308210
Cork

Lita Clarke

From: Joe Noonan <jnoonan@nlcc.ie>
Sent: Monday 2 November 2020 15:13
To: Appeals2
Cc: Pippa Willows - Legal Secretary
Subject: PL04.308208-20 and PL04.308210-20
Attachments: 30.10.2020 Letter to ABP.doc

Importance: High

Dear Sir/Madam,

You will receive the original of the attached letter today. We note that the Board has changed the Reference Numbers for these appeals and only one reference number is given in our letter. The subject matter is clearly set out in the letter but for the avoidance of doubt we are setting out both your reference numbers below.

Kind regards,

Joe Noonan

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RE: **Applicant:** Barna Wind Energy (BWE) Ltd
Development: 6 no. wind turbines
At: Lackareagh and Garranereagh, Lissarda and Barnadivane (Kneeves) Teerelton, County Cork (146760)

An Bord Pleanála Reference Number: PL04.308210-20

AND

Applicant: Arran Windfarm Ltd
Development: Construct electricity substation compound, to replace substation already granted permission under PL04.219620 (05/5907) and extended under 11/6605. Electricity substation layout includes 3 no. control buildings, associated electrical plant and equipment, security fencing and ancillary works. A 10 year permission is sought
At: Barnadivane , Kneeves, Terelton, Co. Cork (14557)

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The Secretary,
An Bord Pleanála,
64 Marlborough Street,
Dublin 1.

30th October 2020
Our ref: 32210-20/JN/PW

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Our clients: **Denis Buckley and others known as Barna Wind Action Group, c/o Denis Buckley, Moneygoff East, Castletown, Enniskeane, Co Cork**

Dear Sir/Madam,

We act on behalf of Denis Buckley and others known as Barna Wind Action Group and we write in response to your two letters dated 13th October 2020 relating to these planning appeals.

You letters both invite *"submissions/observations on how the appeal should be further progressed by the Board."*

Our clients and their neighbours have had to go to the High Court on two separate occasions, so far, due to the failure of the Board to deal with these planning applications in accordance with law.

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That is the background to your letters asking for *"submissions/observations on how the appeal should be further progressed by the Board."*

The wording there is unusual. It is a matter for the Board to decide how to discharge its functions, in accordance with law. We have no role in advising the Board on how to do this.

We will take your letters therefore as an invitation to make further submissions/observations on the appeals which have now been remitted to the Board for fresh consideration.

Our clients submit that the Board should refuse permission.

While the Board is already in possession of the appeal materials submitted to it on behalf of our clients, with the passage of time some additional matters have arisen which should be addressed at this point. We rely on the judgment of the Supreme Court in Balz and Heubach v An Bord Pleanála and in particular we draw the Board's attention to this passage from the judgment:

> *It is a basic element of any decision-making affecting the public that relevant submissions should be addressed and an explanation given why they are not accepted, if indeed that is the case. This is fundamental not just to the law, but also to the trust which members of the public are required to have in decision making institutions if the individuals concerned, and the public more generally, are to be expected to accept decisions with which, in some cases, they may profoundly disagree, and with whose consequences they may have to live.*

No Strategic Environmental Assessment means Board must refuse permission

We wish to draw the attention of the Board to legal precondition to the Board's jurisdiction to permit this type of development. The precondition arises from the requirements of Directive 2001/42/EC ("the SEA Directive") as interpreted by the Court of Justice in the recent case in which judgment was delivered on 25 June 2020 *A and Others v Gewestelijke stedenbouwkundige ambtenaar van het departement Ruimte Vlaanderen, afdeling Oost-Vlaanderen* case *C-24/19*

The Court of Justice in this case considered the consequences of a failure to carry out a Strategic Environmental Assessment (SEA) prior to the adoption of a plan or programme and the impact this would have on the relevant plan or programme, as well as subsequent projects based on that plan or programme.

In the case, local residents in Belgium challenged a wind farm development project of five turbines which had been permitted based on conditions outlined in a regional government order from 2006

and a circular on the Assessment framework and conditions for the installation of wind turbines. They argued that the consent granted should be annulled on the basis that the order and the circular should have been preceded by an SEA, and were therefore in breach of Article 2(a) and Article 3(2)(a) of Directive 2001/42 on the assessment of the effects of certain plans and programmes on the environment (SEA Directive).

A) Plans and Programmes

At issue was the interpretation of the above Articles. Article 2(a) defines plans and programmes as:

> *"plans and programmes ...*
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> *- which are subject to preparation and/or adoption by an authority at national, regional or local level or which are prepared by an authority for adoption, through a legislative procedure by Parliament or Government, and*
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Article 3(2)(a) provides that an environmental assessment shall be carried out for all plans and programmes:

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The Grand Chamber had to consider whether the order and the circular amounted to a plan or programme and the implications on a development such as the wind farm development should there be a violation of EU law by a Member State.

The Court of Justice found that the order and the circular constituted plans or programmes under the SEA Directive and that an SEA should have been carried out prior to their adoption by the Belgian government in 2006.

Both the order and the circular contained various provisions in relation to the installation and operation of wind turbines, including measures on shadow flicker, safety, and noise levels.

B) Consequences of a Breach of EU law

The Court of Justice outlined the consequences of a breach of EU law:

(a) Member States are "*required to eliminate the unlawful consequences*" of breaches of EU law. Competent national authorities are "*under an obligation to take all the necessary measures, within the sphere of their competence, to remedy the failure to carry out an environmental assessment*" which can involve "*adopting measures to suspend or annul that plan or programme*".

(b) Only the Court of Justice may, in exceptional cases, temporarily suspend the application of EU law.

The Court of Justice concluded that in cases where an SEA is required but is not carried out, the plan or programme, as well as all permissions for projects based on same, must be annulled. In this case, construction of the wind farm development had not yet commenced. The Court of Justice stated that it was clear that the consent must therefore be annulled as such consent was adopted on the basis of the plan or programme which "*was itself adopted in breach of the obligation to carry out an environmental assessment*". The Court of Justice also held that where installation of a windfarm project "*has commenced, or is even completed*", consent can be annulled (para 89).

There were limited circumstances in which projects would not be annulled:

i. Where there is a risk that the annulment "*could create a legal vacuum that is incompatible with that Member State's obligation to adopt measures to transpose another act of EU law concerning the protection of the environment*".

ii. If the consequences of such annulment was "*a genuine and serious threat of disruption to the electricity supply of the Member State concerned which could not be remedied by any other means or alternatives*"; referring to C-411/17 *Inter-Environnement Wallonie and Bond Beter Leefmilieu Vlaanderen.*

Neither of these two limited circumstances are relevant here.

In Case C-411/17, the Court stated that it was permissible to continue the operation of an energy plant, being two nuclear reactors, where this was necessary for the security of energy supply of the Member State as a whole. In the *A* case, the Court held that the cessation of activity of a limited number of wind turbines was not likely to have significant implications for the supply of electricity for the whole of Belgium, establishing a high threshold.

The National Renewable Energy Action Plan

The Irish policy framework for wind farms is based on the National Renewable Energy Action Plan (NREAP) which was adopted in 2010. Ireland has submitted four progress reports to the European Commission since its adoption of the Plan, with reports delivered in 2012, 2014, 2016 and 2018. A final report is due from all Member States by 31 December 2021.

The adoption of NREAP is a direct consequence of Article 4(1) of Directive 2009/28/EC on the promotion of the use of energy from renewable sources, which required national authorities to develop a national renewable energy action plan. Ireland set an overall target of meeting 16% of its energy requirements from renewable sources by 2020. Article 4(2) required Member States to notify their NREAP to the Commission by 30 June 2010. Ireland did so in July 2010.

The NREAP document is a significant one which *"sets out the Government's strategic approach and concrete measures to deliver on Ireland's 16% target"* under the Directive. It notes that the *"development of renewable energy is central to overall energy policy in Ireland."* It set out the following targets:

- 40% electricity consumption from renewable sources by 2020
- Increases in the use of biofuels with the accelerated development and use of electric vehicles in Ireland, with a target of 10%
- A target of 12% renewable heat by 2020

NREAP is specifically relied on in the applicant's remedial Environmental Impact Assessment Report (see for example p. 2-10 and p. 2-25) and Environmental Impact Assessment Report. It is a central plank in the project justification and policy context as advanced by the applicant.

NREAP was adopted without carrying out a strategic environmental assessment under Directive 2001/42/EC. That Directive, as noted above in the *A* case, makes it a requirement to carry out an SEA prior to the adoption of certain plans and programmes that set the framework for giving permission for projects which have significant effects on the environment, specifically those requiring an EIA.

The Court of Justice noted in the *A* case that the Belgian Order and 2006 Circular, which fell within the scope of Article 2(a) of the SEA Directive, "*contribute to the implementation of the objectives of Directive 2009/28*". NREAP also constitutes a 'plan and programme' under Article 2(a), and in addition was introduced directly as a consequence of Member State obligations outlined in that Directive.

NREAP is a national plan which has resulted in the promotion of, and increase in, the use of renewable energy, including wind energy, to meet the national target. The failure to carry out any SEA has significant consequences as are clearly outlined in the *A* decision, as the Court of Justice re-affirmed the rule that project consents are illegal if they are adopted in breach of a Member State's EU law obligations. The Court of Justice will allow consent granted in breach of EU law to stand only in limited circumstances, such as where there would be a significant impact on national electricity supply if the project was not undertaken or continued, which would not be the case in this instance.

Wind Energy Development Guidelines 2006
For similar reasons, these s.28 Ministerial Guidelines on Wind Energy Development (2006 WEDG) which were expressly published in order to guide planning decision in relation to wind energy development applications, comprise a plan or programme within the meaning of Directive 2001/42. The were not subjected to Strategic Environmental Assessment, as they should have been.

The status of Wind Energy Development Guidelines as being within the definition of such a plan or programme has been implicitly admitted by the Government. The long running review of the Wind Energy Development Guidelines eventually produced a set of draft revised Guidelines. The Minister confirmed that those draft Guidelines had to be made subject to SEA precisely because they fell within the definition.

We also rely on the decision of the Court of Justice in *D'Oultremont v Region Wallonne* Case C-290/15 in this regard.

The applicant expressly relies on WEDG in support of his application and claims that the development complies with WEDG.

No prior SEA was completed in respect of the 2006 Wind Energy Development Guidelines. In view of the Court of Justice decisions, the Wind Energy Development Guidelines cannot be relied on by the Board in this case. It has been the practice of the Board to invoke the WEDG, and to rely on them to an extent deemed unlawful by the Supreme Court in *Balz and Heubach v An Bord Pleanala.*

The Court of Justice has now made clear the obligation on bodies such as the Board when asked to decide on an application for a development which relies on a plan or programme which should have been subjected to SEA and was not.

The Board therefore is required, we submit, as a matter of law to refuse these applications.

Environmental Impact Assessment
The 2011 version of the EIA Directive has been used by the applicants in their applications and also by the Board in dealing with these applications to date.

The unusual facts in these cases (particularly but not only the antiquity of the baseline information and the modelling and prediction of assessments) take them outside the scope of any reasonable interpretation of the transitional provisions.

In law and in fact the environmental impact information before the Board is wholly out of date and it is not open to the An Bord Pleanála to complete an Environmental Impact Assessment in reliance on that information. Nor is it open to the Board to confine its assessment to one prescribed by the 2011 Directive.

Noise and Industrial Wind Turbines.
The Board's previous exclusionary reliance on the 2006 Wind Energy Development Guidelines ("2006 WEDG") has no legal basis, as the Supreme Court has made clear in *Balz and Heubach v An Bord Pleanala*. By exclusionary reliance we mean regarding those Guidelines as a sufficient basis against which to assess issues such as noise impact from large industrial wind turbines.

Neither has exclusionary reliance on those Guidelines any credible scientific underpinning. Successive Ministers have acknowledged on the record in the Dáil that the 2006 Guidelines are *"unfit for purpose"*. That said, those Guidelines remain in being and it is appropriate for the Board to have some limited regard to them. They must now be treated with caution and circumspection in view in the advances in understanding and experience since they were adopted.

The Board is aware of the long running so-called *"focused review"* of those Guidelines with regard to noise, shadow flicker and distance from properties, commenced in January 2013 and still continuing. We will address the 2006 WEDG and the Draft Revision below.

MAS Report on draft Guidelines, February 2020
We respectfully suggest the Board will find much to consider in the Report prepared in February of this year by expert acoustic consultants MAS Environmental Limited, attached. The Report was a response to the draft Wind Energy Development Guidelines published in December 2019. The content is extremely rich. The executive summary explains succinctly why wind turbine noise is such an intractable problem and why it requires particular care at the permitting stage.

A key flaw identified by MAS and well understood within the acoustics profession is applying standards or conditions which assess noise by taking what is called an averaging approach.

The human ear does not average out noise. It hears noise on a continuous basis. If a loud or intrusive noise is occurring periodically, loud then quiet, the human response will be conditioned by the noise at the time it is heard. The brain does not average out the noise; it responds to the actual noise in real world conditions. The approach urged by the developer's consultants relies on averaging and is not a true reflection of reality. Modelling based on that approach bears no relationship to real world conditions.

At 1.8 of their Executive Summary MAS say

> *"A substantial number of wind farms in Ireland cause widespread community complaints. The planning controls recommended in the WEDG do not address these problems and more insidiously would give the appearance of addressing noise issues without resolving the nuisance caused. The controls do not correlate with protection of living standards or residential amenity. A different approach is required."*

At 1.18:

> *"Additional key findings include:*
>
> *a) Most wind farms causing noise nuisance appear as compliant with the planning guidance now proposed.*
>
> *b) Ambiguity in any guidelines serve to compound issues over their interpretation. There could be compliance despite serious adverse impact upon local communities.*
>
> ...
>
> *d) The MAS website includes a case accepted as causing nuisance but which complies with the proposed Irish guidelines as benevolently interpreted.*
>
> ...
>
> *g) Adverse impact from wind farms most commonly occurs when background sound levels are lowest and worst case AM, thumping and other characteristics such as low frequency effects are greatest. This is lost through averaging."*

The document goes on to support the WHO guidance and quotes important warnings from that guidance which are absent from the EIAR.

1.37:

> *"Recognition of the lack of utility of decibel based controls has progressively led to the abandonment of planning guidance other than in a minor way in the UK that is based on decibel levels. The findings of the WHO support the serious need for caution."*

End of quotations.

The MAS Report provides extensive research underpinning the conclusions summarised above.

We ask the Board to consider the MAS Report in full for two reasons. Firstly it contains a very impressive body of information on the issue of wind turbine noise. Secondly, it identifies flaws in the ETSU based approach to noise impact assessment which underpins the 2006 WEDG, and which are found also in the 2019 draft Guidelines. Those flaws account for the problems experienced by people living and working near certain wind turbine installations permitted by the Board.

New study on WTN effects on sleep.
We also refer to a recent research article on this topic of wind turbine noise (notably noise with AM characteristics) disrupting sleep, published by Oxford University Press in the Journal of the Sleep Society in March 2020 entitled *A laboratory study on the effects of wind turbine noise on sleep: results of the polysomnographic WiTNES study* by Michael G. Smith1,5, , Mikael Ögren1, Pontus Thorsson2,3, Laith Hussain-Alkhateeb1, Eja Pedersen4, Jens Forssén2, Julia Ageborg Morsing1 and Kerstin Persson Waye1,*

1Department of Occupational and Environmental Medicine, School of Public Health and Community Medicine, Institute
of Medicine, Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden,
2Division of Applied Acoustics,
Department of Civil and Environmental Engineering, Chalmers University of Technology, Gothenburg, Sweden,
3Akustikverkstan AB, Lidköping, Sweden,
4Department of Architecture and the Built Environment, Lund University,
Lund, Sweden and
5Present address: Unit for Experimental Psychiatry, Division of Sleep and Chronobiology, University of
Pennsylvania Perelman School of Medicine, Philadelphia, PA

**Corresponding author. Kerstin Persson Waye, University of Gothenburg, Box 414, 405 30 Gothenburg, Sweden.*

We ask the Board to read the study in full. It concludes:

> *A single night of WTN exposure shortened REM sleep. No effects of WTN on other measured physiologic outcomes could be detected, including autonomic activation, arousals, awakenings, salivary cortisol, SOL, sleep time, or deep sleep. Despite the low sound pressure level of 32 dB LAEq,indoor,night, the findings show that continuous environmental noise with AM may impact sleep. Self-reported sleep data support these results, with WTN exposure leading to lower sleep quality and restoration in the morning, which was true for populations who both were and were not habitually exposed to WTN.*

Comment
The science is gradually catching up with lived experience of those exposed to industrial wind turbine noise in close proximity to their homes. This catching up is to be expected and the reason for the lag in catching up highlights the mistaken approach taken to date by the Board in this vitally important area.

Research scientists are not published until they can demonstrate certainty in their findings. In addition their methods must be capable of being replicated – this means their research must facilitate

the using of the same data by other researchers, so that their findings can be seen to be reliable and not in any way distorted or biased.

By definition, the experience of a family in a rural part of County Cork exposed to intolerable wind turbine noise cannot be reproduced in a laboratory setting. There are too many variables. A family does not live in a laboratory, being just one confounding factor.

This is why it is a mistake to demand evidence by way of research papers written under these artificial constraints before taking precautionary measures to protect people.

The corresponding author of the report cited above Professor Kerstin Persson Waye was one of those advising the WHO – Europe Region in the preparation of its 2018 Environmental Noise Guidelines, which for the first time recognised wind turbine noise as a potential source of adverse health effects. These new Guidelines were the product of many years of work by experts on behalf of the WHO.

As an invited guest of the WHO at the launch of the new Guidelines in Basel in October 2018 I was able to discuss these constraints with Prof. Persson Waye and her colleagues. The discussion was illuminating. They explained candidly that their research methods simply cannot take account of the experience on the ground, for the reasons given above. They know that people are reporting their experiences. They even know that Courts are upholding their complaints and awarding compensation. None of this however can be regarded as evidence in the scientific research meaning of the word.

The 2018 WHO Guidelines represent a breakthrough. The WHO recognised for the first time that wind turbine noise can have harmful health effects. It set down a recommendation on noise limitation. It acknowledged that there were indications that the characteristics of wind turbine noise could need additional control measures. That is a reference to the emerging awareness that Amplitude Modulation is prevalent at large wind turbine installations and that it causes disturbance, annoyance and sleep disruption. We ask the Board to familiarise itself with them closely.

The Board needs to update its approach

The Board unfortunately to date has accepted the constrained approach urged on it by consultants for wind turbine developers, namely to discount any evidence that is not scientific research based and peer reviewed in that sense. It has also wrongly accepted the noise provisions in the 2006 WEDG as reliable and sufficient for the purpose of preventing intolerable interference with households (which as it happens were not based on scientific research).

That we submit is entirely the wrong approach for a planning authority to take in deciding on a planning application of this kind. If that constrained approach had been followed in Public Health Departments, cigarette smoking would never have been subject to restrictions that we now universally recognise as necessary and beneficial.

The correct approach, we submit, is found in the precautionary principle and in normal planning principles.

This approach is multi-disciplinary and collaborative. It is an approach which identifies all risks whether proven to cause harm or not and it mitigates those risks appropriately.

That approach takes account of the widespread credible reports of intolerable noise experienced around wind turbine installations previously permitted by the Board. It listens to people. It recognises that public consultation is so important precisely because the public sometimes know things the scientists do not yet certify as scientifically certain.

It requires the Board to examine the effectiveness of its past decision making and the reliability or otherwise of the assumptions and assurances on foot of which those decisions were made.

The Board's past decisions have caused home abandonments at several locations in County Cork and elsewhere to our direct knowledge.

Some of these have been reported in the national and regional media following successful Court actions.

We have had sight of two letters written by householders living close to the four turbines already operating in this area, Ms Geraldine Hanley and Mr Jerome Cohalan, attached. We ask the Board to take what they say as true, relevant and instructive.

The Board is or ought to be aware of these facts about existing serious noise nuisance at certain wind turbine sites. The Board must, we submit, take immediate steps to avoid repeating its past mistakes. The members of the Board making those decisions did not intend to force anyone from their home. Yet that is what happened. The Board needs to ask itself how?

Only by taking a new comprehensive risk based and evidence based approach, informed by expert acousticians independent in the exercise of their function, can the present members of the Board ensure that no other home is abandoned due to noise nuisance from wind turbines permitted by them.

On behalf of our clients we again ask the Board to refuse these applications.

This letter is to be read together with the enclosed submission by our client Barna Wind Action, and the other enclosures supplied, as well as the submissions and materials previously sent to the Board in relation to these applications.

Yours faithfully,

Joe Noonan
NOONAN LINEHAN CARROLL COFFEY

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The National Renewable Energy Action Plan
The Irish policy framework for wind farms is based on the National Renewable Energy Action Plan (NREAP) which was adopted in 2010. Ireland has submitted four progress reports to the European Commission since its adoption of the Plan, with reports delivered in 2012, 2014, 2016 and 2018. A final report is due from all Member States by 31 December 2021.

The adoption of NREAP is a direct consequence of Article 4(1) of Directive 2009/28/EC on the promotion of the use of energy from renewable sources, which required national authorities to develop a national renewable energy action plan. Ireland set an overall target of meeting 16% of its energy requirements from renewable sources by 2020. Article 4(2) required Member States to notify their NREAP to the Commission by 30 June 2010. Ireland did so in July 2010.

The NREAP document is a significant one which *"sets out the Government's strategic approach and concrete measures to deliver on Ireland's 16% target"* under the Directive. It notes that the

"development of renewable energy is central to overall energy policy in Ireland." It set out the following targets:

- 40% electricity consumption from renewable sources by 2020
- Increases in the use of biofuels with the accelerated development and use of electric vehicles in Ireland, with a target of 10%
- A target of 12% renewable heat by 2020

NREAP is specifically relied on in the applicant's remedial Environmental Impact Assessment Report (see for example p. 2-10 and p. 2-25) and Environmental Impact Assessment Report. It is a central plank in the project justification and policy context as advanced by the applicant.

NREAP was adopted without carrying out a strategic environmental assessment under Directive 2001/42/EC. That Directive, as noted above in the *A* case, makes it a requirement to carry out an SEA prior to the adoption of certain plans and programmes that set the framework for giving permission for projects which have significant effects on the environment, specifically those requiring an EIA.

The Court of Justice noted in the *A* case that the Belgian Order and 2006 Circular, which fell within the scope of Article 2(a) of the SEA Directive, "*contribute to the implementation of the objectives of Directive 2009/28*". NREAP also constitutes a 'plan and programme' under Article 2(a), and in addition was introduced directly as a consequence of Member State obligations outlined in that Directive.

NREAP is a national plan which has resulted in the promotion of, and increase in, the use of renewable energy, including wind energy, to meet the national target. The failure to carry out any SEA has significant consequences as are clearly outlined in the *A* decision, as the Court of Justice re-affirmed the rule that project consents are illegal if they are adopted in breach of a Member State's EU law obligations. The Court of Justice will allow consent granted in breach of EU law to stand only in limited circumstances, such as where there would be a significant impact on national electricity supply if the project was not undertaken or continued, which would not be the case in this instance.

Wind Energy Development Guidelines 2006

For similar reasons, these s.28 Ministerial Guidelines on Wind Energy Development (2006 WEDG) which were expressly published in order to guide planning decision in relation to wind energy development applications, comprise a plan or programme within the meaning of Directive 2001/42. The were not subjected to Strategic Environmental Assessment, as they should have been.

The status of Wind Energy Development Guidelines as being within the definition of such a plan or programme has been implicitly admitted by the Government. The long running review of the Wind Energy Development Guidelines eventually produced a set of draft revised Guidelines. The Minister

confirmed that those draft Guidelines had to be made subject to SEA precisely because they fell within the definition.

We also rely on the decision of the Court of Justice in *D'Oultremont v Region Wallonne* Case C-290/15 in this regard.

The applicant expressly relies on WEDG in support of his application and claims that the development complies with WEDG.

No prior SEA was completed in respect of the 2006 Wind Energy Development Guidelines. In view of the Court of Justice decisions, the Wind Energy Development Guidelines cannot be relied on by the Board in this case. It has been the practice of the Board to invoke the WEDG, and to rely on them to an extent deemed unlawful by the Supreme Court in *Balz and Heubach v An Bord Pleanala.*

The Court of Justice has now made clear the obligation on bodies such as the Board when asked to decide on an application for a development which relies on a plan or programme which should have been subjected to SEA and was not.

The Board therefore is required, we submit, as a matter of law to refuse these applications.

Environmental Impact Assessment

The 2011 version of the EIA Directive has been used by the applicants in their applications and also by the Board in dealing with these applications to date.

The unusual facts in these cases (particularly but not only the antiquity of the baseline information and the modelling and prediction of assessments) take them outside the scope of any reasonable interpretation of the transitional provisions.

In law and in fact the environmental impact information before the Board is wholly out of date and it is not open to the An Bord Pleanála to complete an Environmental Impact Assessment in reliance on that information. Nor is it open to the Board to confine its assessment to one prescribed by the 2011 Directive.

Noise and Industrial Wind Turbines.

The Board's previous exclusionary reliance on the 2006 Wind Energy Development Guidelines ("2006 WEDG") has no legal basis, as the Supreme Court has made clear in *Balz and Heubach v An Bord Pleanala.* By exclusionary reliance we mean regarding those Guidelines as a sufficient basis against which to assess issues such as noise impact from large industrial wind turbines.

Neither has exclusionary reliance on those Guidelines any credible scientific underpinning. Successive Ministers have acknowledged on the record in the Dáil that the 2006 Guidelines are *"unfit for purpose"*. That said, those Guidelines remain in being and it is appropriate for the Board

to have some limited regard to them. They must now be treated with caution and circumspection in view in the advances in understanding and experience since they were adopted.

The Board is aware of the long running so-called *"focused review"* of those Guidelines with regard to noise, shadow flicker and distance from properties, commenced in January 2013 and still continuing. We will address the 2006 WEDG and the Draft Revision below.

MAS Report on draft Guidelines, February 2020

We respectfully suggest the Board will find much to consider in the Report prepared in February of this year by expert acoustic consultants MAS Environmental Limited, attached. The Report was a response to the draft Wind Energy Development Guidelines published in December 2019. The content is extremely rich. The executive summary explains succinctly why wind turbine noise is such an intractable problem and why it requires particular care at the permitting stage.

A key flaw identified by MAS and well understood within the acoustics profession is applying standards or conditions which assess noise by taking what is called an averaging approach.

The human ear does not average out noise. It hears noise on a continuous basis. If a loud or intrusive noise is occurring periodically, loud then quiet, the human response will be conditioned by the noise at the time it is heard. The brain does not average out the noise; it responds to the actual noise in real world conditions. The approach urged by the developer's consultants relies on averaging and is not a true reflection of reality. Modelling based on that approach bears no relationship to real world conditions.

At 1.8 of their Executive Summary MAS say

> *"A substantial number of wind farms in Ireland cause widespread community complaints. The planning controls recommended in the WEDG do not address these problems and more insidiously would give the appearance of addressing noise issues without resolving the nuisance caused. The controls do not correlate with protection of living standards or residential amenity. A different approach is required."*

At 1.18:

> *"Additional key findings include:*
>
> *a) Most wind farms causing noise nuisance appear as compliant with the planning guidance now proposed.*
>
> *b) Ambiguity in any guidelines serve to compound issues over their interpretation. There could be compliance despite serious adverse impact upon local communities.*
>
> ...

d) The MAS website includes a case accepted as causing nuisance but which complies with the proposed Irish guidelines as benevolently interpreted.

...

g) Adverse impact from wind farms most commonly occurs when background sound levels are lowest and worst case AM, thumping and other characteristics such as low frequency effects are greatest. This is lost through averaging."

The document goes on to support the WHO guidance and quotes important warnings from that guidance which are absent from the EIAR.

1.37:

"Recognition of the lack of utility of decibel based controls has progressively led to the abandonment of planning guidance other than in a minor way in the UK that is based on decibel levels. The findings of the WHO support the serious need for caution."

End of quotations.

The MAS Report provides extensive research underpinning the conclusions summarised above.

We ask the Board to consider the MAS Report in full for two reasons. Firstly it contains a very impressive body of information on the issue of wind turbine noise. Secondly, it identifies flaws in the ETSU based approach to noise impact assessment which underpins the 2006 WEDG, and which are found also in the 2019 draft Guidelines. Those flaws account for the problems experienced by people living and working near certain wind turbine installations permitted by the Board.

New study on WTN effects on sleep.

We also refer to a recent research article on this topic of wind turbine noise (notably noise with AM characteristics) disrupting sleep, published by Oxford University Press in the Journal of the Sleep Society in March 2020 entitled *A laboratory study on the effects of wind turbine noise on sleep: results of the polysomnographic WiTNES study* by Michael G. Smith1,5, , Mikael Ögren1, Pontus Thorsson2,3, Laith Hussain-Alkhateeb1, Eja Pedersen4, Jens Forssén2, Julia Ageborg Morsing1 and Kerstin Persson Waye1,*

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**Corresponding author. Kerstin Persson Waye, University of Gothenburg, Box 414, 405 30 Gothenburg, Sweden.*

We ask the Board to read the study in full. It concludes:

> *A single night of WTN exposure shortened REM sleep. No effects of WTN on other measured physiologic outcomes could be detected, including autonomic activation, arousals, awakenings, salivary cortisol, SOL, sleep time, or deep sleep. Despite the low sound pressure level of 32 dB LAEq,indoor,night, the findings show that continuous environmental noise with AM may impact sleep. Self-reported sleep data support these results, with WTN exposure leading to lower sleep quality and restoration in the morning, which was true for populations who both were and were not habitually exposed to WTN.*

Comment
The science is gradually catching up with lived experience of those exposed to industrial wind turbine noise in close proximity to their homes. This catching up is to be expected and the reason for the lag in catching up highlights the mistaken approach taken to date by the Board in this vitally important area.

Research scientists are not published until they can demonstrate certainty in their findings. In addition their methods must be capable of being replicated – this means their research must facilitate the using of the same data by other researchers, so that their findings can be seen to be reliable and not in any way distorted or biased.

By definition, the experience of a family in a rural part of County Cork exposed to intolerable wind turbine noise cannot be reproduced in a laboratory setting. There are too many variables. A family does not live in a laboratory, being just one confounding factor.

This is why it is a mistake to demand evidence by way of research papers written under these artificial constraints before taking precautionary measures to protect people.

The corresponding author of the report cited above Professor Kerstin Persson Waye was one of those advising the WHO – Europe Region in the preparation of its 2018 Environmental Noise Guidelines, which for the first time recognised wind turbine noise as a potential source of adverse health effects. These new Guidelines were the product of many years of work by experts on behalf of the WHO.

As an invited guest of the WHO at the launch of the new Guidelines in Basel in October 2018 I was able to discuss these constraints with Prof. Persson Waye and her colleagues. The discussion was illuminating. They explained candidly that their research methods simply cannot take account of the experience on the ground, for the reasons given above. They know that people are reporting their experiences. They even know that Courts are upholding their complaints and awarding compensation. None of this however can be regarded as evidence in the scientific research meaning of the word.

The 2018 WHO Guidelines represent a breakthrough. The WHO recognised for the first time that wind turbine noise can have harmful health effects. It set down a recommendation on noise limitation. It acknowledged that there were indications that the characteristics of wind turbine noise could need additional control measures. That is a reference to the emerging awareness that Amplitude Modulation is prevalent at large wind turbine installations and that it causes disturbance, annoyance and sleep disruption. We ask the Board to familiarise itself with them closely.

The Board needs to update its approach

The Board unfortunately to date has accepted the constrained approach urged on it by consultants for wind turbine developers, namely to discount any evidence that is not scientific research based and peer reviewed in that sense. It has also wrongly accepted the noise provisions in the 2006 WEDG as reliable and sufficient for the purpose of preventing intolerable interference with households (which as it happens were not based on scientific research).

That we submit is entirely the wrong approach for a planning authority to take in deciding on a planning application of this kind. If that constrained approach had been followed in Public Health Departments, cigarette smoking would never have been subject to restrictions that we now universally recognise as necessary and beneficial.

The correct approach, we submit, is found in the precautionary principle and in normal planning principles.

This approach is multi-disciplinary and collaborative. It is an approach which identifies all risks whether proven to cause harm or not and it mitigates those risks appropriately.

That approach takes account of the widespread credible reports of intolerable noise experienced around wind turbine installations previously permitted by the Board. It listens to people. It recognises that public consultation is so important precisely because the public sometimes know things the scientists do not yet certify as scientifically certain.

It requires the Board to examine the effectiveness of its past decision making and the reliability or otherwise of the assumptions and assurances on foot of which those decisions were made.

The Board's past decisions have caused home abandonments at several locations in County Cork and elsewhere to our direct knowledge.

Some of these have been reported in the national and regional media following successful Court actions.

We have had sight of two letters written by householders living close to the four turbines already operating in this area, Ms Geraldine Hanley and Mr Jerome Cohalan, attached. We ask the Board to take what they say as true, relevant and instructive.

The Board is or ought to be aware of these facts about existing serious noise nuisance at certain wind turbine sites. The Board must, we submit, take immediate steps to avoid repeating its past mistakes. The members of the Board making those decisions did not intend to force anyone from their home. Yet that is what happened. The Board needs to ask itself how?

Only by taking a new comprehensive risk based and evidence based approach, informed by expert acousticians independent in the exercise of their function, can the present members of the Board ensure that no other home is abandoned due to noise nuisance from wind turbines permitted by them.

On behalf of our clients we again ask the Board to refuse these applications.

This letter is to be read together with the enclosed submission by our client Barna Wind Action, and the other enclosures supplied, as well as the submissions and materials previously sent to the Board in relation to these applications.

Yours faithfully,

Joe Noonan
NOONAN LINEHAN CARROLL COFFEY

MAS
ENVIRONMENTAL

Ireland's Draft

Wind Energy Development Guidelines 2019

Review of guidelines by

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19th February 2020

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This report and its content are produced relative to the conditions and context of the relevant circumstances at the time of writing based on the facts and information gathered by, or provided to, MAS on the basis this information is accurate. The findings should not be relied upon at a later date when additional information, research or guidance changes or misrepresent the facts, methodology or findings as presented. MAS reserve the right to reassess, modify and present the findings as knowledge and assessment methodologies change.

The facts and findings are specific to this case based on the circumstances and should not be taken out of context when applied to the circumstances of any future assessment by MAS including the methodology applied, interpretation of guidance or findings. MAS assume no responsibility to any third party in connection with the use of this report or its contents.

Contents

1.0 Executive Summary

1.1 MAS Environmental have exceptional expertise in relation to wind farm noise effects on residential neighbours and draw upon 45 years experience as well as its considerable background in research. MAS have been fundamental in identifying noise issues and how to evaluate them and provide wholly independent analysis of the draft guidelines.

1.2 Observations are based on our considerable experience and extensive wind farm noise database that is unrivalled in the information it provides.

1.3 Intended principles of tighter controls and addressing some AM character as well as low frequency noise is supported but the methods and wording adopted result in the guidelines permitting substantially more noise and undermine any enforcement of controls due to extensive ambiguity and misdirection of statements.

1.4 The approach adopted does not follow the science of acoustics, permits higher noise during periods of adverse impact due to long term averaging and applies insignificant penalties. I understand similar inappropriate averaging was recently considered in the case of *Lies Craeynest and others v Brussels Hoofdstedelijk Gewest and Others 2019* in an opinion of Advocate General Kokott.[1] At around paragraph 85 it was stated:

> *"There is a risk of adverse effects on health wherever the limit values are exceeded. Appropriate measures must be taken there in order to prevent adverse effects. It is only of limited importance to that risk whether an exceedance applies to the entire zone or agglomeration on average. This is clearly illustrated by the joke about the statistician who drowns in a lake even though it averages only a few centimetres in depth."*

1.5 Notwithstanding the averaging problem, procedures proposed to be adopted have been shown using our extensive database to fail to recognise the main forms of amplitude modulation experienced and that proposed for low frequency

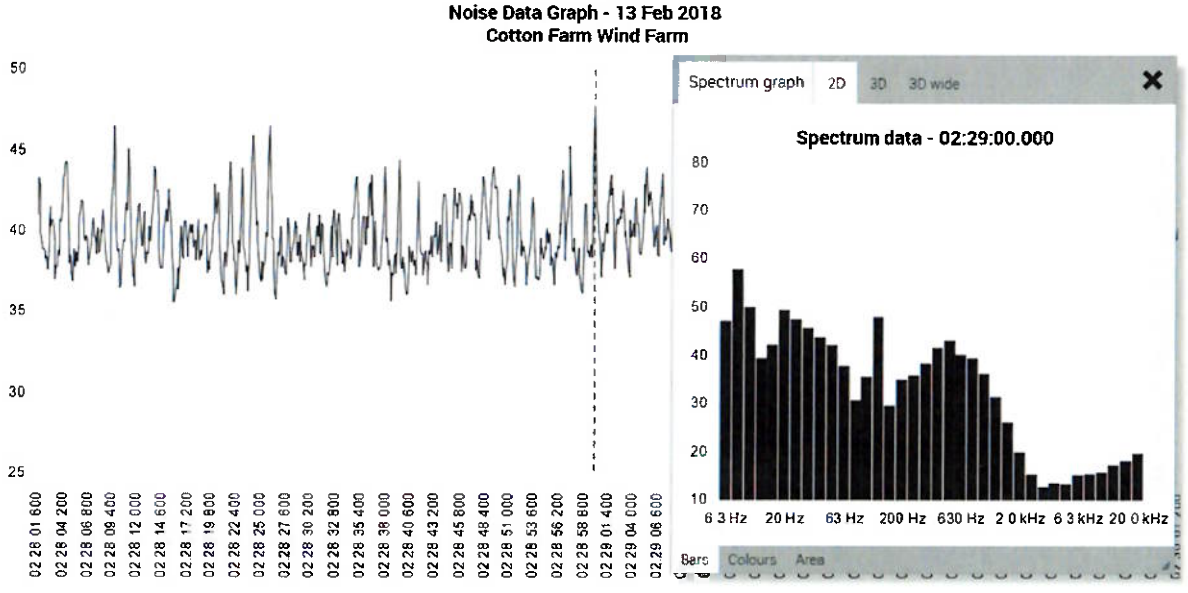
[1] http://curia.europa.eu/juris/document/document.jsf;jsessionid=CC659AAC994F94CDA0EA7FC24F86309F?text=&docid=211190&pageIndex=0&doclang=EN&mode=req&dir=&occ=first&part=1&cid=6525478

noise can only be used post development inside dwellings. This contradicts the objective of using external measurements only and reliance on prediction that is incapable of identifying this problem.

1.6 At the link directly below the noise shown and audible using good quality headphones attracts a penalty but is still compliant with the guidance as the penalty is small. This is before the period with the penalty is averaged with those periods when the noise impact does not arise and no penalty is applied. In reality even with the noise demonstrated in the graph and which can be listened to using the link, substantial margin remains through averaging. The spectrum graph on the right shows a significant low frequency peak at the point of an AM peak. This is common.

1.7 https://www.masenv.co.uk/webgraphs/cotton_farm_180213

On-line graph shows a level of AM wind farm noise compliant with proposed guidelines occurring 02:28 at night. Compliance arises when considered in isolation and before long term averaging



1.8 A substantial number of wind farms in Ireland cause widespread community complaints. The planning controls recommended in the WEDG do not address these problems and more insidiously would give the appearance of addressing noise issues without resolving the nuisance caused. The controls do not

correlate with protection of living standards or residential amenity. A different approach is required.

1.9 There are some positive points in the draft guidelines but ambiguity within terminology and phraseology permitting multiple interpretations is a major problem and is avoidable. Methods of control are employed which operate contrary to the science of acoustics and noise such any minor penalty arising will not change adverse noise into an acceptable level or form of noise. Intrusive characteristics will remain dominant and prominent resulting in inconsequential changes.

1.10 Attempts to reflect the WHO use of Lden exacerbates impact as erroneous adjustment for character is applied. An appearance of protection is given with prolonged investigation and measurement but incapable of preventing impact.

1.11 The procedures permit substantially more noise than other commercial and industrial sources when using BS4142:2014. There is no justification for this especially as wind farm noise can impact 24/7/365.

1.12 Benevolent interpretation of controls is required which ensures the most lenient interpretation would have to be applied regardless of intent. This is avoidable with clearer phrasing of the guidance. It can be concluded the methods of assessment being adopted facilitate the wind farm development to the detriment of all other concerns.

1.13 Good evidence of the extent of problems now exists but has not been drawn upon to evaluate the proposals. Many noise characteristics are ignored including important forms of AM. Further the prosed penalty becomes diluted by averaging in a manner not used in other guidance rendering it entirely insignificant.

1.14 Procedures in BS4142:2014 are entirely applicable and effective for wind farm noise and would place them on "a level playing field" with all other sources of industrial and commercial noise.

1.15 Guidance in England and Wales has moved away from specifying decibel limits due to the failure of such an approach and has not led to difficulties. The decibel level is a minor consideration in the human response to noise in cases where

impact is due to dominance or prominence. In England and Wales each case is assessed on its merits. A framework can readily be formulated that is fair, as found in BS4142 and that would be wholly applicable to wind farm noise mixing sound energy and noise character control requirements.

1.16 There is widespread support for adopting a different approach instead of the recognised flawed ETSU-R-97 approach. There are fundamentally two types of noise and their assessment and control for each differ significantly. Both arise with wind farms but separating their assessment and control is wholly undermined by the draft guidelines. Noise with special character affects people moment by moment and the frequency and duration of adverse incidents needs to be addressed. This is not addressed through long term averaging when incidents of impact are lost through averaging. Long term averaging can apply and assist with benign steady wind farm noise but not the moment by moment characteristics which impact due to their dominance and prominence at the time.

1.17 Wind noise has significantly different spectrum content to turbine noise as experienced at residential receptors. Even when of a similar level wind does not mask turbine noise. The exceedance permitted indicates it can always be dominant and prominent and comply. Furthermore, when moving inside dwellings the difference in spectrum means the wind noise is differentially reduced far more resulting in increased dominance by turbine noise inside. What is required is to ensure periods of significant adverse impact rarely occurs as it is masked.

1.18 Additional key findings include:

a) Most wind farms causing noise nuisance appear as compliant with the planning guidance now proposed.

b) Ambiguity in any guidelines serve to compound issues over their interpretation. There could be compliance despite serious adverse impact upon local communities.

c) There are repeated cases that arise where data shows serious intrusion, but assessment of planning guidance leads to arguments of compliance.

Adoption of these procedures as part of the Irish guidelines can only be likely to produce the same conflicts and contradictions.

d) The MAS website includes a case accepted as causing nuisance but which complies with the proposed Irish guidelines as benevolently interpreted.

e) The wording of the document introduces considerable ambiguity and this permits application of the most lenient interpretation following the need to meet criminal standards of proof. These problems and contradictions can readily be addressed.

f) Long term averaging of what already is the average level, using the LA90 index (the wind farm's quietest 10%) is being adopted in these draft guidelines. This is contrary to commercial noise guidance equally applicable such as contained within BS4142: 2014.

g) Adverse impact from wind farms most commonly occurs when background sound levels are lowest and worst case AM, thumping and other characteristics such as low frequency effects are greatest. This is lost through averaging.

h) Long term averages are useful in terms of benign sources of continuous noise occurring 24/7/365 that lack significant attention drawing character. Noise which draws attention due to its character and also non-acoustic elements is unsuitable for assessment using such methods.

i) Adjusting such long term average limits to reflect special character in the noise with an average penalty is fundamentally flawed as it needs to relate to its dominance and prominence moment by moment. It can be described as a "smoke and mirrors" procedure that does not address the problems.

j) No support for the procedures adjusting the noise controls adopted in these draft guidelines are found in the WHO European Guidelines 2018. Instead they provide significant warnings.

1.19 Low frequency noise has been shown as a major and common problem with modern wind farms but this appears denied in the draft guidelines. We have routinely measured low frequency noise problems at wind farms in Ireland and

the UK. Procedures to address this are not adequately formulated in the draft guidelines and mislead.

1.20 Reference is made to the Defra curve but this is an internal procedure where different time periods of measurement could be applied. There are other methods for low frequency noise not considered. The draft guidance argues against internal measurements. There are various misrepresentations summarised as follows:

1) Internal impact is commonly very different to external impact.

2) Various internal measurement locations can be utilised giving different results so no consistency.

3) Argument arises how external levels relate to internal levels.

4) The Defra method does not consider varying amplitude modulation as a form of low frequency noise nor impulse content.

5) It is impractical to measure its effects pre-development.

6) Alternative external procedures based on detailed research have been developed but are ignored.

1.21 Analysis of background sound levels is misleading. Graphs used falsely show levels barely dropping below 20dB LA90 but this is dictated by the limitations of instruments. A serious problem arises over false indication of higher that actual background sound due to common use of instruments with limitations. This is not addressed in the draft but perpetuated and misleads. At MAS we use special microphones with a noise floor between 6.5-8dBA. We routinely record level externally in rural Ireland as low as 10-12dBA.

1.22 Arguments ETSU-R-97 and therefore the draft guidelines reflect BS4142 is seriously misleading. It is stated in ETSU-R-97 but false. In this document I demonstrate this is wrong in relation to averaging, index used, analysis of background sound applied, the way penalties are applied and their extent and principles of acceptability. Simple comparison reveals the draft guidelines indicate acceptable noise when BS4142 identifies unacceptable noise.

1.23 The draft guidelines wrongly argue changes to ETSU-R-97 reflect development of modern large turbines. The converse is true. They operate to hide the added impact of large turbines.

1.24 For example, there is the adoption of standardised wind speeds rather than wind near the ground that reflects wind masking noise. This means true wind speeds are ignored at any moment in time and a standardised one is substituted. The greatest adverse impact arises under an atmospheric state called "stable atmosphere". This is a common occurrence at night. During these conditions the blades experience high wind speeds at the top of their rotation but at ground level there is extremely little wind due to high wind sheer. In terms of background sound it is quiet.

1.25 Standardised wind speeds assume much higher masking winds at ground level that arise and much higher background sound levels are assumed.

1.26 The outcome is that the worst periods of adverse impact occur with very low masking noise but much higher background sound levels are assumed. Resulting in significant understatement of impact.

1.27 The method of evaluating Amplitude Modulation (AM) proposed has been shown to manifestly fail to reflect or be triggered for two critical forms of AM. No explanation why such a flawed methodology is proposed or recognition that it has been shown to fail. There are various serious flaws:

a) Extensive ambiguity how to apply the procedures permitting a range of outcomes and interpretations.

b) Penalties are applied to the LA90 index general noise but AM is not measured by it and requires separate control. At most it means very slightly lower energy levels are permitted but without any change to the adverse impact.

c) Averaging of the penalties wholly diminishes any adjustment they might apply..

d) Evaluation of correct application is impractical.

e) False positives and more commonly false negatives are common.

f) It does not relate to actual impact during any period other than potentially identifying one form of AM arose. It misses much AM.

1.28 It is questioned why a set of procedures which knowingly miss many forms of adverse character impact and result in minor and irrelevant penalties are proposed. Annual averaging also renders the analysis and adjustments impractical.

1.29 There is reliance on ETSU-R-97 based procedures but Defra wind farm nuisance guidance confirms its lack of usefulness. This is not addressed.

1.30 The procedures underrate or wholly miss the effects of:

a) Erratic and irregular AM

b) Simultaneous occurrence of whistling and whirring in some cases with the AM.

c) Occurrence of low frequency noise with the AM which may or may not also modulate.

d) The effect of very large variations which can be up to 15dBA on a second by second basis.

e) Changes in the character and spectral content of the AM beats on a moment by moment basis such that successive beats exhibit a different pitch or characteristic.

f) Changes in impulsivity of AM beats where some rise more gradually and others have distinct impulse content with sudden change.

g) Directional effects where different forms of AM arise in different directions.

h) The additional underlying roar of general wind farm noise on top of the characteristics identified.

1.31 There is selective reporting of the guidance provided by the WHO 2018 in the draft guidelines. The WHO's precautionary application of an Lden also includes

substantial concerns and caveats regarding noise character that the Lden does not cover or address.

1.31.1 Due to a lack of high-quality evidence, as defined by the WHO, the recommendations on wind turbine noise are conditional and for many of the investigated health effects there was insufficient evidence. However, the WHO has set a recommendation for reducing noise levels from wind turbines below 45dB Lden.[2] It is also noted within the guidelines that below this exposure level there might still be a risk of annoyance. In addition, and of note, the WHO caveats that the descriptors Lden and Lnight may not be appropriate for describing wind turbine noise and this may limit the ability to draw associations between wind turbine noise and health effects.

1.32 The Lden precautionary recommendations cannot differentiate locations such as being adjacent a motorway, within a dock or large industrial complex where there are high levels of masking noise. These do not compare to a remote rural area where there is no mechanical or industrial noise other than the wind farm. The application of the same limits to both is illogical and not intended.

1.33 There is no basis to try to adjust the Lden based on averaging penalties especially when the index is viewed highly precautionary. Such an approach is in scientific terms, perverse. Penalties can apply to short periods of noise impact but not in relation to long term values in this way.

1.34 The WHO lists several characteristics of wind farm noise that may exacerbate impact compared to the sound energy level alone and why the Lden and Lnight descriptors may not be appropriate. This is a case of inappropriateness and not trying to adjust them by minor penalties that are unrelated to the impact at the time. They state:

[2] The Lden is a long term average noise level. It is calculated assuming that there is an equal (or equivalent) level of noise over a whole day. Greater weighting is given to periods where more freedom from noise is expected, evening and night time. It is a descriptor typically used for transportation sources. It can be used to investigate noise dose; however, caution must be exercised when looking at sources such as wind turbine noise where there are specific characteristics to the sound which may cause adverse reaction at lower levels than sources without these characteristics. The Lden cannot describe how the sound environment changes on an hourly, minute by minute or second by second basis.

"Wind turbines can generate infrasound or lower frequencies of sound... The noise emitted from wind turbines has other characteristics, including the repetitive nature of the sound of the rotating blades and atmospheric influence leading to a variability of amplitude modulation, which can be a source of above average annoyance (Shäffer et al 2016). This differentiates it from noise from other sources and has not always been properly characterized. Standard methods of measuring sound, most commonly including A-weighting, may not capture the low frequency sound and amplitude modulation characteristics of wind turbine noise (Council of Canadian Academies, 2015).

1.35 Rather than apply an averaged penalty to an Lden value the WHO caution against use of A weighted values. The WHO guidance reinforces a common theme recurring throughout recent noise guidance and research that context and character play a large part in determining human response to sound. The WHO were unable to determine a separate night time criteria for protecting health from wind farm noise. This seriously undermines the attempted adjustments which are unsupported by WHO advice.

1.36 Adopting the guidelines as written is predicted to lead to continued serious land use conflicts where local residents have abandoned their homes or live in continuous stress with no relationship whatsoever between acceptable noise in the home and the levels permitted by the proposed guidelines.

1.37 Recognition of the lack of utility of decibel based controls has progressively led to the abandonment of planning guidance other than in a minor way in the UK that is based on decibel levels. The findings of the WHO support the serious need for caution. However an effective method is found, with minor adjustments in BS4142:2014 and such an approach is recommended.

1.38 Part 2 of this submission provides extensive research which demonstrates the principles and observations made in this part.

2.0 Expertise of MAS Environmental and background to comments

2.1 MAS Environmental Ltd. (MAS) have unrivalled expertise in wind farm noise impact upon local communities which is combined with its unique work and experience in nuisance investigations. We employ a team of five environmental noise specialists four of whom work extensively in relation to wind farm noise.

2.2 Our main research and publications are found on our website at the link below along with a large number of wind farm noise samples which demonstrate many of the characteristics. The second link connects with more of our work and actual samples of wind farm noise.

https://www.masenv.co.uk/publications

https://www.masenv.co.uk/windfarms

2.3 Much of the work of MAS is focussed in assessment of apparently compliant wind farms but which result in serious and continued community complaints. We consider we are able therefore to provide extensive guidance on the proposed guidance.

2.4 MAS operate internationally and in collaboration with researchers across the world. This includes providing data for other researchers from our extensive database obtained from a community monitoring station which has run continuously for over six years. We are responsible for some of the most exhaustive studies and international papers looking at wind farm noise characteristics which cause extensive problems within homes. s that affect people inside their homes.

2.5 Our work identified amplitude modulation as a common and serious problem through a survey of 18 wind farms 9 years before this was finally admitted by the industry in the UK and similarly spearheaded research showing there were significant low frequency problems.

2.6 At MAS we hold potentially the largest database of wind farm noise in the world which correlates with community complaints and as a result have been able to test different measurement methods for their efficacy. We also have extensive

survey within dwellings which demonstrate real life impacts permitted by planning limits.

2.7 MAS pioneered listening room experiences to better understand industrial wind farm noise and are responsible for exposing the wide range of amplitude modulation forms and how they impact residential neighbours differently.

2.8 Our internationally recognised expertise is supplemented by extensive work on nuisance determination and separately issues with constructing enforceable planning conditions.

2.9 **Independence.** Throughout all our research and work on wind farms MAS Environmental have maintained a complete independent position where all our research is self funded.

2.10 **Support for wind farm development.** MAS strongly support wind farm development and consider this is best achieved through better identification and understanding of any impact in order that these can be appropriately balanced.

2.11 We have been extensively involved in noise issues relating to wind farms since 2004. We highlighted the problems of amplitude modulation and low frequency noise from that time including presenting evidence at Institute of Acoustics meetings from 2009.

2.12 **Industry denial of wind farm noise problems.** Denial of these problems within the UK by wind industry acousticians continued until 2013 when publishing our work internationally at the same time the Japanese released their almost identical findings but with more extensive study marked a turning point. This led to what can best be described as reluctant acceptance albeit seven years on effective controls are still not in place.

2.13 Low frequency noise problems are still denied by many UK acousticians despite my releasing data in 2009, months before the majority of the industry acousticians released a statement stating there are not low frequency noise problems. I understand, many of them maintain resistance to such findings. This arises even though the WHO now recognise this aspect of the problem and

others providing extensive independent study of research confirm the situation[3]. In part 2 of this response I also provide some references of the independent study.

2.14 Denial of AM and low frequency noise problems from wind farms in the UK at the time of ETSU-R-97 and since persists and as a result it is recommended little weight is given to what happens in terms of UK guidance. Independent research such as contained in the Colin Hansen book identified in footnote 1 demonstrates significant criticism of the ETSU-R-97 methods upon which the Irish draft guidelines seek to rely.

2.15 In my experience most nuisance cases being pursued in the UK and Ireland relate to AM and low frequency noise character as well as the general level of noise and all the cases I am aware of are argued as compliant with the UK and Irish planning guidelines. There is now widespread acceptance of serious low frequency noise problems, especially by the WHO. This is discussed further below and in part 2 of these comments.

2.16 **Cotton Farm permanent monitoring station.** In 2013/2014 the MAS team established a permanent monitoring station with the community and have over 6 years of continuous data with probably the most comprehensive database of wind farm noise that is directly correlated to community complaints, in the world. This has enabled us to provide extensive independent research and also test metrics proposed for testing features such as AM.

2.17 Tests show the UK IoA method manifestly fails in many respects and serious concern arises that the Irish guidance is looking at adopting it. Simply put the metric has failed to adequately characterise the noise in every single nuisance case we have looked at since around 2013.

2.18 **Independent Noise Working Group.** MAS were asked to assist and provide research for an independent group reviewing wind farm noise issues in the UK and have been instrumental in relation to significant parts of their work.

[3] See for example the comprehensive study in "Wind Farm Noise : Measurement, Assessment, and Control" 2017 by Colin Hansen. This detailed book provides extensive study by experienced and neutral academics.

2.19 **Work in Ireland in relation to wind farms.** At MAS we have been working on wind farm noise issues in Ireland since 2013.

2.20 **Support for the intention of lowering limits.** The draft guidance appears to present stricter controls compared to 2006 and as a concept MAS support this principle. There is also an indicative intent to control amplitude modulation and low frequency noise. Regretfully due to the way these controls are formulated, experience demonstrates they will make control and restriction farm more difficult and effectively and extensively fail their intended purpose.

3.0 Discussion and principle conclusions of MAS analysis

3.1 It can be concluded a substantial number of wind farms in Ireland cause widespread community complaints. The planning controls recommended in the WEDG do not address these problems and more insidiously would give the appearance of addressing noise issues without resolving the nuisance caused. This includes every case recognised as causing nuisance or where people are complaining that I am aware of, including many where residents have abandoned their homes.

3.2 The extent of noise nuisance permitted by these draft guidelines is readily demonstrated in an example case on the MAS Environmental UK website at the link below:

https://www.masenv.co.uk/windfarms

3.3 As far as we can establish, to date the noise limits proposed show no correlation with protection of communities and the proposed draft guidelines do not have any credible evidence to substantiate their application to control noise nuisance in an Irish context where there is extensive dispersed rural settlement.

3.4 **Need to address core guidance issues.** As a result of the serious and almost universal lack of any correlation between controls and impact upon humans, attempts to address minor technical issues without addressing the core noise nuisance problems serves as a "smoke and mirrors" coverup of the real issues. Whilst increased controls and stricter limits is to be encouraged, without relating them to the factors that actually affect humans discredits and undermines their use.

3.5 **The ability to protect communities and permit wind turbine development** requires a different approach to the problem that cannot be addressed through a technical review of the current draft proposals.

3.6 Whilst there are some positive points arising in relation to the wind farm guidelines, issues of serious professional concern arise. To take two main points:

3.7 **Ambiguity within terminology and phraseology**. This permits multiple interpretations is a major feature. This was present in the 2006 guidelines leading to current abuse. As an example it is argued reference to ETSU-R-97 in the 2006 guidelines meant variations developed to procedures re-interpreting ETSU-R-97 in the UK post 2006 are also applicable to the Irish guidelines. This appears to have been accepted in a large number of cases in Ireland which then introduced the application of long term averaging. This effectively undermined the controls. This long term averaging was contrary to how ETSU-R-97 was written and introduced much later. In the new draft guidelines controls applied could be interpreted in an extremely lenient format which in effect results in no control. This widespread and extensive flaw appears to arise in part through misunderstanding how some of the procedures operate. Thus problems found with the 2006 guidelines over interpretation are repeated in the current draft guidance. It is avoidable and it is questioned why this is not addressed. Ambiguity and multiple interpretations relate both to the main limits and procedures for AM and low frequency noise.

3.8 **Unscientific forms of control.** Methods of control are employed which operate contrary to the science of acoustics and noise. This arises as it adopts a limited decibel penalty adjustment for the effects of character content in the noise. This fails to recognise the important premise that reducing a highly intrusive noise slightly in level but without it then being masked and / or no longer dominant does not address the effects it has on humans. This should be obvious to experienced acousticians.

4.0 Summary review of key issues and proposal.

4.1 It is my expert finding that the draft guidelines adopt a fatally flawed approach to assessment and now increasingly recognised as not reflecting impact upon people. This is exacerbated due to the attempt by its authors to try and reflect the precautionary interim limit proposed by the WHO in 2018. However, the WHO limit relates to long term permanent health effects regardless of character content but not harm to amenity or nuisance.

4.2 **False appearance of protection.** The approach adopted will subsequently present an appearance of protection as it will involve prolonged measurements and data filtering but which is ultimately incapable of reflecting or addressing the impacts that occur moment by moment and thus not remotely protecting homes. This is due to misapplication of the science of how noise intrudes.

4.3 Thus the approach adopted does not follow the science of acoustics, permits higher noise during periods of adverse impact due to long term averaging and applies insignificant penalties.

4.4 I understand similar inappropriate averaging was recently considered in the case of Lies Craeynest and others v Brussels Hoofdstedelijk Gewest and Others 2019 in an opinion of Advocate General Kokott. At around paragraph 85 it was stated:

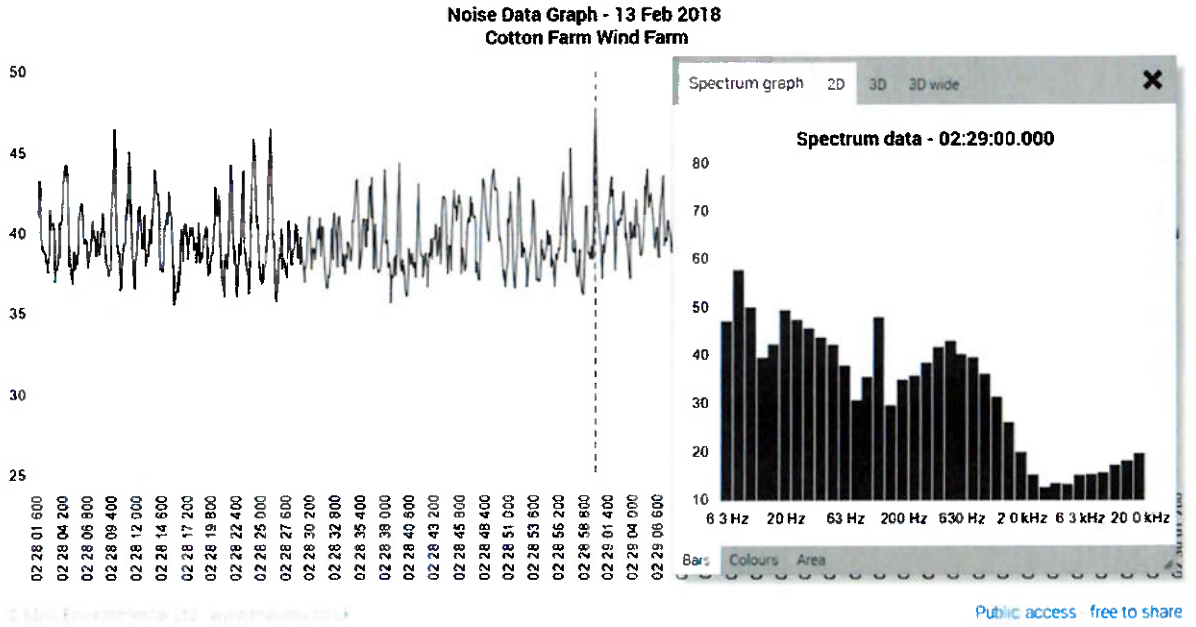
> *"There is a risk of adverse effects on health wherever the limit values are exceeded. Appropriate measures must be taken there in order to prevent adverse effects. It is only of limited importance to that risk whether an exceedance applies to the entire zone or agglomeration on average. This is clearly illustrated by the joke about the statistician who drowns in a lake even though it averages only a few centimetres in depth."*

4.5 Notwithstanding the averaging problem, the procedures proposed to be adopted have been shown using our extensive database to fail to recognise the main forms of amplitude modulation experienced and that proposed for low frequency noise can only be used post development inside dwellings. This contradicts the objective of using external measurements only and reliance on prediction that is incapable of identifying this problem.

4.6 At the link directly below the noise shown in the interactive graph and which is audible with good headphones attracts a minor penalty but is still compliant with the guidance as the penalty is small. This is before the period with the penalty is averaged with those periods when the noise impact does not arise and no penalty is applied. In reality even with the noise demonstrated in the graph and which can be listened to using the link, substantial margin remains through averaging.

4.7 https://www.masenv.co.uk/webgraphs/cotton_farm_180213

On-line graph shows a level of AM wind farm noise compliant with proposed guidelines occurring 02:28 at night. Compliance arises when considered in isolation and before long term averaging



4.8 **Permitting of higher noise than other industrial sources.** The methods proposed allow substantially more noise than any other industrial sources such as factories, warehouses, docks, transport depots and other commercial sites. These are commonly assessed using BS41432:2014. There is no basis for permitting substantially more of a source of noise especially where it is recognised as highly intrusive compared to other industrial sources. This is particularly relevant in remote rural areas where such noise is an alien and incongruous element. In context it would normally be the case that such rural locales would be given higher protection due to the absence of mechanical and

industrial noise other than in relation to farming machinery which is normally limited in occurrence.

4.9 It is instructive that most industrial sites are quiet or quieter at night and weekends but in the case of wind farms there is no distinction and they function 24/7/365 days a year. In context and having regard to rural pastoral type sound environments, stricter standards would be expected rather than substantial relaxation.

4.10 Interpretation of planning controls.

4.11 Benevolent interpretation of any controls applied would be necessary for enforcement or compliance assessment purposes. In turn this favours developers as any enforcement would need to consider criminal standards of proof. Reference in the draft guidelines to Lden, an annual averaging method strongly supports such benevolent interpretation as using long term averaging.

4.12 In practice use of long term averaging renders enforceable conditions which follow the draft guidelines impractical. Monitoring cannot extend a full year and would operate contrary to the Human Rights Convention as such a period of loss of sleep before evaluating effects cannot be reasonable.

4.13 An annual method can be used for prediction purposes where variations are known statistically but not as a measurement procedure. The averaging of periods of no or minimal impact with those of significant impact and assessing the average does not consider the actual impact and the effects of variations at the time it occurs. Concern arises over the failure to recognise this fundamental limitation.

4.14 The outcome of benevolent interpretation is the permitting of serious and uncontrolled nuisance. There is a plethora of evidence that shows this. Some is discussed in this document.

4.15 Frequency and duration of impact varies with distance.

4.16 At distances of only 500m the most serious and intrusive forms of noise arise including both upwind and downwind impact, meaning those dwellings at such

distances would not get respite even when the wind was towards the turbines. Work by MAS in its six year study and at sites in Ireland have shown this.

4.17 The draft guidelines provide no advice in relation to frequency and duration of exposure to noise. It is no consolation when there is a sustained wind direction resulting in residents being seriously impacted until the wind changes direction again. Long term averaging would undermine this impact by averaging it with periods of little or no impact.

4.18 Balance in favour of wind farm development over residential needs.

4.19 It can be concluded the methods of assessment being adopted facilitate the wind farm development to the detriment of all other concerns. This was not the case to the same extent with the 2006 guidelines as they did not consider long term averaging as now applied and any period of exceedance could be argued a breach in isolation. It is important to recognise; the historical guidelines were developed on a basis the noise was of a type that was benign and devoid of character such as AM except when very close to the turbines. In effect it was misled by the discussions in ETSU-R-97 that have consistently been shown as flawed and are widely criticised[4].

4.20 The former 2006 guidelines were formulated at a time it was believed levels below 43dB LA90 at night would not disturb and that there was not a plethora of intrusive characteristics contained within the wind farm noise. This has been consistently shown as erroneous. The erroneous statements and beliefs in 2006 are therefore understandable.

4.21 The draft guidelines now proposed are produced at a time when there is a plethora of good evidence of the adverse effects of wind farm noise. A starting point would be to consider the book by Colin Hansen, Con Doolan and Kristy Hansen, 2017 on wind farm noise as discussed in this submission as it represents an entirely independent set of views reliant wholly on research. This independent scholarly book contradicts a lot of what is reported in the draft guidelines.

[4] See the 2017 book by Colin Hansen for a resume of some of these.

4.22 Multiple wind farm characteristics arise additionally to AM.

4.23 Low frequency noise and amplitude modulation are important regular features of wind farm noise impact but are part of a wider range of effects and it is disappointing there is a failure to consider the wider range of effects. It is questioned why this is not recognised.

4.24 Adopting a procedure recognised in research as missing the majority of AM incidents and especially erratic and irregular AM and that is more intrusive because of these factors, is of serious concern.

4.25 Failure of decibel penalty as wholly inadequate.

4.26 Applying a penalty structure that permits AM to remain dominant and prominent and therefore its intrusiveness does not reduce, is of serious concern. This should have been obvious to the authors. It provides an illusion of control that is ineffectual and it is asked why this is being replicated.

4.27 In noise impact terms, rendering a noise slightly less loud but that remains dominant and prominent does not stop its effects on the unconscious listener and its distracting effects. It does provide argument noise character has been taken into account but then fails to address its effects. It is akin to cladding a building in a slightly less flammable cladding arguing it is better as a result. In the event of a fire it will still rapidly combust as temperatures significantly exceed their point of combustion. It is similarly like reducing flood water levels with better drainage. Reducing the flood level to half a metre than 1 metre does not stop complete disruption and loss of the home. Rendering a noise less intrusive but still exceeding the point it seriously disrupts is effectively an insignificant change in the same way. This is effectively what is provided in this case, especially as many features including two main types of AM do not trigger a penalty and it only applies to the impacted periods which are then averaged.

4.28 Existing effective procedure available.

4.29 A perfectly good procedure (albeit it has some elements which could be better defined) exists in the form of BS4142:2014. This industrial and commercial noise guidance would place wind farm noise "on a level playing field" with other

sources of industrial noise. No basis for ignoring such a set of procedures as developed and evolved since 1967 has been put forward. BS4142 is wholly unlike either ETSU-R-97 or the Irish Guidelines despite a statement to the contrary in the draft Irish guidelines. This is further discussed below. The critical difference is that it includes decibel penalties that place far more weight on the noise character than the sound energy level. It also appropriately uses LAeq and not LA90 for source noise.

4.30 Concerns with RPS analysis.

4.31 The RPS analysis fails to recognise and correctly apply the principles of the science of noise and acoustics, inappropriately mixing methods that were shown not to work previously but still using them as they were used before. This is inappropriate with current understanding and as a result can only continue to lead to the serious land use conflicts now commonly arising in rural Ireland.

4.32 In simple terms the guidelines are ineffectual in controlling noise impact due to the ambiguity and resulting ability to formerly look at long term averaging. In addition there is the use of procedures which ignore many characteristics in the wind farm noise including many forms of AM at the same time combining periods of less and more noise. It is also skewed by adopting unrealistic adjustments such as averaging periods where penalties are applied with perids that are devoid of a penalty. Also assuming a standardised wind speed applies which in turn hides impact during worst case conditions by adopting an unrealistically high background sound level.

4.33 The lengthy and complex algorithms built into the procedures devised by acousticians and as now proposed to be adopted rather than the more simplistic approach previously identified leads to significant and prolonged data processing. Whilst this raises acoustician's fees it is effectively indecipherable and incapable of mirroring or reflecting elements in the noise that actually impact upon people. In contrast measuring the noise as it impacts people on a moment by moment basis relates the character of the noise to the effects and their regularity and duration. The long term averaging both hides this but is also incapable of providing a realistic boundary between acceptability and unacceptability. One important reason for this is two wind farms can produce

identical average levels but in one case impact is minor as periods of high noise character arise when it is masked and the converse arises in the other case. The long term average cannot be analysed in a way that shows how dominant or prominent the noise is and separating the differences. Nor can it address when this occurs and what the corresponding background sound level was at that time. It cannot show what was disrupted nor for how long.

4.34 The mathematical procedures introduced are not understood by many acousticians and lead to an automated process that cannot be properly examined or related to actual impact upon people as they occur and clearly does not match human experiences.

4.35 In 2020 it is clear the introduction of long term averaging and adopting character penalties but which ignore much of the noise character or apply small penalties when averaged, is contrary to the science as to how such noise impacts upon people. It allows substantial noise although appearing, simplistically, to introduce tighter controls than those in 2006. It does not introduce tighter controls . The approach is wholly undermined by the science. The main problem is the application of ambiguous terms and phrases which permit various inappropriate interpretations. This transfers into a lack of control in practice.

4.36 Move of UK planning guidance away from decibel limits.

4.37 For many years planning guidance in England and Wales on noise has moved away from setting decibel controls that cannot relate to non-acoustic characteristics and attention grabbing special characteristics within noise. This is seen in the England and Wales National Planning Policy Framework and Planning Practice Guidance with only wind farms and minerals sites remaining that need revision. This change arises mainly as it is recognised the decibel level is a minor consideration in the human response to noise.

4.38 Abandonment of decibel based limits in guidance in England and Wales has not led to chaos and decibel controls remain an important element but are informed on a case by case basis adjusting to the circumstances.

4.39 A framework can readily be formulated that is fair, as found in BS4142 and that would be wholly applicable to wind farm noise. For the avoidance of doubt wind

farm noise in the UK can and is appropriately assessed using BS4142: 2014. This arises as it is only disapplied where other guidance applies and ETSU-R-97 only relates to town and country planning considerations. Where subsequently complaints arise BS4142 is appropriate and helpful.

4.40 Wider support of MAS observations.

4.41 Many of my findings are supported by the comprehensive book Wind Farm Noise: Measurement, Assessment, and Control, 2017 by Colin Hansen and colleagues. Various other supporting guidance is also provided in summary in part 2 of these comments. Whilst I have raised this here the independent views of the book by Colin Hansen and his colleagues warrant further consideration, especially in relation to procedures following ETSU-R-97 methodologies and low frequency noise.

4.42 Types of noise.

4.43 It is well recognised there are effectively two types of environmental noise[5] when considered simplistically. The methods adopted in ETSU-R-97 and now being considered in the draft Irish guidelines were formulated on the basis the noise was steady and relatively benign, readily being masked by wind noise. This was factually incorrect and misleading. Wind farms do exhibit general wind farm noise considered similar by some to road traffic on a concrete road which roars in a relatively steady way but it also includes a wide range of noise forms that draw attention and trigger adverse human responses not related to level but audibility, dominance and prominence of their attention drawing features.

4.44 Wind noise has significantly different spectrum content to the wind farm noise as experienced at residential receptors and even when of a similar level does not mask it. Furthermore, when moving inside dwellings the difference in spectrum means the wind noise is differentially reduced far more than the wind turbine noise. As a result the latter becomes even more dominant, prominent and obtrusive.

[5] To properly address the range of noise types and differences would require an extensive document but to provide some insight the attached article in Appendix A and published recently in the IoA journal provides some background.

4.45 The long term averaging and applying an averaged penalty as now proposed in the draft Irish guidelines in relation to the latter form of noise (containing special characteristics) including obtrusive and inobtrusive periods offends the science of how the human brain is triggered and runs contrary to long established principles how humans react to such noise.

4.46 Reaction to noise with special character is a moment by moment response depending on a range of factors such as what is disrupted, how often, how avoidable, importance of the living elements disrupted, duration, frequency of occurrence, expectation and neuron development of memories in relation to the noise along with other elements. Importantly UK planning guidance on noise is now recognising these factors and the seriously limited assistance of the decibel level. Ultimately we need decibel level controls but many features inform how they are to be derived when containing special characteristics.

4.47 In simplistic terms to consider a noise which perhaps seriously disrupted sleep for a period of five nights during a particular month and led to lower quality sleep another five nights, as acceptable is wrong. Just because on average over the 30 nights, levels were, on average, okay, is to seriously mislead as to impact. This is effectively what the methods appear to adopt. It is accepted there is significant ambiguity in the draft guidance but this simply permits such an interpretation. What is required is to ensure periods of significant adverse impact rarely occurs as it is masked.

4.48 Findings based on experience

4.49 Some important findings in my 45 years of experience of noise impact and the detailed studies of wind farm noise I have been involved with since 2004 are discussed below. It generally shows and can be demonstrated that:

a) most wind farms causing noise nuisance and serious repeated complaints in the UK and Ireland may appear as compliant with the planning guidance now proposed.

b) Ambiguity in any guidelines serve to compound issues over their interpretation and their application as to whether it is complied with. However, in general the contradiction still arises that there could be

compliance despite serious adverse impact upon local communities. Despite this the draft guidelines appear to seek procedures that will continue the lack of correlation between impact and guideline level.

c) MAS Environmental have reviewed repeated cases that arise where data shows serious intrusion, extensive and continued community complaints arise but assessment of planning guidance leads to arguments of compliance. This includes where the procedures proposed as in these draft guidelines are applied. In one case in England there are literally thousands of complaints and six years of data corroborating them but it is argued as compliant. Adoption of these procedures as part of the Irish guidelines can only be likely to produce the same conflicts and contradictions.

d) The MAS website includes a case accepted as causing nuisance but which complies with the proposed Irish guidelines as benevolently interpreted. There are many cases where homes have been abandoned due to impact of this level and type and what would be considered acceptable under the proposed guidelines. This contradiction could be addressed in revised guidelines that reflect human response.

e) The procedures being adopted and the wording of the document introduce considerable ambiguity and multiple interpretations as to how they apply. In turn this then permits application of the most lenient interpretation following the need to meet criminal standards of proof. These problems and contradictions can readily be addressed but as worded are permitting continuation of such ambiguity. It is not understood why this is so worded.

f) A long term averaging approach of what already is the average level, using the LA90 index (the wind farm's quietest 10%) is being adopted in these draft guidelines, contrary to commercial noise guidance equally applicable such as contained within BS4142: 2014. There is no basis for such differentiation for what is simply a mechanical and industrial noise impact significant rural areas of Ireland.

g) Evidence shows adopting the long term average using an index that is itself a statistical average of the quietest emissions of wind farm noise leads universally to compliance outcomes. Thus even in worst cases of noise and

community complaints, compliance is commonly indicated. This is instructive that the proposed procedures do not remotely relate to actual moment by moment and day by day impact. They are also wholly impractical to determine in practice. Critically though it permits substantially more noise as it averages quiet and noisy periods together compared with averages of low and high background sound levels.

h) Adverse impact from wind farms most commonly occurs when background sound levels are lowest and worst case AM, thumping and other characteristics such as low frequency effects are greatest. This low background versus high noise containing lots of intrusive character is lost through averaging.

i) Long term overall exposure limits are recognised as useful in terms of benign sources of continuous noise occurring 24/7/365 and lacking significant attention drawing character. In terms of this aspect of wind farm noise in isolation it can have value. However, noise which draws attention due to its character and also non-acoustic elements is unsuitable for assessment using such methods. This is partly why the WHO are clear in their 2018 guidelines that their guidelines do not apply to industrial and commercial sources of noise, other than leisure noise and wind farms to a limited extent.

j) Adjusting such long term average limits to reflect special character in the noise is fundamentally flawed as it needs to relate to its dominance and prominence moment by moment. This is how it impacts. In contrast BS4142 applies penalties designed to achieve loss of dominance and prominence. Applying small penalties to sources with special character as arises with the procedures proposed offends the science of acoustics in this regard as it mixes loudness and character methodologies but does not counter the effects of either. It can be described as a "smoke and mirrors" procedure that does not address the problems. Simply it does not stop the impact of AM and low frequency noise etc. and results in barely perceptible changes in loudness if at all.

k) No support for the procedures adjusting the noise controls adopted in these draft guidelines are found in the WHO European Guidelines 2018. The

precautionary adoption of an Lden of 45dB LAeq by the WHO relates to all forms of communities exposed and is subject to various caveats. These are ignored by the draft guidelines. If those procedures proposed in the draft guidelines were remotely appropriate, it is reasonable to conclude the WHO would indicate this. Instead they provide significant warnings, discussed later in this document.

4.50 Low frequency noise.

4.51 This has been shown as a major and common problem with modern wind farms but this appears denied in the draft guidelines. It is instructive this problem is recognised by the WHO but virtually ignored in the draft guidelines. Denial of low frequency noise was long made by industry acousticians even after I released data showing its presence in relation to the well documented case of Deeping St. Nicholas in 2009. Denial has continued by a number of acousticians since despite the WHO recognition of it and recognition by other serious independent researchers.

4.52 At MAS we have routinely measured low frequency noise problems at wind farms in Ireland and the UK.

4.53 Procedures to address low frequency noise are not adequately formulated in the draft guidelines leading to serious ambiguity. Reliance on the Defra curve is flawed as it is internal criteria, which when reached serves to confirm a problem. Problems arise at lower decibel levels than this curve applies but is not considered in the draft guidelines nor are the procedures for assessing this.

4.54 The Defra procedure can only be used post development so fails as a tool used to assess acceptability of a planned development. This can be readily addressed but has not been.

4.55 Analysis of background sound levels is misleading.

4.56 Graphs used show levels barely dropping below 20dB LA90 but the reality is this is dictated by the instruments used with have a noise floor (limit that they cannot record below) of 18-20dBA and corruption affects recorded levels up to around 28dBA. This means a recording of say 20dBA is possibly and most likely only

showing electrical noise generated within the instrument. This wholly misleads as to the true sound environment.

4.57 At MAS we use special microphones with a noise floor between 6.5-8dBA. In turn this means a measurement of 20dBA is an accurate reflection of levels unlike that used in the draft guidance. We routinely record level externally in rural Ireland as low as 10-12dBA. Limitations on equipment seriously corrupts data and has led to a common misunderstanding that normal background sound levels are in excess of 20dBA and typically 30dBA or more. It is noted many acousticians report internal bedroom levels of 30-35dBA as normal when it actually relates to levels where critical health effects, even from benign sources of noise are likely.

4.58 There is an extensive problem of instrument limitations leading to false readings and it is concern this has filtered into the draft guidelines.

4.59 Wrongly argued adopt BS4142 principles.

4.60 The Draft guidelines claim ETSU-R-97 is based on BS4142 and in effect it is adopting those principles. This is seriously misleading. Demonstrating this is wrong requires extensive examination so some key points demonstrating this are provided only. Whilst the ETSU-R-97 document states this, it is clearly not the case and simple application of BS4142 to wind farm noise reveals the stark difference in results. In other words apply both and the ETSU-R-97 and Irish draft guidelines indicate acceptability when BS4142 shows significant adverse impact.

4.61 ETSU-R-97 as now applied (not as originally intended) uses long term arithmetic averaging ranging from two weeks to 6 months. This was never the intent but an interpretation permitted through ambiguity in wording and so adopted by operators as it permits substantially more noise. The draft guidelines aim to extend this to a year. Human response to noise is moment by moment. If an alien sound wakes someone as we commonly find wind farms do, they do not assess acceptability of that incident based on either a two week or six month average and now annual noise level. Impact relates to the noise at the time but the draft guidelines indicate this is to be ignored. BS4142 as worded at the time

ETSU-R-97 was developed assessed impact over a 5 minute period at night with no averaging of that. This is a fundamental difference.

4.62 The approach now adopted in the draft guidelines means any intrusive noise events which intrude due to their frequency and duration of occurrence as well as the times they occur, what they affect and the nature and character of the noise, would now be viewed in terms of its annual average. These events are averaged as part of the overall long term decibel level. It cannot relate to the circumstances of the case or the intrusion experienced. This averaging approach can work in relation to road traffic noise that is relatively continuous every day of any year and that does not commonly and unconsciously draw attention due to any special characteristics. However, it would not work if there were regular horn sounding and tyres screeching but this is rare experience and the norm is a background steady roar. Averaging includes periods of little or no noise and so hides the impact from wind farm noise which is highly variable.

4.63 **Typical analogy.** This averaging approach to noise is equivalent to saying an individual's driving is safe because their annual average speed is below the speed limit. In the same way this does not relate to safe driving on a particular road, in particular circumstances. The annual wind turbine noise dose does not reflect how many awakenings or periods of disruption occur and has very limited utility.

4.64 **Flaws using LA90 index.** The draft guidelines adopt the LA90 index for the source noise. BS4142 does not as this excludes important elements and it is lower in level, typically 2dB less. This difference can be much more when the noise is erratic. BS4142 adopts the LAeq value that takes variations into account. Not only does BS4142 compare the level of background masking sound at the time of impact rather than an average, it seeks to ensure any noise which intrudes more during a period than other periods, due to its character, is actually at or below the background sound level to mask it. In contrast the draft guidelines allow an exceedance of the background sound level by 5dB using the LA90 index. This translates to a 7dBA exceedance when comparing the BS4142 methods. Thus, as a minimum the draft guidelines and ETSU-R-97 equate to an exceedance of background sound by 7dB when using the LAeq index as applied in BS4142. This equates to a substantial difference to BS4142. This 7dB level

is a point where the noise is wholly dominant and prominent even when it is absent any intrusive character such as AM and thumping.

4.65 ETSU-R-97 and the 2006 Irish guidelines adopted the LA90 index on the basis levels were believed to be steady. At times they are but critically at times of high intrusion they are erratic and very unsteady.

4.66 **High decibel penalties in BS4142.** The decibel penalties used in BS4142 serve to require the resulting noise to be progressively masked the more the character in the noise draws attention. The principle is a good one where intrusive character is masked to minimise its unconscious attention drawing features. The greater it draws attention the lower it must be in relation to background masking sound. In contrast the draft Irish guidelines apply an extremely limited penalty which adopts the IoA method that in turn misses most forms of amplitude modulation, especially the erratic and irregular forms. It is not in practice a 5dB penalty. The penalty is only applied to the periods it was observed meaning it is further averaged out and would rarely be at 5dB in any event. Commonly a 1-2dB penalty might arise from the process but only applied to the periods where it was triggered meaning that even if triggering 50% of the time it would add half this. The outcome that results is permissible levels remain dominant and prominent and continue to draw attention. The adverse effects are not prevented. Conversely BS4142 now applies penalties that could, in theory total 21dB and penalties of 10-12dB are common.

4.67 **Different background levels used compared to BS4142.** BS4142 uses a typical background sound level so that protection is based on what is commonly occurring. In other words it looks for the most commonly occurring background sound level and how the sound emerges above this. ETSU-R-97 and the Irish draft guidelines do not, they apply an arithmetic average which, in relation to rural localities is always higher due to windy periods that would be ignored when using BS4142. These differences increasingly add up to substantial differences between intruding noise and masking background levels.

4.68 Human response does not apply background sound experienced during windy periods to the wind farm noise but periods of little or no noise. This is how human memory and characterisation occurs. Applying a higher background

level based on higher wind is misleading. Furthermore, high wind shear conditions also mean this is a false comparison.

4.69 BS4142 applies a penalty to a wide range of sound characteristics that increase intrusiveness simply due to their presence. ETSU-R-97 and the Irish guidelines, as interpreted by Irish acousticians working for wind energy developers have been applying fractions of the penalties based on the fraction of periods when they occur. This further understates their impact. Such interpretations are permitted by the proposed guidelines but not applied in BS4142. Furthermore, a significant range of intrusive characteristics are ignored by the draft Irish guidelines and the ETSU-R-97 procedures, meaning many elements that intrude are simply ignored. BS4142 does not ignore them and has another penalty category for other characteristics within a source of noise.

4.70 Summary in terms of BS4142. It can be seen the procedures adopted in BS4142 are manifestly different to ETSU-R-97 and the Irish draft guidelines. To imply otherwise is to mislead in precisely the same way the original ETSU document misled.

4.71 Whether adjustments to ETSU-R-97 reflect impact from modern turbines?

4.72 To argue this is the case as the draft guidelines do is to seriously mislead. The draft guidelines, if adopted provide added protection to the wind farm industry but seriously diminish it for residents. One simple example is adoption of standardised wind speeds. This means true wind speeds are ignored at any moment in time and a standardised one is substituted.

4.73 The greatest adverse impact at night arises under an atmospheric state called "stable atmosphere". This is a common occurrence and in our six year data study this can arise typically up to 80% of night time periods although occurrence will vary. During these conditions the blades experience high wind speeds at the top of their rotation but at ground level there is extremely little wind (pin drop quiet). This happens as there is high wind sheer and lack of atmospheric friction leading to atmospheric layers. This means faster winds high up do not transmit down to ground level where it becomes still and in terms of background sound it is quiet.

4.74 Standardised wind speeds assume that when the wind turbine is at maximum noise output there are much higher masking winds at ground level that arise in reality with high wind sheer. In turn much higher background sound levels are assumed and compared than actually occur.

4.75 The outcome is that during the worst periods of adverse impact the assessment method planned to be adopted assumes a much higher background sound level to compare against. This understates impact. It is also the case that greatest AM occurs during these stable atmospheric conditions as the blades encounter the greatest range of wind speed differences from top to bottom of a rotation and cannot be pitched appropriately for the range of wind speeds using standardised wind speeds. AM thumping commonly occurs during these meteorological conditions. However, the method adopted assumes a much higher and false level of masking noise. This problem is exacerbated as measurement equipment uses standard microphones which cannot go low enough to show the true difference between the very low background sound levels during stable atmospheric conditions and the resulting high levels of turbine noise and thumping AM.

4.76 In summary, the critical point is that the worst impact arises when weather effects generate minimal masking noise and there is an expectation of quiet and tranquillity. Instead this is precisely when the most serious forms of noise intrusion commonly occur. Rather than address this the adoption of standardised wind speeds hides this impact.

4.77 The draft guidelines make little reference to wind speed but adopting the language it has and procedures proposed, it will have to use standardised wind speeds which then hide the periods of greatest adverse impact.

4.78 Method of evaluating Amplitude Modulation.

4.79 The method proposed to be adopted has been shown to manifestly fail to control two critical forms of AM which arguably are the most intrusive. There is no explanation why such a flawed methodology is proposed or even recognition that it has been shown to fail as identified. In effect no effective control is applied.

4.80 There are many serious flaws with the method proposed to be adopted. Some are outlined here:

a) There is extensive ambiguity how to apply the procedures permitting a range of outcomes and interpretations.

b) Penalties are applied to the general more steady wind farm noise which is measured using the LA90 index. AM is not measured by it. This is contrary to the need to separately control noise with special characteristics as a standalone problem. This penalty approach means at most very slightly lower energy levels are permitted but without any change to the noise impact itself.

c) Averaging of the penalties as interpreted as permitted in the procedure by only applying them to individual periods where it is triggered further reduces its effect. This results in a false element of protection produced which in fact does not change impact as it does not take the character in the noise below any point where it no longer draws attention or unconsciously disrupts thought processes, including leading to awakening.

d) The complex technical procedures render it hard to evaluate whether any analysis using data has properly or reasonably been applied in the evaluation of the data.

e) False positives and more commonly false negatives are highly common with the process wrongly indicating periods do not contain such noise when they do. There is no method of addressing this.

f) The dense virtually indecipherable procedures cannot be related to the impact experienced at any point in time and therefore it cannot properly be tested for efficacy. Our analysis has shown it repeatedly fails to trigger when erratic and irregular (arguably the worst forms) AM occur.

4.81 In summary it is to be questioned why a set of procedures which knowingly miss many forms of adverse character impact and result in minor and irrelevant penalties that permit the intrusive noise to continue are being adopted.

4.82 Averaging noise over an annual basis would also effectively render assessment of the effects of noise character impractical. This does not reflect the intent of the WHO where predictive methods are primarily used to look at and compare general noise exposure.

4.83 **Defra nuisance guidance identifies limitations of ETSU-R-97.** The UK ETSU-R-97 procedures have been recognised as not reflecting impact upon people where UK Defra guidance on investigating nuisances from wind farms reflect this by recognising the lack of usefulness of ETSU-R-97 in that regard. Furthermore ETSU-R-97 recognises this. Despite this it is proposed to adopt procedures following these methods.

4.84 **Recognition the procedures fail to protect communities.** Despite extensive and clear international evidence wind farms commonly introduce noise character that intrudes at very low decibel levels and which the UK ETSU-R-97 procedures ignored, and continue to fail to address, the draft Irish guidelines seek to mimic their flawed and failed procedures. These have now been long exposed as failing to protect communities.

4.85 Almost universally wind farms which cause complaints of nuisance and that are corroborated by independent investigation could show compliance with the proposed planning guidance. Where they are not compliant, extremely minor adjustments of a decibel or two could potentially render them compliant. This level of difference falls within the range of uncertainty in sound level meters and could not be enforced.

4.86 Approach adopted is contrary to science.

4.87 The approach to noise control adopted operates contrary to the science of noise impact. I have already discussed this above but set out some additional points here. In summary:

a) We can apply threshold values to sources such as benign road traffic which mainly impact due to triggering neurons in the brain relating to loudness in isolation. We cannot apply this to noise containing special character which triggers many more and differing neurons. This relates to constant brain surveillance of our environment for threats or the need to apply attention /

action. These lead to unconscious attention grabbing and thus disruption of day to day activities, especially rest and relaxation.

b) Noise with intrusive attention grabbing character intrudes where it is either prominent, dominant or sufficiently alien that it draws attention. The effect of alien and incongruent noise is long recognised. Later when we have adjusted to recognising the alien noise, attention is drawn due to the associated memories of adverse effects with that noise. We therefore sensitise to it. For example, hearing a noise which led to loss of sleep before an important interview would trigger memories associated with the adverse outcome. This noise is not assessible by application of a decibel penalty unless that ensures the noise is primarily masked preventing any trigger. The penalties proposed in the draft procedures do not remotely cause an outcome where they are masked or hidden unlike those applied when using BS4142.

c) There are a wide range of interacting characteristics which intrude for a variety of reasons and applying an average and small penalty to just one category which is broadly identified as AM but in fact the methods miss most forms of AM means it cannot follow the science. Broadly there are three forms of AM and only the regular unchanging form is adequately picked up using the procedure proposed. The procedures underrate or wholly miss the effects of:

- Erratic and irregular AM
- Simultaneous occurrence of whistling and whirring with the AM.
- Occurrence of low frequency noise with the AM which may or may not also modulate.
- The effect of very large variations which can be up to 15dBA on a second by second basis despite the procedures considering such variation is not possible. It is recorded and whilst not common is a startling effect.

- Changes in the character and spectral content of the AM beats on a moment by moment basis such that successive beats exhibit a different pitch or characteristic.

- Changes in impulsivity of AM beats where some rise more gradually and so the rate of change is not so stark and others have distinct impulse content with sudden change.

- Directional effects where different forms of AM arise in different directions.

- The additional underlying roar of general wind farm noise which the AM emerges above. This means there is a contributory industrial type noise that exacerbates the effects of AM in many cases.

4.88 WHO (2018). Environmental Noise Guidelines for the European Region.6

4.89 There is selective reporting of the guidance provided by the WHO 2018 in the draft guidelines. The WHO's precautionary application of an Lden also includes substantial concerns and caveats regarding noise character that the Lden does not cover or address. The Lden precautionary recommendations cannot differentiate locations such as being adjacent a motorway, within a dock or large industrial complex where there are high levels of masking noise. Compare these to a remote rural area where there is no mechanical or industrial noise other than the wind farm. The application of the same limits to both is illogical and contrary to the science of human response to noise. The effects of this cannot be factored into the WHO recommendations and the WHO express significant caution.

4.90 In 2018 the WHO published their updated guidance for Europe for protecting human health from exposure to environmental noise. Whilst the guidelines focus mainly on transportation and leisure noise, they include a section on wind turbine noise. Key points are summarised below.

[6] World Health Organisation (WHO) (2018). *Environmental* Noise *Guidelines for the European Region*. Copenhagen : WHO

4.91 The 2018 guidelines recommend exposure levels aimed at protecting human health. This includes cardiovascular and metabolic effects, annoyance, effects on sleep cognitive impairment, hearing impairment and tinnitus, adverse birth outcomes, quality of life, mental health and well being. As such, they concern effects of greater consequence than comfort and convenience, harm to amenity or unreasonable interference with the use and enjoyment of land. The latter is, in my understanding, part of the definition of nuisance. Whilst the WHO discussion on impact is helpful for reference, the recommended exposure level should be treated with some caution when considering comfort and convenience or unreasonable interference.

4.92 Due to a lack of high quality evidence, as defined by the WHO, the recommendations on wind turbine noise are conditional and for many of the investigated health effects there was insufficient evidence. However, the WHO has set a recommendation for reducing noise levels from wind turbines below 45dB Lden.[7] It is also noted within the guidelines that below this exposure level there might still be a risk of annoyance. In addition, and of note, the WHO caveats that the descriptors Lden and Lnight may not be appropriate for describing wind turbine noise and this may limit the ability to draw associations between wind turbine noise and health effects.

4.93 The WHO lists several characteristics of wind farm noise that may exacerbate impact compared to the sound energy level alone and why the Lden and Lnight descriptors may not be appropriate.

Wind turbines can generate infrasound or lower frequencies of sound ... The noise emitted from wind turbines has other characteristics, including the repetitive nature of the sound of the rotating blades and atmospheric influence leading to a variability of amplitude modulation, which can be a source of above average annoyance (Shäffer et al 2016). This differentiates it from noise from

[7] The Lden is a long term average noise level. It is calculated assuming that there is an equal (or equivalent) level of noise over a whole day. Greater weighting is given to periods where more freedom from noise is expected, evening and night time. It is a descriptor typically used for transportation sources. It can be used to investigate noise dose; however, caution must be exercised when looking at sources such as wind turbine noise where there are specific characteristics to the sound which may cause adverse reaction at lower levels than sources without these characteristics. The Lden cannot describe how the sound environment changes on an hourly, minute by minute or second by second basis.

other sources and has not always been properly characterized. Standard methods of measuring sound, most commonly including A-weighting, may not capture the low frequency sound and amplitude modulation characteristics of wind turbine noise (Council of Canadian Academies, 2015).

4.94 The importance of assessing impacts in context is also raised as a key consideration for wind turbine noise and this accords with other recent editions of guidance (for example BS4142:2014).[8] The difference in human response to wind turbine sound in comparison with other sources, for example transportation noise, is also noted.

Wind turbines... size and type have increased significantly over recent years. As they are often built in the middle of otherwise quiet and natural areas, they can adversely affect the integrity of a site. Furthermore, residents living in these areas may have greater expectations of the quietness of their surroundings and therefore be more aware of noise disturbance... These situational variables and the values and preferences of the population may differ between wind turbines and other sources...

4.95 Whilst the WHO provide a recommendation for prevention of health effects using the Lden value, the guidance also highlights uncertainty with the appropriateness of the descriptor for describing the full nature of impact from wind turbine noise. The WHO guidance reinforces a common theme recurring throughout recent noise guidance and research that context and character play a large part in determining human response to sound. The WHO were unable to determine a separate night time criteria for protecting health from wind farm noise.

4.96 Methods of assessing low frequency noise

4.97 Reference is made to the Defra curve but this is an internal procedure where different time periods of measurement could be applied. Despite this the draft guidance argues against internal measurements. There are various misrepresentations summarised as follows:

[8] British Standards Institution (2014) *BS4142:2014: Methods for rating and assessing industrial and commercial sound*. London: BSI.

a) Internal impact can be very different to external impact due to room dimensions which affect levels.

b) A variety of different internal measurement locations can be utilised giving different results.

c) There will be argument how external levels relate to internal levels. In one case where I used international research on the likely difference as the houses were not built, extensive disagreement still arose.

d) Whilst the Defra method does consider varying low frequency noise it was never derived to address regular second by second low frequency noise including in case where it also exhibits impulse content.

e) When proposing a wind farm it is impractical to measure its effects inside residential property and there are a significant number of variables that affect the results.

f) Alternative external procedures based on detailed research have been developed but are ignored.

4.98 Summary key problems with guidelines as written

4.99 The two most fundamental problems that arise which if adopted as written render the guidelines toothless and formulated to enable serious land use conflicts between wind farms and residential uses:

4.100 Adopting the procedures and an approach first applied in the UK document ETSU-R-97 that assumes impact upon people is as found for benign and anonymous (no related adjacent land use) transport sources despite no supporting evidence. Further that this can be adapted by applying minimal decibel penalties. It is noteworthy the extensive Canadian Health studies has shown human response to wind farm noise is typically equivalent to road traffic noise 16dBA higher. It follows the wind farm noise would need to be about 16dB lower than road traffic levels for equal impact. The procedures do not remotely follow this.

4.101 In adopting language to which there is significant ambiguity and multiple interpretations serves to permit application of the most lenient methods such as long term averaging of background sound, source noise, penalties and low frequency noise. An example would be considering the noise both downwind and upwind. Upwind noise can sometimes be of the order 12dBA lower than downwind. Only the downwind noise may be causing problems but the method would allow the averaging of both.

4.102 Need for listening experience to better understand impacts

4.103 MAS commonly create a listening experience where noise experienced in homes is reproduced to enable parties and the courts to understand how the noise actually experienced impacts residents. In turn this can inform on what is being proposed as permitted by the draft guidelines.

4.104 MAS will happily set this up to inform the Irish Government what the guidelines actually translates to and will permit residential neighbours to have to suffer. As a starting point please visit the MAS website at

https://www.masenv.co.uk/wind-farm-case-study

4.105 The draft guidelines would permit these sources of noise to occur and they would likely comply with the guidelines. This is a case recognised and agreed at court as causing a legal nuisance. It was considered a serious nuisance by those affected.

4.106 Some additional findings;

a) The wording is ambiguous and confused in a manner allowing multiple interpretations and in doing so permit far more noise than might at first appear. Eg. A limit of 43dBA can be interpreted as a long term arithmetic average of 43dBA meaning 50% of the time it could be substantially higher.

b) 3dBA increase is recognised as noticeable but the minimum change permitted here is 7dBA in terms of the average noise over the background LA90 sound level. Stating it as 5dBA by using the LA90 is misleading.

c) Background sound levels of 20-25dBA are commonly accepted but in reality they fall well below 20dBA on a common basis and this often coincides with the worst windfarm noise impact.

4.107 Ambiguity

4.108 There is a plethora of issues with ambiguity including:

a) The process of relating noise limits to wind speed at hub height even though masking noise commonly does not relate to this and human response also does not. We do not tolerate more noise because it is windier.

b) Long term arithmetic averaging of limits. This has arisen due to failure of UK conditions to prevent such a process and a court decision permitting professional judgement / interpretation meaning where wind energy acousticians choose to permit long term averaging of both background sound and turbine noise including when each are high and low due to different meteorological conditions, all the data points are averaged. This completely ignores the original intent of ETSU-R-97 to look at the impact on each individual night and also it no longer maps over time individual periods of high wind farm noise when background sound levels are low. Instead compliance is argued as can be based on very long term averaging as a professional judgement permits this. Taking periods of serious intrusion and averaging them with periods of no or little intrusion leads to compliance even when there are substantial periods of intrusion.

4.109 The issue is that the generation of highly attention drawing and therefore intrusive characteristics which include a variety of forms of amplitude modulation, mechanical noise sources, low frequency sources and irregularity in the noise lead to serious adverse impact unless the noise is sufficiently masked and no longer dominant or prominent.

4.110 The approach adopted in the draft guidelines is to treat the noise as equivalent to a benign, anonymous type source which when containing special character that prevents climatization and habituation and conversely draw attention and cause sensitisation, making it slightly lower in energy addresses the problem. This is perverse. The introduction of the character changes human response

and its loudness is then of limited relevance. Simply put making a loud (in relative terms) and dominant noise slightly less loud but which still disrupts and draws attention unconsciously in a manner you cannot stop it doing because it remains sufficiently dominant or prominent is a barely perceptible improvement.

4.111 There is no basis for adopting such a flawed approach to noise. Whilst this approach is partially accepted in the UK to address failings with the deeply flawed ETSU-R-97 it has not led to any cases where unreasonable and intolerable noise intrusion has been rendered even remotely acceptable. ETSU-R-97 was developed on the basis intrusive attention drawing character other than limited tonality was absent. It was formulated long before a reasoned understanding of the WHO guidelines and its misconstrued approach developed on the basis all noise was more or less acceptable below certain thresholds. Conversely the WHO guideline values were not setting acceptable values but the onset of critical health effects for transport sources devoid of specific characteristics.

4.112 If the UK Government had permitted wind farm development to be undermined through acceptance of the increasingly recognised flaws in ETSU-R-97 it would have had serious consequences for its entire renewable energy programme. It is instructive that in the case of all the wind farm developments considered or demonstrated as causing civil nuisance in the UK all comply with wind industry interpretation of ETSU-R-97 despite widespread evidence of nuisance.

4.113 Simply put, adopting the guidelines as written will lead to continued serious land use conflicts where local residents have abandoned their homes or live in continuous stress with no relationship whatsoever between acceptable noise in the home and the levels permitted by the proposed guidelines. It is instructive the UK ETSU-R-97 guidelines and adaptations for amplitude modulation have not led to a single situation where those affected have been able to use the controls to achieve protection from nuisance.

4.114 It is also instructive recognition of the lack of utility of decibel based controls has progressively led to the abandonment of planning guidance other than in a minor way in the UK based on decibel levels. These only really now remain for minerals developments and wind farms. In the main National Planning Policy Framework

and the Planning Practice Guidance emphasis is placed on the effects upon humans and changes in life style such as having to close windows and not decibel levels. Decibel levels still form valuable controls and will commonly be applied as a backstop control but the inability to set a single value due to the variables in how noise affects people value is now well established. Thus for example two sources of noise and background levels may be the same (e.g. compressor noise) but different limits would be applied because one is in an industrial area where such noise is common but the other a rural area near a major road and so the sound environment is different. Each case has different factors which influence. Thus the WHO Lden value for wind farm noise and adverse health effects rather than on comfort and use of the home is an upper limit that will consider wind turbines in industrial areas and near motorways as well as remote rural areas. The idea this precautionary Lden value of 45dB is a suitable control in isolation in the extremely remote, quiet areas of Ireland which normally widely experience natural sounds and some farming is a perverse interpretation.

4.115 Consequences of adopting the new guidelines.

4.116 Much of the differences and reasons why the draft guidelines are discussed below. In the case of the 2006 guidelines, there is the clear argument their age is such the statements which now mislead over wind farm noise arise due to the lack of adequate understanding at the time. This defence could not be said about any guidelines adopted in 2020. Not only are the scientific failings of what is proposed very clear in 2020 but a substantial number of cases have arisen with a large number of actions being pursued where the wind farms that are causing serious problems for residential neighbours may be wholly compliant with the draft guidelines now proposed. A simple test of this can be seen on the MAS Environmental website, in a case accepted at court as causing serious nuisance but wholly compliant with the draft guidelines.

5.0 Background to the assessment of sound and relevant wind farm controls.

5.1 Principles to be applied - Assessment of sound and noise

5.2 Human hearing has been referred to as "the sentinel of senses".[9] Its capacity to respond to information and changes to that information in light, dark, consciousness and sleep is incredibly sophisticated.[9] As noted by Jones et al (2010) it appears that human hearing is obligatory, we cannot help but hear, attend to (specifically or inadvertently) and respond to our aural environment.[9] It is a fundamental human response and dates back to our evolutionary past when certain sounds would have had significant meaning. Many of these basic responses remain engrained and are even exploited, for example in music and film, to elicit emotional response.[10]

5.3 Our environment is made up of many different natural and man made sounds. Human responses to sound combine both physiological responses, i.e. a response to the disturbance of a sound wave moving through the air and through our auditory pathways, and psychological responses. Psychological responses can be influenced by physiological responses, how these responses are processed by the brain and many other subjective factors including non acoustic factors such as attitudes to the sound source.

5.4 The difference between sound and noise is dependent on a number of subjective, personal and situational variables. Subjective responses may be acoustic and non acoustic and can depend on factors such as age, absolute decibel level, character of the sound, time of the day at which the sound occurs, personal attitudes to the sound and historical experiences, the attitudes of those generating the sound, character of the area etc. As defined by others, "sound can be measured by a sound level meter or other measuring system. Noise is

[9] Davis H. Preface. In Stevens SS, Warshofsky F, ed. (1970) Sound and hearing. Netherlands: Time Life Books. Cited in Jones DM, Hughes, RW, Macken WJ. (2010). Auditory distraction and serial memory: The avoidable and the ineluctable. Noise Health. 12:201-209.

[10] For example the lack of wildlife sounds and silence in woodland scenes to indicate danger or the Jaws theme, a low frequency sound increasing in pace and getting louder indicating advancing danger.

related to a human response and is routinely described as unwanted sound, or sound that is considered undesirable or disruptive".[11]

5.5 The distinction between sound and noise at an individual level is subjective. Just as there are different preferences for musical taste the judgement of sound versus noise can vary widely from person to person. This includes differences both in sounds that are considered pleasant and unpleasant but also individual sensitivities to noise, for example hearing thresholds.[12]

5.6 The assessment of whether sound is noise and whether that noise is unreasonable is not always simple but most people will commonly recognise levels and types of noise that they find unpleasant and that materially affect the use of property especially in relation to rest and relaxation.

5.7 There are certain features of sound that are generally considered to increase annoyance and reduce tolerance and these can be treated as exacerbating factors of noise impact. These are mainly features that attract attention, rendering a sound more discernible. They include impulsivity, tonality and intermittency. Steady, continuous, anonymous sounds, for example distant road traffic noise, are generally considered easy to acclimatise to and habituation can arise relatively quickly.

5.8 Sounds that have an identifiable source, impart a particular message, are variable, unpredictable and have specific identifiable characteristics such as a hum or drone are more annoying at lower sound levels than steady continuous sounds. These attention drawing sounds typically spark adverse reaction and ongoing complaints without acclimatisation. In many cases increased sensitivity to the sound source can arise and it is generally accepted that this aspect of sensitisation is a normal and typical response.

5.9 Our brains are constantly analysing and interpreting our sensory environment. As noted in Baars & Gage (2010) "The central role of the auditory perception

[11] British Standards Institution (2014) *BS4142:2014: Methods for rating and assessing industrial and commercial sound*. London: BSI.

[12] With regards to assessment it is generally accepted that those who are hypersensitive to noise are not protected.

system is to extract information from the listening environment in order to determine what is happening around us".[13] Attention can be drawn to sounds voluntarily or involuntarily. It is often involuntary attention that can cause annoyance as this disturbs other tasks to which we are trying to direct our attention. On hearing a loud or unexpected sound we become instantly alert, entering a state of heightened arousal in assessing what the noise was and where it came from. This is also true when there are changes in our auditory environment that perhaps are unexpected or cannot be easily explained. The effect is described by Baars (1997) in relation to the Orientating Response (OR):[14]

Suppose you hear the sound of a refrigerator pump – a series of noise bursts of a certain duration, spectral distribution, onset, offset envelope, location in space, cycle time, and so on. If the sound is not painfully loud, people will tend to lose awareness of it rather quickly, but they will tend to be conscious of the noise again as soon as any parameter of the sound changes: The noise can become louder or softer, the time between the noise bursts can change, the intensity envelope can change, or the noise bursts can just stop. Any of these changes will trigger a new OR, just as we may become aware of the noisy refrigerator as soon as the noise stops. [15]

5.10 Theories relating to our expectations of sound and how we react to and perceive events that do not correlate with our previous experiences have been much discussed in relation to our perception of music. The same basic principles can be applied more generically to sound and noise. Constant sound with little change to volume, pitch / frequency or character will be easily accustomed to and requires little cognitive appraisal or attention. Negative responses are more likely to be associated with unexpected changes in loudness, frequency content and more generally by sounds not behaving in a predictable manner.

[13] Baars, B. & Gage, N.M. (2010). *Cognition, Brain and Consciousness: Introduction to Cognitive Neuroscience.* 2nd ed. Oxford: Elsevier.

[14] The orientating response, or orientating reflex, is a response to a change in an organism's environment usually elicited by novel stimuli.

[15] Baars, J. B. (1997) Contrastive phenomenology, in: Block, N.J. Flanagan, O. and Güzeldere, G. (eds) The nature of consciousness, philosophical debates. Massachusetts: MIT, p. 191

5.11 Furthermore, our previous associations and memory of sound will influence and guide future reactions and interpretations. For example, one night of disrupted sleep due to an irritating mechanical hum may elicit an early adverse response to any future occurrences of the hum compared to the first experience due to the pre existing associations with sleep disturbance. Much of this again relates to the character of the noise and the interpretation of any message imparted by the noise in assessment of noise impact.

5.12 Restful and relaxing environments are typically those with a lack of attention drawing characteristics and with positive associations. For example, music labelled as 'relaxing' typically has a slow tempo with predictable, consonant harmony and minimal melodic, dynamic and harmonic variation. The same is true for relaxing soundscapes, which typically have a higher proportion of natural (biological) sounds such as water running (a predictable, smooth sound) and fewer sources of loud mechanical sounds (impulsive, harsh sounds).

5.13 In seeking rest and relaxation, we are therefore typically searching for 'quiet'. This can have several relevant meanings with respect to noise and sound as described in Andringa and Lanser (2013). 16 Firstly and most simply it can refer to a lack of (or little) noise / sound. Secondly, 'quiet' can also refer to a lack of activity or disturbance, for example the relaxing music with minimal changes in melody / harmony or one simple noise source as opposed to multiple different noise sources. Finally 'quiet' can refer to mind states that are not disturbed or interrupted, i.e. a lack of attention drawing character such as the constant, broadband noise from a fan compared to a mobile phone with a melodic ring tone that keeps ringing.[16]

5.14 Consideration of sound versus noise is not simply limited to level (decibel level / loudness) but specific features of the noise / sound and how they interact with and influence our environment. As noted by van den Bosch et al (2018) "...auditory appraisal is greater than the sum of its decibels... the very definition

[16] Andringa, T.C., & Lanser, J.J.L, (2013). How Pleasant Sounds Promote and Annoying Sounds Impede Health: A Cognitive Approach. *International Journal of Environmental Research and Public Health*. 10 pp 1439-1461

of 'noise' as unwanted sound entails appraisal on the dimension of desirability that has no obvious relation to decibels".[17]

5.15 Notwithstanding the above, the decibel level is commonly used to measure and quantify sound. Whilst it provides a universal measure of sound energy, it should be treated with caution if used in isolation to describe the impact of a sound or noise on the human population.

5.16 The human hearing mechanism is incredibly sophisticated, perceiving sounds from around 0-130 decibels (dB) over a range of 20 cycles a second (Hz) - 20kHz. The human ear can adjust to and be startled by very quiet sounds especially when there is little or no other sound, for example a twig breaking in the countryside at night time. At the other extreme the human ear can perform temporary threshold shifts to adjust the auditory threshold and protect itself from very high and / or sudden exposure to sound (for example a loud rock concert).

5.17 The human ear is more sensitive to certain frequencies, typically between 1kHz and 4kHz (approximately the top two octaves on a piano) as this is an important part of the range of speech. However, when a sound is dominated by lower frequency content, typically below around 200-250Hz, it is also recognised as more intrusive than noise that has a more 'balanced' spectrum and so warrants special attention.[18] The A weighting decibel scale (dB(A)) is used to adjust the absolute sound levels measured to reflect the approximate sensitivities of the human ear, though it is recognised it cannot reflect all elements of the noisiness and intrusiveness of a sound, especially low frequency sounds.

5.18 Sound is most commonly measured in decibels, though there are other means for assessing sound, for example using loudness scales. Some common sound sources and approximate decibel levels are given below. A change of 3dB(A), in

[17] van den Bosch, K. A., Welch, D., & Andringa, T. C. (2018). The Evolution of Soundscape Appraisal Through Enactive Cognition. *Frontiers in psychology*, *9*, 1129.

[18] See Leventhall H G. Low frequency noise and annoyance. Noise Health 2004;6:59-72. A balanced spectrum has an accepted fall off in noise level per octave. In an office an acceptable fall of per octave was found to be 5dB / octave. Where there is an excess of low frequency noise this is typically perceived as a 'rumble'. The difference between C weighted and A weighted levels (see glossary for definitions) has also been found to indicate dominance of low frequency noise. If the difference between C weighted and A weighted values is greater than around 20dB then there is a potential for a low frequency problem. Caution should be exercised in low noise environments.

a sound without other change in its content, is just noticeable to most people in an environmental location and an increase of 10dB(A) in the sound level is typically perceived to be twice as loud.

5.19 Some examples of typical decibel levels measured by MAS are given in table 2 below as a guide. However, it is noted that these are decibel levels alone and do not include a description or penalty for character or context of the noise which in reality would contribute to its acceptability / unacceptability.

Table 1: Typical short term decibel levels for common sources of noise[19]

Amplified music in bar	85-88dB LAeq,T
Road traffic - busy dual carriage way, approximately 20m from centre of carriageway	73dB LAeq,T
Light aircraft flying directly overhead	70dB LAeq,T
Restaurant extract fan at 1m	68dB LAeq,T
Skate park average sound level at 6m	61dB LAeq,T
Mixed residential and industrial area, evening ambient sound level (external)	55dB LAeq,T
Open plan office average daytime sound levels	50dB LAeq,T
Urban residential ambient sound level, night time (external)	35dB LAeq,T
Rural night time ambient sound level (external)	25-30dB LAeq,T
Noise in flat from neighbour's TV located in flat directly above. Clearly audible though content (words) not discernible (internal)	23dB LAeq,T
Inside remote rural bedroom, night time (window partly open) ambient sound level	12dB LAeq,T

5.20 Whilst research in to threshold levels for sounds with specific attention drawing characteristics is limited, for example the onset point of annoyance in a given set of circumstances, some basic sound level thresholds have been found for steady continuous sources such as road traffic noise and relating to the onset of critical health effects.

5.21 A long term steady level of noise of approximately 42dB(A) outside a window from transport sources at night is recognised as the point above which there are

[19] Significant variation can arise, for example, music levels in a bar may drop typically to around 80-85dB(A) in cases and external levels will depend on context and time of day.

increasing adverse sleep effects. [20] An impulsive / peak noise of 35dB inside is recognised as likely to cause some sleep disturbance and a maximum level internally of 42dB(A) is recognised as commonly leading to awakenings when there is repeated incidence, especially during periods of lighter sleep. These threshold levels are based on research into sources of noise typically considered benign (e.g. road traffic noise). It follows that there will be sleep disturbance effects, such as lower quality sleep, at some intermediary level where the noise contains specific character.[21]

5.22 Whether or not noise creates annoyance is a matter of degree and depends on the circumstances, for example on matters such as how loud it is, the type and character of the noise, where, when and how frequently it occurs, how long it lasts etc.[22] It follows assessment of annoyance requires consideration of a range of factors and should not focus on one factor, such as decibel level, alone.[23] The assessment of nuisance and annoyance has been guided by case law and considers both subjective and objective judgements. Nuisance can generally be considered a set of circumstances or 'state of affairs' where there are periods of intrusive noise, which is unreasonable and excessive to the extent that they affect the use of enjoyment of a property in a material way. In MAS' experience, and as identified in many judgements, the following factors have been found to influence the assessment of nuisance and annoyance:

[20] This is an Lnight,outside value. See: World Health Organisation (2009) *Night noise guidelines for Europe*. Geneva: WHO.

[21] It is noted that sleep criteria, and indeed many other threshold levels of acceptability, have often been based on transportation sources and it follows that sounds that do not have the same benign, steady, anonymous character are likely to disrupt sleep at lower levels. This is likely a combination of lack of habituation to sounds that are not steady, anonymous etc, to which a listener might actually become more sensitised, and due to attention grabbing characteristics that are not always recognised in traffic noise. For example it is commonly accepted that audible music bass beats at night in a dwelling are unacceptable and likely to disrupt sleep, regardless of level.

[22] Bontoft & Others v East Lindsey District Council 2008 QBD

[23] Noise impact has long been recognised as relating to so much more than its decibel level. I understand a noise can be effectively immeasurable above ambient or background levels and still be a nuisance where it is incongruent and depending on its nature and character (see for example Godfrey v Conwy County BC (2000)).

- character - both of the noise and of the area
- duration
- time of occurrence
- loudness
- message imparted by the noise
- variation in noise over time
- spectral content of the noise
- frequency of occurrence
- regularity / predictability of the noise
- respite from the noise, length / duration of respite
- how easily the noise can be avoided
- impact of the noise on basic needs such as sleep and communication
- cumulative impact of noise intrusions (different noise sources from single or multiple sites)
- the necessity of the noise also in relation to greater society
- decibel level of the noise
- visual or other impacts associated with the noise

5.23 Assessment of impact on the use and enjoyment of premises can relate to both human responses such as annoyance and irritation but also the coping strategies adopted by people and how they try to adapt to the noise. Coping strategies can relate to changes in behaviour including complaining, trying to mask the noise with other sounds, avoiding the noise through leaving the house to find respite, not using gardens, avoiding social events such as family events, keeping windows and doors closed and in extreme cases, moving house. The coping strategies adopted provide evidence of actual outcomes and are not restricted to evidence based on emotional descriptors. These inform extensively on wind farm impact where abandoning homes is higher than for any other noise case we have ever come across.

5.24 I understand that a noise nuisance and annoyance is not only disturbance and adverse impact but that this disturbance and impact is unreasonable, exceptional or excessive in a material way, affecting the use and enjoyment of a property. It is not trivial impact.

5.25 Assessing wind farm noise impact

5.26 Initial assessments of noise impact from a wind farm (once the wind farm is operational) concerns planning approval noise limits. Currently these types of assessment most commonly look only at average noise level (dB), but is just one factor of many that affect perception and impact of sound in an environment.

5.27 In many cases long term averages are considered that do not relate even to the noise level and how it dominates at any moment in time. Thus, it is common for assessments to report the noise level alone often adding comment that at this 'low (sound energy) level' adverse impact cannot arise. This is seriously misleading and indicates a failure to understand noise.

5.28 In these cases, complaints often continue. This should not be surprising given that the factors commonly contributing to the annoyance (i.e. factors outside of the decibel level alone) have not been included in planning assessments. Thus, the conclusion that noise is not capable of being highly intrusive because sound energy levels are low is incorrect. Notably, UK guidance on wind farm noise nuisance recognises the importance of noise character and the limitation of the decibel level.[24]

5.29 Understanding why wind farm noise can cause complaints is related to many of the basic principles of our perception of sound and noise as discussed above. A human perception of sound or noise is relative to our sound environment. Many of the factors that this relative approach includes cannot be described by an absolute decibel level alone. Wind turbine noise intrudes mainly because of the psycho-acoustic characteristics it exhibits, the sensation level of the noise, how dominant or prominent the noise is in the environment, its relative audibility and the extent to which it draws attention. A similar set of principles arise with music noise where mere audibility at night-time, or where impact occurs regularly, is recognised within guidance as unacceptable.[25]

[24] See paragraph 7.13 below for discussion on "Wind Farm Noise and Statutory Nuisance Complaint Methodology" (NANR 277)

[25] The Institute of Acoustics (IoA) (2003) *Good Practice Guide on the Control of Noise from Pubs and Clubs* St Albans: IoA.

5.30 Wind farm noise annoyance.

5.31 Wind farm noise complaints pertain largely to noise annoyance and similar adverse responses, i.e. the noise is not painfully loud but is considered highly annoying, irritating or affects uses of the dwelling such as quiet relaxation. The assessment of noise impact and annoyance is often related to decibel levels and whilst this offers an easy approach to assessment it often oversimplifies the judgements and interacting factors that occur in reality. The WHO (2000) state:

Whilst sound can be measured with the help of acoustical instruments such as sound level meters, the actual extent of noise nuisance cannot be measured in this way. One of the negative noise effects is annoyance. Large-scale population studies show that only one third of noise annoyance can be accounted for through exposure to varying sound levels. Non-acoustical factors, including personal factors such as noise sensitivity, and social factors, can have as much effect as the sound level. [26]

5.32 The WHO use the word "annoyance" to describe a wide range of human responses which go beyond the lay use of this word. The relationship between noise and annoyance is well summarised by Guski et al (1999).[27] In reality, annoyance is likely to be influenced by a combination of acoustic and non acoustic factors. Guski et al (1999) found that annoyance was mainly a result of "*(1) immediate behavioural noise effects aspects like Disturbance and Interfering with intended activities, and (2) evaluative aspects like Nuisance, Unpleasantness and Getting on one's nerves*". Guski et al (1999) define annoyance as "*a psychological concept which describes a relation between an acoustic situation and a person who is forced by noise to do things he/she does not want to do, who cognitively and emotionally evaluates this situation and feels partly helpless*" [my emphasis].

5.33 These definitions go a long way towards identifying why wind farm noise can be highly intrusive and annoying even at lower decibel levels. By interfering or

[26] World Health Organisation (WHO) (2000) *Noise and Health* Copenhagen: WHO

[27] Guski, R., Felscher-Suhr, U. & Schuemer, R. (1999). The Concept of Noise Annoyance: How International Experts See It. *Journal of Sound and Vibration*. 223(4) pp 513-527

disrupting activities in the home (by attracting attention away from the intended activity) and because of variable and tonal noise characteristics (typically evaluated as unpleasant noise characteristics) wind farm noise satisfies two basic and influential factors associated with annoyance.

5.34 Nuisance (and annoyance) as defined above concerns interference with rest and relaxation. A primary consideration therefore is whether there are features or aspects of the wind farm noise that directly impact this i.e. causing reduced ability to relax, rest and be calm, disrupting 'quietness'. Andringa and Lanser (2013) note the importance of a quiet environment in promoting restorative behaviour (rest, calm etc.) and highlight the detrimental and disruptive affect that annoying sounds can have.[28]

5.35 Andringa and Lanser (2013) use the figure below as a means of describing how the appraisal of our sound environment influences our reaction to that environment, what we feel like as a result and how we respond. The right hand side figure influences the left hand side figure, which in turn influences how we interact with our environment. The left hand side figure shows the relationship between unpleasant and pleasant feelings (horizontal axis) and arousal (deactivation and activation) (vertical axis). This is influenced by our appraisal of the sound environment, shown in the right hand side figure. The horizontal axis shows unpleasant and pleasant sounds and the vertical axis sound 'eventfulness'.

[28] Andringa, T.C., & Lanser, J.J.L, (2013). How Pleasant Sounds Promote and Annoying Sounds Impede Health: A Cognitive Approach. *International Journal of Environmental Research and Public Health*. 10 pp 1439-1461

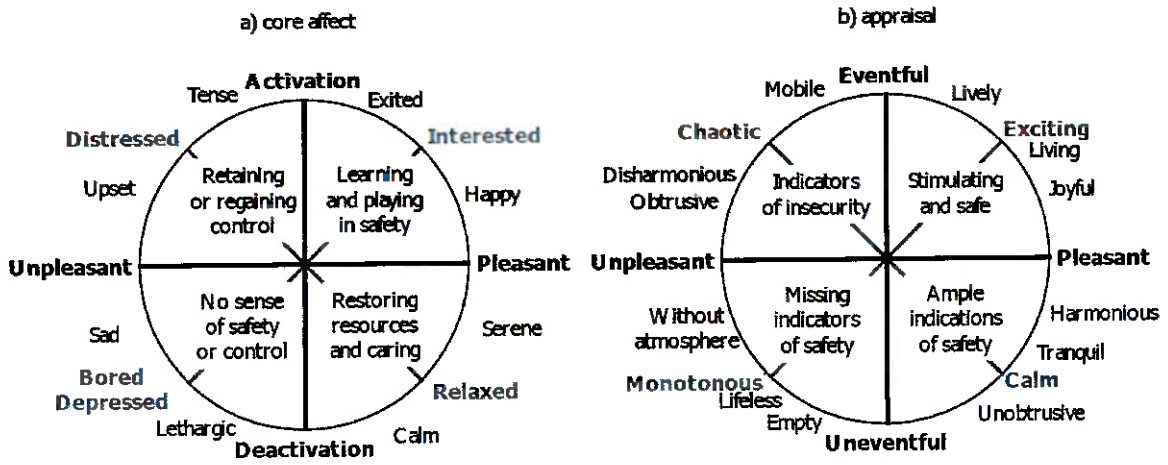


Figure 1: Interaction between appraisal of noise and how this influences emotional experience and arousal

5.36 With respect to wind farm noise, if either of the left hand side quadrants of the appraisal figure (right hand figure) are satisfied then a negative response, such as annoyance, will arise. For example, looking at the top left hand side quadrant, if the wind farm generates sound judged as unpleasant (e.g. loud compared to the underlying sound environment, or highly tonal sound) and eventful or chaotic (e.g. containing many characteristics, intermittent characteristics, unpredictable and changeable characteristics) then this will result in behavioural affects and emotional responses associated with being tense, distressed and upset. It will require more attention thus disrupting other activities by drawing on mental capacity.

5.37 The relationship between the perception of our sound environment and positive / negative feelings and arousal (core affect), and in turn how this can then impact on rest and relaxation (quiet) is described by the authors below:

"...boring sonic environments and sonic environments that contain annoying sounds lack safety indicators or are indicative of potential or actual danger. These environments function as exogenous motivators that force us to be more alert and/or to attend particular sources that then may come to dominate mind-states. Prolonged presence in annoying sonic environments reduces the freedom to self select adaptive behaviour, reduces opportunities for the proactive optimization of long-term needs, and leads to ensuing health effects." Andringa & Lanser (2013) [my emphasis]

5.38 The conclusions of Andringa and Lanser (2013) are concordant with Guski et al (1999). Annoyance is generated by interference and disruption of activities in the home and being forced by the noise to behave in a manner that was not intended or sought.

5.39 Wind turbine noise character.

5.40 There are many factors to consider when assessing noise impact. Historically the character of the noise, how this varies with time, frequency and duration of the noise and the character of the area have all been considered relevant to the existence of annoyance or nuisance. Many of these factors are referenced in the way that wind turbine noise is described by those affected.

5.41 Wind turbine noise and AM is commonly described by affected residents in various ways. Some of the descriptions are collated below and show the range of analogies and features attributed to the noise.[29] It is suggested that such a range of descriptions arise due to the alien nature of the noise, which those impacted struggle to try to correlate with other familiar and commonly arising noises in an environment.

[29] These are collated primarily from large wind turbines but many are equally appropriate for small wind turbine descriptors.

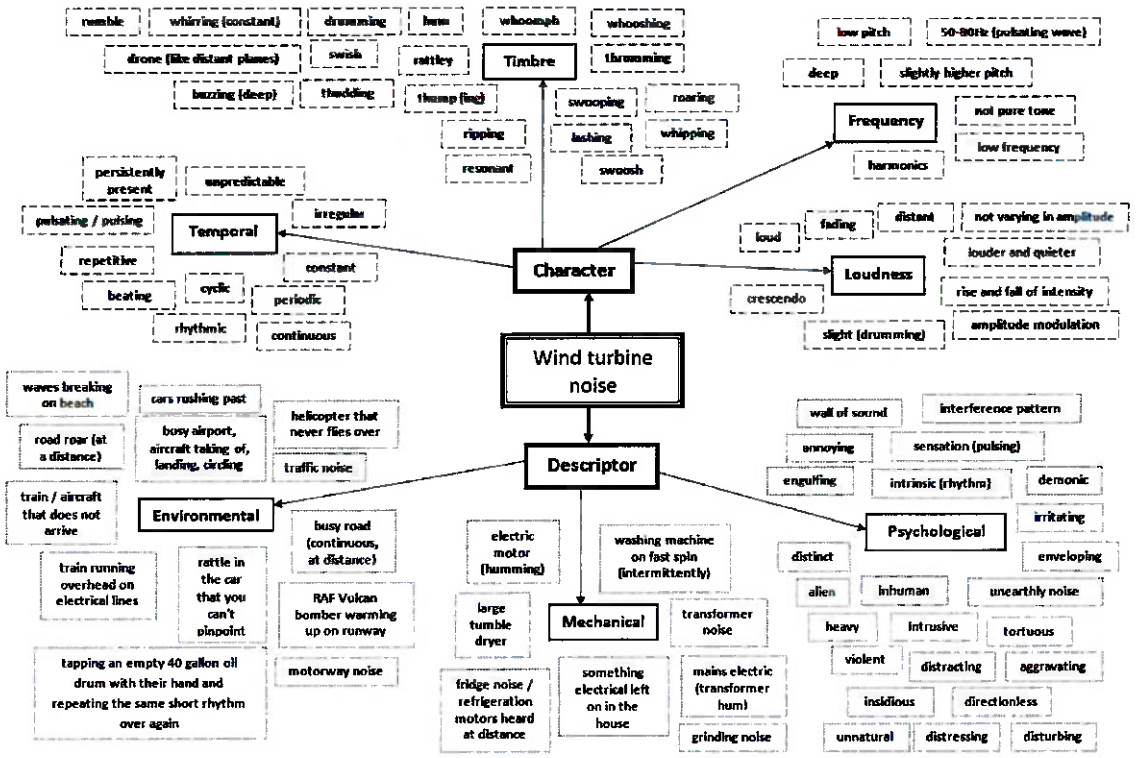


Figure 2: Terms used by affected residents to describe wind farm noise and AM

5.42 Amplitude modulation, which is a major feature of wind farm noise, itself exhibits different characteristics. Categories or types of AM could quite easily form a sub group of wind farm noise characteristics including, for example:

Regular AM where there is little variation or change in the level of AM (this could be linked with the 'repetitive' descriptor often used by those affected).

b) Erratic AM, where there is not a clear periodicity or rhythm but with individual AM peaks (often with a high peak to trough difference) can arise with little warning.

c) Intermittent AM, where the AM comes and goes, fades in and out - this is a fairly common feature.

5.43 The figure below shows some of the factors that can be considered when trying to assess the extent and severity of AM impact.

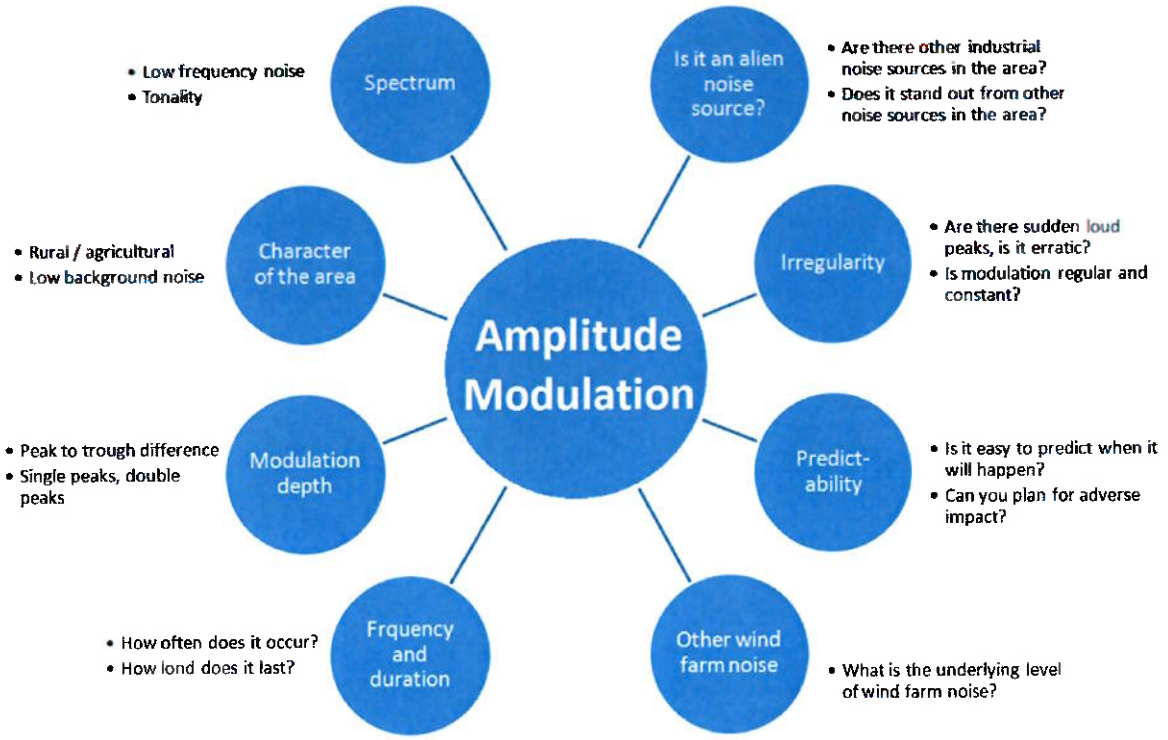


Figure 3: Aspects contributing to AM assessment

5.44 As already discussed, people react differently to sound and noise. Whereas some might not object to a certain level or type of wind farm noise, others clearly do find it intrusive. Why this is so and how it can be explained has been the subject of research but clear conclusions have not always been reached.

5.45 Several studies have found that annoyance is not necessarily related to sound level and that wind farm noise is more annoying at lower levels than other sources of noise.[30,31,32] Pedersen (2007) (2009) listed moderating factors as visual

[30] Yokoyama, S., Sakamoto, S., & Tachibana, H. (2013). Perception of low frequency components contained in wind turbine noise. 5th International Conference on Wind Turbine Noise. Denver.

[31] Pedersen E,. & Waye, K. (2004). Perception and annoyance due to wind turbine noise - a dose response relationship. J. Acoust. Soc. Am. 116 (6) pp. 3460 -- 3470.

[32] Schäffer, B., Schlittmeier, S., Pieren, R., Heutschi, K., Brink, M., Graf, r., & Hellbrück, J. (2016). Short-term annoyance reactions to stationary and time-varying wind turbine and road traffic noise: A laboratory study. J Acoust. Soc. Am. 139(5) pp2949-2963.

impact, low background sound levels and lack of respite at night time. [33,34] Michaud et al (2016) found that response to wind turbine noise is related to the overall A weighted noise level but that communities are between 11dB and 26dB less tolerant of wind turbine noise than of transportation noise sources.[35]

5.46 Ioannidou et al (2016) focused on analysis of annoyance from AM and confirmed that for sources of AM of a fixed decibel level, modulation depth (peak to trough difference) was the primary determinant of annoyance.[36]

5.47 The research of my colleague Sarah Large at MAS found that differences between types of AM can clearly be heard and that differences in responses are largely a result of AM characteristics rather than sound energy levels.[37] Regularity, irregularity, constancy and repetitiveness were identified as both positive and negative features of AM whereas rhythmic features, low frequency sounds and drones / hums were all consistently identified as annoying. [37]

5.48 It is clear that there are many features of wind turbine noise and any one of these features might draw our attention, including changes within these features. The role that this has in wind farm noise disturbance is described by Gabriel et al (2013) [38]:

...he might wake up with the first peak of AM not knowing this was the reason, but half awake and listening if there might be some "danger". He might identify

[33] Pedersen, E. (2007) Human response to wind turbine noise - perception, annoyance and moderating factors. Göteborg: Göteborg University

[34] Pedersen, E., van den Berg, F., Bakker, R., & Bourma, J. (2009) Response to noise from modern wind farms in The Netherlands. J. Acoust. Soc. Am 126(2) pp. 634-643

[35] Michaud, S. et al (2016). Personal and situational variables associated with wind turbine noise annoyance. *J. Acoust. Soc. Am.* 139 (3) pp. 1455 -- 1466.

[36] Ioannidou, C., Santurette, S., & Jeong, C.H. (2016). Effect of modulation depth, frequency, and intermittence on wind turbine noise annoyance. J. Acoust. Soc. Am 139 (3) p.1241-1251.

[37] Large, S. (2016) A quantitative and qualitative review of amplitude modulation noise from wind energy development. Internoise 2016. Hamburg, Germany.

[38] Gabriel, J. et al. (2013). Amplitude Modulation and Complaints about Wind Turbine Noise. 5th International Conference on Wind Turbine Noise. Denver.

the wind farm as origin of noise with the next "peak" of AM and from now on it might be hard for him to rest or to fall asleep again.

5.49 Character of wind farm noise.

5.50 In contrast to a rural pastoral character, wind farms generate a mechanical and industrial source of noise that characterises the area as one in close proximity of and dominated by commercial / industrial activity. There is usually an overall increase in noise level that saturates the sound environment with broadband sound energy and masks many of the natural sources that would otherwise be heard.

5.51 In addition to the overall increase in sound energy there are additional characteristics associated with industry such as low frequency noise, hums, whines and AM that creates a cacophony of mechanical sound. It is a stark change to the otherwise quiet and tranquil soundscape devoid of such sources until a wind farm operates. It is an incongruous sound that can dominate and dictate the character of the area during day, evening and night and for sustained periods.

5.52 Spectral content of the noise.

5.53 The spectral content of the noise is usually variable and depends on the measurement location (indoors or outdoors) and the range of acoustic characteristics present. In turn these commonly depend on meteorological conditions, the make of turbine, distance and orientation. There are several key acoustic characteristics generated by a wind farm that have a specific spectral footprint. Lower frequency energy is commonly prevalent within the data. This can arise as an overall increase in low frequency energy (broad band) or with some tonality (specific third octave bands creating a humming sound) or with tonality and pulsing (a pulsing hum).

5.54 The presence of low frequency noise and hums / whines / tones is commonly associated with increased annoyance and is likely to make the noise more intrusive at lower levels than a sound of the same sound energy level but absent specific spectral content.

5.55 Regularity / predictability of the noise.

5.56 There is an element of predictability and regularly in wind farm noise impact from a wind farm. Whenever there is wind, there is likely to be impact and this will occur continuously until the wind farm is turned off or the wind drops. However, the level and type of impact is highly unpredictable. AM can arise for short periods or bursts within a longer period of sustained general wind farm noise impact or continuously for several hours at a time. Similarly, low frequency noise can arise briefly as a pulsing hum or for longer periods. No clear pattern to the type of noise impact that will arise is seen and the severity of noise impact is readily variable but apparent. The lack of predictability prevents residents from implementing effective coping mechanisms such as planning social events.

5.57 The impact of the noise on basic needs such as sleep and communication.

5.58 Wind farm noise level is never of a magnitude that would cause speech interference or would likely mask speech or other typical household sounds. However, it is of a level that is clearly audible and could cause annoyance or interference with other sounds and activities. The level and nature of impact is commonly of a type and magnitude that would be expected to result in sleep disturbance.

5.59 Levels of internal low frequency noise measured within bedrooms often exceed the Defra low frequency noise curve. Average internal noise levels also commonly exceed the threshold set for sleep preservation for steady continuous noises, such as road traffic noise. This is often the case as attenuation moving inside can be low. Attention is highly likely to be drawn to the noise of the wind farm due to acoustic features such as pulsing, tonality and AM and this is highly likely to interfere with the return to sleep once awoken.

5.60 Cumulative impact of noise intrusions

5.61 The noise impact from a wind farm can be treated as a whole (a single impact) and this is reasonable for many aspects of the noise. However, the location of different turbines relative to a dwelling can result in what appears to be multiple sound effects arising from different turbines. This particularly relates to AM. The effect of multiple characteristics arriving from different turbines and different

directions will have a cumulative impact on the sound environment and how the sound is perceived, creating an impression of being surrounded by the sound. Localisation of multiple sources also constitutes another aspect of the wind farm noise that will draw attention (making the noise harder to ignore).

5.62 In addition to cumulative noise impacts, there may also be the cumulative impact of shadow flicker and noise. It is not possible to quantify this cumulative effect.

5.63 Annoyance

5.64 Many of the factors discussed above are clear indicators of annoyance. Unlike other sources, for example transportation or industrial noise, the wind farm noise can occur 24/7/365 for as long as there is sufficient wind. Transportation sources would typically reduce at night time and strict controls are typically placed on industrial activity to either limit frequency and duration of intrusive sources or reduce the overall dominance of the noise if it is to occur regularly. Such controls and restrictions are not in place for the majority of wind energy developments. Thus, the wind farm noise is constant and therefore conflicts with day to day living far more so than many other sources of noise.

5.65 The lack of respite and lack of escape from wind farm noise is another factor readily associated with annoyance. A lack of control over an intruding noise or a lack of control over your environment is a common cause of annoyance. Residents have no control over the noise from a wind farm and there are no controls on its operation to the extent that there are no predictable or guaranteed periods of respite. For example, there is no ability to cope with a noise that occurs all night in the knowledge that the next night will not be affected.

5.66 There is commonly a lack of escape from the noise. External amenity areas at dwellings are commonly affected and it readily penetrates residential buildings leading to no where to escape it except leaving the area. When inside the wind farm noise remains clearly audible and dominant with windows open in most cases. In many cases aspects of wind farm noise are also audible indoors with the windows shut. As such, to escape entirely from the noise residents must leave the dwelling or generate a source of masking noise within the dwelling. The lack of control and extreme coping responses needed remove autonomy of

residents' actions and living within their own home. This is highly likely to lead to annoyance.

5.67 There are many other factors of annoyance discussed including common explanatory themes that arise throughout discussion papers on noise annoyance. If a sound attracts attention, if it is incongruous with the sound environment absent the specific sound, if the sound is much louder than other pre-existing sound sources then annoyance can be expected to arise. Such factors commonly arise in the case of wind farm noise. Multiple acoustic characteristics generated by a wind farm will attract attention for that reason alone.

5.68 A mechanical / industrial wind farm source of noise is an alien sound in an otherwise quiet, rural soundscape. Most wind farms generate substantial increases in sound energy above pre-existing background and ambient sound levels for significant periods but this is lost with averaging times when they do not.

5.69 Guski et al (1999) found that annoyance was mainly a result of "(1) immediate behavioural noise effects aspects like Disturbance and Interfering with intended activities, and (2) evaluative aspects like Nuisance, Unpleasantness and Getting on one's nerves".[27] The evaluative aspect of any wind farm noise commonly fits with annoyance, nuisance, unpleasantness and 'getting on one's nerves' responses.

5.70 Andringa and Lanser (2013) highlight the importance of 'quiet' in a sound environment. A level of quiet is needed to promote restorative behaviour. The presence of a quiet or restorative environment is marked by aural cues as to the safety of the environment. It would normally include aural cues such as wildlife sounds, birdsong.[39] These sounds are commonly masked or subsumed within wind farm noise and as such the wind farm noise works against aural cues that promote rest and relaxation.

[39] Natural sounds are typically considered with safety and lack of danger. For example, the sound of a forest or jungle will suddenly be silenced by the presence of a predator. This effect is commonly used in film scoring to indicate imminent danger or cause for concern.

5.71 There is a clear case for expected heightened annoyance with most wind farms for multiple reasons. Empirically there is a significant increase in noise and this is accompanied by acoustic character (multiple features) that attract attention and render the noise more annoying, harder to ignore. Qualitatively the noise conflicts with periods when residents would expect greater freedom from noise. It conflicts with and disrupts periods of sleep. There is a lack of control over the noise, lack of respite from the noise and limited escape from the noise. The combination of all of these factors commonly result in a state of affairs where it is expected residents to be highly annoyed. This arises at the levels which would comply with these draft guidelines.

5.72 This submission is by me based on my analysis of the draft guidelines but is extensively informed by much of the research and analysis of criteria, especially included in Part 2 that has previously been prepared by Sarah Large.

Mike Stigwood
Director and Lead Environmental Health Consultant
MAS Environmental Ltd.

19th February 2020

Case no's. ABP-308208-20 & 308210-20

Re: Response by BWAG to An Bord Pleanála letter of 13th October 2020

This is our response to the letters dated 13th October 2020 concerning the reactivation of the planning application for 6 no. wind turbines at Lackareagh and Garranereagh, Lissarda and Barnadivane, Teerelton, Co Cork and the reactivation of the application for an electrical substation to replace the substation previously granted permission, ABP ref no. 219620, at Barndivane, Kneeves, Teerelton, Co Cork.

These letters ask for observations/ submissions on how we wish the appeal to be further progressed. This is our response.

Participation and natural justice

In the first instance we want it noted that as a group and due to the level 5 restrictions in place since Wednesday 20th October and level 3 restrictions prior to that we as private individuals making up Barna Wind Action Group are at a serious disadvantage as we cannot meet as a group to discuss this question. Our meetings are always either held in private homes or in community halls, we have members who are cocooning and who have health concerns. We also live in an area where rural broadband does not exist and therefore holding online meetings are not possible. Even if it was possible the profile of our members would mean not all could participate. We are not going to repeat the advice given by Dr. Tony Holohan, CMO, but we cannot hold a public meeting, distribute leaflets door to door or erect information signs or meet in members homes. Indeed, all our normal social gatherings such as mass and sporting events are cancelled and with it most community interaction. For the Bord to ask us to consult and consider this reactivated case at this time is against the regulations and the spirit of the Level Five Restrictions as laid down by NPHET and the government.

It also means the provisions of the Arrhus Convention where public participation and access to justice in environmental matters cannot be met as we cannot consult with each other or the wider community, access to records held publicly is restricted to us and this places us at a serious disadvantage.

Passage of time, outdated application documents – what is the plan now?

The planning applications for this substation and windfarm were lodged back in September and December 2014. It is our opinion that so much time has passed, so many requests for further information, so many submissions and observations by the company looking to develop this windfarm and substation, submissions by the public, submissions by ourselves and expert reports provided, that what exactly constitutes case no's. 308208-20 and 308210-20 must be defined and clarified for us by the Bord.

As planning applications they have been through the hands of Cork County Council planning department where there were several requests for further information, the opportunity for the public to make additional submissions after receipt of such further information. The developer also provided further unsolicited information for the files. The cases were approved, the windfarm with 32 planning conditions, and the substation with 28 conditions.

Both cases have been through the offices of An Bord Pleanála twice, with 2 sets of inspectors reports on file for them, wind farm: ABP ref 245824 and 248153, substation: 219620 and 248152. In 2016 when the Bord granted permission for the windfarm 17 planning conditions were applied. In 2019 the Bord again granted permission this time with 21 planning conditions applied. The substation was recommended for refusal by the ABP inspector in 2015, but this was overruled and granted by the Bord in 2016 with 12 conditions. In 2018 it was again granted permission by the Bord with 11 conditions. Concurrently with this case no ABP 219620 was live.

The planning documents for this windfarm and substation contain the spectre of the then extant permission for 14 wind turbines and substation at the current site, ABP ref 219620, CCC ref 05/5907 & 11/6605. This was used as a lever to cause confusion from which the developer elicited maximum benefit. All the documents in the EIS for the windfarm are full of the permitted 14 turbine wind farm and substation. It shadows every section and statement made about the current proposal. It hung as a permanent threat to extract a positive planning outcome for the developer and it worked. That lever no longer exists. Its shadow should be removed from the application documents and windfarm EIS for clarity. The permission expired in February 2017; a significant amount of time has passed since then.

There were also many other windfarms in the planning stage in the vicinity of this proposed development. These are now either built or being built. We think a restated file where the cumulative impact both visually, environmentally and on the communities concerned should be prepared for us and the planners to consult. These developments, in particular, Carrigareirk, ABP ref 246353 & 301563, and Shehymore, ABP refs 243486 & 246915, windfarms are now near completion. While both our cases at Barna were under consideration previously a web of options were proposed by the developer as to what the actual final development might consist of with these 3 developments forming a triangle of options. We need to know what exactly 'the plan' is now that other developments are granted and being built. A glance through the files mentioned above will reveal the extent of the web that has been woven around these developments with the current cases at Barna, ABP ref 308208 & 308210, very central to the lot.

It must not be a desktop report it must be based on the reality the planners have effected in this area of county Cork. And in particular without the confusing effect of a planning permission for 14 wind turbines and substation at the site concerned that were never going to be built. It is safe to say the file and documents are both large and complex. We need to know what exactly the EIS for this planning application is stating so we can make an informed judgement. And we need an EIS for the substation as it was not provided at the time due to the reliance on the then extant planning permission.

The planning department in Cork rejected Carrigareirk, 15/730, and the most recent application from Wingleaf Ltd for Gougane Barra, 20/350. These applications generated considerable public objection and were refused by Cork County Planning Dept. It is abundantly clear that local public opinion has grown vastly as the people in Upper Lee Valley see what the result of clever project splitting has done to the once beautiful and sacred valley. The views for instance from the local beauty spot at The Lee Bridge crossing the Gearagh SPA, has been transformed and will be for a very long time, in a way that very few Corkonians could

have imagined. Is this really considered sensible and responsible planning? What has happened to the concept of protection the visual landscape in this area? Why are the planning guidelines being interpreted in a way that is contrary to other decisions by the Bord in other parts of the country? Why is the Bord ignoring the advice and decisions in this regard of their own inspectors and that of that of the local Planning Authority. We have tirelessly fore warned the Bord that project splitting is rife in the area that straddles Cork/Kerry and if one flew over the area one would see a huge wind farm that is growing all the time. The Bord would not allow a developer to build a housing estate one house at a time but has turned a blind eye to this. We know for example that there is currently an SID application under consideration with the Bord, ref 308173, for another windfarm in the upper Lee Valley.

We refer the Bord to the recent case in the ECJ on the requirement for a national level SEA on 'plans and programmes', such as energy programmes, that have the capacity to impact the environment. The upper Lee Valley demonstrates exactly why this should have happened many years ago. The case ref is A v Others C-24/19 and full details are provided in the submission from our solicitor on our behalf.

We do not believe that the developer has any intention of building the wind farm as currently proposed in this reactivated planning application. It is now out of date. He just wants to get the permission at any cost after which he will seek to amend the plans by increasing turbine height. This will be to a minimum of 178.5m as his more recent applications will attest, Cork county planning ref 20350. Are we to see another sleight of hand by the developer? For this reason, the developer should have to go back to the public and let them have their say over what his plans really are. After all there were 258 objections to the original plans, a majority of the people in the townlands effected.

Cumulative Impact

The landscape in the area of county Cork near this proposed development has now been filled with the wind turbines of many other developments. We have counted 100+ in a semi-circle from a road very close to the site of this application south, west and north encompassing the upper valley area. We urge the planning inspector from the Bord to come and drive around the upper Lee Valley not just in the daylight but also by night. It has been saturated with wind turbines in the last few years. Every angle we look from when we walk near our homes has a wind farm obscuring the views. By night the light emissions are truly appalling, endless rows of winking hot red lights burning through what used to be a clear dark sky where the stars where the attraction. Visually there isn't even relief at night. This area does not need another windfarm polluting it visually and with noise, shadow flicker and light pollution. It needs proper coherent and balanced planning to be applied to it.

Unenforceable planning conditions

We have raised the issue of noise repeatedly as it is a major concern for us as we have first-hand evidence of its impact. Trying to get compliance with noise limits is a continuous effort we as a community face because of the 4 wind turbines we already have to live with. Cork County Council cannot enforce the noise limits. Now we are being asked to add another operator to the problem, another set of contacts we will have to deal with. This is not acceptable and for the families who will be living between 2 windfarms this is unimaginable.

Proximity to dwellings
Again, we raise the alarm with regard to the very low set back distances the developer has chosen to apply between homes and wind turbines. 524m is not acceptable, nor is 609m. This is how close some residents will be to these turbines. Does the Bord want to be responsible for the effects this will have on these people?

Substitute consent/ consent by the back door
This planning application is nearly 6 years old now. We believe that the current turbine size that the developer is seeking permission for, 131m, is not now what he would wish to build, he has sought permission recently at Derreendonee, Curraglass and Cappaboy Beg, Co Cork (Gougane Barra) for 178m high turbines, planning ref 20350, revealing where the ambition of this wind farm developer now lies. We do not want to find ourselves back where we were in 2014, opposing a windfarm planning application for larger wind turbines with the spectre of 6 x 131m windfarm being used as the 14 turbine windfarm and substation was used back then. Surely a function of the Bord is to ensure planning takes place in an orderly manner where the citizens of the country are afforded some protection from the everchanging ambition of the developer, and that a planning application put before them states clearly and definitively what the plan actually is.

We know as soon as the planning went through for Shehymore windfarm an application was made to Cork County Council to change the turbine model and specification and increase the rotor diameter by 12.9%. This tells us a number of things, firstly the plan is not the plan until it is built and there are opportunities for the developer to affect the granted permission after it has been granted. We the people have no such opportunity. It also shows that such applications do not come before the people affected for their consideration; this is very concerning to us. We attached the relevant file relating to the Shehymore application.

It also tells us that the noise modelling in windfarm applications is academic in the sense it will have little or no bearing on the real world reality on the ground once the wind farm is built. This is because the turbine model used for the noise modelling may not be the turbine placed on the site. This is concerning and alarming to us and should be of paramount interest and concern to the Bord. Noise is one of the biggest nuisance and pollution issues related to windfarms, many mistakes have already been made on this matter. There is no need to make any more. Our solicitor has included more evidence to support our concerns in this matter.

Substation 308208-20 Proof of its necessity required
We have been told by the developer of this windfarm and substation that the substation at Barna was to connect the windfarm to the grid. Yet he sought and received planning for another substation at the Carrigareirk windfarm, ABP ref 246353 and 301563. Permission also exists for a 33kv cable route between Carrigareirk, Shehymore and Barna. At the time planning was sought the idea suggested was that this cable route would take the power from Carrigareirk to Barna substation. It could also take the power in the opposite direction.

Can the Bord please clarify what grid connection offer now exists at Barna? It had a 60MW supply agreement with Eirgrid. After much probing by the planning authority over an extended period and multiple planning applications it became evident that the 60MW's was to be made up of the output from Carrigareirk, Shehymore and Barna windfarms. It would

now appear, and it needs to be clarified, that the connection offer was moved to the substation at Carrigareirk windfarm for expediency reasons and to ensure that these windfarms could prove they had a grid connection offer and a permitted substation to get planning through while the Barna substation was experiencing issues in the planning system. What we want to be clarified is what is the need to build the substation on Barna now if the power can go to Carrigareirk substation?

We also feel it is useful to point out that while all these developments have had separate planning applications, different names and are registered to different companies, albeit with the same address is Lissarda, Co Cork, there has been a rather startling level of coherence in how the planning permissions have unfolded and fitted together like a jigsaw puzzle. This has left almost everyone in the communities surrounding these developments sure that it is one project that has been split into palatable bites sizes for said communities and Cork planning authority to consume. The concern being that we might perhaps have choked if the whole puzzle was unveiled before us at once. It is remarkable too that the planners and Cork County Council have not sought to lead and guide the development of the upper Lee Valley in a balanced and sustainable way but have instead been content to collaborate in the piecemeal colonisation of it with one single type of development - wind turbines.

Finally, the local population, who have had this wind farm thrust upon them, have been fighting this development in one shape or another for over 20 years. They have had to come up with €150,000 to do so. Money has had to be put into the bank and kept there in readiness for legal costs. We the ordinary citizen, against the limitless capital and state subsidised business of the wind farm developer, are simply seeking the protection of the law and the Bord. We request that you refuse this planning application.

COMPLIANCE REPORT

APPLICATION NO.	13/00551
APPLICANT	Shehy More Windfarm Ltd
DESCRIPTION	Ten year permission sought to construct a windfarm and all associated infrastructure. The proposed windfarm will comprise the provision of a total of 12 no. wind turbines, with a maximum overall blade tip height of up to 131m, upgrading of existing and provision of new internal access roads, provision of a wind anemometry mast (height up to 90m), 4 no. borrow pits, underground electricity connection cabling, upgrading of site access junctions an electricity sub-station with control room and associated equipment, temporary construction compound and all ancillary site and ground works. The Planning Application is accompanied by an Environmental Impact Statement (EIS) and a Natura Impact Statement (NIS).
LOCATION	Cloghboola, Gortnacarriga, Tooreenalour, Garryantorna, Shehy More, Dunmanway, Co. Cork
DECISION DUE DATE	27/05/2014

Assessment

Condition 6(a)

A letter of compliance issued to the developer from Cork County Council on 06/09/2018 advising that the use of Nordex N100 turbines was compliant with condition 6(a) of the decision.

On 25/03/2019 the developer submitted proposals for compliance for a revised turbine type. The turbine now proposed is a Vesta V105.

Permitted

12no. turbines with an overall blade tip height of 131m.

Condition for Compliance

Condition 6(a) – "The permitted turbines shall have a maximum tip height of 131 metres. Details of the turbine design, height and colour and shall be submitted to, and agreed in writing with, the planning authority prior to commencement of development."

Existing Compliance

Compliance with condition 6(a) issued on 06/09/2018 for Nordex N100 – HH81m and RD of 100m.

Revised Turbine

Vesta V105 – HH71.5m and RD105m.

Original Application

Permission granted for 12no. turbines. The EIS submitted was based on an unspecified turbine and EIA modelling assumed HH84.5 and RD93m with maximum tip height of 131m.

Comment

The developer is seeking to submit an alternative turbine for compliance with condition 6(a) in lieu of the Nordex N100 which has previously been deemed to be compliant. The submitted documentation includes an Environmental Report specific to the revised turbine type.

The proposed alteration is seeking the provision of a blade with a maximum length of 52.5m, giving an overall diameter of 105m and a hub height of 78.5m ensuring that the maximum permitted tip height of 131m is not exceeded.

The increased blade length represents a 12.9% increase in rotor diameter to that which was modelled in the EIS submitted under 13/551.

Having reviewed the Environmental Report it is not considered appropriate, in this instance, to determine that the revised turbine type would not have potential to give rise to additional impacts on the environment over and above those taken into consideration in the assessment of the application. Notwithstanding the tip height of 131m which accords with the permission granted, the revised turbine type represents a 12.9% increase to the rotor diameter to that which was modelled in the EIS submitted under 13/551. The Planning Authority considers that the scale of change in rotor diameter would constitute a material change to the development.

Conclusion

Please advise the developer that the proposed Vesta V105 turbine is not acceptable because of the scale of change in rotor diameter from that modelled in the EIS submitted under 13/551.

Please refer to Senior Executive Planner for sign off prior to issuing correspondence.

A. O'Keeffe

Annie O'Keeffe

COMPLIANCE REPORT

12/06/2019

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Original Article

ORIGINAL ARTICLE

A laboratory study on the effects of wind turbine noise on sleep: results of the polysomnographic WiTNES study

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Abstract

Study Objectives: Assess the physiologic and self-reported effects of wind turbine noise (WTN) on sleep.

Methods: Laboratory sleep study (n = 50 participants: n = 24 living close to wind turbines and n = 26 as a reference group) using polysomnography, electrocardiography, salivary cortisol, and questionnaire endpoints. Three consecutive nights (23:00–07:00): one habituation followed by a randomized quiet Control and an intervention night with synthesized 32 dB L_{Aeq} WTN. Noise in WTN nights simulated closed and ajar windows and low and high amplitude modulation depth.

Results: There was a longer rapid eye movement (REM) sleep latency (+16.8 min) and lower amount of REM sleep (−11.1 min, −2.2%) in WTN nights. Other measures of objective sleep did not differ significantly between nights, including key indicators of sleep disturbance (sleep efficiency: Control 86.6%, WTN 84.2%; wakefulness after sleep onset: Control 45.2 min, WTN 52.3 min; awakenings: Control n = 11.4, WTN n = 11.5) or the cortisol awakening response. Self-reported sleep was consistently rated as worse following WTN nights, and individuals living close to wind turbines had worse self-reported sleep in both the Control and WTN nights than the reference group.

Conclusions: Amplitude-modulated continuous WTN may impact on self-assessed and some aspects of physiologic sleep. Future studies are needed to generalize these findings outside of the laboratory and should include more exposure nights and further examine possible habituation or sensitization.

Statement of Significance

Renewable wind power is crucial in reducing global reliance on fossil fuels. Wind turbines produce low-frequency noise, which during the nighttime in particular propagates for long distances and into dwellings, potentially impacting sleep. This study is the first investigation of wind turbine noise and physiologic sleep in a controlled environment. The effect of long-term noise exposure on physiologic and self-reported response was also investigated. A single night of wind turbine noise led to reduced rapid eye movement sleep duration and impaired self-reported sleep quality. Overall the physiologic effects were modest, with the majority of measured outcomes not affected by wind turbine noise. Further work should generalize these findings outside of the laboratory.

Key words: wind turbine noise; polysomnography; cortisol awakening response; self-reported sleep; habituation

Submitted: 15 October, 2019; **Revised:** 16 March, 2020

Introduction

In efforts to meet greenhouse gas reduction goals, a continued increase of renewable energy infrastructure, including wind turbines, is expected globally [1, 2]. As a result, a greater number of people will likely be exposed to wind turbine noise (WTN) at home. Environmental noise is recognized as a public health concern by the World Health Organization (WHO), which estimates that sleep disturbance constitutes the majority of the disease impacts of environmental noise in Europe, with the annual loss of over 900,000 healthy life years [3]. Adequate sleep is vital for maintaining good health and wellbeing, and chronic short or interrupted sleep duration is associated with an increased risk for obesity, diabetes, hypertension, cardiovascular disease, and all-cause mortality [4–8]. To protect sleep, the WHO recently recommended nighttime noise limits for road, rail, and air traffic in Europe, but concluded that the quality of evidence of nighttime exposure to WTN was too low to allow a recommendation [9]. Therefore, studies on potential effects of WTN on sleep are needed.

Amplitude modulation (AM) is a broadband, rhythmic change in the level of WTN corresponding to the rotational frequency of the turbine blades [10]. AM has been reported as a particularly unpleasant and annoying characteristic of WTN [11–13]. Local meteorological conditions at the turbine, for instance wind speed gradient across the rotor area, wind shear, and turbulence, affect the acoustical character of the AM [14]. This effect is strongest during the stable atmospheric conditions typical of nighttime, with strong AM "beats" in the 400–2,500 Hz range as a consequence [15]. Furthermore, the stable atmospheric conditions at night are favorable for the propagation of low-frequency noise, such as that emitted by wind turbines, over longer distances than in the daytime [10, 14]. A larger number of dwellings could therefore be exposed to WTN at sound pressure levels relevant for disturbance. Combined with lower nocturnal anthropogenic noise, and lower ambient noise levels due to more stable meteorological conditions, there could be increased audibility of WTN and AM at nearby dwellings during the night.

A series of recent epidemiological studies by Poulsen et al. did not find significant associations between calculated short- or long-term WTN and cardiovascular or metabolic outcomes including stroke and myocardial infarction [16, 17], antihypertensive medication redemption [18], or diabetes [19]. The same authors did however find that 5-year average outdoor WTN was associated with increased use of sleep medications among people aged at least 65 years, although there were no significant associations for people aged younger than 65 years or between sleep medication use and indoor average WTN across all age groups [20]. There is some limited evidence from two previous studies that living within 2 km of wind turbines is associated with lower perceived sleep quality, lower health-related quality of life, and reduced energy levels, compared to in demographically similar areas [21, 22]. The underlying reasons for these differences are unclear, especially since noise exposure was neither measured nor calculated in either study. Some studies have explicitly investigated associations between nocturnal WTN and sleep but have been inconsistent in their findings. Nighttime WTN was associated with sleep disturbance in some cross-sectional studies [23–25], and other investigators found no direct associations between WTN and sleep [26, 27]. The lack of congruence among these previous studies could be due to differences in methodologies, and the small numbers of participants exposed to high levels of WTN at which any adverse effects on sleep may be anticipated to manifest. Furthermore, the majority of studies have relied on questionnaires, which capture only certain aspects of sleep quality and disturbance, and may not reflect underlying physiologic alterations of sleep structure. Noise can induce changes in sleep architecture without being subjectively perceived [28], and although some measures of physiologic sleep may correlate with self-reported outcomes, the agreement between objectively and subjectively assessed sleep can be poor, particularly for questionnaire items that explicitly mention the exposure as the source of disturbance [29]. Noise-induced sleep fragmentation may be dangerous for health, even without conscious awareness [30, 31], and objective studies on possible deleterious effects of WTN are needed.

To our knowledge there have been only two previous investigations of WTN and objectively measured sleep. Jalali et al. [32] reported that there were no changes of sleep measured in the field with polysomnography (PSG) after the installation of wind turbines nearby, although there was a worsening of self-reported sleep. However, there were also no differences in the mean nighttime noise levels before and after the installation of the wind turbines, limiting conclusions that should be drawn regarding the impact of WTN. Michaud et al. [27] performed a large-scale field study where sleep was measured with actigraphy for a mean of 6.2 consecutive nights in 707 participants. There were no significant associations between calculated 1-year averaged WTN and actigraphically assessed sleep latency, sleep efficiency, total sleep time, time awake after sleep onset, or number of awakening bouts. Although actigraphy has high sensitivity in correctly detecting sleep periods, it has a poor specificity in detecting wakefulness during sleep episodes [33, 34] and does not provide information on sleep architecture. Changes of sleep structure and awakenings by WTN may be relevant from a public health perspective, and these are most accurately measured with PSG, which remains the "gold standard" of sleep research. Within the Wind Turbine Noise Effects on Sleep (WiTNES) project, we therefore performed a laboratory study using PSG and questionnaires to determine how a single night of WTN may impact on sleep.

Methods

Participants

Study participants were recruited using a combination of postal mailings, telephone contact, and public advertising, which is described in Supplementary Methods. A total of 50 participants completed the study (51.2 ± 9.8 years, range 36–70 years, 27 women). They were required to be aged 30–70 years, have a body mass index (BMI) less than 30 kg/m^2, and keep habitual sleep times broadly comparable with the 23:00–07:00 sleep opportunity period of the study protocol. The mean habitual sleep and wake times were 23:24 (SD ± 48 min, range 22:00–01:00) and 07:35 (SD ± 64 min, range 05:00–10:00), respectively, with a mean sleep duration of 8.2 ± 1.0 h. Applicants who used medication to aid sleep or experienced self-reported sleep apnea were ineligible to participate. Participants were required to have good self-reported auditory acuity, which we confirmed on the first night of the study by measuring hearing thresholds with pure tone audiometry and comparing against age-dependent norms [35]. The study was performed in accordance with the principles of

the Declaration of Helsinki and was approved by the Gothenburg regional ethical review board (Dnr 974-14). All participants provided informed written consent before the study began and were financially compensated for participating.

Twenty-four participants lived close to wind turbines, and 26 did not live close to wind turbines. The group that did not live close to wind turbines is hereafter termed *Reference*. The group living close to wind turbines was potentially exposed to WTN at home and is hereafter termed *Exposed*. A participant was classed as *Exposed* if they lived within 1 km of the nearest wind turbine and/or reported annoyance or sleep disturbance by WTN at home over the past month during eligibility screening (rating of *Somewhat*, *Very* or *Extremely* annoyed or sleep disturbed on five-point Likert scale following recommendations of the International Commission on the Biological Effects of Noise [ICBEN]) [36]. Participants in the *Exposed* group were required to have lived at their current home for at least 1 year. The demographics of the participants, stratified by study group, are given in Table 1. There were no indications that sex, age, BMI, self-reported health (five-point Likert scale), regular medication use (yes/no), or noise sensitivity (Weinstein questionnaire [37]) were different between the *Reference* and *Exposed* groups (χ^2 tests for categorical data, Student's *t*-test for continuous data). Relative to the *Reference* group, a greater proportion of the *Exposed* group generally had a more negative attitude to wind turbines (five-point Likert scale) and were more tired and tensed in mornings (11-point numerical scales with endpoints *Very alert and well-rested*—*Very tired* and *Very relaxed*—*Very tense*, respectively). Most participants rated their home bedroom as very or rather quiet and were not at all or not very disturbed by road, rail, fridge/fan, or neighbor noise at home (Supplementary Table S1). There were no significant differences for bedroom environment/noise disturbance at home between the *Reference* and *Exposed* study groups, determined using Fisher's exact test of independence. Seventeen participants (34%) were using medications during the study. The different medications used and the number of participants using each type of medication are given in Supplementary Table S2.

Participants were prohibited from consuming alcohol throughout the study. As caffeine is a major part of Swedish social culture, in the interest of allowing participants to follow their normal daytime routines as closely as possible and therefore improving the ecological validity, we permitted caffeine consumption during the study.

Study protocol

Study design.

Each participant spent three consecutive nights (Friday night to Monday morning) in the noise- and vibration-insulated sound exposure laboratory at the University of Gothenburg. Because of the first night effect [38], the first night served only as a habituation period to the environment and wearing the sleep measurement apparatus (see *Sleep measurement*) and was excluded from analysis. We played back WTN into the bedrooms on one night (see *Noise exposure*), hereafter termed *WTN-night*. One night was

Table 1. Demographics of Study Participants From the *Reference* and *Exposed* Groups

Variable		Reference	Exposed	Test of independence
Sex (*n*)	Women	15	12	$\chi^2(1) = 0.297$ $p = 0.586$
	Men	11	12	
Age (mean, years)		50.7 ± 10.5	51.8 ± 9.0	$t(48) = -0.321$ $p = 0.749$
BMI (mean, kg/m^2)		25.6 ± 3.4	25.3 ± 3.1	$t(48) = 0.380$ $p = 0.706$
Health status (*n*)*	Very good	5	4	$\chi^2(3) = 0.622$ $p = 0.891$
	Rather good	14	15	
	Neither good nor bad	4	3	
	Rather bad	1	2	
	Very bad	0	0	
Regular medication use (*n*)		9	7	$\chi^2(1) = 0.260$ $p = 0.610$
General attitude to wind turbines (*n*)	Very positive	6	3	$\chi^2(4) = 13.17$ $p = 0.008$
	Positive	17	7	
	Neither positive or negative	3	7	
	Negative	0	6	
	Very negative	0	1	
Attitude to impact on landscape (*n*)	Very positive	0	0	$\chi^2(3) = 26.6$ $p < 0.0001$
	Positive	13	1	
	Neither positive or negative	12	6	
	Negative	1	11	
	Very negative	0	6	
Annoyed or disturbed by WTN at home over last month (mean, 1–5)		—	3.5 ± 1.3	
Annoyance by WTN indoors at home over last month (mean, 1–5)		—	2.5 ± 1.1	
Annoyance by WTN outdoors at home over last month (mean, 1–5)		—	3.7 ± 1.1	
Sleep disturbance by WTN at home over last month (mean, 1–5)		—	2.2 ± 1.3	
Duration of residence (mean, years)		—	20.1 ± 15.7	
Tiredness in mornings (mean, 0–10)		3.5 ± 2.0	6.3 ± 2.4	$t(47) = 4.325$ $p < 0.0001$
Tense in mornings (mean, 0–10)		3.4 ± 1.7	4.5 ± 2.1	$t(47) = 2.023$ $p = 0.049$
Noise sensitivity score (mean)†		74.6 ± 17.2	79.1 ± 13.3	$t(43) = 0.992$ $p = 0.327$

Data reported as frequencies (*n*) or means ± standard deviations.
*Two participants did not respond to the health status item.
†Weinstein noise sensitivity scale [37].

kept quiet, to measure baseline sleep, and is hereafter termed the *Control* night. The order of the *WTN-night* and *Control* was counterbalanced within the *Reference* and *Exposed* study groups.

To improve ecological validity, the laboratory (described in detail elsewhere [39]) was furnished to resemble a typical apartment, and participants were free to come and go during the daytime. Participants arrived at the laboratory by 18:00 on the first evening and by 20:00 on the second and third evenings, to allow sufficient time for relaxation and setup of the sleep-measurement equipment before bedtime. The earlier arrival time on the first evening was to allow for audiometric testing and familiarization to the study environment and protocol. The scheduled sleep opportunity was 23:00–07:00 each night, and daytime naps were not permitted. We instructed participants to turn out their bedroom lights and to begin trying to sleep at 23:00, but in 11 nights (9 participants) they did not adhere to the self-enforced protocol and were already asleep at this time. Data from these nights were excluded from analysis of sleep timing variables (Data analysis - *Sleep measurement*). Participants were woken by an automated alarm call played into the bedrooms at 07:00, and a researcher ensured they arose.

Sleep measurement.

Sleep electrophysiology was measured each night using PSG. All electroencephalogram (EEG: Fpz, F3, F4, Cz, C3, C4, O1, O2, M1, M2), electrooculogram (EOG), electromyogram, and electrocardiogram electrode placements, electrical impedances, and sampling and filter frequencies followed recommendations of the American Academy of Sleep Medicine [40]. Data were recorded offline onto an ambulatory device (SOMNOscreen plus, Somnomedics, Germany) and downloaded each morning.

Salivary cortisol measurement.

Saliva samples were taken from each participant at 07:00, 07:30, and 07:45 every morning via sterile synthetic oral swabs (Sarstedt Salivette Cortisol, code blue). Each sampling period was 3 min. No food or fluids other than water were permitted until the final sample had been taken. The samples were refrigerated immediately and transferred to frozen storage (−80°C) within 3 h. Samples were thawed on the day of analysis and centrifuged at 1,500 ×*g* for 15 min. Cortisol concentrations were extracted in duplicate using an enzyme-linked immunosorbent assay (ELISA) technique (coefficient of variation 0.0–12.95%, mean 2.88%) designed for analysis of salivary cortisol (Salimetrics Salivary Cortisol Enzyme Immunoassay Kit).

Morning questionnaires.

Each morning between 07:00 and 07:15, participants completed a questionnaire that contained a number of sleep- and restoration-related items that we have previously validated against field data and PSG sleep data [29]. The complete questionnaire is given in Supplementary Methods. Tiredness, tension, irritation, and five measures of sleep quality were measured with 11-point numerical scales. Self-reported sleep quality was additionally measured on a five-point verbal scale (*Very good* to *Very bad*).

Sleep disturbance by WTN was recorded on an 11-point numerical scale following phraseology recommended by ICBEN [36]. WTN causing poor sleep, awakenings, difficulty sleeping, or morning tiredness were measured using five-point verbal scales (*Not at all* to *Extremely*). Participants also estimated their sleep latency (minutes) and number of awakenings (*n*) and reported whether they had difficulty falling asleep after awakenings (yes/no). Two dimensions of mood, Pleasantness and Social Orientation, were constructed according to Sjöberg et al. [41]. These mood measures are continuous variables from 1 to 4, constructed using the respondent's agreement (four-point verbal scale) with 23 words describing their current emotional state.

Noise exposure.

Noise exposure in the bedrooms was introduced through 88 loudspeakers mounted within the ceiling of each room. In the *WTN-night*, we played back continuous synthesized WTN from 22:00 to 07:00. The synthesis of the WTN was based on analysis of short- and long-term recordings of WTN from the field and has been described in detail previously [10, 42]. Briefly, we analyzed the frequency spectra and AM parameters (number of turbine blades; blade rotational frequency; and in each 1/3 octave band the AM depth, frequency of occurrence, rise and decay slopes, and top width) of four different turbines recorded 550–650 m downwind in a variety of meteorological conditions. These parameters were used to generate WTN with characteristics of our choosing in a signal free from wind, wildlife, or anthropogenic noise. Random variations in time were added to the WTN signal to mimic the recordings. Throughout the *WTN-night*, we included acoustic "beating," here defined as high AM depth in the frequency range 400–2,500 Hz. We found indications in a pilot study that there was increased wakefulness during periods of WTN when the turbine had a rotational speed of 13 revolutions per minute (rpm), whereas WTN periods with 17 rpm did not increase wakefulness [43]. Since a lower rotational speed could reflect a worse-case scenario in terms of sleep-disrupting effects of WTN, we held the turbine rotational speed during the *WTN-night* constant at 13 rpm. We also added artificial background noise simulating wind in distant trees to the WTN signal at an A-weighted equivalent sound pressure level (L_{AEq}) of 13 dB, since even on the quietest nights it is never completely silent.

Within the 8-h *WTN-night*, there were four distinct 2-h noise scenarios, constructed from a 2 × 2 arrangement of high and low AM depth, and a level and frequency spectrum difference corresponding to a filter simulating the bedroom window being fully closed or slightly ajar. The WTN frequency spectrum was different between the window ajar and closed scenarios (Figure 1, A) and was independent of AM depth, i.e. the spectrum was identical for low AM/ajar and high AM/ajar, and identical for low AM/closed and high AM/closed. The measured average and maximum sound pressure level at the pillow position for each 2-h period is given in Table 2. A 10-min audio sample of each WTN scenario is available from the Swedish National Data Service [44]. The order of the scenarios was randomized across different noise nights to avoid any ordering or time of night effects.

Discrete noise events during sleep can evoke EEG arousals, awakenings, and elevations of heart rate [45]. These cortical and autonomic arousals may be risk factors for the development of disease, particularly cardiovascular disease, following chronic noise exposure (see Münzel et al. [31, 46] for two reviews). We therefore included four 10-min periods without WTN in the *WTN-night*, to examine whether WTN offset and onset "events" at the start and end of these periods would evoke cortical or autonomic arousal. There was one WTN-free period during each of the 2-h noise scenarios, starting 70 min into the noise

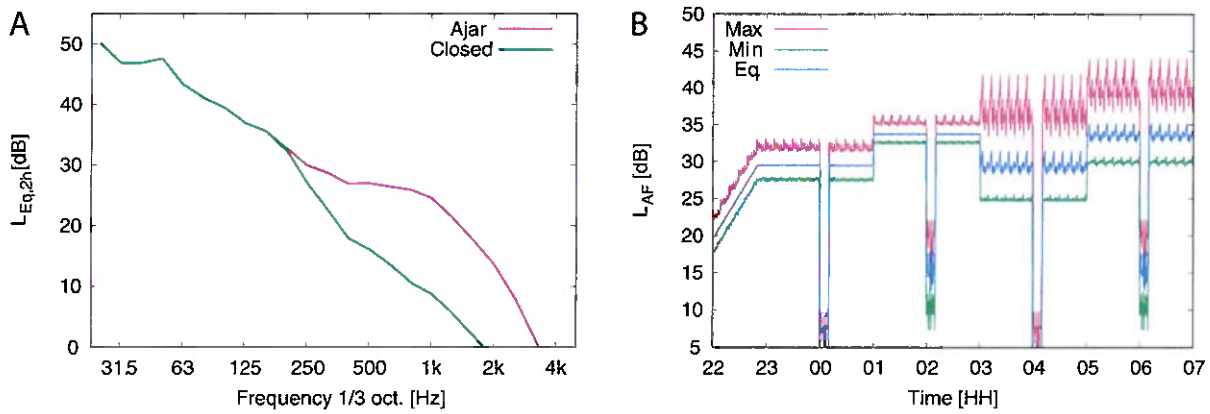

Figure 1. (A) Frequency spectrum of WTN during 2-h periods with filters simulating window ajar and window closed scenarios. The spectra were identical for the low and high AM cases. (B) Eight-hour nocturnal noise exposure with additional 1-h lead-in noise. In this example, the constituent 2 h scenarios are in the order low AM/closed window, low AM/ajar window, high AM/closed window, high AM/ajar window. The periodicity of WTN level within each 2-h period is due to random time-varying fluctuations introduced into the 10-min synthesized file, which was repeatedly played back within the 2-h period.

Table 2. Acoustic Characteristics of Wind Turbine Noise Across 2-h Periods of the WTN Nights

		Window filter	
		Ajar	Closed
AM depth	1–2 dB (low)	$L_{AEq,2h}$ = 33 dB $L_{AF,max}$ = 37 dB	$L_{AEq,2h}$ = 29 dB $L_{AF,max}$ = 34 dB
	7–9 dB (high)	$L_{AEq,2h}$ = 34 dB $L_{AF,max}$ = 45 dB	$L_{AEq,2h}$ = 29 dB $L_{AF,max}$ = 43 dB

Noise levels were measured at the pillow position.
AM, amplitude modulation; $L_{AEq,2h}$, equivalent A-weighted sound pressure level over a 2-h period; $L_{AF,max}$, maximum A-weighted sound pressure level with a fast (0.125 s) time constant.

scenario, i.e. at 00:10, 02:10, 04:10, and 06:10. During these WTN-free periods, the noise simulated a quiet background sound environment of wind noise from distant trees only. The noise exposure in these periods corresponded to an outdoor level that was 20 dB L_{AEq} below the outdoor level when WTN was present. Since the spectrum of wind noise is rather high frequency in character, the WTN-free level in the bedrooms during the closed window periods was more attenuated compared to the window ajar periods. The nonlinear transition to and from the WTN-free periods was approximately 2 s, which is shorter than a typical change that would be expected in a naturalistic environment. We purposefully chose to keep this transition as short as feasible to maximize the likelihood of these noise onset and offset events evoking a response, while also avoiding audible clicking.

The WTN signal in the bedrooms was calibrated to represent an outdoor 8-h nighttime average L_{AEq} ($L_{AEq,outdoor,night}$) of 45 dB for the complete sound file as a free field sound level. This level exceeds the current Swedish target value of 40 dB $L_{AEq,outdoor,night}$ [47] but is within recommended levels for some other nations [48]. We filtered the WTN signal to account for outdoor to indoor frequency-dependent sound pressure level differences, based on analysis of indoor WTN measurements described in detail elsewhere [49]. The WTN level was increased linearly from 22:00 to 22:50 (see Figure 1, B) to avoid any startle effects following sudden noise onset at lights-out at 23:00. The resulting indoor 8-h WTN exposure in each bedroom was 32 dB $L_{AEq,indoor,night}$, measured 15 cm above the center of the pillow. The measured noise level during the different 2-h noise scenarios (low or high AM; window closed or ajar) is given in Table 2. Previous measurements of low-frequency noise indicated there was a spatial-dependent level variation of less than 1 dB at positions ±15 cm horizontally around this central pillow position [50]. As such, WTN levels at the calibration position would closely match WTN levels at the ears of the study participants during sleep, even if they moved around. A whole-night measurement of the WTN at the calibration position is shown in Figure 1, A.

Data analysis

Polysomnography.

A single trained sleep technologist, who was blind to the study design, manually scored every 30 s epoch as wakefulness (W), rapid eye movement (REM) sleep, or non-REM sleep stages N1, N2, or N3 according to scoring rules from the American Academy of Sleep Medicine [40]. EEG arousals, which are abrupt changes in EEG frequency (>16 Hz) reflecting intrusion of wakefulness in sleep [49], were scored according to the American Sleep Disorders Association guidelines [51], with arousals longer than 15 s classified as awakenings.

The PSG data were used to derive the following sleep macrostructure variables: sleep-onset latency (SOL) defined as the first occurrence of a non-wake sleep stage after lights out; REM latency following sleep onset; N3 latency following sleep onset; latency of first awakening; total time in wake after sleep onset (WASO); sleep period time (SPT) between sleep onset and sleep cessation; total sleep time (TST); sleep efficiency (SE) as a percentage of TST relative to time in bed; minutes in N1, N2, N3, non-REM (NREM) and REM sleep; proportion of TST in N1, N2, N3, NREM and REM sleep; maximal continuous N1, N2, N3 and REM duration, total number of arousals, awakenings, summed arousals + awakenings, and sleep stage changes (SSCs). Arousal Index, Awakening Index, and SSC Index were calculated respectively as the number of arousals, awakenings, and SSCs per hour of TST. The Sleep Fragmentation Index was calculated as the number of awakenings and arousals per hour of TST.

Event-related cortical and autonomic arousal, EEG arousal, awakenings and changes of sleep state, indicating cortical arousal, and elevations of heart rate, indicating autonomic (vegetative) arousal, have been observed during noise exposure [45]. These responses are nonspecific to noise and occur spontaneously throughout sleep, and so it is unclear whether an observed response was induced by noise [49], or whether it would have occurred even without the noise. When screening for event-related reactions, the analysis window should therefore be long enough in duration to capture responses induced by the noise event and short enough to minimize capturing endogenous reactions occurring after the noise event. Previous studies on traffic noise have found that a 60 s analysis window maximized the difference in cortical arousal probabilities during noise exposure compared to periods without noise [45, 52, 53] and is also sufficiently long to capture noise-induced autonomic arousal [54]. We therefore a priori selected a 60 s analysis window for event-related analysis of WTN onset and offset. For every event in the *WTN-night* (total of 8 per night: n = 4 WTN offset; n = 4 WTN onset 10 min after offset), we screened the analysis window for EEG arousals and awakenings. Here, a response that started during this window was scored as event-related. For event-related SSC analysis, we compared the two 30 s sleep epochs in the screening window to the baseline epoch immediately before the WTN event. Here, an event-related SSC was scored if there was a change to a different sleep stage in one or both of the screened epochs compared to the preevent baseline sleep state. We also analyzed sham events during the *Control* night at times corresponding to WTN events in the *WTN-night*. This allowed us to determine the probability of spontaneously occurring arousal, awakening, and SSC in the absence of WTN onset and offset.

We calculated two event-related measures of autonomic arousal that we previously found were sensitive to low-frequency noise at low maximum sound pressure levels [50] and could therefore be suitable for detecting response to WTN events. For each event we calculated the maximum change in heart rate (ΔHR_{max}) in the screening window relative to the mean baseline heart rate in the 30 s epoch preceding the event. We also calculated the heart rate amplitude (HRA) as the difference between the maximum and minimum heart rates in the screening window from event onset.

All WTN events where participants were already awake were excluded from analysis of cortical and autonomic arousal (n = 91 excluded, 11.9%). A total of 675 events (88.1%) therefore contributed to the event-related analyses.

Salivary cortisol.

We used a number of different measures of the cortisol awakening response (CAR) that are commonly reported in the literature [55–57]. ACOR is the absolute cortisol concentration at each of the three measurement times (0, 30, and 45 min after awakening). CARauc is the overall volume of cortisol released given by the total area under the CAR curve. CARi is the change in the overall volume of cortisol released relative to the waking value. AINC is the absolute increase in cortisol, defined as the difference between the maximal value of post-awakening cortisol relative to the awakening value. MINC is the difference between the mean values of post-awakening cortisol relative to the awakening value.

Statistical analysis

Regression models.

The primary objective in the current analysis was to examine the association between WTN exposure and sleep. We therefore analyzed all PSG macrostructure, CAR, and questionnaire outcomes in mixed effects regression models with dichotomous study night (*Control*/*WTN-night*) included as the primary independent (treatment) variable of interest. Models included a random subject intercept to account for repeated measurements on the same individuals. The assumptions of the regression model used for each outcome were dependent on the data: linear regression for continuous data; ordinal logistic regression for ordered categorical data; and binary logistic regression for event-related data (reaction/no reaction). Results are reported as unstandardized regression coefficient β or estimated marginal means (EMM). The level of statistical significance was set at $\alpha = 0.05$. Data were analyzed in SPSS (v. 26; IBM Corp, Armonk, NY) and STATA (Release 14.1; StataCorp, College Station, TX).

Data were visually inspected to ensure conformity with model assumptions. If appropriate, data were transformed prior to regression analysis. SOL, N3 latency, WASO, TST, and ΔHR_{max} were substantially positively skewed and were log-transformed. REM latency, number of awakenings during the night, awakening frequency per hour, HRA, and absolute cortisol concentrations (ACOR) were slightly positively skewed and were square-root transformed. The distributions of the pleasantness and social orientation mood measures were negatively skewed, so both were recorded into three-level ordinal variables.

Individual-level covariates.

Both psychologic and physiologic responses to environmental noise are moderated by individual factors [58]. Long-term exposure to noise may lead to a certain, but nontotal, degree of acclimatization for some outcomes including self-reported sleep, but other biological responses, particularly autonomic activation, appear not to habituate [59]. Noise sensitivity may be a better predictor of the nonauditory effects of noise, including insomnia, than noise level [60], and noise-sensitive persons generally report worse self-reported sleep and greater disturbance by noise than nonsensitive counterparts. We therefore included the following covariates in all regression models: study group (dichotomous Reference/Exposed), sex (dichotomous Female/Male), age (continuous), and noise sensitivity (dichotomous low/high) determined by median split of the noise sensitivity score (median = 73).

Habitual perceived sleep difficulties and tiredness could influence self-reported sleep during the study. Regression models for all questionnaire items therefore included covariates for regular difficulty falling asleep (dichotomous yes/no) and excessive tiredness (dichotomous yes/no) determined by a response of at least several times per month on four-level ordinal scales with the following levels: Seldom or never, Once or several times a month, Once or several times per week, Daily or almost daily.

To ensure we did not have issues with multicollinearity, we confirmed that all individual-level covariates did not covary in a correlation analysis (see Supplementary Table S3).

We hypothesized that there could be differential effects of WTN on the study groups, due to either sensitization or habituation. A study night × study group interaction term was therefore included in all models. Main effects of study night

or study group were interpreted only if the interaction was not significant.

To minimize the risk of overfitting the questionnaire data regression models we employed likelihood ratio tests to define the best-fit adjusted models.

Experimental- and sleep-level covariates.
Models of event-related cortical and autonomic response included sleep stage at event onset (four-level categorical: REM/N1/N2/N3), event type (dichotomous WTN offset/WTN offset, reflecting whether the event was a WTN offset at the start of the 10 min quiet period or WTN offset at the end of the 10 min quiet period), and event number (ordinal 1–8, reflecting the order of each of the repeated discrete events within the night from first to eighth) as covariates. Changes of sleep stage would be expected to have corresponding changes in cardiac activity [49], therefore an SSC variable (dichotomous yes/no) was included as a covariate in models of autonomic activation.

In the model for ACOR, measurement time (0, 30, and 45 min after awakening) was included as an ordinal covariate.

Within-night analysis of WTN character.
Within-night analysis was performed to examine effects of AM depth and window filter. The following sleep data were calculated for each of the 2-h sound character periods in the *WTN-night*: sleep time (minutes), amount of each sleep stage during the sound character period as a proportion of time asleep in the sound character period (%), arousal index, awakening index, sleep fragmentation index, and SSC index. Data were analyzed in mixed effects regression models with a random subject intercept, as for all other analyses described above, with the following differences. The models included Window (dichotomous Closed/Ajar) and AM depth (dichotomous low/high) as the treatment variables of interest. Because of the rather limited sample size (n = 48 participants with PSG data), to minimize the risk of overfitting we aimed to limit the number of variables in each model. Candidate variables to include were the covariates included in analysis of sleep macrostructure (study group, sex, noise sensitivity, and age) and the window × AM interaction. The presentation number of the sound character period (ordinal: 1, 2, 3, 4) was also considered as a candidate variable, since sleep structure changes over the course of the night. The final choice of covariates was via a purposeful stepwise selection procedure described fully in Supplementary Methods.

Results

Polysomnography

Due to a technical failure, PSG data from a single night were missing for two women from the *Reference* group. We therefore collected PSG data from both the *Control* and the *WTN-night* from 24 participants in each study group for analysis (complete data for both nights from n = 48 participants). On 11 subject nights (11.5%), participants were already asleep at the scheduled lights-out period, and data from these instances are not included in analysis of SOL, N3 latency, or REM latency. We did not find evidence that SOL, N3 latency, or REM latency were affected by habitual sleep time at home (see Supplementary Results).

Sleep macrostructure.
Means and standard errors for whole-night data are given in Table 3. Results of the regression model for each variable are given in Supplementary Table S4. There were no significant interactions between study night and study group for any outcomes except N3%. For this single outcome, the significant interaction indicates that there was a differential relationship between N3% and study night for the *Reference* group compared to the *Exposed* group (Supplementary Figure S1).

There were significant main effects of *study night* (i.e. WTN exposure) on the latency and absolute and proportional amount of REM sleep. There was EMM = 11.1 min less REM time in the *WTN-night* than in the *Control*, which largely accounts for the longer REM latency of EMM = +16.8 min in the same night. The lower REM time in the *WTN-night* corresponds to EMM = 2.2% less time in REM sleep over the full sleep duration. Accordingly, there was a 2.2% greater time in non-REM sleep, distributed throughout N1, N2, and N3 sleep rather than a single sleep stage. There were no significant differences between the *WTN* and *Control* night for sleep onset, sleep duration, or indicators of sleep fragmentation or sleep continuity. The total time in each of the non-REM sleep stages did not differ between the *WTN* and the *Control* nights.

Individuals in the *Exposed* group had EMM = 6.8 min longer maximum continuous N3 duration than the *Reference* group (p = 0.037). High noise sensitivity individuals had a lower TST than the low sensitivity group (log-transformed, β = −0.024).

Sound character.
Results from the final regression models for the sound character period are presented in Table 4. There was a lower percentage of N2 sleep during periods of WTN with high AM than periods with low AM, with no significant (interaction or main effect) influence of window (Figure 2, right pane). There was a significant interaction between window and AM for awakening frequency and REM sleep. When the window was closed, there was a higher awakening frequency during high AM periods than in low AM periods, and the relationship was in the opposite direction when the window was ajar (Figure 2, left pane). The same pattern was found for REM sleep (Figure 2, center pane). There were no significant effects of WTN sound character on sleep time, N1%, N3%, REM%, SSC frequency, or arousal frequency.

Event-related reactions.
Results of the regression models for event-related response to WTN onset and offset are given in Table 5. There was insufficient power to analyze event-related awakenings (n = 16 event-related awakenings across all events and participants), thus awakenings are not reported. There were no significant interactions between study night and study group for any of the outcomes. There was no main effect of study night on event-related cortical or autonomic arousal. There were no effects of study group, noise sensitivity, age, or sex for any cortical or autonomic arousal measures.

Cortisol awakening response

There was no significant study group × study night interaction for any CAR measures (Supplementary Table S5). There were no significant main effects of study night or study group for any measures of CAR (Supplementary Figure S2 and Table S5).

Table 3. Whole-Night Polysomnography Data, Presented as Mean and SE

Variable category	Variable	Participants in analysis (*n*)		Control		WTN-night		Night × group *p*-value
		Control	WTN-night	Mean	SE	Mean	SE	
Sleep times	TIB (min)	48	48	479.8	0.16	478.2	1.77	0.354
	TST (min)	48	48	415.6	5.51	402.9	8.55	0.543
	Sleep period time (min)	48	48	448.0	4.03	438.6	5.25	0.179
	Sleep efficiency (%)	48	48	86.6	1.15	84.2	1.74	0.483
	Sleep onset latency (min)	42†	43‡	21.3	3.48	25.3	3.68	0.165
	REM latency (min)*	42†	43‡	**79.1**	**7.51**	**94.6**	**8.13**	0.594
	N3 latency (min)	42†	43‡	31.0	4.52	34.8	6.00	0.136
	WASO (min)	48	48	45.2	5.28	52.3	7.51	0.500
Sleep architecture	N1 (min)	48	48	61.1	3.08	59.4	3.25	0.392
	N2 (min)	48	48	187.1	5.33	186.7	6.27	0.082
	N3 (min)	48	48	81.9	3.20	81.2	3.73	0.062
	REM (min)*	48	48	**85.6**	**3.57**	**75.5**	**3.23**	0.607
	NREM (min)	48	48	330.1	5.43	327.4	7.44	0.232
	N1 (% of TST)	48	48	14.9	0.83	15.1	0.85	0.476
	N2 (% of TST)	48	48	44.8	1.01	46.0	1.01	0.083
	N3 (% of TST)	48	48	19.7	0.73	20.1	0.96	0.034
	REM (% of TST)*	48	48	**20.6**	**0.81**	**18.8**	**0.76**	0.354
	NREM (% of TST)*	48	48	**79.4**	**0.81**	**81.2**	**0.76**	0.354
Sleep fragmentation	Arousals (*n*)	48	48	86.2	5.70	82.4	6.37	0.283
	Arousal index (*n*/h)	48	48	12.5	0.85	12.3	0.91	0.268
	Awakenings (*n*)	48	48	11.4	1.08	11.5	1.16	0.207
	Awakening index (*n*/h)	48	48	1.7	0.16	1.7	0.18	0.288
	Combined arousals + awakenings (*n*)	48	48	97.5	6.05	93.9	6.47	0.230
	Sleep fragmentation index (*n*/h)	48	48	14.2	0.92	14.1	0.93	0.230
	SSCs (*n*)	48	48	146.5	6.12	143.5	5.70	0.079
	SSC index (*n*/h)	48	48	21.4	0.99	21.8	0.90	0.196
Sleep continuity	First awakening (min)	48	48	21.6	2.37	15.2	4.01	0.540
	Final awakening (min)	48	48	466.6	4.59	461.2	3.65	0.595
	Max uninterrupted time in W (min)	48	48	29.1	3.62	31.8	3.99	0.435
	Max uninterrupted time in REM (min)	48	48	16.2	1.35	14.0	0.95	0.590
	Max uninterrupted time in N1 (min)	48	48	4.9	0.24	4.5	0.26	0.839
	Max uninterrupted time in N2 (min)	48	48	23.4	0.95	24.0	1.25	0.419
	Max uninterrupted time in N3 (min)	48	48	28.0	1.61	28.0	1.86	0.974

Statistically significant ($p < 0.05$) effects of study night are indicated with * and bold typeface.
†Six participant nights (five in Exposed group, one in Reference group) excluded due to participants already sleeping at 23:00.
‡Five participant nights (four in Exposed group, one in Reference group) excluded due to participants already sleeping at 23:00.

Table 4. *P*-Values from Multilevel Mixed Effects Regression Models for Effect of Sound Character Period on PSG Data

Outcome	Type III effect *p*-values							
	Window × AM	Window	AM depth	Study group	Sex	Noise sensitivity	Age	Period number
Sleep time (min)	—	0.097	0.164	0.187	**0.035**	—	—	**<0.001**
N1%	—	0.865	0.538	**0.029**	0.022	—	—	**0.044**
N2%	—	0.202	**0.007**	0.017	—	—	—	0.179
N3%	—	0.413	0.131	—	—	—	—	<0.001
REM%	**0.047**	0.412	0.305	—	**0.010**	0.420	—	<0.001
SSC index	—	0.815	0.781	0.305	**0.019**	—	—	0.153
Awakening index	**0.002**	0.969	0.858	—	0.107	—	0.203	—
Arousal index	—	0.743	0.772	—	0.072	—	—	0.093

Data for all outcomes obtained from 48 participants. Statistically significant (<0.05) *p*-values are highlighted with bold typeface. Empty cells indicate that the covariate or interaction was not statistically significant and did not contribute to the model and was therefore not included.

Self-reported sleep

Results of the regression models for the questionnaire data are presented in Table 6. Unadjusted means for the *Control* and *WTN-night*, stratified and unstratified by study group, are given in Supplementary Figure S3. There were no significant interactions between study night and study group. Compared to the morning after the *Control* night, the participants reported lower sleep quality in mornings after the *WTN-night*, as well as increased tiredness, increased irritation, greater difficulty falling back to sleep following awakenings, increased difficulty

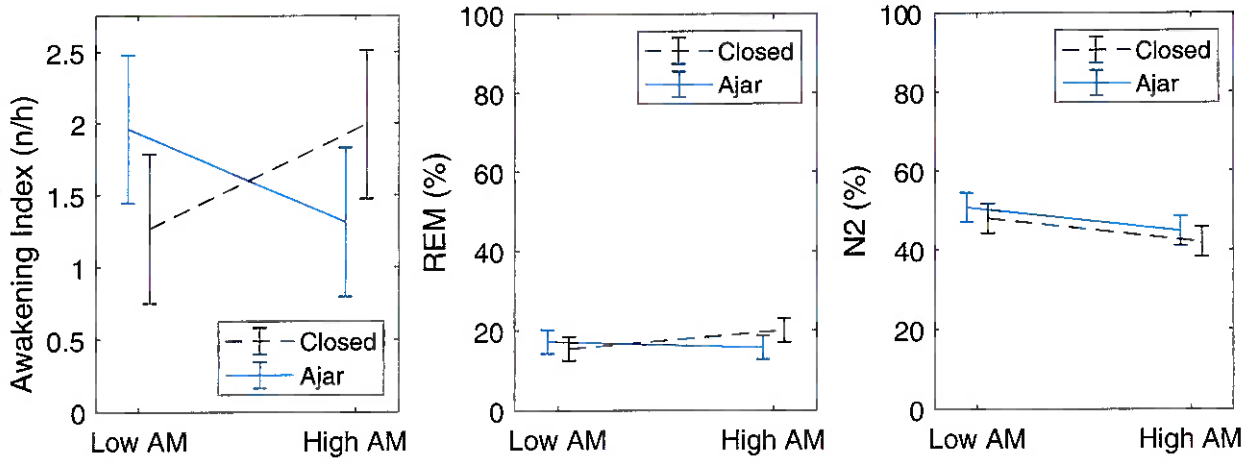

Figure 2. Left pane: Interaction between AM depth and window filter for awakening frequency. The Window × AM interaction was significant ($p = 0.002$). Center pane: Interaction between AM depth and window filter for proportion of REM sleep. The Window × AM interaction was significant ($p = 0.047$). Right pane: Interaction between AM depth and window filter for N2 sleep. The Window × AM interaction was not statistically significant, $p = 0.777$. There was a significantly lower proportion of N2 sleep during High AM WTN periods than Low AM WTN periods ($p = 0.011$). All data shown are estimated marginal means from the mixed regression model, adjusted for covariates included in the model (Table 4). Error bars indicate 95% confidence intervals.

Table 5. Results of Regression Models for Event-Related Cortical and Autonomic Arousal

		Study night		Study group		Event type		*p*					
Outcome	Night × group *p*	β*	*p*	β*	*p*	β*	*p*	Sex	Noise sensitivity	Age	Sleep stage	Event number	SSC
EEG arousals	0.517	0.106	0.243	0.201	0.148	−0.412	0.669	0.148	0.882	0.390	<0.001	0.275	—
SSCs	0.443	0.050	0.292	−0.323	0.326	**−2.574**	**0.043**	0.101	0.104	0.073	<0.001	0.301	—
HRA†	0.903	0.094	0.317	−0.212	0.344	0.211	0.577	0.402	0.432	0.426	0.002	0.262	<0.001
ΔHR_{max}†	0.857	0.044	0.090	−0.036	0.488	−0.126	0.234	0.389	0.767	0.756	0.004	0.360	<0.001

Statistically significant effects on variables of interest are highlighted in bold typeface.
SSC, sleep stage change; HRA, heart rate amplitude; ΔHR_{max}, maximum change in heart rate compared to pre-event baseline.
*Reference categories (β = 0): *Control* night; *Reference* group; WTN offset.
†HRA was square-root transformed and ΔHR_{max} was log-transformed before analysis.

sleeping, sleeping worse than usual, waking more frequently, and lower pleasantness. For the five measures of noise-induced sleep disturbance, sleep was significantly more disturbed during the *WTN-night*. There were no effects of WTN on morning tension, perceived sleep depth, or social orientation.

The *Exposed* study group gave a more negative rating of sleep quality, tiredness, and sleeping worse than usual compared to the *Reference* group in both the *Control* and *WTN-night*. They also reported higher noise-induced sleep disturbance overall, in both the *Control* and *WTN-night* compared to the *Reference* group.

Discussion

We performed an investigation of physiologic sleep and WTN in a controlled environment. The effects of WTN on sleep were limited to a longer REM sleep latency and less REM sleep in nights with WTN. Self-reported sleep was adversely affected by WTN, with the responses in 14 of 17 questionnaire items indicating worse sleep quality and less restorative sleep compared to the quiet control night. No effects of WTN were observed for other measures of physiologic sleep architecture, event-related autonomic response or cortical arousal or awakening, or in the CAR. With regard to the sound character of WTN, there was less N2 sleep during high AM and an interaction between AM depth and window filter on awakening frequency. This suggests that AM could be a particularly sleep-disrupting characteristic of WTN, although the most deleterious effect, i.e. awakenings, was dependent on the WTN spectrum.

Only one previous study has aimed to examine the effect of measured (rather than estimated) WTN on physiologic sleep [32]. Those authors found no differences among 16 participants for nocturnal indoor noise levels before (36.6 dB $L_{AEq,time\ in\ bed}$) and after (36.5 dB $L_{AEq,time\ in\ bed}$) wind turbine operation, and no differences in objective sleep before and after turbine operation. However, average noise level alone is not an adequate predictor of response to WTN and does not necessarily capture possible influences of frequency spectrum and AM. To our knowledge, the present study therefore represents the first effort to establish a causal link between real-time measurements of WTN exposure and physiologic impacts on sleep. In terms of overall sleep architecture, significant effects were found only for the impact of WTN on REM sleep. Effects of noise on REM sleep are not specific to wind turbines. For instance, it was recently reported that nights with rather low levels (35–45 dB $L_{AEq,indoor,night}$) of ground-borne low-frequency noise from railway tunnels led to a reduction in total REM time of around 5–7 min compared to a quiet control night [50]. Longer REM latencies have been

Table 6. Best-Fit Adjusted Regression Models for Self-Reported Sleep Outcomes

	Participants in analysis (*n*)		Study night (WTN exposure)†			Study group‡		Sex♠		Sensitivity♣		Sleep difficulties at home♦		Tiredness at home♥	
Variable	Control	WTN-night	β	*p*	95% CI	β	*p*	β	*p*	β	*p*	β	*p*	β	*p*
Sleep quality (0–10)*	50	50	2.25	<0.001	1.17–3.33	1.60	<0.01	0.81	n.s.	—	—	0.94	n.s.	−0.14	n.s.
Sleep quality (5-point semantic)*	50	50	2.04	<0.001	0.97–3.10	1.72	<0.001	0.76	n.s.	0.31	n.s.	1.89	<0.001	—	—
Tired–Rested (0–10)*	50	50	1.13	<0.01	0.28–1.98	1.45	<0.01	—	—	—	—	1.26	<0.05	—	—
Tense–Relaxed (0–10)*	50	50	0.68	n.s.	−0.11–1.48	—	—	—	—	—	—	—	—	—	—
Irritated–Happy (0–10)*	50	50	1.49	<0.01	0.54–2.43	—	—	—	—	0.17	n.s.	1.29	<0.05	1.33	<0.05
Hard to sleep following awakenings? (no/yes)	47	47	1.34	<0.05	0.09–2.59	—	—	—	—	—	—	1.54	n.s.	—	—
Easy–Difficult to sleep (0–10)	50	50	0.89	<0.05	0.13–1.65	0.76	n.s.	—	—	—	—	1.26	<0.01	—	—
Slept better–Worse than usual (0–10)	50	49	1.84	<0.001	0.84–2.83	1.65	<0.01	—	—	—	—			−0.56	n.s.
Deep–Light sleep (0–10)	49	50	0.72	n.s.	−0.9–1.52	—	—	0.84	<0.05	0.79	n.s.	1.41	<0.001	—	—
Never woke–woke a lot (0–10)	50	50	1.18	<0.01	0.37–2.00	—	—	—	—	—	—	1.56	<0.001	—	—
Sleep disturbance by WTN (0–10)	50	50	3.57	<0.001	2.43–4.72	2.11	<0.001	—	—	—	—	—	—	—	—
WTN impaired sleep quality (5-point semantic)	49	50	5.49	<0.001	3.11–7.88	4.12	<0.001	1.24	n.s.	—	—	2.05	<0.05	−0.93	n.s.
WTN caused awakenings (5-point semantic)	49	50	4.15	<0.001	2.37–5.95	2.52	<0.001	0.94	n.s.	—	—	1.19	n.s.	−0.81	n.s.
WTN making it hard to fall back asleep (5-point semantic)	49	49	3.94	<0.001	2.32–5.56	2.08	<0.01	1.45	<0.05	—	—	1.11	n.s.	—	—
WTN cause tiredness in morning (5-point semantic)	49	49	3.03	<0.001	1.70–4.36	2.16	<0.001	0.88	n.s.	1.18	<0.05	1.32	<0.05	−0.64	n.s.
Mood: Pleasantness (1–4)* ♪	49	47	1.00	<0.05	0.08–1.92	0.66	n.s.	—	—	1.71	<0.01	—	—	0.99	n.s.
Mood: Social orientation (1–4)* ♫	49	47	0.98	n.s.	−0.08–2.01	1.51	n.s.	—	—	2.2	<0.01	—	—	—	—

β, regression beta coefficient; 95% CI, 95% confidence interval; n.s., not statistically significant.
Empty cells indicate the measure was both nonsignificant and did not contribute to the final model and was hence omitted from the model.
*Response scale inverted for analysis.
♪Converted from continuous data to categories with the following cutoff points: <2.8; ≥2.8 and <3.5; ≥3.5.
♫Converted from continuous data to categories with the following cutoff points: <3.0; ≥3.0 and <4.0; ≥4.0.
Reference categories as follows: †, WTN-free *Control* night; ‡, *Reference* group; ♠, Women; ♣, Low sensitivity to noise; ♦, No sleep difficulties; ♥, No excessive tiredness.

observed during nights with road or rail traffic noise [61, 62], although other studies have found shorter REM latencies or no effect [63, 64]. The precise function(s) of REM sleep remains controversial, but it may be important for cognition, consolidation of procedural and declarative memories, and synaptic pruning and strengthening [65–67]. Furthermore, a reduced percentage of REM sleep and increased REM latency have been associated with an increased incidence of dementia, but the direction of this association (i.e. which is the cause and which is the effect) and underlying mechanisms are unclear [68].

Except for the effects on REM sleep, no other measured sleep macrostructure parameter was significantly affected by WTN. However, the 32 dB noise level in the WTN nights is low relative to other environmental noise pollutants and corresponds to levels that have been used as "quiet" or "control" nights in some previous investigations of noise and sleep [69, 70]. The effects of noise from other sources (air, road, and rail traffic) at comparable levels to the WTN nights in the current study have accordingly found no effects on sleep macrostructure [50, 63, 71].

There was a lower amount of N2 sleep during high AM WTN than periods with low AM, potentially indicating a sleep-disrupting effect of AM that would to our knowledge be a novel result. AM of WTN is a rhythmic variation in the sound pressure level corresponding to the rotational speed of the turbine blades, which can contribute to self-reported annoyance by WTN [72]. Humans continue to evaluate and react to the acoustic environment during sleep [73] and may therefore respond to the stronger "pulsing" sensation of high AM, more readily than the low AM WTN where the rhythmic fluctuations in level were less pronounced. However, there was mixed support for this hypothesis in the finding of differential effects of AM on awakenings and REM sleep depending upon the window filter. One the one hand, when the window was closed, and therefore had less acoustical energy above 200 Hz compared to when it was ajar,

the higher awakening index during periods of high AM supports a sleep fragmenting role of AM. On the other hand, when the window was ajar and therefore there was more energy above 200 Hz, the awakening index was higher during periods of low AM, suggesting that a more continuous, less time-varying sound pressure level was more disruptive to sleep when WTN was not as "low," "deep," or "boomy" in character.

Comparison of study groups living both close to and apart from wind turbines generally revealed no differences in measures of overall sleep macrostructure or sleep structure across different WTN scenarios, morning cortisol concentrations, or cortical reaction probability or autonomic activation following WTN onset and offset events. On the one hand, this does not provide support for a hypothesis that chronic exposure to WTN leads to physiologic sensitization, otherwise a greater response would be expected among the *Exposed* individuals during the *WTN-night*. On the other hand, where effects of WTN were observed in the PSG data, they were independent of study group, suggesting that neither does physiologic habituation (as opposed to sensitization) to WTN occur for the outcomes assessed here. Habituation to chronic noise exposure, at least partially, was seen for railway noise by Tassi et al. [74, 75], who found that autonomic response to nocturnal railway noise persists among individuals who have lived near railway lines for more than 10 years. However, some habituation did occur and the autonomic response was lower than in individuals who were not habitually exposed to railway noise. Although effects of railway noise may not be directly comparable to WTN, due to differences in intermittency, spectral content, time course, and the influence of meteorological conditions, it is possible that if habituation or sensitization to WTN does occur, the *Exposed* group may not have been exposed to WTN for a long enough period for these processes to fully develop. The *Exposed* group had lived in their current homes for an average of 20 years, but we do not know when the wind turbines became operational, and so do not know how long they were potentially exposed to WTN. Since we did not perform noise measurements or calculations at the dwellings, it is also possible that the *Exposed* group was not chronically exposed to WTN at levels high enough in level to trigger the development of habituation or sensitization. Furthermore, the impact of noise on sleep varies widely between individuals, with interindividual differences reported to account for around 50% of the variance in physiologic arousal and awakening to noise [76]. It is therefore possible that the most affected individuals, i.e. those whose sleep may be objectively disrupted by WTN at home, were not recruited into the study, perhaps because they were either unwilling to take part in a study where they knew there would be WTN, were underrepresented in the sampled population, or had moved away from the area to avoid the noise.

Physiologic effects of WTN were not found for the majority of sleep measures, which implies that nocturnal WTN may not be of major public health relevance. On the other hand, the self-reported data give indications of poorer sleep quality and restoration, which may contribute to a risk for long-term health effects in ways not captured by PSG. While PSG remains the "gold standard" of sleep research, it is limited by the fact that according to the current guidelines [40], sleep scoring is performed in discrete 30-s epochs, with the EEG activity in the majority of the epoch determining the sleep stage scored. Any epoch can therefore include EEG activity from a sleep stage different from the scored stage, providing such activity occupies less than 15 s of the epoch. As such, classical sleep scoring may not capture short duration, yet potentially biologically relevant, noise-induced changes of sleep. It was recently reported that autonomic arousals during sleep were longer when there was highly intermittent nighttime railway noise, and there was a correlation between cumulative autonomic arousal in nights with highly intermittent road traffic noise and next-day evening cortisol, yet there were no differences in PSG-measured sleep macrostructure [77]. In future investigations of WTN, it would be advantageous to analyze other measures of the sleep EEG which may be sensitive to disruption by noise and which may include power spectral density [78], cyclic alternating pattern [79], and continuous measures of sleep depth and stability such as the odds ratio product [80]. The reasons for lack of physiological effects of WTN in the present study could also relate to the rather continuous nature of the noise exposure, with only four short quiet periods during the *WTN-night*. In reality, WTN in the bedroom would likely be more intermittent, changing with meteorological conditions such as temperature and wind direction. Some authors have found intermittency effects of noise, for instance nocturnal traffic noise with a moderately intermittent exposure pattern may be of higher importance for causing autonomic response, and consequently the development of cardiovascular disease, than continuous or highly intermittent noise [81, 82]. Further work investigating the intermittency of WTN on sleep-related outcomes would be valuable in informing a potential link between WTN and adverse short- and long-term effects. Finally, the lack of observed effects of WTN could result from type II error. Although 50 participants is a somewhat large sample size for a sleep study of this type compared to previous PSG studies on the effects of noise, only medium or large effect sizes are likely to reach statistical significance. Any effects of WTN on sleep may therefore be too small to detect in our current sample.

Self-reported sleep disturbance by noise is per se recognized by the WHO as a health concern [3]. There were clear negative effects of WTN on self-reported sleep, agreeing with results from some cross-sectional field studies [23, 24], but in disagreement with others [26, 27]. In line with a field study by Jalali et al. [32], we found that regardless of the presence or absence of nocturnal WTN, self-reported sleep was worse among individuals living near wind turbines. A possible criterion for classification as a member of the *Exposed* group was annoyance by WTN at home, and consequently the majority of this *Exposed* group reported at least some annoyance at home by WTN. The higher self-reported seep disturbance among this group could offer some support to the hypothesis that annoyance by wind turbines may be a better predictor of sleep disturbance than noise level [26]. Nevertheless, self-reported data from the *Reference* group indicate that WTN itself has the potential to elicit at least some degree of disturbance, at least at the 45 dB $L_{AEq,outdoor,night}$ level used here.

Limitations

It cannot be excluded that our study population is affected by self-selection bias, especially since the recruitment strategy for the *Exposed* group partially involved contacting individuals who had formally complained about wind turbines. In the *Exposed* group, only two individuals reported no degree of disturbance by WTN at home, although disturbance was one of the two criteria

for classification of a participant as *Exposed*. The *Exposed* group had a more negative attitude that the *Control* group toward wind turbines in general, which could be a consequence of disturbance at home. Disturbed individuals could conceivably be interested in the research questions of the WiTNES project, and therefore they might be more likely to participate than counterparts living near wind turbines who were not interested [83].

Our efforts to maximize ecological validity by allowing participants to pursue their normal daytime routines with minimal interference are not without limitations. Firstly, any caffeine consumption late in the afternoon would likely have affected sleep, although this could reflect a habitual caffeine drinker's typical sleep at home. Secondly, we also did not exclude people who were using medication associated with potential side effects on sleep, although only three participants (6%) used any medication that would frequently be expected to affect sleep. Thirdly, we did not record participants' activity during the daytime prior to or during the study, or actively monitor the participants during sleep. Although they were instructed to go to bed at 23:00, this time was self-enforced, and some of them did not adhere to this bedtime schedule and were already asleep when the PSG recording began, and we do not know for how long. There may also have been nonadherence regarding napping, and without daytime activity data we cannot conclude that naps did not occur. Naps, if they did in fact occur, would be expected to dissipate sleep pressure, which may have affected the nighttime PSG. We also relied on self-reported habitual sleep times, and so cannot exclude that the participants slept for short or longer durations in the nights prior to the study, which may have affected the representativeness of their sleep in the study period. The study was performed in a laboratory rather than in participants' own homes, which, despite our efforts to ensure that the ecological validity was high as possible, may have influenced the response. Some investigators have not found differences in response to noise in field and laboratory settings [84, 85], and results from previous studies in the same laboratory where we performed the WiTNES study have been comparable with results from field settings [39, 86]. However, it has also previously been found that there can be a stronger response to noise in laboratories than in the field [87], which means our findings could potentially overestimate the effects of WTN on sleep.

A limitation of the study is that due to the nature of the exposure, i.e. WTN that the participants would perceive, it was not possible to blind the participants to the experimental conditions. We cannot exclude that this may have influenced the outcomes, particularly for the self-reported measures.

Conclusions

A single night of WTN exposure shortened REM sleep. No effects of WTN on other measured physiologic outcomes could be detected, including autonomic activation, arousals, awakenings, salivary cortisol, SOL, sleep time, or deep sleep. Despite the low sound pressure level of 32 dB $L_{AEq,indoor,night}$, the findings show that continuous environmental noise with AM may impact sleep. Self-reported sleep data support these results, with WTN exposure leading to lower sleep quality and restoration in the morning, which was true for populations who both were and were not habitually exposed to WTN. Future work should include several exposure nights rather than a single night and further explore whether long-term exposure to these types of exposures may induce self-reported or objective habituation or sensitization.

Supplementary Material

Supplementary material is available at *SLEEP* online.

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Gurranreigh,
Lissarda,
Co. Cork.
P14WC58

30th October 2020

To whom it may concern,

In response to An Bord Pleanala's letter to Geraldine Hanley and I dated 13th October 2020 inviting submissions/observations to the appeal I wish to make the following submission:

I believe that the proposed development of 6 no. wind turbines should not be permitted as it will have a detrimental effect on residents living in the vicinity of the proposed development. I can say this for certain as we are living within 1 kilometre of an existing 4 turbine wind farm to the east of our property at Gurranreigh Lissarda, Co. Cork. This wind farm was erected in 2013 one year after we build our house. The reason we chose to build and live in Gurranreigh was because it was where I grew up but also because the area is very scenic and peaceful and we believed that it would be a perfect place to raise kids and enjoy the peace and beauty of the countryside.
We very much enjoyed the first year after we built our property but once he wind farm was commissioned and became operational in 2013 it became apparent what we would now have to endure living so close to a wind farm. The noise from the wind farm is almost constant and is unbearable at times. It varies from a light swishing noise to a thumping noise to a low droning noise which is particularly hard to endure. It is particularly difficult at night time when we can hear the noise inside the eastern side of our house and in some of the bedrooms. This regularly leads to sleepless nights for my wife and I and our 3 kids. It has also led to a massive change to how we enjoy our property, we used to spend a lot of time in the garden as we were both keen gardeners, now we no longer spend much time outdoors as the turbine noise is almost constant.
In an effort to tackle the issue we have made numerous complaints to Cork County Council regarding the noise, shadow flicker etc. that we have been enduring since 2013, the response of Cork County Council is to write to the wind farm operator asking them to demonstrate that they are in compliance with their planning condition relating to noise. The operator then confirms that they are in compliance and the County Council confirms to residents that there are no issues in relation to compliance instead of the County Council commissioning their own acoustic expect to monitor compliance. We believe that Cork County Council have a duty of care when it grants permission for these developments to ensure that they are not causing nuisance for adjoining residents, in reality this does not happen.

If the proposed development of 6 turbines receives approval then we will be living in the middle of 10 wind turbines, the existing 4 turbines to the east of our property and the proposed 6 to the west of our property. This is absolutely unacceptable as the cumulative effect of being surrounded by 10 wind turbines will be too much to bear. I would appeal to the An Bord Pleanala that this development should not be granted approval.

Regards,
Jerome Cohalan

To whom it may concern

My name is Geraldine Hanley and I live in Hornhill on our beautiful farm of 7 acres with my children, which we purchased 14 / 15 years ago, im a separated mom working ouside the home and running a small farm holding also, supplying the olde English Market with rose`veal.
We bought this dream property when there was no turbines, if we knew then what we know now, we would not have bought the place. We bought peace and quiet away from the city life which we spent 30 years living in, but all that changed when the turbines started turning.
Its been hell at times on our farm, the constant continuous humming is head wrecking, sometimes the swooshing gets so loud we have to come indoors.
So this year I made the unthinkable decision to sell up as I felt we couldn't continue living under these turbines.
It went on the market between lockdowns at 280,000 which was, so far off what we paid for it, 450,000 bought us our dream without turbines and with turbines 280,000.
There was great interest at first but unfortunately, people could see how close the turbines were. So 3 weeks ago I took it off the market.
I love my farm, my neighbours and my community, why should we be forced out of our dream home, is that not what everyone is looking for..... their dream home ??
In a pandemic when everyone wants to feel safe, I want my children to feel safe, and im going to continue to fight for our safe place which we call home.
My new fabulous neighbours with treble glazing can hear these turbines in their kitchen. I can hear them all over my house, even when im in the shower, I would like to invite the people making the decision on these wind farms to come and stay with us and listen to what we live with everyday.
I will finish on this note, life is hard enough please dont make it harder by permitting more noise and hardship in our lives.
Our homes are our castles.

Regards
Geraldine Hanley
Ashmore House
Hornhill
Lissarda
Co.Cork