hunting. The consequence, particularly on remote places, is the increase in human presence, affecting large mammals via significant disturbance, habitat loss and habitat fragmentation. These negative effects are expected to be particularly relevant for species that are more sensitive to human presence and activities, such as large carnivores. Large carnivores, such as the wolf, bear, lynx or wolverine, tend to avoid areas that are regularly used by humans and—especially for breeding—show a preference for rugged and undisturbed areas (Theuerkauf et al. 2003; George and Crooks 2006; May et al. 2006; Elfstrom et al. 2008; Sazatornil et al. 2016), which are often chosen for wind power development (Passoni et al. 2017). … Results have shown that the main impact of wind farms on wolves is the induced reduction on breeding site fidelity and reproductive rates. These effects, particularly when breeding sites shift to more unsuitable areas, may imply decreasing survival and pack viability in the short term."*

Watson et al., 2018 *"The global potential for wind power generation is vast, and the number of installations is increasing rapidly. We review case studies from around the world of the effects on raptors of wind-energy development. Collision mortality, displacement, and habitat loss have the potential to cause population-level effects, especially for species that are rare or endangered."*

Aschwanden et al., 2018 *"The extrapolated number of collisions was 20.7 birds/wind turbine (CI-95%: 14.3–29.6) for 8.5 months. Nocturnally migrating passerines, especially kinglets (Regulus sp.), represented 55% of the fatalities. 2.1% of the birds theoretically exposed to a collision (measured by radar at the height of the wind turbines) were effectively colliding."*

Naylor, 2018 *"While wind energy provides a viable solution for emission reductions, it comes at an environmental cost, particularly for birds. As wind energy grows in popularity, its environmental impacts are becoming more apparent. Recent studies indicate that w[…] proximate wildlife. These impacts can be […] indirect—habitat loss (Fargione et al. 2012; Glen et al. 2013). Negative impacts associated with operational wind farms include collision mortalities* *from towers or transmission lines and barotrauma for bats. Habitat loss and fragmentation, as well as avoidance behavior, are also consequences resulting from wind farm construction and related infrastructure. The potential harm towards protected and migratory bird species are an urgent concern, especially for wind farms located along migratory flyways. In terms of mortality, wind turbines kill an estimated 300,000 to 500,000 birds, annually (Smallwood 2013). The high speed at which the fan wings move and the concentration of turbines create a gauntlet of hazards for birds to fly through. … [T]he height of most wind turbines aligns with the altitude many bird species fly at (Bowden 2015). Birds of prey— raptors—are of particular concern because of their slow reproductive cycles and long lifespans relative to other bird species (Kuvlesky 2007).”*

Lange et al., 2018 *“Results from our surface water extractions and aerial surveys suggest that the wind farm has negatively affected redheads through altered hydrology and disturbance displacement. Our surface water extraction analysis provides compelling evidence that the local hydrology has been greatly affected by the construction of the wind farm. … Our results suggest the occurrence of direct habitat loss and disturbance displacement of redheads from the wind farm along the lower Texas coast. Although our study was directed solely toward redheads, it is likely that this wind farm has affected other species that use these wetlands or migrate along the lower Texas coast (Contreras et al. 2017). Studies in Europe investigating the effects on waterfowl by wind turbines have reported similar results, showing that turbines have likely compromised foraging opportunities for waterfowl through disturbance displacement (Larsen and Madsen 2000).”*

Chiebáo, 2018 *“I studied the large-scale movements of white-tailed eagles during the dispersal period, assessing their space use in relation to the distribution of existing and proposed wind farms across Finland. I found that a breeding pair holding a territory closer to an installation has a lower probability to breed successfully when compared to a pair from a territory lying farther away. Such lower probability may in part reflect a harmful interaction between the eagles and wind turbines in the form of collision mortality, to which the adults appear to be particularly vulnerable during the breeding season. Regarding the post-fledging period, I found that the probability of a young eagle approaching a wind turbine decreases sharply as the turbine is installed at increasing distances from the nest.”*

Frick et al., 2017 *“Large numbers of migratory bats are killed every year at wind energy facilities. However, population-level impacts are unknown as we lack basic demographic information about these species. We investigated whether fatalities at wind turbines could impact population viability of migratory bats, focusing on the hoary bat (Lasiurus cinereus), the species most frequently killed by turbines in North America. Using expert elicitation and population projection models, we show that mortality from wind turbines may drastically reduce population size and increase the risk of extinction. For example, the hoary bat population could decline by as much as 90% in the next 50 years if the initial population size is near 2.5 million bats and annual population growth rate is similar to rates estimated for other bat species ($\lambda = 1.01$). Our results suggest that wind energy development may pose a substantial threat to migratory bats in North America. If viable populations are to be sustained, conservation measures to reduce mortality from turbine collisions likely need to be initiated soon. Our findings inform policy decisions regarding preventing or mitigating impacts of energy infrastructure development on wildlife.”*

Hammerson et al, 2017 *“Conservationists are increasingly concerned about North American bats due to the arrival and spread of the White-nose Syndrome (WNS) disease and mortality associated with wind turbine strikes. To place these novel threats in context for a group of mammals that provides important ecosystem services, we performed the first comprehensive conservation status assessment focusing exclusively on the 45 species occurring in North America north of Mexico. Although most North American bats have large range sizes and large populations, as of 2015, 18–31% of the species were at risk (categorized as having vulnerable, imperiled, or critically imperiled NatureServe conservation statuses) and therefore among the most imperiled terrestrial vertebrates on the continent.”*

Vasilakis et al., 2017 *“Numerous wind farms are planned in a region hosting the only cinereous vulture population in south-eastern Europe. We combined range use modelling and a Collision Risk Model (CRM) to predict the cumulative collision mortality for cinereous vulture under all operating and proposed wind farms. Four different vulture avoidance rates were considered in the CRM. Cumulative collision mortality was expected to be eight to ten times greater in the future (proposed and operating wind farms) than currently (operating wind farms), equivalent to 44% of the current population (103 individuals) if all proposals are authorized (2744 MW). Even under the most optimistic scenario whereby authorized proposals will not collectively exceed the national target fo (960 MW), cumulative collision mortalit population) and likely lead to population extinction.”*

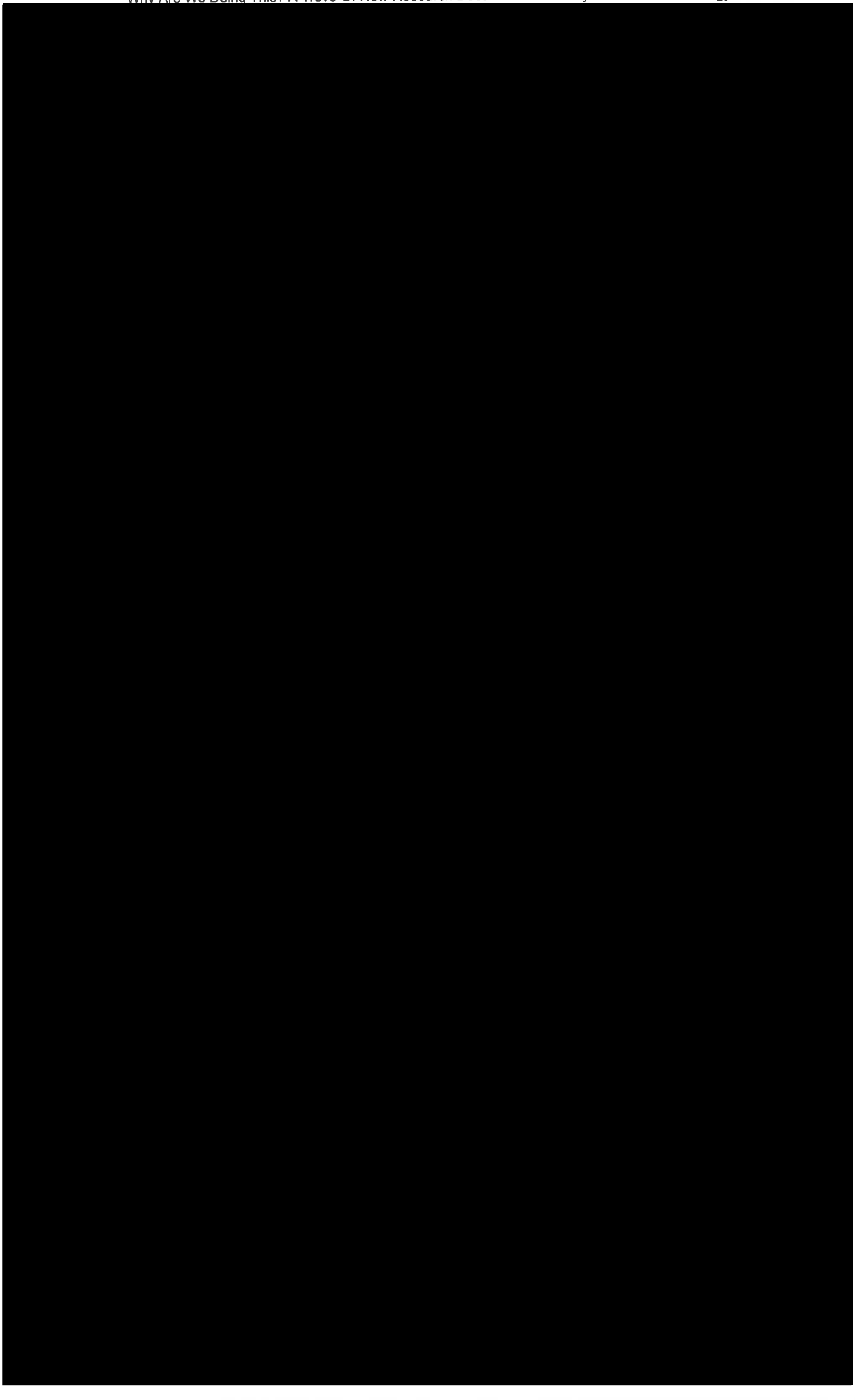
12. Wind Turbine Blade Waste Disposal A Growing Ecological Nightmare

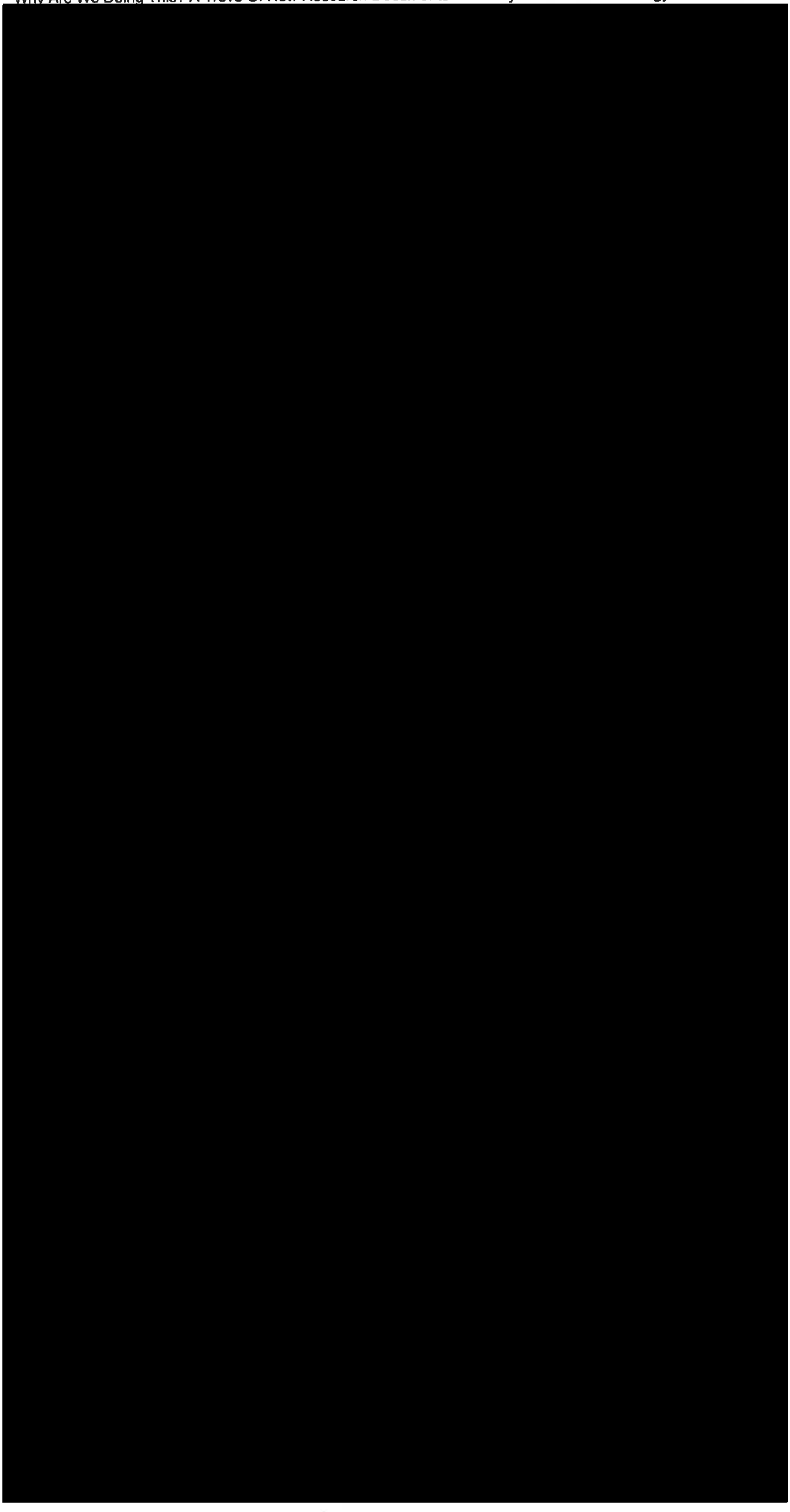
> Liu and Barlow, 2017 *"Wind energy has developed rapidly over the last two decades to become one of the most promising and economically viable sources of renewable energy. Although wind energy is claimed to provide clean renewable energy without any emissions during operation, but it is only one side of the coin. The blades, one of the most important components in the wind turbines, made with composite, are currently regarded as unrecyclable. With the first wave of early commercial wind turbine installations now approaching their end of life, the problem of blade disposal is just beginning to emerge as a significant factor for the future. … The research indicates that there will be 43 million tonnes of blade waste worldwide by 2050 with China possessing 40% of the waste, Europe 25%, the United States 16% and the rest of the world 19%."*

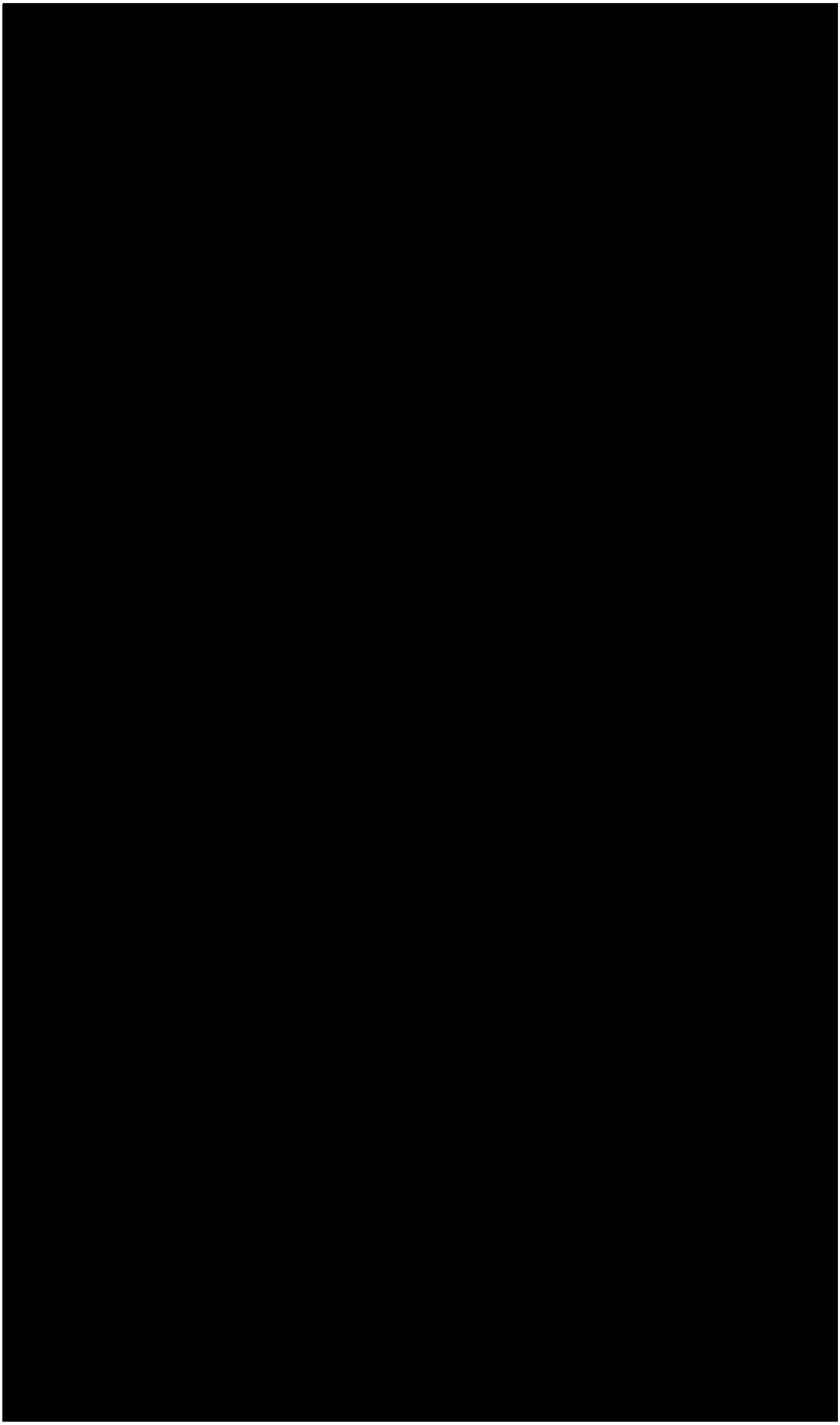
> Ramirez-Tejeda et al., 2017 *"Globally, more than seventy thousand wind turbine blades were deployed in 2012 and there were 433 gigawatts (GW) of wind installed capacity worldwide at the end of 2015. Moreover, the United States' installed wind power capacity will need to increase from 74 GW to 300 GW3 to achieve its 20% wind production goal by 2030. … The wind turbine blades are designed to have a lifespan of about twenty years, after which they would have to be dismantled due to physical degradation or damage beyond repair. … Estimations have suggested that between 330,000 tons/year by 2028 and 418,000 tons/year by 2040 of composite material from blades will need to be disposed worldwide. That would be equivalent to the amount of plastics waste generated by four million people in the United States in 2013. This anticipated increase in blade manufacturing and disposal will likely lead to adverse environmental consequences. … Despite its negative consequences, landfilling has so far been the most commonly utilized wind turbine blade disposal method. … Landfilling is especially problematic because its high resistance to heat, sunlight, and moisture means that it will take hundreds of years to degrade in a landfill environment. The wood and other organic material present in the blades would also end up in landfills, potentially releasing methane, a potent greenhouse gas, and other volatile organic compounds to the environment."*

Posted in Green Follies, Solar, Wind Power | 53 Responses

[redacted]

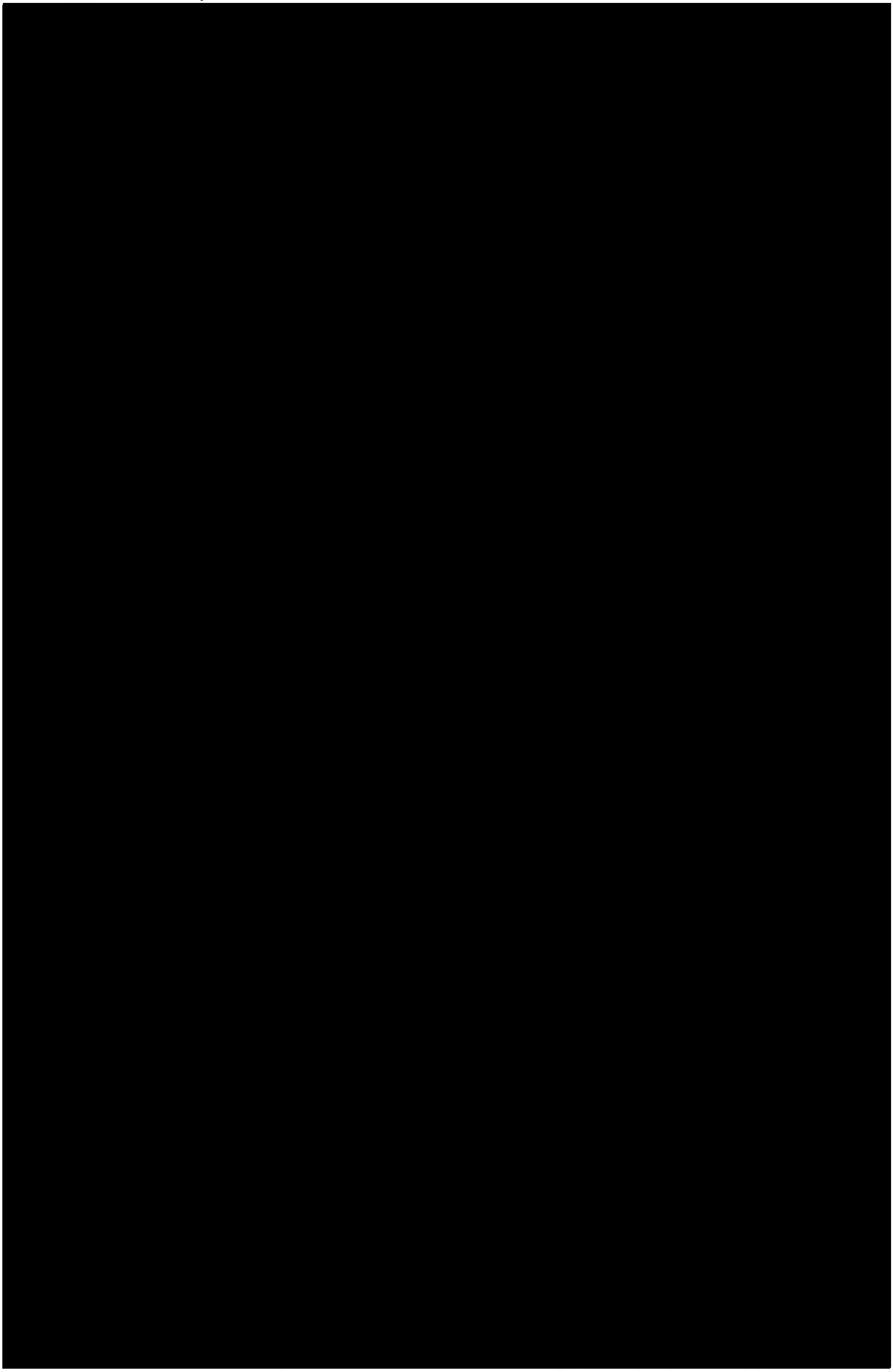


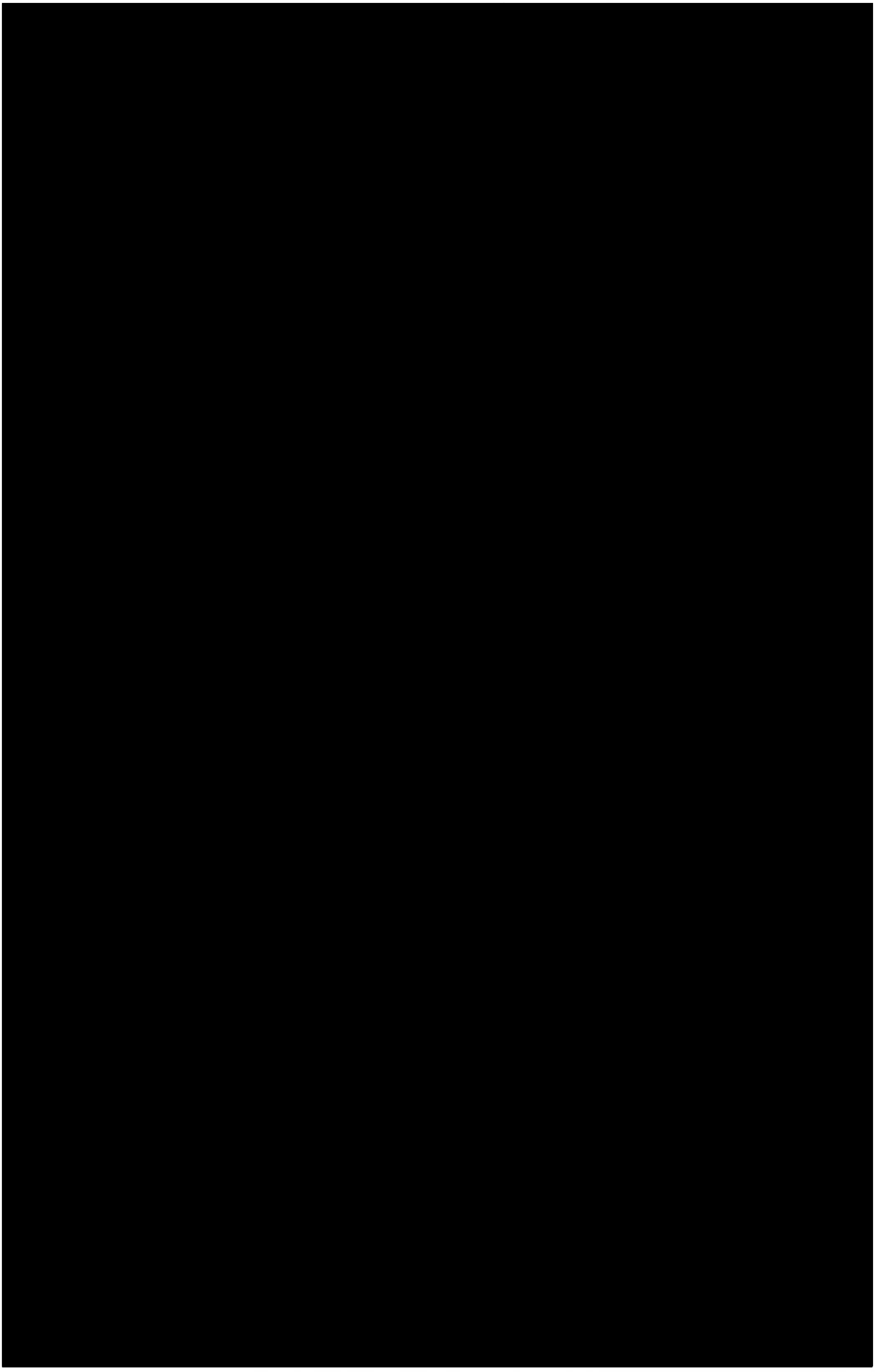


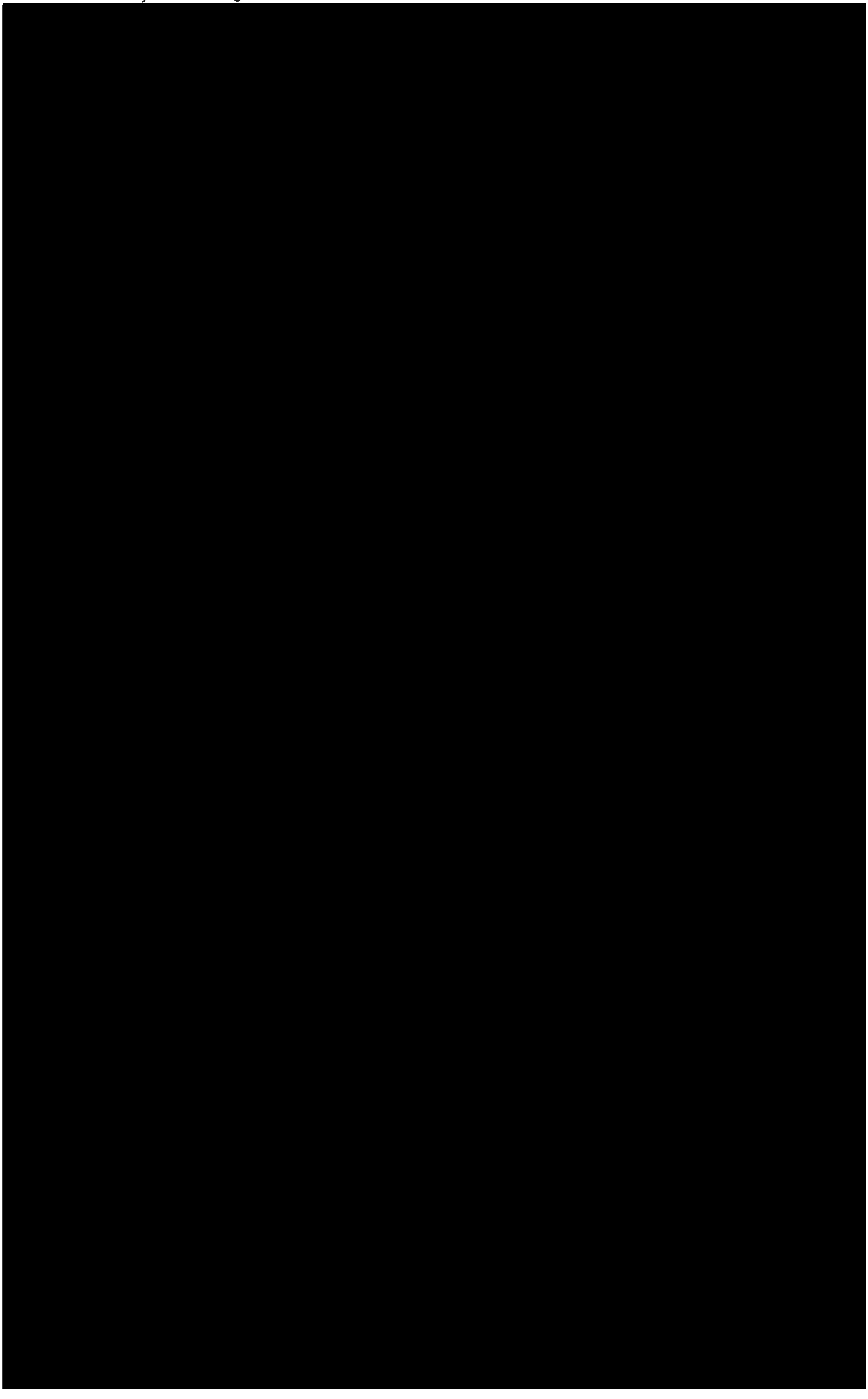


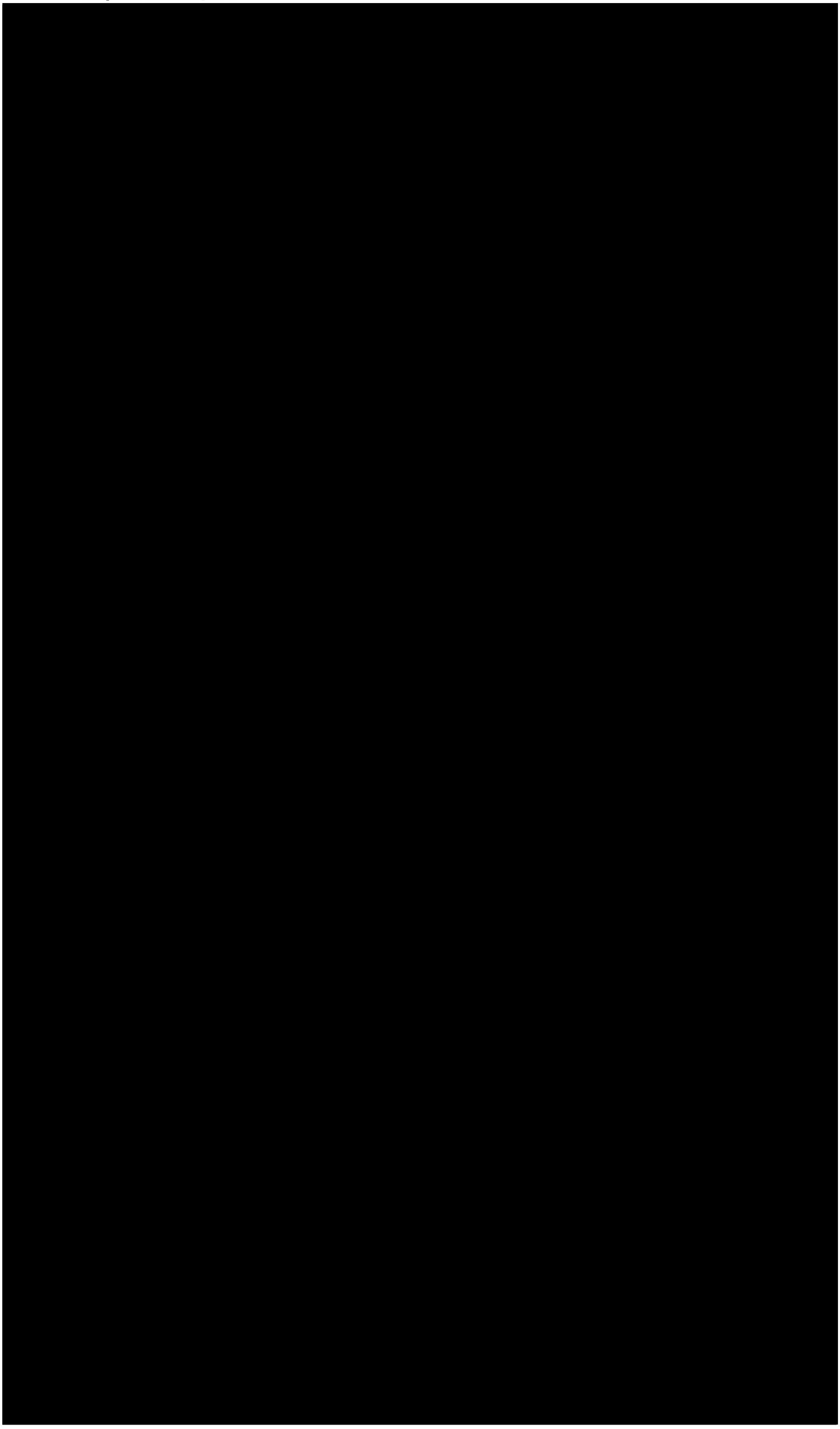
[redacted]

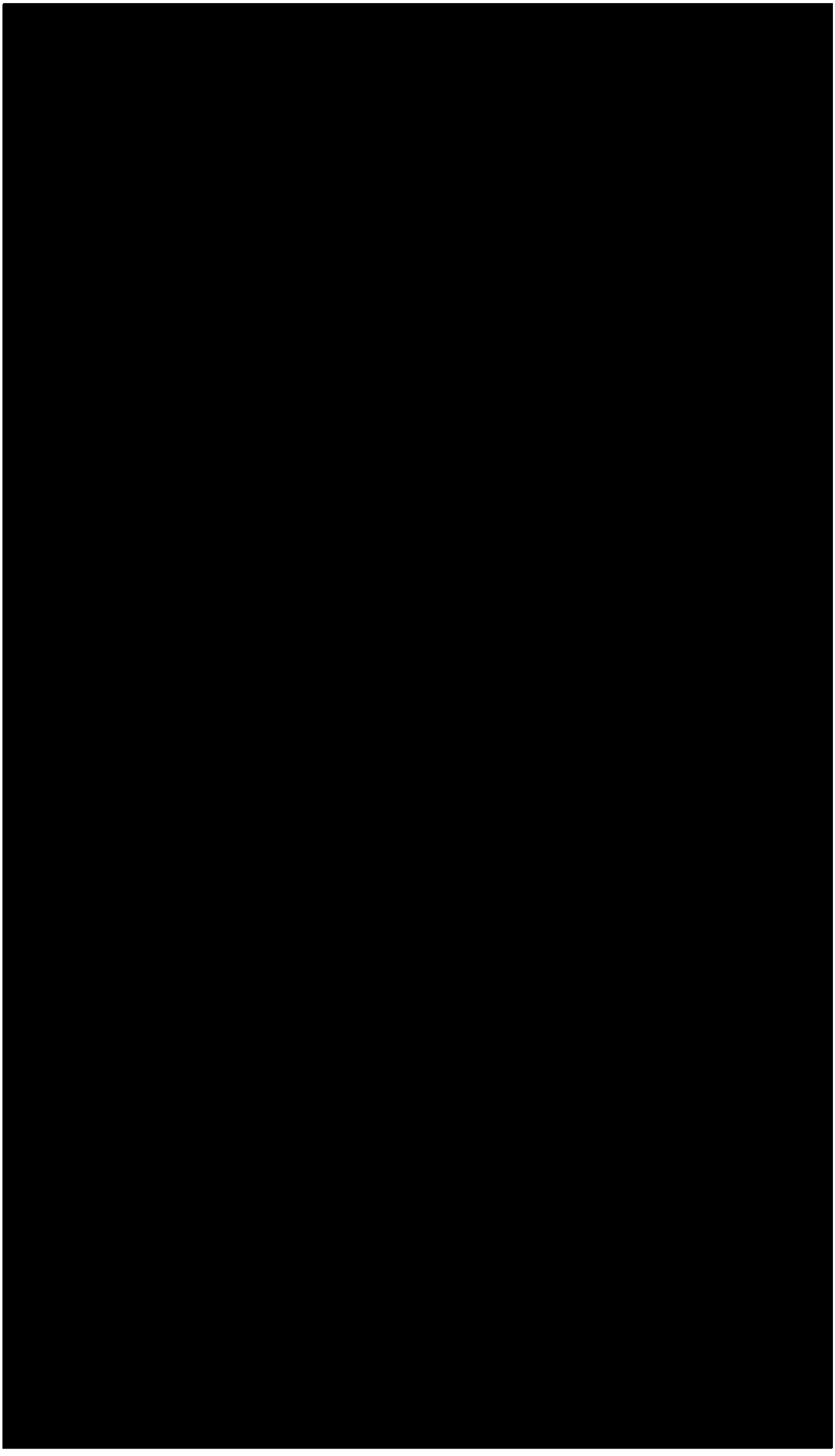
[redacted]

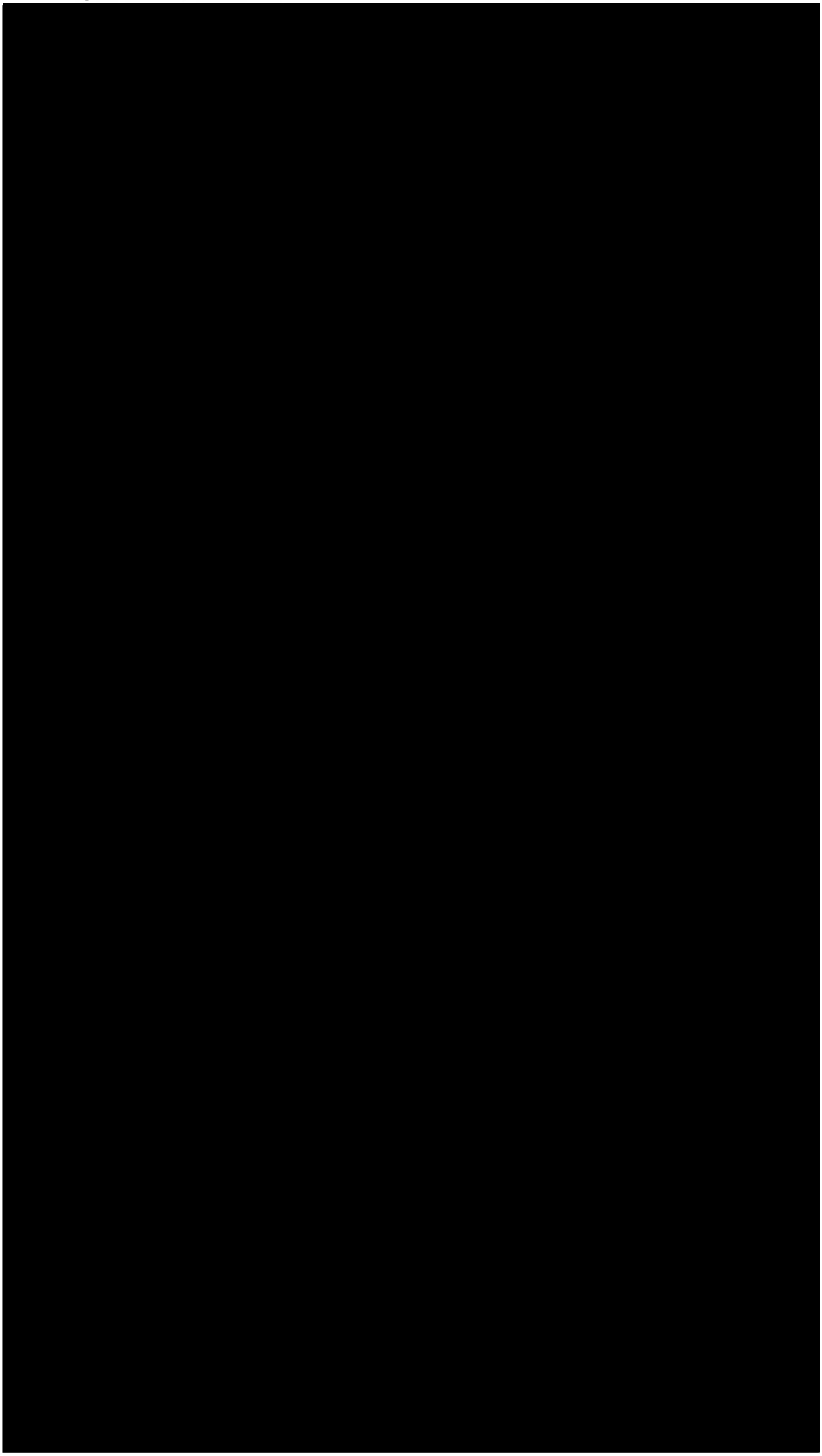


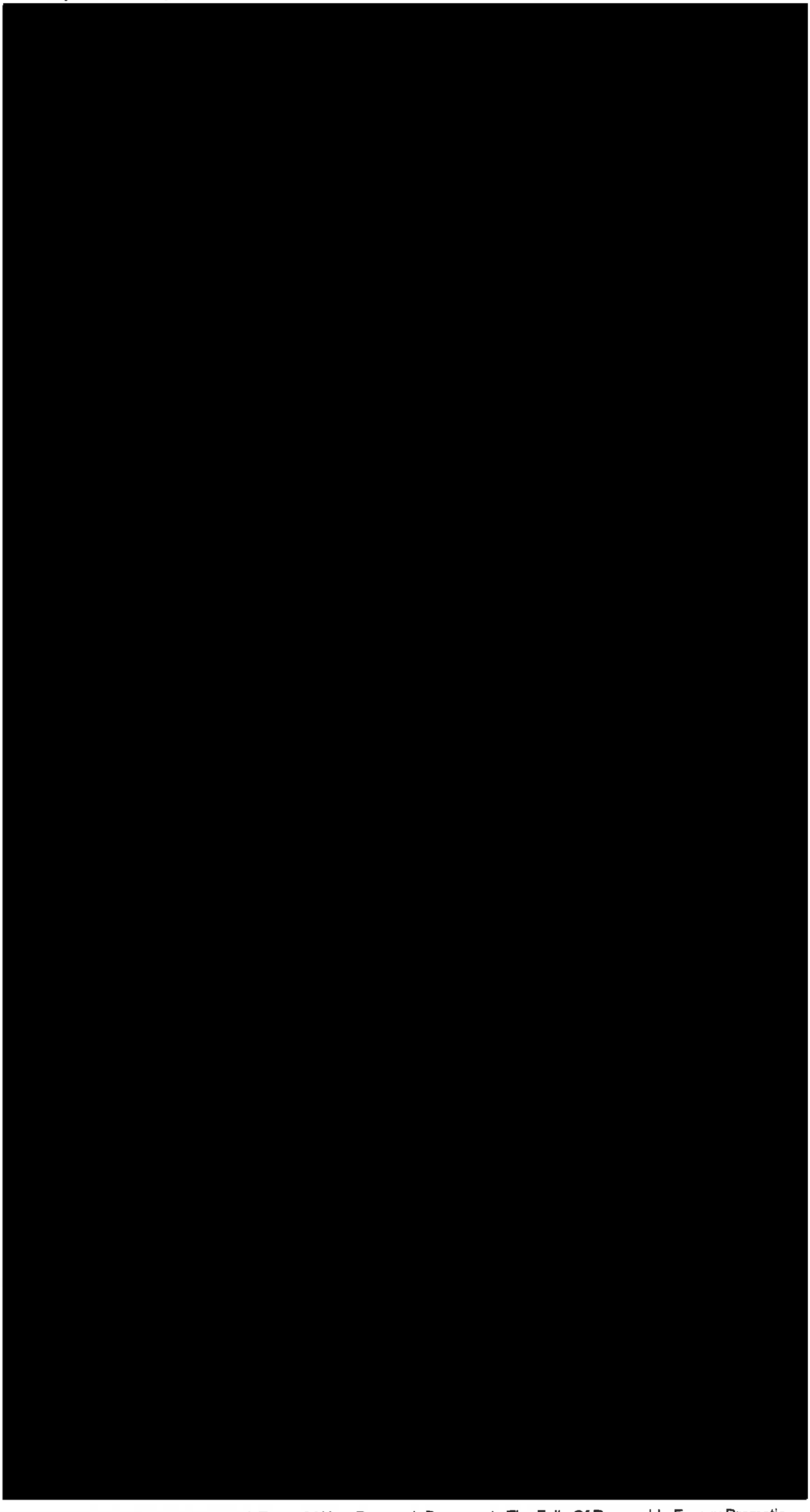


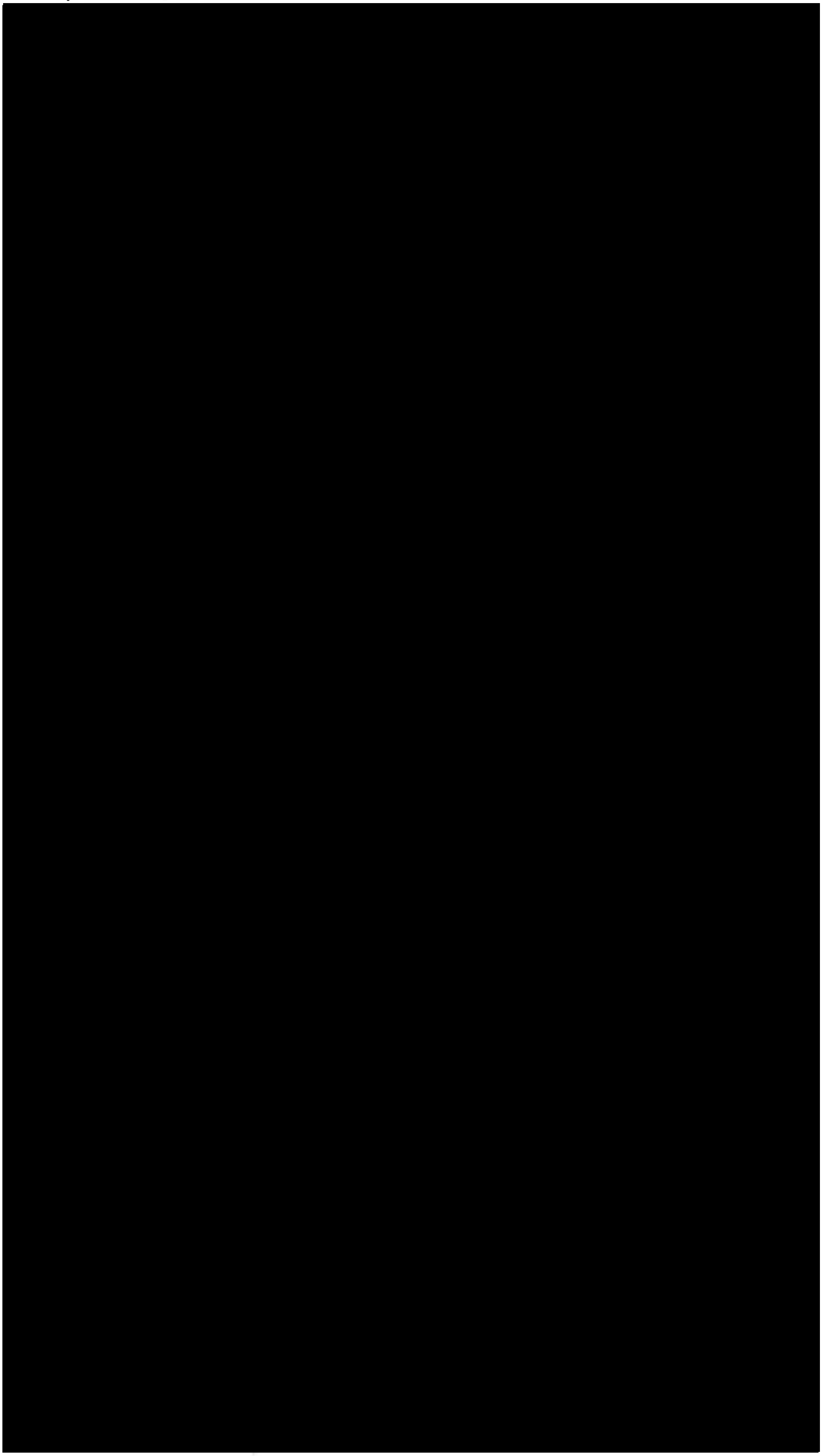




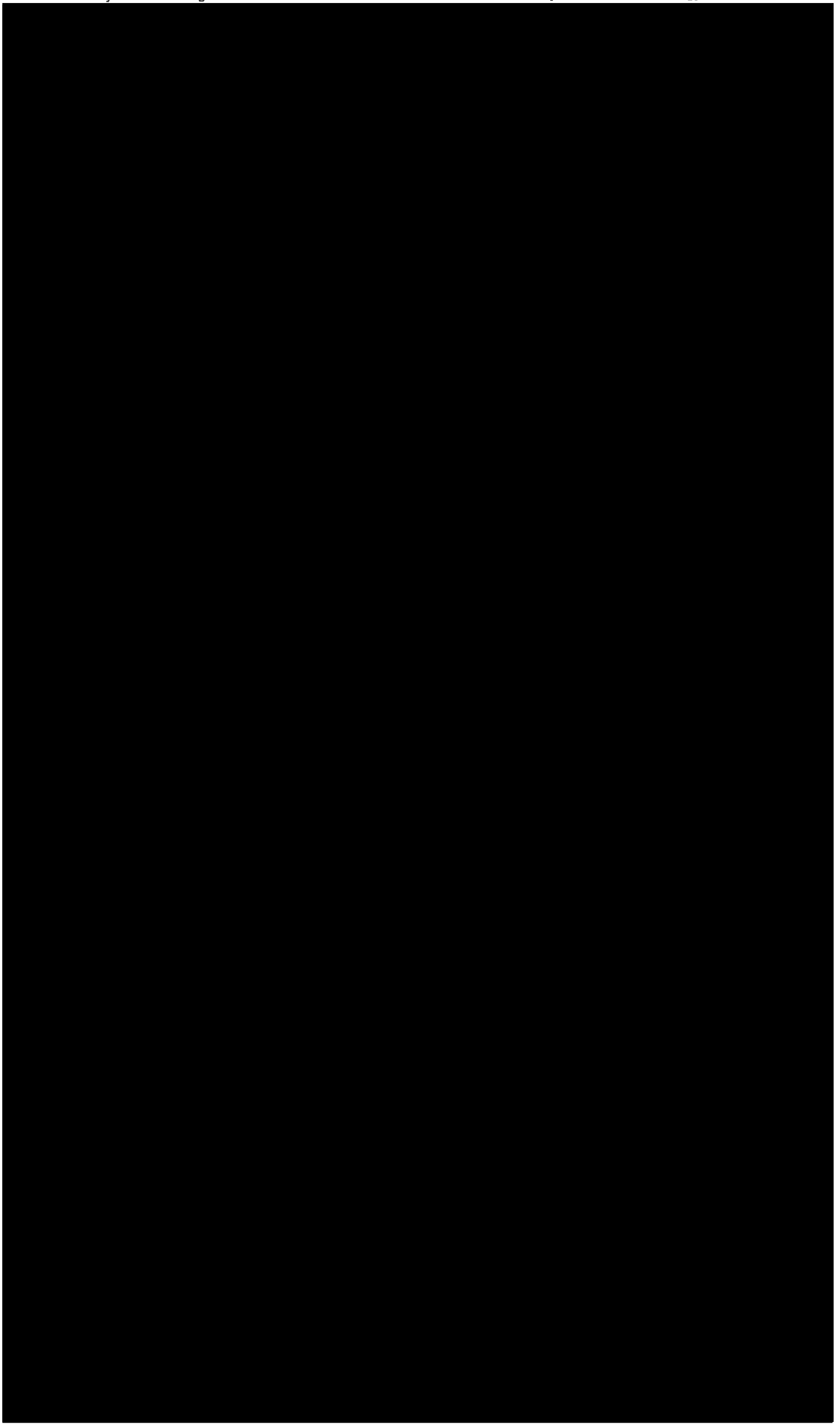


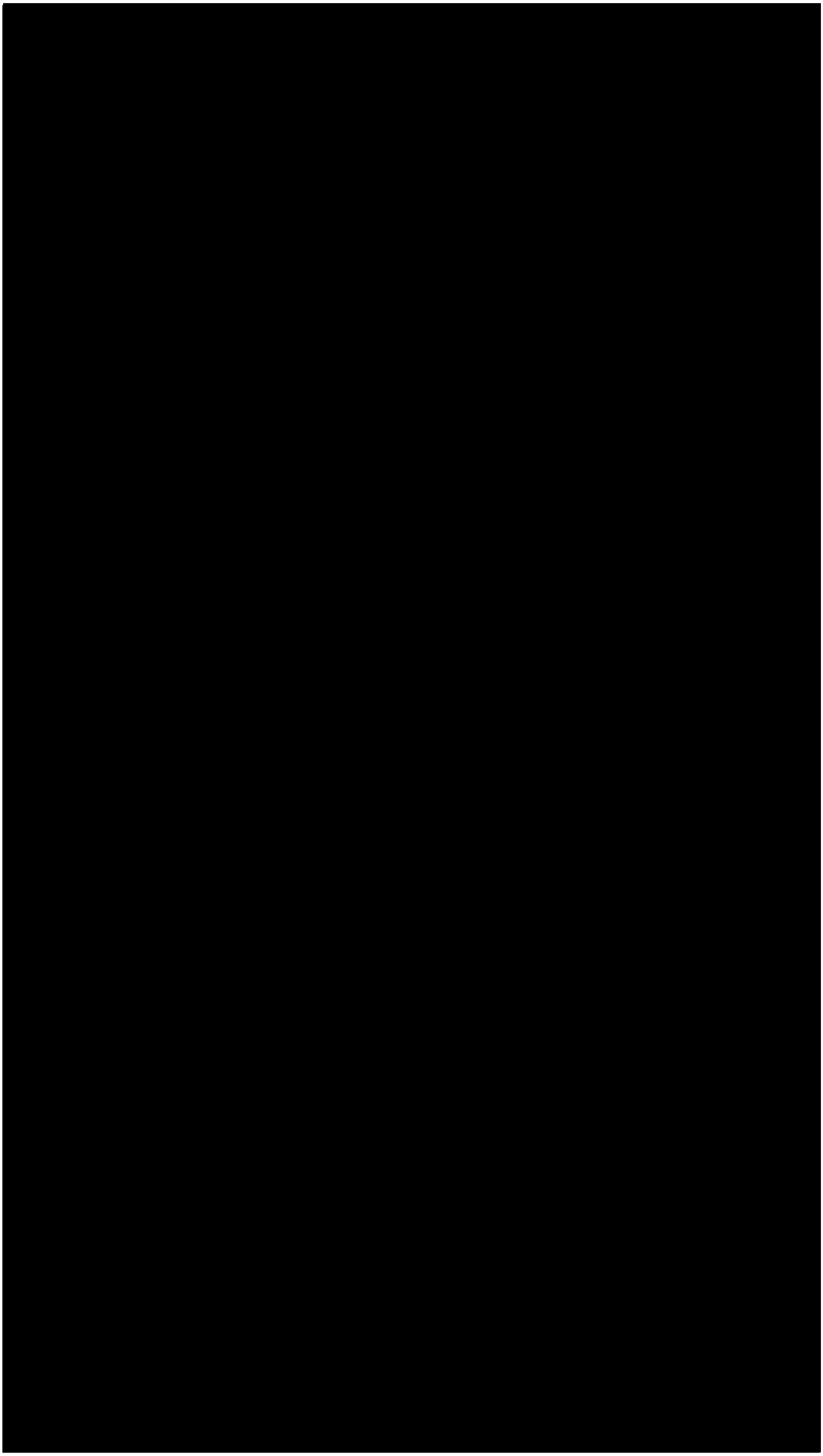


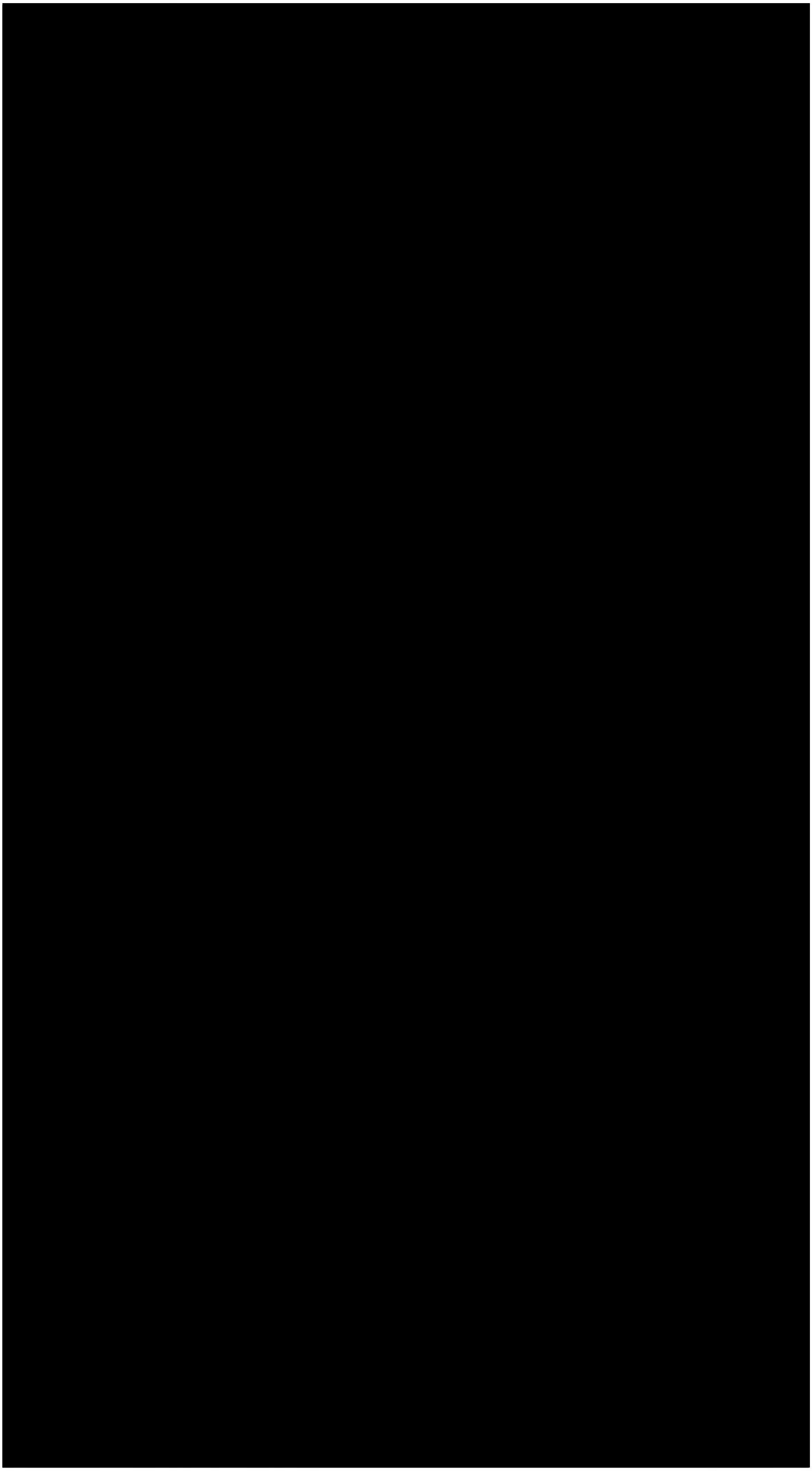


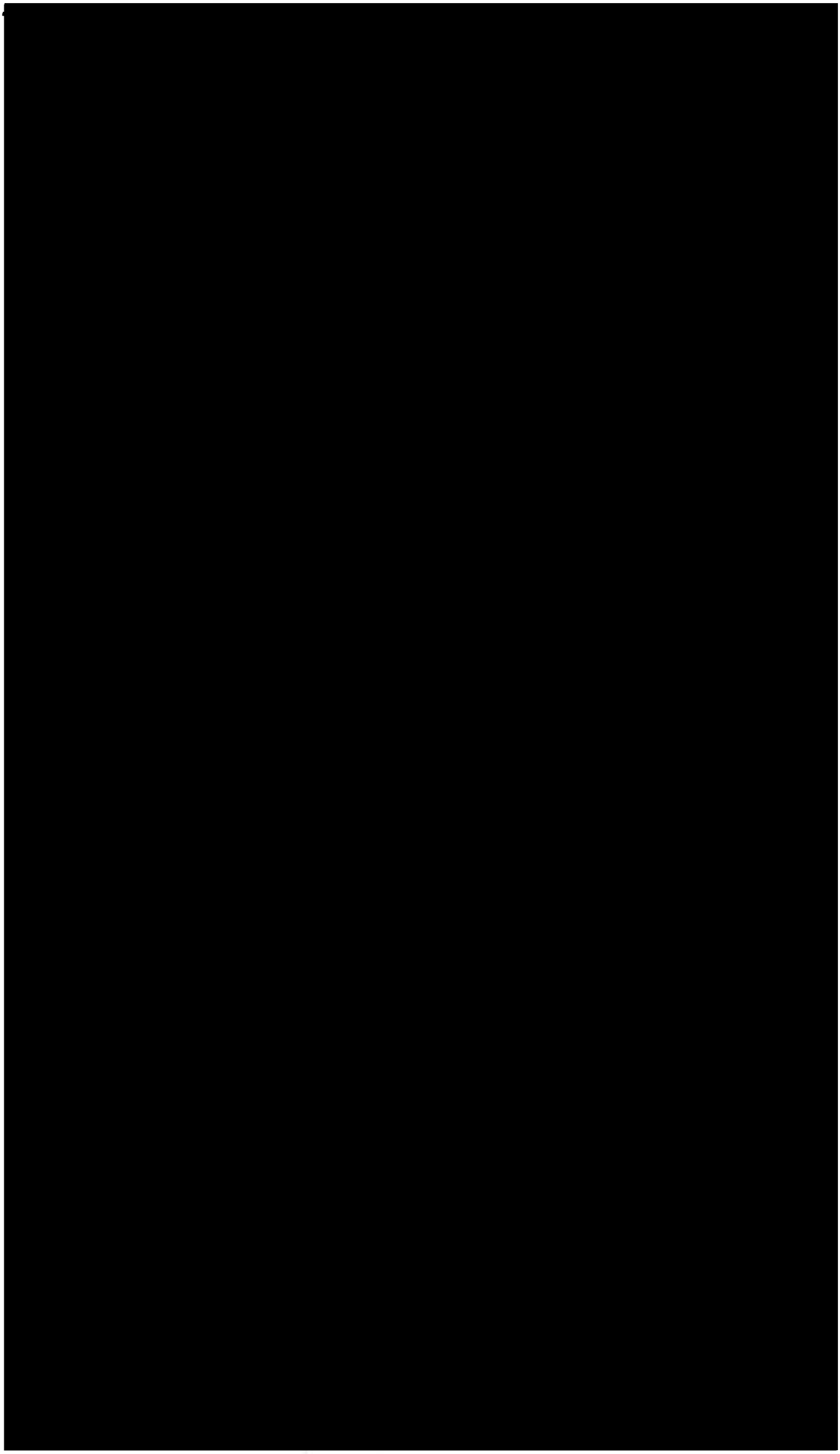


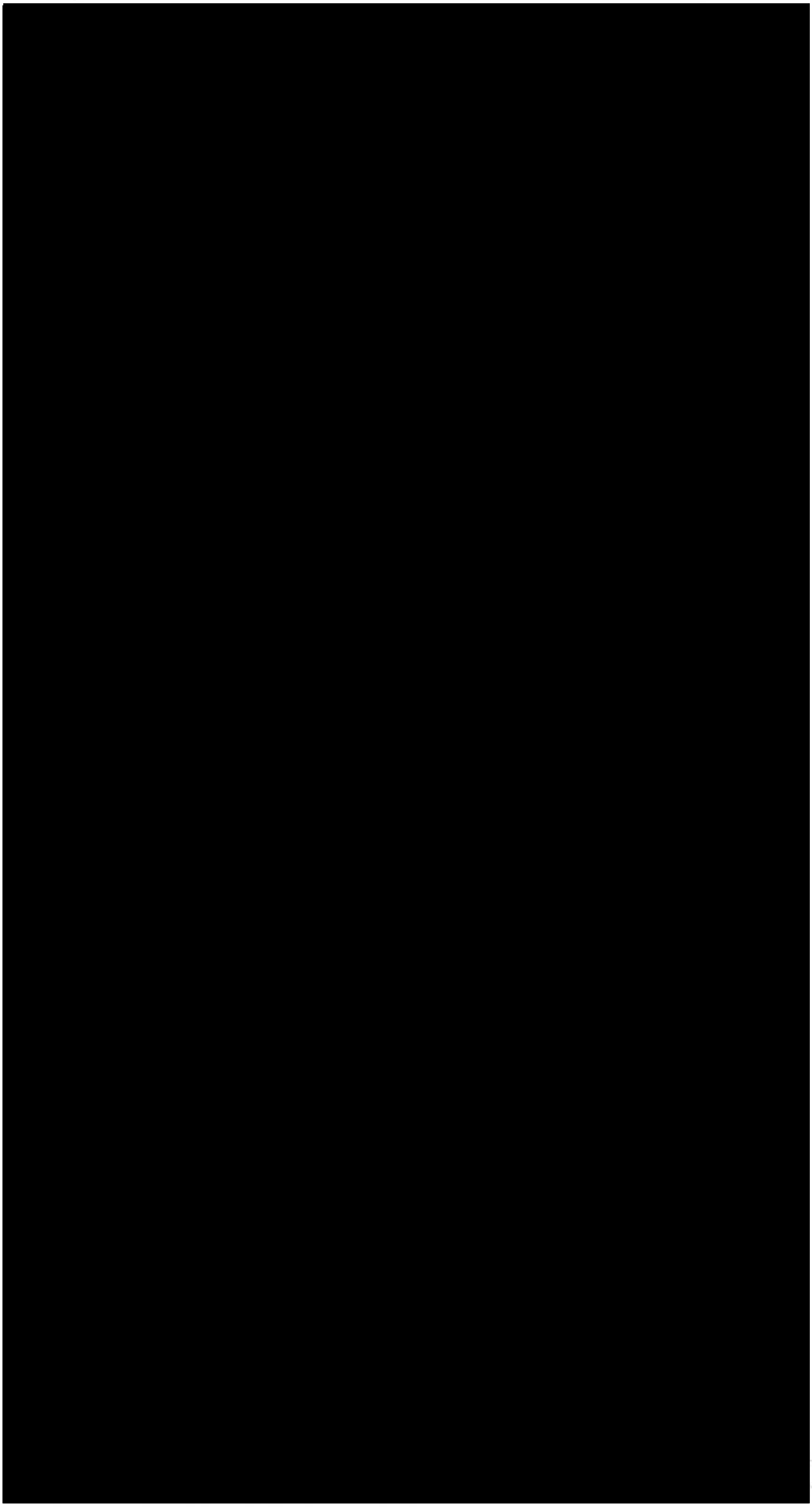
[redacted]

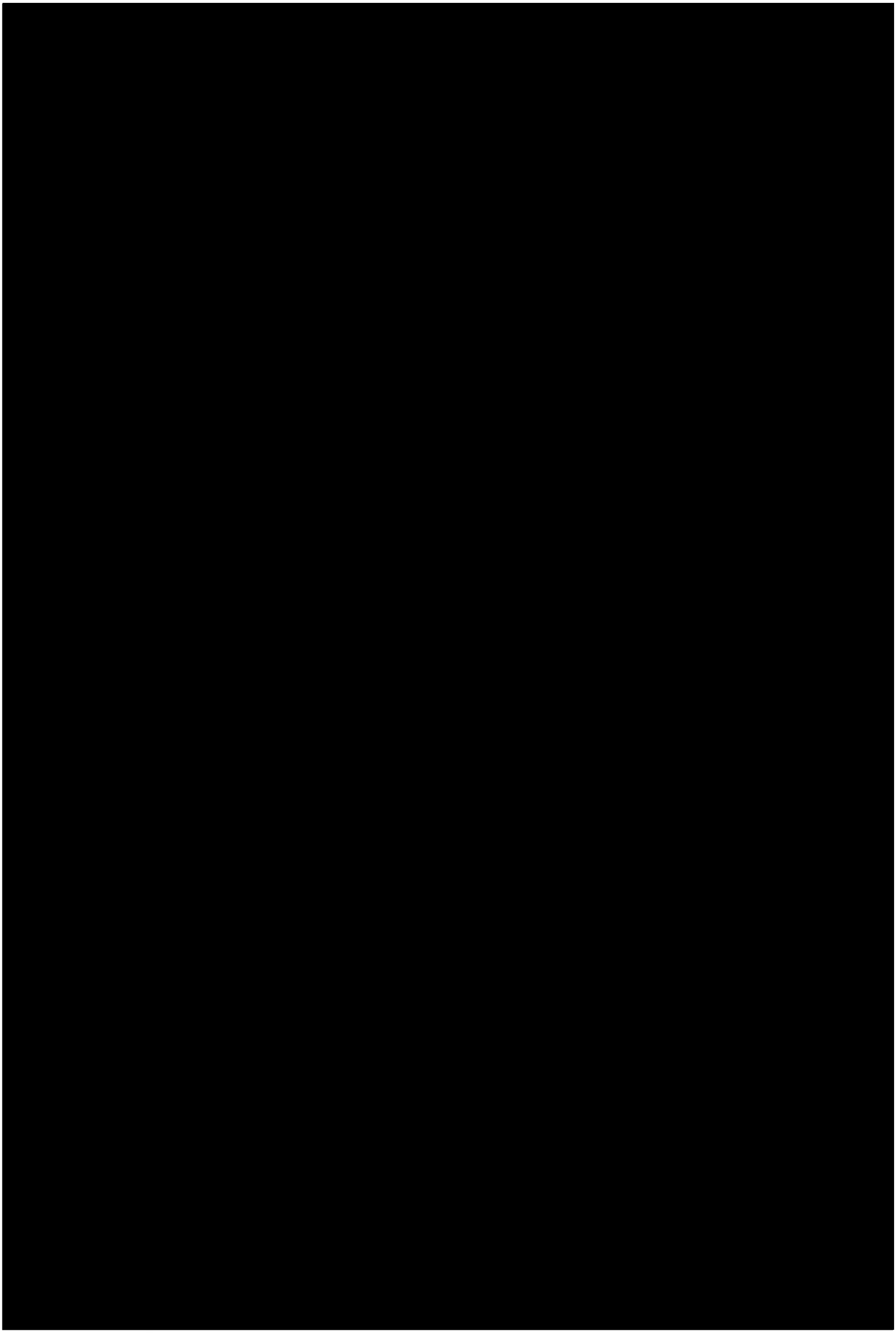


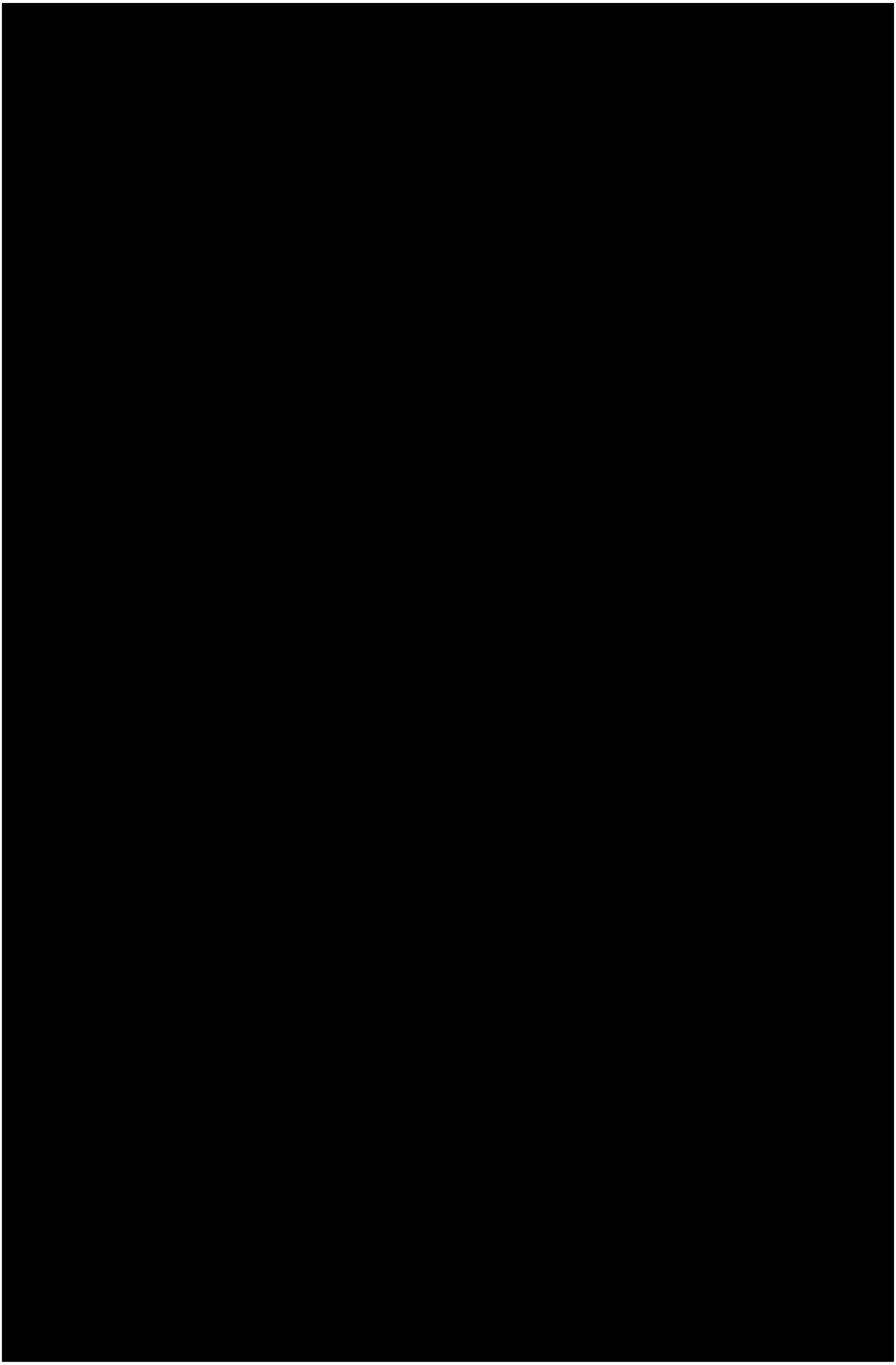






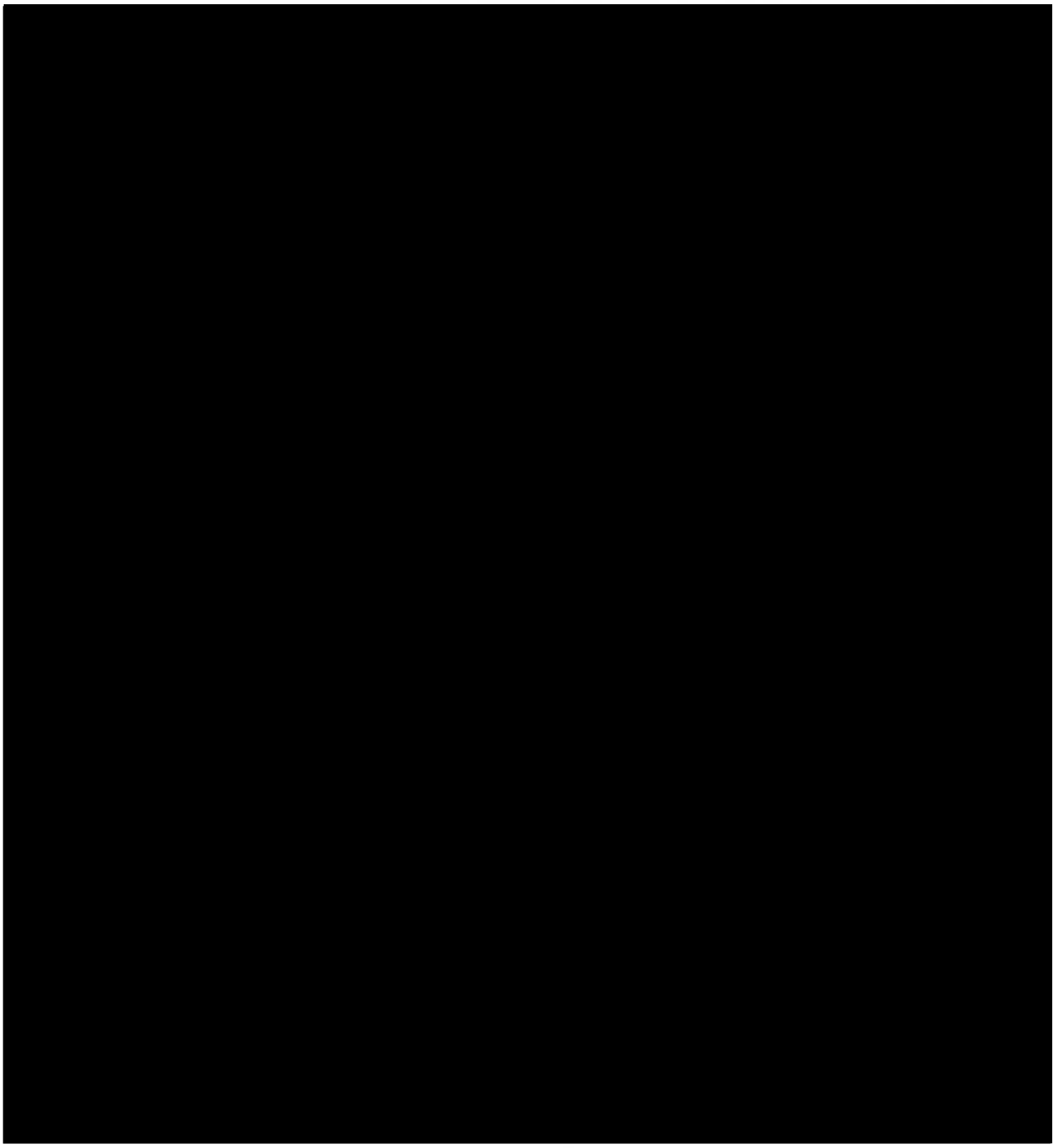






[redacted]

[redacted]



Leave a Reply

Comment

Name *

Email *

Website

Post Comment

« Previous

Next »

ANNEX 8

Demonstrable fallacies in PPS 18 BPG

These are just some examples to illustrzate the problems of continuing with an uncritical adherence to this flawed document.

1.3.43 (and up to 1.3.49 are all inaccurate or worse) Well designed wind farms should be located so that increases in ambient noise levels around noise-sensitive developments are kept to acceptable levels with relation to existing background noise. This will normally be achieved through good design of the turbines and through allowing sufficient distance between the turbines and any existing noise-sensitive development so that noise from the turbines will not normally be significant...

> Response: See Annex 1, particularly 3. Amplitude Modulation. ETSU is totally ineffective because the specified noise descriptor ignores the noisiest 90% of each ten-minute measurement period and gives a result based on the loudest noise during the quietest 10% of the period. It also fails to take account of the fact that aerodynamic modulation noise can be heard at considerable distances from a noise source but difficult to detect nearby. Excess AM is now shown to be neither rare nor only causing minor effects.

Dr Jeremy Bass of RES, the main opponent of the Den Brook condition said in 2013: "foolishly ... we went along the industry line that amplitude modulation is rare". He accepted the argument that it can be dealt with by statutory nuisance was wrong. He continued "I think that argument is completely exploded by the weight of evidence presented by Mike Stigwood in particular .... we are in a difficult position now ... the landscape has changed and I suspect .... in the future developers will no longer try the argument that AM is rare".

> Noise levels from turbines are generally low and, under most operating conditions, it is likely that turbine noise would be masked by wind-generated background noise.

Response: As can be seen in Annex 5, especially 'Summary ETSU IoA Article' this is simply not true.

> 1.3.50 Experience indicates that properly designed and maintained wind turbines are a safe technology. The very few accidents that have occurred involving injury to humans have been caused by failure to observe manufacturers' and operators' instructions for the operation of the machines. There has been no example of injury to a member of the public.

Response: See Annex 4, particularly 'Wind Turbine Accidents to 30 June 2019'.

1.3.51 The only source of possible danger to human or animal life from a wind turbine would be the loss of a piece of the blade or, in most exceptional circumstances, of the whole blade. Many blades are composite structures with no bolts or other separate components. Blade failure is therefore most unlikely. Even for blades with separate control surfaces on or comprising the tips of the blade, separation is most unlikely.

Response: See Annex 4, especially comments in introduction to 'Wind Turbine Accidents to 30 June 2019'. Note introduction to statistics including 3500 blade failures in one year. Also 'Numerical Modelling of Wind Turbine Blade Throw' and the sparation distance for wind farm employees mandated by Vestas and other manufacturers.

1.3.52*For wind farm developments the best practice separation distance of 10 times rotor diameter to occupied property should comfortably satisfy safety requirements. For a smaller individual wind turbine, for example on a farm enterprise, the fall over distance (i.e. the height of the turbine to the tip of the blade) plus 10% is often used as a safe separation distance.*

Response: See Annex 3, particularly 'Single Turbine Separation Distances', Part 6. Fall over plus 10% has no evidential basis whatsoever, as revealed in it's ultimate source. Similarly, 10 times the rotor diameter is not based on the failure of any part of a turbine, but on a discredited piece of shadow flicker estimation that has now been demonstrated to be incorrect.

1.3.72 Under certain combinations of geographical position and time of day, the sun may pass behind the rotors of a wind turbine and cast a shadow over neighbouring properties. When the blades rotate, the shadow flicks on and off; the effect is known as 'shadow flicker'. It only occurs inside buildings where the flicker appears through a narrow window opening. A single window in a single building is likely to be affected for a few minutes at certain times of the day during short periods of the year….

Response: See Annex 2, particularly 'Shadow Impacts' and its Appendix 2 on 'Germany and Shadow Flicker', which demonstrates how the German research has been deliberately misquoted.

1.3.73 Shadow flicker generally only occurs in relative proximity to sites and has only been recorded occasionally at one site in the UK.

Response: See contrary evidence in Annex 2 'Shadow Impacts'.

1.3.76 Problems caused by shadow flicker are rare. At distances greater than 10 rotor diameters from a turbine, the potential for shadow flicker is very low…

Response: See Annex 2 'Shadow Impacts' and its Appendix 6 'light and shadow effects from wind turbines in Scotland stages 1 and 2'. The 10 times the rotor diameter metric has been deliberately misquoted and has been shown to have no robust evidential basis.

> 1.3.79 The build-up of ice on turbine blades is unlikely to present problems on the majority of sites in Northern Ireland. Even where icing does occur the turbines' own vibration sensors are likely to detect the imbalance and inhibit the operation of the machines.

Response: Claims such as this that rotor sensors would stop the turbine blades when ice build-up was detected, have now been shown to be in error, as were previous claims that icing would not occur at this latitude. It has been discovered that 'rime' ice formation appears to occur with remarkable symmetry on all turbine blades, with the result that no imbalance occurs and the turbine continues to operate until the ice fractures. shedding ice will then be thrown a significant distance as a result of the rotor spinning or wind blowing the ice fragments. See Annex 4, particularly 'Numerical Modelling of Wind Turbine Blade Throw', which also applies to ice throw from turbine blades, and images of hazard warning signs. .

> 1.3.80 In many areas in Northern Ireland, recreation and tourism are a significant element of the local economy and can depend to varying degrees on the quality of the environment. It is not considered that wind energy developments are necessarily incompatible with tourism and leisure interests, but it is acknowledged that care does need to be taken to ensure that insensitively sited wind energy developments do not impact negatively on tourism potential. The results of survey work conducted in 2003 in the Republic of Ireland indicate that tourism and wind energy can co-exist happily[4].

Response: Not according to the response to the draft of PPS 18 by Invest N I and the Northern Ireland Tourist Board.

"While this assessment might be valid from a 2003 perspective. there has been an acceleration in wind energy developments in both parts of the island in the intervening five years...Our primary concern is... but the qualitative impact of the destination of wind farm proliferation, particularly in highly visible upland areas."

"*As a* general comment, the Board has concerns regarding the development of wind farms, relating primarily to their visual impact and noise generation and in turn the potential impact on tourism, particularly in scenic areas. Although many of the constraints on wind farm development_ such as noise and safety issues can be addressed by appropriate action, *the* visual impact of the wind farm is largely unavoidable, Wind farms present a difficult challenge to all those involved in landscape protection and, depending on the scale of development, they can be regarded as a potential major threat to the natural beauty of the countryside. which is often the main resource of the area."

As can be seen, this is a very different position from that portrayed in the Best Practice Guide.

> 1.3.82 The educational potential of wind energy developments should also be considered. For example, there may be scope for an interpretive centre on alternative energy resources to be located at accessible location in proximity to a wind energy development. It would be helpful if established long distance walking routes/amenity rights-of-way were identified and mapped to enable an assessment both of the extent to which recreational pursuits can be accommodated and facilitated either within or adjacent to wind energy developments. Local councils would be a useful contact point to provide information on this matter.

Response: According to the response to the draft of PPS 18 by Invest NI and the Northern Ireland Tourist Board, 'The additional educational benefits of wind energy development is overstated **(at** A113 p.3) and, while a few sites might be suitable for this purpose…this should not be used as justification for a wind farm development." But as can be seen, it is!

Further, the fact that major wind turbine suppliers stress the separation distances necessary to protect their own staff and the warnings in place at site entrances, clearly mitigate against members of the public or children being permitted to approach close to turbines. To encourage them to do so, while being aware of the dangers, is criminally irresponsible. See Annex 4, particularly 'Vestas Confidential – Health & Safety Instruction Manual' and Images of Warning Signs.