

Independent Noise Working Group

Wind Turbine Amplitude Modulation and Planning Control Study

Work Package 3.2 – Excessive Amplitude Modulation, Wind Turbine Noise, Sleep and Health

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Abbreviations

AM ASD	Amplitude Modulation Autistic Spectrum Disorders
EAM	Excessive Amplitude Modulation
EEG	Electroencephalogram
ESS	Epworth Sleepiness Scale
ETSU	ETSU-R-97 The Assessment & Rating of Noise from Wind Farms
GHQ	General Heath Questionnaire
IoA	Institute of Acoustics
IWT	Industrial Wind Turbine
LFN	Low Frequency Noise
MPI	Mass Psychogenic Illness
NSR	Noise Sensitive Receptors, individuals living or working close to turbines
PSQI	Pittsburgh Sleep Quality Index
REM	Rapid Eye Movement
SD	Standard Deviation, a statistical measure of the spread of data
SF-36	The Short Form (36) Health Survey
SPL	Sound Pressure Level
SWS	Slow Wave Sleep
WHO	World Health Organisation

1 Executive summary

- Excessive noise is harmful to human health, particularly through adverse effects on sleep (WHO 2011¹). Regulation of wind turbine noise is recognised as necessary to prevent adverse effects on the human population.
- 1.2 UK guidance ETSU-R-97² ('ETSU') states in its executive summary "This document describes a framework for the measurement of wind farm noise and gives indicative noise levels **thought** (my emphasis) to offer a reasonable degree of protection to wind farm neighbours, without placing unreasonable restrictions on wind farm development or adding unduly to the costs and administrative burdens on wind farm developers or local authorities.". It is reasonable to infer that the authors had no certainty that their recommendations were adequate nor were they solely concerned with protecting the sleep and health of wind farm neighbours and therefore moderated their recommendations accordingly.
- 1.3 The acoustical shortcomings of ETSU have been discussed in detail elsewhere (Bowdler 2005³ and Cox, Unwin, Sherman 2012⁴). Despite the growing evidence of harm and the authors' caveats, no substantive review of the fundamental principles of ETSU has been conducted nor has any substantive research been conducted in the UK. The Hayes McKenzie Partnership conducted a small study on behalf of the DTI⁵ in 2006 as a result of which they recommended reductions in night time noise levels. These were removed from the final report, only emerging after the earlier drafts were obtained using Freedom of Information requests (DTI 2006, a, b, c⁵).
- 1.4 The methodology and indicative noise levels of ETSU have been adopted in many other jurisdictions.
- 1.5 A large body of evidence, presented below, demonstrates that human sleep and health are adversely affected at wind turbine noise levels permitted by ETSU. There is particular concern for the health of children exposed to excessive wind turbine noise. The inadequate consideration of excessive amplitude modulation (EAM) is a major factor in the failure of ETSU to protect the human population.

¹ WHO 2011 Burden of disease from Environmental Noise

² ETSU-R-97 1996 The Assessment & Rating of Noise from Wind Farms

³ Bowdler D 2005 ETSU: Why it is wrong New Acoustics

⁴ Cox R Unwin D Sherman T 2012 Wind turbine noise impact assessment, where ETSU is silent

⁵ DTI 2006 The Measurement of Low Frequency Noise at Three UK Wind Farms – W/45/00656/00/00 – Hayes McKenzie Partnership Plus draft reports 2006 a, b, c.

2 Objective and Scope

2.1 **Objective**

To summarize the effects of Excessive Amplitude Modulation (EAM) on people living close to wind turbines including annoyance, sleep disturbance and health effects through a review of the available health related literature.

Scope

- 2.2 This report discusses ETSU's ability to protect noise sensitive receptors ('receptors') from sleep disruption and therefore harm to their health and in this context to consider the contribution of EAM. Sections 3 and 4 discuss necessary preliminary matters relating to noise levels and setback distances and the characteristics of wind turbine noise. Section 5 describes the evidence of the inadequacy of ETSU.
- 2.3 Appendix A is included to explain the effects of noise on sleep. Appendix B lists the author's qualifications. Appendix C includes the figures and tables referred to by Sections 3, 4 and 5 and Appendix D the bibliography

2.4 Source material

Publications cited and other source material are noted at the foot of each page and the complete list, including website links where appropriate, is attached as Appendix D. Where several articles come to the same conclusion, only the most recent may be cited, in the interests of brevity. As far as possible, articles published in peer-reviewed journals are cited. However, it is inevitable that some of the material is available only on the internet reflecting the paucity of government sponsored research. Reviews are generally only cited if they have been published recently and are comprehensive reviews of the literature.

2.5 Work Package 3.1 details a survey of local planning authorities which demonstrates convincingly that EAM and complaints are a common feature of UK wind farms yet most research of the effects of wind turbine noise is from outside the United Kingdom.

3 Noise levels and setback distance

- 3.1 The predicted wind turbine noise experienced by receptors is generally calculated from manufacturer's predictions as to turbine noise at varying wind speeds using standard formulae for the attenuation of sound with distance, allowing for wind direction, ground conditions etc. As an approximation, it is assumed that noise levels will decrease by 6dBA for a doubling of distance. Allowance is made for additional turbines to derive a predicted noise level. Comparison is then made to background noise levels with the assumption that the turbine noise is masked by background noise. As is shown below, neither assumption is justified. Contrary to logic and common sense, ETSU permits a higher external noise level of 43dBA at night even though background noise levels are generally lower at this time.
- 3.2 After the application of the ETSU methodology, setback distances for human habitation from modern 2.5-3MW turbines in the UK are typically in the region of 500-600m.
- 3.3 An Institute of Acoustics (IoA) working group (Bowdler et al 2009⁶) issued advice on allowing for wind shear where wind speeds at hub height are greater than those at ground level. In theory, this should have led to greater setbacks as receptor predicted noise levels would have been greater, especially during the night. In practice, setbacks have remained unchanged or decreased. Stigwood 2011⁷ has investigated the method and concluded "... in all cases analysed there was a loss of community protection when adopting the article (IoA) method."
- 3.4 Most published research has used setback distance rather than measured or calculated noise levels, not least because of the expense of measurement and the inaccuracies of calculation. ETSU mandates setbacks of around 600m. Therefore any study which shows harm at distances of 1000m or greater is unequivocal evidence that ETSU does not provide adequate protection for wind farm neighbours.

⁶ Bowdler D et al 2009 Prediction and assessment of wind turbine noise Acoustics Bulletin March/April:35

⁷ Stigwood M 2011 The effect of common wind shear adjustment methodology on the assessment of wind farms when applying ETSU. MAS Environmental 27th September 2011.

4 Characteristics of wind turbine noise

- 4.1 Wind turbine noise is not comparable to that from other common environmental sources such as traffic, rail and aircraft. Several studies have shown it be more annoying than these sources for comparable A weighted noise levels (van den Berg et al 2008⁸ Fig 1, Pedersen and Persson Waye 2004⁹ Fig 2). "Annoying" in this context is used in the psychological sense of causing a degree of stress sufficient to cause concern for health, not simply an irritation (WHO 2009¹⁰) (Appendix A 1.29, 1.30 and 1.31). In addition, wind turbine noise is not well masked by ambient noise, being audible 10-15dB below background noise (Nelson 2007¹¹, Hayes 2007¹², Bolin 2009¹³, Pedersen et al 2010¹⁴).
- 4.2 Two characteristics of wind turbine noise have been advanced to explain these differences, modulation and low frequency noise (LFN) (James 2012¹⁵, Thorne 2012¹⁶, Large and Stigwood 2014¹⁷).
- 4.3 Wind turbine noise emissions are amplitude modulated (AM) as the turbine blades pass the tower and pass through areas of differing wind speeds. The effect may be increased if there is interaction between the emissions from nearby turbines. The result is an impulsive noise character often described as "thumping" or "rumbling" (Lenchine & Song 2014¹⁸). The degree of AM varies with a number of factors including wind speed and direction and blade configuration. Especially prominent modulation is deemed to be excessive amplitude modulation (EAM). ETSU makes some allowance for AM (3dB peak to trough) in the near field but makes no allowance for far field modulation nor for lower frequency noise content.
- 4.4 There is a large body of evidence to show that AM is more annoying than un-modulated noise (See WP2.2 for detailed consideration). Of particular note is a laboratory based study by Lee et al 2011¹⁹. 30 subjects were exposed to recorded wind turbine noise at varying volumes and degrees of AM. They concluded that "....the equivalent sound level and the amplitude modulation of wind turbine noise both significantly contribute to noise annoyance." Pohl et al 2014²⁰ asked residents near the Wilstedt windfarm in Germany to record annoying sounds. They concluded that perceived annoyance correlated with the presence of AM.

⁸ van den Berg GP et al 2008 WINDFARM Perception. Visual and acoustic impact of wind turbine farms on residents. FP6-2005-Science-and-Society-20. Specific Support Action Project no 044628

⁹ Pedersen E and Persson Waye K 2004 Perception and annoyance due to wind turbine noise - a dose-response relationship J Acoust Soc Am 116 3460–347

¹⁰ World Health Organisation 2009 Night noise guidelines for Europe, Copenhagen

¹¹Nelson D 2007 Perceived loudness of wind turbine noise in the presence of ambient sound. Second International Meeting on Wind Turbine Noise. Lyon, France

¹² Hayes M 2007 Affidavit in reply Makara Wind Farm New Zealand Environmental Court W59/2007

¹³ Bolin K 2009 Wind Turbine Noise and Natural Sounds-Masking, Propagation and Modeling Doctoral Thesis Royal Institute of Technology, Stockholm

¹⁴ Pedersen E, van den Berg F, Bakker R, Bouma J 2010 Can road traffic mask sound from wind turbines? Response to wind turbine sound at different levels of road traffic sound *Energy Policy* 38:2520-7

¹⁵ James R 2012 Wind Turbine Infra and Low-Frequency Sound: Warning Signs That Were Not Heard Bulletin of Science, Technology & Society 32 108–127

¹⁶ Thorne R 2012 Submission to the Senate Environment and Communications Legislation Committee

¹⁷ Large S and Stigwood M 2014 The noise characteristics of "compliant" wind farms that adversely affect its neighbours Presented to inter.noise 2014, Melbourne, Australia

¹⁸ Lenchine V and Song J 2014 Special noise character in noise from wind farms Presented to inter.noise 2014, Melbourne, Australia

¹⁹ Lee S et al 2011 Annoyance caused by amplitude modulation of wind turbine noise Noise Control Eng J 59:38-46

²⁰ Pohl J et al 2014 Untersuchung der Beeinträchtigung von Anwohnern durch Geräuschemissionen von Windenergieanlagen und Ableitung übertragbarer Interventionsstrategien zur Verminderung dieser. Deutsche Bundesstiftung Umwelt

- 4.5 Noise character is an important factor in determining whether a subject arouses or awakens from sleep, impulsive noises being more likely to cause an arousal (Solet 2010²¹). An arousal is a brief lightening of sleep. Both arousals and awakenings fragment sleep, impairing its restorative properties. Impulsive sounds are chosen for fire alarms as being more likely to awaken sleepers (Bruck 2009²²). Such studies provide support for the assertion that EAM is an important factor in the effects of wind turbine noise on sleep.
- 4.6 Wind turbine noise contains a large element of LFN, the contribution increasing with turbine size (Moller and Pedersen 2011²³). The adverse effects of LFN on health have been recognised for decades, although they have been generally overlooked until recent years (Enbom 2013²⁴). A WHO report in 1999²⁵ stated *"It should be noted that a large proportion"* of low-frequency component in a noise may increase considerably the adverse effects on health." Kelley (1985²⁶, 1987²⁷) reported adverse health effects from wind turbines over 25 years ago and identified LFN as the likely cause. James (2012¹⁵⁾ has documented the failure of the wind industry to acknowledge the early research. Pedersen (2004⁹) reviewed the available evidence in 2004 and concluded "... low frequency noise, at comparatively low sound pressure levels, disturbs sleep." Schomer, an American acoustician and one of the cooperators in the survey of LFN (Clean Wisconsin 2012²⁸), subsequently stated in a letter to the Public Service Commission of Wisconsin (2013²⁹) "....this case as well as the literature and case studies all over the world have suggested that people are leaving their homes because they are being exposed to significant levels of pulsating ultra-low frequency sound produced by wind turbines. In addition there is no question that larger turbines produce more infrasound below 1 hertz which increases the likelihood that health problems will occur unless noise limits are dramatically reduced through the use of smaller turbines or lower noise limits are required at each house." Schomer (2015³⁰) has recently proposed that the biological effects of LFN from turbines are related to susceptibility to motion sickness (Schomer 2015)
- 4.7 ETSU makes no allowance for LFN despite the increase in turbine size since its formulation.

²⁵ World Health Organization 1999 Guidelines for community noise

²¹ Solet JM et al 2010 Evidence-based design meets evidence-based medicine: The sound sleep study Concord CA: The Center for Health Design

²² Bruck D et al 2009 How does the pitch and pattern of a signal affect auditory arousal? Journal of Sleep Research 18:196-203

²³ Moller H and Pedersen CS 2011 Low frequency noise from large wind turbines J Acoust Soc Am 129: 3727-3744

²⁴ Enbom H and Enbom I 2013 Infrasound from wind turbines: an overlooked health hazard *Läkartidningen* 110:1388

²⁶ Kelley ND et al 1985 Acoustic noise associated with the MOD-1 wind turbine: its source, impact and control Solar Energy Research Institute Report SERI/TR-635-1166

²⁷ Kelley ND 1987 A proposed metric for assessing the potential of community annoyance from wind turbine low-frequency noise emissions Solar Energy Research Institute Report SERI/T9-217-3261

²⁸ Clean Wisconsin 2012 Report Number 122412-1 A Cooperative Measurement Survey & Analysis of Low Frequency & Infrasound at the Shirley Wind Farm in Brown County, Wisconsin.

²⁹ Schomer P 2013 Letter to Zuelsdorff Environmental Analysis and Review Coordinator, Public Service Commission of Wisconsin

³⁰ Schomer P et al 2015 A theory to explain some physiological effects of the infrasonic emissions at some wind farm sites J Acoust Soc Am 137:1356

5 Wind turbine noise, sleep and health

5.1 Introduction

Several types of evidence lead to the conclusion that ETSU does not provide sufficient protection for receptors:

- 1 Epidemiological studies and anecdotal reports of harm following exposure to wind turbine noise;
- 2 Opinions from other experts as to appropriate setback distances and noise limits;
- 3 Studies of health related effects such as annoyance. Some of these studies have commented on the effects of sleep but have not used appropriate outcome measures;
- 4 Studies of health effects and sleep disturbance.

5.2 Epidemiological and anecdotal studies

There are a large number of anecdotal reports and surveys. In the interests of brevity, they will not be detailed here but are described in an online review (Hanning 2010³¹). One survey is particularly worthy of mention, WindVOiCe (Krogh 2011³²), as the results have been published in a peer-reviewed journal. WindVOiCe is a self-reporting survey of Canadian communities affected by wind turbine noise. As of July 2010, 144 responses had been received of which 118 reported one or more health effects of which 84 (58%) reported sleep disturbance. There were no age differences between those that reported sleep disturbance (mean (range)) (51.5 yr (19-79)) and those that did not (52.2 yr (26-86)). All bar five of those reporting sleep disturbance live within 1500m of turbines adding further support to a minimum setback of at least that distance.

5.3 Anecdotal reports are commonly dismissed in industry sponsored reviews (eg Colby et al 2009³³) as not acceptable evidence. Phillips, an epidemiologist, in a peer-reviewed article (Phillips 2011³⁴), has examined these claims, reviewed the evidence and concluded:

"There is overwhelming evidence that wind turbines cause serious health problems in nearby residents, usually stress-disorder type diseases, at a nontrivial rate. The bulk of the evidence takes the form of thousands of adverse event reports. There is also a small amount of systematically-gathered data. The adverse event reports provide compelling evidence of the seriousness of the problems and of causation in this case because of their volume, the ease of observing exposure and outcome incidence, and case-crossover data. Proponents of turbines have sought to deny these problems by making a collection of contradictory claims including that the evidence does not "count", the outcomes are not "real" diseases, the outcomes are the victims' own fault, and that acoustical models cannot explain why there are health problems so the problems must not exist. These claims appeared to have swayed many non-expert observers, though they are easily debunked."

³¹Hanning C 2010 Wind turbine noise, sleep and health

³² Krogh C et al 2011 WindVOiCe, a Self-Reporting Survey: Adverse Health Effects, Industrial Wind Turbines, and the Need for Vigilance Monitoring *Bull Sci Tech Soc* 31: 334

³³ Colby et al 2009 Wind Turbine Sound and Health Effects; an Expert Panel Review American and Canadian Wind Energy Associations

³⁴ Phillips C 2011 Properly interpreting the epidemiologic evidence about the health effects of industrial wind turbines on nearby residents *Bull Sci Tech Soc* 31:303-8

5.4 The weight of epidemiological evidence is that wind turbine noise adversely effects health at distances of at least 1.5km.

5.5 Expert opinion

The opinions on setback distances for 19 groups of scientists, legislators and acousticians are shown in Table I, Appendix C (Hanning 2010³¹). The mean (range) setback distance recommended is 2.08km (1-3.2). Other recommendations are given in the text.

- 5.6 Thorne, an Australian acoustician who has investigated wind turbine noise and its health effects, concludes, in a peer-reviewed article "A sound level of LAeq 32 dB outside a residence and above an individual's threshold of hearing inside the home are identified as markers for serious adverse health effects affecting susceptible individuals." (Thorne 2011³⁵). Thorne 2014³⁶ also has recommended a 2km setback as a result of health studies on three Australian windfarms.
- 5.7 Schomer (one of the co-operators in Clean Wisconsin 2012²⁸) recommended "....a criterion level of 33.5 dBA".
- 5.8 Arra et al 2014³⁷ conducted a systematic review of the literature and noted that "All peerreviewed studies captured in our review found an association between wind turbines and human distress." They concluded "....we have demonstrated the presence of reasonable evidence (Level Four and Five) that an association exists between wind turbines and distress in humans. The existence of a dose-response relationship (between distance from wind turbines and distress) and the consistency of association between studies found in the scientific literature argues for the credibility of this association."
- 5.9 A recent exhaustive review (Schmidt and Klokker 2014³⁸) concluded "Exposure to wind turbines does seem to increase the risk of annoyance and self-reported sleep disturbance in a dose-response relationship. There appears, though, to be a tolerable level of around L_{Aeq} of 35dB". This is about 6dB less than the permitted ETSU night time level, implying a doubling of the setback (assuming a decay of noise level of 6dB per doubling of distance).
- 5.10 Jefferey and et al 2014³⁹ reviewed the literature, with special reference to LFN, and concluded *"we expect that, at typical setback distances and sound pressure levels of IWTs in Ontario, a nontrivial percentage of exposed people will be adversely affected."*
- 5.11 The weight of independent expert opinion is that wind turbine noise adversely effects health at distances of at least 1.5km.

³⁵ Thorne R 2011 The Problems With "Noise Numbers" for Wind Farm Noise Assessment *Bulletin of Science Technology Society* 31:262-290

³⁶ Thorne R 2014 The Perception and Effect of Wind Farm Noise At Two Victorian Wind Farms An Objective Assessment June 2012. Reissued June 2014

³⁷ Arra I et al 2014 Systematic review 2013: Association between wind turbines and human distress Cureus 6:e183

³⁸Schmidt JH and Klokker M 2014 Health effects related to wind turbine noise exposure: a systematic review *PLoS ONE* 9:e114183.

³⁹ Jefferey RD et al 2014 Industrial wind turbines and adverse health effects. *Can J Rural Med* 19:21-26

5.12 Studies of health related effects

Phipps et al 2007⁴⁰ surveyed 1100 New Zealand households sited up to 3.5 km from a wind farm of which 604 responded. Seventy-five percent (75%) of all respondents reported being able to hear the noise. Two separate developments have placed over 100 turbines with capacities from 600kW to 1.65MW in a hilly to mountainous area. It has been suggested that mountainous areas may allow low frequency noise to travel further which may explain the long distance over which the turbines were heard.

- 5.13 Phipps 2007a⁴¹ reported a further analysis of this data. All subjects lived more than 2km from the turbines but 85% lived within 3.5km. Thirteen percent (13%) of 284 respondents heard the turbines at night either frequently or most of the time. Forty two households reported occasional sleep disturbance from turbine noise and 26 were disturbed either frequently or most of the time. Phipps concludes that the New Zealand Standard for Wind Turbine Noise should be modified so that *"the sound level from the wind farm should not exceed, at any residential site, and at any of the nominated wind speeds, the background sound level (L₉₅) by more than 5 dBA, or a level of 30 dBA L₉₅, whichever is less."*
- 5.14 Van den Berg 2004⁴² found that receptors up to 1900m from a wind farm expressed annoyance with the noise, a finding replicated in his more recent study, Van den Berg et al 2008⁸. Dr Amanda Harry 2007⁴³, a UK GP, conducted surveys of a number of receptors living near several different turbine sites and reported a similar constellation of symptoms from all sites. A study of 42 respondents showed that 81% felt their health had been affected, in 76% it was sufficiently severe to consult a doctor and 73% felt their life quality had been adversely impacted. This study is open to criticism for its design, which invited symptom reporting and was not controlled. While the proportion of those affected may be questioned it nevertheless indicates strongly that some receptors are severely affected by wind turbine noise at distances thought by governments and the industry to be safe.
- 5.15 Van den Berg et al 2008⁸ from the University of Groningen in the Netherlands, have published a major questionnaire study of residents living within 2.5km of wind turbines called Project WINDFARMperception. A random selection of 1948 residents were sent a similar questionnaire to that used by Pedersen in her studies in Sweden (2003⁴⁴, 2004⁹, 2007⁴⁵ and 2008⁴⁶) with added health questions (compliant with the validated General Heath Questionnaire method). Seven hundred and twenty-five (37%) residents replied which is good for a survey of this type but, nevertheless, this response rate may be seen to be a weakness. Non-respondents were asked to complete a shortened questionnaire. Their responses did not differ from full respondents suggesting the latter are representative of the population as a whole.

- ⁴² van den Berg GP 2004 Effects of the wind profile at night on wind turbine sound. *Journal of Sound and Vibration* 277:955-970
- ⁴³ Harry A 2007 Wind turbines, noise and health

⁴⁰ Phipps R et al 2007 Visual and noise effects reported by residents living close to Manawatu wind farms: preliminary survey results Evidence to the *Joint Commissioners, 8th-26th March 2007, Palmerston North*

⁴¹ Phipps R 2007a Evidence of Dr Robyn Phipps, In the Matter of Moturimu Wind Farm Application heard before the Joint Commissioners 8th – 26th March 2007 Palmerston North

⁴⁴ Pedersen E and Persson Waye K 2003 "Perception and annoyance of wind turbine noise in a flat landscape", Proceedings of Inter.noise 2002, Dearborn

⁴⁵ Pedersen E and Persson Waye K 2007 Wind turbine noise, annoyance and self-reported health and well-being in different living environments *Occup Environ Med* 64;480–6

⁴⁶ Pedersen E and Persson Waye K 2008 Wind turbines – low level noise sources interfering with restoration? *Environmental Research Letters* 3:015002

- 5.16 Relevant conclusions include "Sound was the most annoying aspect of wind turbines" and was more of an annoyance at night. Interrupted sleep and difficulty in returning to sleep increased with calculated noise level as did annoyance, both indoors and outdoors. Even at the lowest noise levels, 20% of respondents reported disturbed sleep at least one night per month. At a calculated noise level of 30-35dB LAeq, 10% were rather or very annoyed at wind turbine sound, 20% at 35-40dB LAeq and 25% at 40-43dB LAeq, equivalent to 38-41dB LA₉₀.
- 5.17 Project WINDFARMperception further found that "Three out of four participants declare that swishing or lashing is a correct description of the sound from wind turbines. Perhaps the character of the sound is the cause of the relatively high degree of annoyance. Another possible cause is that the sound of modern wind turbines on average does not decrease at night, but rather becomes louder, whereas most other sources are less noisy at night. At the highest sound levels in this study (45 decibel or higher) there is also a higher prevalence of sleep disturbance." It should be noted that only recalled sleep disturbance was studied.
- 5.18 Van den Berg⁸ concluded also that road noise does not adequately mask turbine noise and reduce annoyance and disturbance. In addition, the authors compared their results with studies by Miedema⁴⁷ on the annoyance from road, rail and air related noise. Wind turbine noise was several times more annoying than the other noise sources for equivalent noise levels (Fig 1). Similar data is given by Pedersen 2004⁹ (Fig 2).
- 5.19 Pedersen, van den Berg and others (Pedersen 2009a⁴⁸&b⁴⁹) have further analysed the data in an attempt to model a generalised dose-response relationship for wind turbine noise. A noise metric, Lden, was calculated. Lden is based on long-term equivalent sound pressure levels adjusted for day (d), evening (e) and night. Penalties of 5 and 10dB are added for evening and night hours respectively to reflect the need for quietness at those times. DB(A) LAeq values for wind turbines may be transformed to Lden values by adding 4.7±1.5 dB (van den Berg⁸). Annoyance is used as the principal human response to wind turbine noise in this analysis. In this context, "annoyance" is more than simply irritation but is a measure of lack of well-being in a wider sense (Pedersen 2009a⁴⁸) and is contrary to the WHO definition of health⁵⁰.
- 5.20 Annoyance increased with increasing sound levels, both indoors and outdoors. The proportion who were rather and very annoyed at different sound levels are shown in Table II, Appendix C. In summary, when outside, 18% were rather or very annoyed at sound levels of 35-40 and 40-45 dB LAeq compared to 7% at 30-35dB LAeq and 2% at <30dB LAeq. When inside, the equivalent figures were 1% at <30dB LAeq, 4% at 30-35dB LAeq, 8% at 35-40dB LAeq and 18% at 40-45dB LAeq. Those respondents who had an economic interest in the turbines had lower levels of annoyance while negative views of the visual impact of turbines increased the likelihood of annoyance.

⁴⁷ Miedema HME and Oudshoorn CGM 2001 Annoyance from Transportation Noise: Relationships with Exposure Metrics DNL and DENL and Their Confidence Interval Environmental Health Perspectives Vol. 109, No. 4, pp. 409-416, 2001

⁴⁸ Pedersen E 2009a Effects of wind turbine noise on humans. Third International Meeting on Wind Turbine Noise, Aalborg 17-19 June 2009

⁴⁹ Pedersen E et al 2009b Response to noise from modern wind farms in The Netherlands J Acoust Soc Am 126:634-643

⁵⁰ WHO 1946 Preamble to the Constitution of the World Health Organization as adopted by the International Health Conference, New York, 19-22 June, 1946; signed on 22 July 1946 by the representatives of 61 States (Official Records of the World Health Organization, no. 2, p. 100) and entered into force on 7 April 1948

- 5.21 Although the authors do not seek to recommend minimum sound levels, they note that turbine noise was more annoying than other sources, with the possible exception of railway shunting yards and was more noticeable at night. They conclude that "...night time conditions should be treated as crucial in recommendations for wind turbine noise limits." Nevertheless, it is clear from this analysis that external predicted turbine sound levels should be less than 35dB LAeq (33dB LA₉₀) in order to reduce effects on nearby receptors to acceptable levels.
- 5.22 Pedersen (2009a⁴⁸&b⁴⁹) has recently combined the datasets from three studies (Pedersen 2004⁹ SWE00 and 2007⁴⁵ SWE05, and van den Berg⁸ NL07)) as they used similar questionnaires giving a total of 1764 subjects. A strong correlation was seen in all studies between calculated A weighted sound pressure levels and outdoor annoyance as noted above.
- 5.23 Even at sound pressures of 30-35 dB LAeq, 5-12% of subjects were very annoyed. Correlations were found also between annoyance and symptoms of stress (headache, tiredness, tension and irritability) confirming that "annoyance" is more than irritation and is a marker of impaired health. The sleep disturbance question did not ask causation of the sleep disturbance and a background level would therefore be expected from other causes (traffic noise, weather, etc). Nevertheless, there was a clear increase in levels of sleep disturbance with A-weighted sound pressure in studies SWE00 and NL005. (Fig 3, Appendix C). Pedersen states "In the first Swedish study (SWE00) the increase of respondents that reported sleep interruption appears to be between the sound level interval 35-40 dB(A) and 40-45 dB(A). The increase came at higher sound levels in the Dutch study (NL07); between the interval 40-45 dB(A) and >45 dB(A)". All values are LAeq. There is no true measurement of background levels of sleep disturbance as no study had a control group, it is difficult therefore to determine at what sound pressure level turbine noise begins to have an effect.
- 5.24 In one of the earliest studies of the health effects of wind turbine noise, Iser 2004⁵¹ sent a questionnaire to 25 residents living between 1 and 1.5km from the Toora Wind Farm in South Australia. Of the 19 respondents, 11 reported no problems, 5 reported mild problems including sleep disturbance and 3 major health problems including sleep disturbance, stress and dizziness requiring medical intervention.
- 5.25 Morris 2012⁵² presented a survey of the Waterloo Wind Farm in South Australia to the Parliamentary Select Committee on Wind Power. An anonymous, self-reporting survey was sent to all 230 residences within 10km of the turbines. Ninety-three (40%) were returned, 40% reported night-time disturbance and 27 (29%) reported sleep disturbance (Fig 4, Appendix C)
- 5.26 This is not a strong study in that it has not been peer-reviewed, has no control group and the survey instrument asked generalised questions to avoid leading respondents. Nevertheless, it had a good response rate for this type of study and its findings are in accord with other similar studies. It represents strong supporting evidence.

⁵¹ Iser D 2004 Health effects questionnaire

⁵² Morris M 2012 Waterloo Wind Farm Survey

- 5.27 Schneider 2012⁵³ conducted a similar study of the Cullerin Range Wind Farm in New South Wales, Australia. Responses were obtained from 73% of residences within 5km of the turbines of which 78.5% reported sleep disturbance from the development (Fig 5, Appendix C). A follow-up study was conducted in 2013 (Schneider 2013⁵⁴) to answer allegations by Chapman 2013⁵⁵ in his "nocebo" studies that residents had not complained at Cullerin. A similar response rate was achieved with 91% of respondents living within 8km reporting an impact on their sleep. All had complained to a variety of authorities.
- 5.28 This is also not a strong study in that it has not been peer-reviewed, has no control group and the survey instrument asked generalised questions. Nevertheless, it had a good response rate and its findings in both studies are in accord with each other and with other similar studies. It represents strong supporting evidence.
- 5.29 Mroczek et al 2012⁵⁶ reported a survey of 1277 adults living near wind farms in Poland of whom 424 (33.2%) lived >1.5km, 221 (17.3%) 1-1.5km. 279 (21.9%) 700-1000m and 220 (17.2%) <700m from a turbine. The Polish version of the Short Form (36) Health Survey ('SF-36') was administered with a Visual Analogue Scale for Health Assessment.
- 5.30 Taking all subjects together, they concluded that "Close proximity of wind farms does not result in the worsening of the quality of life" and "Within all scales, the quality of life was assessed highest by residents in areas located closest to wind farms, and the lowest by those living more than 1,500m from wind farms." These conclusions are at odds with all other studies reported here. The authors offered no mechanism for the apparent benefit of living close to a wind farm. In a personal communication (Mroczek 2013⁵⁷), the lead author, stated that not all of the wind farms were operational at the time of the survey, some were under construction or in the planning stage. It would appear also that no allowance was made for any financial interest in the turbines which would be more likely for those living close to the turbines.
- 5.31 This analysis is therefore meaningless as it includes subjects not exposed to turbine noise at all and those living over 1.5km from the turbines. Taking into account also the failure to allow for any financial interest in the turbines, the conclusions cannot be regarded as reliable.
- 5.32 McBride et al 2014⁵⁸ administered the WHO Health Related Quality of Life⁵⁹ test instrument to 25 persons living 700-3500m (average 1400m) from wind turbines. The study group had lower scores in all domains when compared to community and hospital inpatients and outpatient groups indicating a significant reduction in quality of life. They conclude ".., the fact that so many individuals scored so poorly must be a cause for concern."

⁵³ Schneider P 2012 Cullerin Range Wind Farm Survey

⁵⁴ Schneider P 2013 Cullerin Range Wind Farm Survey – Follow-up survey. July-August 2013

⁵⁵ Chapman S et al 2013 The pattern of complaints about Australian wind farms does not match the establishment and distribution of turbines: Support for the psychogenic, 'communicated disease' hypothesis *PLoS One*;8:e76584

⁵⁶ Mroczek B, Kurpas D, Karakiewicz B Influence of distances between places of residence and wind farms on the quality of life in nearby areas *Ann Agric Environ Med*. 2012; 19(4): 692-696

⁵⁷ Mroczek B 2013 Personal Communication 2nd February 2013

⁵⁸ McBride D et al 2014 Investigating the impacts of wind turbine noise on quality of life in the Australian context: A case study approach Presented to inter.noise 2014, Melbourne, Australia

⁵⁹ WHO 1991 Quality of Life-BREF (WHOQOL-BREF)

- 5.33 Magari et al 2014⁶⁰ administered a survey questionnaire to a small sample of residents living in and around a wind farm an average of 586m (range 315m 1205m) from the nearest turbines. Twenty-six percent (26%) reported sleep disturbance from the wind turbines. 8.9% had made noise complaints even though all residents were receiving a substantial property tax reduction and other financial benefits. The authors were clearly surprised at the level of sleep disturbance as they concluded *"Additional research should include a detailed investigation of sleep patterns and possible disturbance in those living in and near operating wind turbine projects."*
- 5.34 The Cape Bridgewater Wind Farm in Victoria, Australia has been subject to a recent, detailed acoustic testing program in response to receptors' ongoing complaints of six years of sleep disturbance and other adverse health effects (Cooper 2014⁶¹). The study is unique in that it was undertaken by an independent group of acousticians and commissioned by the developer, Pacific Hydro. The latter co-operated fully in the study, including: allowing full access to the wind turbines; enabling background noise measurements to be taken when the turbines were switched off for other reasons; and publishing the report in full. Pacific Hydro are to be commended for their actions.
- 5.35 The survey was based on the six occupants of three houses sited between 650 and 1600m from the nearest turbines. The full spectrum of acoustic frequencies and vibration inside and outside homes were measured for 8 weeks. Cooper analysed the complaints of receptors and noted that, in addition to sleep disturbance, they referred to "sensations" including headache, head, ear or chest pressure, tinnitus and heart racing. Cooper asked the residents to grade their sensations on a 0-5 scale. During the study period, residents were blinded to the acoustic measurements, and contemporaneously recorded detailed diaries of their individual perceptions of noise, vibration, and "sensations". A dose response relationship is suggested by the trend line from the data relating to the occurrence of severe sensations (level 5) at the same time as elevated levels of infrasound, when compared with lesser severity sensations (level 2) and lower sound pressure levels (SPL) of infrasound but Cooper concluded more data is required in order to properly establish correlation. These results are consistent with the Kelley research from thirty years earlier (Kelley 1985²⁶ and 1987²⁷).
- 5.36 Receptors also documented sleep disturbance when it occurred but no formal assessment of sleep was undertaken. The report states that *"All of the residents indicated that over time their sensitivity to "noise" from the wind farm has increased and that there is regular occurrence of sleep disturbance to the point that their health has been affected (to varying degrees)"*. One home has been abandoned.
- 5.37 The report concludes that " with respect to sleep disturbance where ambient noise levels at night inside dwellings are typically below 15dB(A), then the concept of a 30dB(A) Leq threshold level identified in the New Zealand Standard would appear to be an inappropriate threshold for the assessment of internal noise levels associated with wind farms."

⁶⁰ Magari S et al 2014 Evaluation of community response to wind turbine-related noise in Western New York State Noise & *Health* 16-17:228-239

⁶¹ Cooper S 2014 The results of an acoustic testing program: Cape Bridgewater Wind Farm The Acoustic Group

- 5.38 The Australian and New Zealand Standards permit similar noise levels to ETSU, and indeed were based on it (Turnbull 2013⁶²). It can be concluded that ETSU will not provide adequate protection against sleep disturbance.
- 5.39 The weight of evidence of the health related consequences are that wind turbine noise adversely effects health at distances of at least 1.5km and thus that noise levels permitted by ETSU are inadequate to protect human health.

5.40 Sleep disturbance and health effects

Even though they used an insensitive measure of sleep disturbance, the Pedersen and van den Berg studies cited above, showed that a significant proportion of receptors are affected at noise levels less than those permitted by ETSU. The studies by Shepherd⁶⁴ and Nissenbaum et al⁶³ show convincingly that wind turbine noise levels permitted under ETSU guidance have a serious adverse effect on sleep and health.

- 5.41 Daniel Shepherd 2011⁶⁴ a psychoacoustician from the University of Auckland, New Zealand, has published, in a peer-reviewed journal, a case-control study of the health status of residents living within 2km of the Makara windfarm. Health related quality of life (HRQoL) was measured using the WHO QOL-BREF which has four subscales, physical including sleep, psychological, social and environmental. The questionnaire was disguised as a general health survey by adding questions on neighbourhood problems, amenity and noise and air pollution annoyance as distractors.
- 5.42 Thirty nine (34%) of those living within 2km of the Makara turbines responded and were compared with 158 subjects from a socio-economic matched group who lived at least 8km from a turbine. Examination of a map of the area (Shepherd 2011 page 335⁶⁴) shows that the residences are between 800m and 2km from the turbines, the mean being about 1.4km. While noise levels were not measured simultaneously with the study, earlier measurements showed outdoor noise levels of between 20 and 50dBA L_{95(10min)} depending on meteorological conditions.
- 5.43 The turbine group had significantly lower (P = 0.017) mean physical HRQoL domain scores than the comparison group. This was due to a difference in perceived sleep quality between the two areas (P = 0.006) and between self-reported energy levels (P = 0.028). The turbine group had significantly lower (P = 0.018) environmental QoL scores than the comparison group. The turbine group considered their environment to be less healthy (P < 0.007) and were less satisfied with the conditions of their living space (P = 0.031). Mean ratings for an overall quality of life item were significantly lower (P = 0.019) in the turbine group.
- 5.44 There were no differences between groups for traffic or neighbourhood annoyance. A comparison between ratings of turbine noise was not possible, but the mean annoyance rating for turbine group individuals who specifically identified wind turbine noise as

⁶² Turnbull C and Turner J 2013 Recent developments in wind farm noise in Australia Presented at the 5th International Conference on Wind Turbine Noise Denver 28-30 August 2013

⁶³ Nissenbaum M, Aramini J, Hanning C 2012 Effects of Industrial Wind Turbine Noise on Sleep and Health *Noise and Health* 14;237-43

⁶⁴ Shepherd D, McBride D, Welch D, Dirks K, Hill E 2011 Evaluating the impact of wind turbine noise on health related quality of life *Noise Health* 13:333-9

annoying (n=23) was 4.59 (Standard deviation SD = 0.65), indicating that the turbine noise was perceived as extremely annoying.

- 5.45 This carefully conducted, controlled peer-reviewed study clearly demonstrates that living within 2km of wind turbines is harmful to health. To quote the authors "Demonstrably, our data have also captured the effects of wind turbine noise on sleep, reinforcing previous studies suggesting that the acoustic characteristics of turbine noise are well suited to disturb the sleep of exposed individuals." and "....we conclude that night-time wind turbine noise limits should be set conservatively to minimise harm and, on the basis of our data, suggest that setback distances need to be greater than 2km in hilly terrain."
- 5.46 Botha 2011⁶⁵ reports on sound monitoring carried out at the Makara wind farm. He notes that noise complaints were received immediately after the site became operational in 2009. The operators adjusted the turbines to reduce the tonal character of the noise shortly thereafter. Botha states that the sound levels recorded were within those permitted by the then current New Zealand standard which is largely based on ETSU. It is important to note that Shepherd's study⁶⁴ was conducted **after** the adjustments to the turbines that were intended to eliminate noise complaints and that the sleep and health impairments occurred at levels permitted by NZ standards.
- 5.47 Nissenbaum 2010⁶⁶ has presented the preliminary results of a study of residents living downwind and within 300-1100m (mean 800m) of a wind farm at Mars Hill, Maine, USA where the 28 1.5MW turbines are sited on a 200m high ridge overlooking the homes. Twenty-two of about 35 adult residents were interviewed and compared with a randomly selected control group living a mean 6km away. Of these, 18 reported new or worsened sleep onset disturbance at least twice a week, and for 9 at least 5 times per week (controls 1/28). Eight of 22 reported new or worsened headaches (controls 1/28) and 18/22 reported new or worsened mental health symptoms (stress 12/22, anger 18/22, anxiety 8/22, hopelessness 12/22, depression 10/22) (controls 0/28).
- 5.48 The 22 subjects received 15 new or increased prescriptions from their physicians in the 18 months between the start of turbine operation and the study, the majority for psychoactive medication (controls 4 prescriptions, none for psychoactive medication). Twenty-one of 22 reported reduced quality of life and 20/22 considered moving away (controls 0/28 for both).
- 5.49 As a result of the complaints, noise monitoring during turbine operation was undertaken at the community test sites at which background noise monitoring and calculated turbine noise levels had been derived during the planning stage. The residents surveyed generally lived between the 40 and 45dB contours, two lived within the 45 and 50dB contours. Noise control regulations in Maine call for test sites to be more than 500ft from "protected properties". Six test sites are relevant to the study group and the results are given below:

⁶⁵ Botha P Wind turbine noise and health-related quality of life of nearby residents: a cross-sectional study in New Zealand INCE Europe ISBN:978-88-88942-33-9 Rome, Italy: Proceedings of the 4th International Meeting on Wind Turbine Noise; 2011 pg 1-8 ⁶⁶ Nissenbaum M 2010 Mars Hill study, preliminary results http://www.windvirilance.com/mars_hill aspx

⁶⁶ Nissenbaum M 2010 Mars Hill study, preliminary results <u>http://www.windvigilance.com/mars hill.aspx</u>

Site	Model estimate	Range of measured
No.	(dB)	sound levels (dB)
1	51.0	42-52
5	39.0	39-40
6	43.0	39-45
6A	42.0	38-44
7	40.0	39-44
8	47.5	41-50

It can be seen that model estimates generally underestimated the actual maximum noise levels by between 1 and 4dB.

- 5.50 The study may be criticised for its relatively small numbers of subjects but the presence of a control group, well matched for age and gender, adds considerable strength. All differences between the groups are statistically highly significant. The turbine noise levels may be enhanced by the high concentration of turbines and the geography but the severe sleep disturbance, psychiatric symptomatology and increased medication requirement in the study group confirms the potential of wind turbine noise to adversely affect health at distances claimed to be safe.
- 5.51 A second study, published in a peer-reviewed journal (Nissenbaum et al 2012⁶³) was conducted at two sites, Mars Hill and Vinalhaven, Maine, USA. In contrast to Mars Hill, the Vinalhaven site comprises three 2.5MW turbines on a flat tree covered island.
- 5.52 A questionnaire was offered to all residents meeting inclusion criteria living within 1.5 km of an IWT and to a random sample of residents meeting inclusion criteria living 3 to 7 km from an IWT between March and July of 2010. The questionnaire comprised validated instruments relating to mental and physical health (SF-36v2) (QualityMetric Inc), sleep disturbance (Pittsburgh Sleep Quality Index (PSQI) and the Epworth Sleepiness Scale (ESS), in addition to headache functional inquiry questions and a series of attitudinal questions relating specifically to changes with exposure to IWT noise. The PSQI asks a series of questions about sleep and daytime functioning over the preceding few weeks to give an overall score of sleep quality. The ESS asks subjects to rate their likelihood, over the past few weeks, of falling asleep in eight situations on a 0-3 scale. A typical score is about 5 and scores >10 are deemed significantly sleepy.
- 5.53 Thirty-three and 32 adults were identified as living within 1500m of the nearest IWT at the Mars Hill (mean 805m, range 390-1,400) and Vinalhaven sites (mean 771m range 375-1,000) respectively. Twenty-three and 15 adults at the Mars Hill and Vinalhaven sites respectively completed questionnaires. Recruitment of control group participants continued to approximately the same number as study group participants, 25 and 16 for Mars Hill and Vinalhaven respectively.
- 5.54 There were no significant differences between the groups with respect to household size, age, or gender.

Distance range from residence to nearest IWT (mean) in meters				
Parameter	375-750 (601)	751-1,400 (964)	3,300-5,000 (4,181)	5,300-
Sample size	18	20	14	27
Household clusters	11	12	10	23
Mean age	50	57	65	58
Male/Female	10/8	12/8	7/7	11/16

5.55 Demographic data

5.56 The study group had worse sleep as evidenced by significantly higher mean PSQI and ESS scores and a greater number with PSQI >5. More subjects in the study group had ESS scores >10 but the difference did not reach statistical significance (p=0.1313). The study group had worse mental health as evidenced by significantly higher mean mental component score of the SF-36. There was no difference in the physical component scores.

Parameter	Distance to IWT	Р	
	375-1,400	3,000-6,600	
PSQI Mean (LSmean)	7.8 (7.6)	6.0 (5.9)	0.0461
% PSQI >5	65.8	43.9	0.0745
ESS Mean (LSmean)	7.8 (7.9)	5.7 (5.7)	0.0322
% ESS >10	23.7	9.8	0.1313
SF-36 MCS Mean (LSmean)	42.0 (42.1)	52.9 (52.6)	0.0021

5.57 Sleep and mental health parameters

5.58 ESS, PSQI and SF-36 scores were modeled against distance from the nearest IWT using the equation: Score = ln(distance) + gender + age + site [controlled for household clustering]; and are shown in Graphs 1-3. In all cases, there was a clear and significant relationship with the effect diminishing with increasing distance from the IWT.



Graph 1 Modeled PSQI vs Distance (mean, 95 % confidence limits), p-value=0.0198



Graph 2 Modeled ESS vs Distance (mean, 95 % confidence limits), p-value=0.0331



Graph 3 Modeled SF-36 MCS vs Distance (mean, 95 % confidence limits), p-value=0.0014

5.59 Those living within 1.4km of IWT suffered sleep disruption sufficiently severe to affect their daytime functioning and mental health. Both the ESS and PSQI are averaged measures, i.e. they ask the subject to assess their daytime sleepiness and sleep quality respectively, over a period of several weeks leading up to the present. For the ESS to increase, sleep must have been shortened or fragmented to a sufficient degree on sufficient nights for normal compensatory mechanisms to have been overcome. It must be concluded that at least some of the residents living near the Vinalhaven and Mars Hill IWT installations have suffered serious harm to their sleep and health.

- 5.60 Thorne 2012¹⁶ in a submission to an Australian Senate inquiry into wind farm noise regulations has reported a survey of residents reporting health concerns living within 700 to 3500m of two wind farms. The purpose of the study was to explore sound levels and character to inform future research. Similar health instruments were used to those in the Nissenbaum⁶³ and Shepherd⁶⁴ studies discussed above.
- 5.61 The general health effects were considered by McBride 2014⁵⁸ (Section 3.4.10)
 - 1 Predicted sound levels at the residences ranged from 44-<28dBLAeq. Measured sound levels at 5 residences ranged from 61-43dBLAeq and exceeded predicted levels by between 4-25dBA.
 - 2 Twenty-three of 25 (92%) participants reported PSQI scores >5 confirming that sleep disturbance is a major feature of health effects of wind turbine noise.
- 5.62 Thorne concluded "The measures of wind turbine noise exposure that the study has identified as being acoustical markers for excessive noise and known risk of serious harm to health (significant adverse health effects) are:
 - 1 An LAeq or 'F' sound level of 32 dB(A) or above over any 10 minute interval, outside;
 - 2 An LAeq or 'F' sound level of 22 dB(A) or above over any 10 minute interval inside a dwelling with windows open or closed.
 - 3 Measured sound levels shall not exhibit unreasonable or excessive modulation ('fluctuation').
 - An audible sound level is modulating when measured by the A-weighted LAeq or 'F' time-weighting at 8 to 10 discrete samples/second and (a) the amplitude of peak to trough variation or (b) if the third octave or narrow band characteristics exhibit a peak to trough variation that exceeds the following criteria on a regularly varying basis: 2dB exceedance is negligible, 4dB exceedance is unreasonable and 6dB exceedance is excessive.
 - 5 A low frequency sound and infrasound is modulating when measured by the Zweighted LZeq or 'F' time-weighting at 8 to 10 discrete samples/second and (a) the amplitude of peak to trough variation or (b) if the third octave or narrow band characteristics exhibit a peak to trough variation that exceeds the following criteria on a regularly varying basis: 2dB exceedance is negligible, 4dB exceedance is unreasonable and 6dB exceedance is excessive.
 - 6 Definitions 'LAeq' means the A-weighted equivalent-continuous sound pressure level; 'F' time-weighting has the meaning under IEC 61672-1 and ref. 18; "regularly varying" is where the sound exceeds the criterion for 10% or more of the measurement time interval of 10 minutes; and Z-weighting has the meaning under AS IEC 61672.1 with a lower limit of 0.5Hz.

- 7 Approval authorities and regulators should set wind farm noise compliance levels at least 5 dB(A) below the sound levels in criterion (1) and criterion (2) above. The compliance levels then become the criteria for unreasonable noise."
- 5.63 Paller et al (Paller 2013⁶⁷) presented the results of a survey of nearly 5000 residences in Ontario counties containing 10 or more wind turbines at a conference organised by the Ontario government. Paller subsequently presented a fuller account as a doctoral thesis. (Paller 2014⁶⁸). A highly statistically significant relationship was found between ln(distance) from turbines and PSQI and vertigo. Modelled relationships had the same general form as those of Nissenbaum⁶³). They conclude that "….future research should focus on the effects of wind turbine noise on sleep disturbance and symptoms of inner ear problems." Minimum setback distance in Ontario is 550m and over 80% of respondents lived more than 1km from the turbines. The strength of the relationship between distance and effect is strong evidence for a causal relationship.
- 5.64 The preliminary findings of a survey conducted under the auspices of Health Canada have just been made available (Health Canada 2014⁶⁹) and were previously presented as a conference poster. A range of health and sleep measures were compared to measured and calculated wind turbine noise. The survey did not find a direct association between wind turbine noise and self-reported sleep, illness, stress and quality of life. A statistically significant relationship was found between annoyance and wind turbine noise exposure when calculated noise levels exceeded 35dBA. Wind turbine noise annoyance was statistically related to self-reported sleep disturbance (PSQI), migraines, tinnitus, dizziness and objective measures of stress (hair cortisol, blood pressure and resting heart rate). It is reasonable to conclude from the data that adverse health effects occur at external turbine noise levels above 35dBA yet ETSU permits night time noise levels of 43dBA. Calculated outdoor A weighted wind turbine noise levels reached 46dBA. The authors compare the noise levels to those recommended by WHO (2009¹⁰) from which it can be inferred that most subjects were exposed to lower levels. The WHO noise levels are based upon traffic noise. It is inappropriate to base wind turbine noise levels on traffic research for the reasons given above.
- 5.65 This study, and its interpretation, have been criticised (Krogh and McMurtry 2014⁷⁰) but its findings confirm that wind turbine noise has adverse health effects at noise levels permitted by ETSU.
- 5.66 The weight of evidence, most of which is peer-reviewed, from investigations of the effects of wind turbine noise on sleep and health is conclusive that it causes adverse effects at distances of at least 1.5km and at turbine noise levels of less than 40dBA. It follows that the noise limits of ETSU used in UK are inadequate for the protection of human sleep and health.

⁶⁷ Paller C et al 2013 Wind Turbine Noise, Sleep Quality, and Symptoms of Inner Ear Problems Poster presented at Symposia of the Ontario Research Chairs in Public Health

⁶⁸ Paller C 2014 Exploring the Association between Proximity to Industrial Wind Turbines and Self-Reported Health Outcomes in Ontario, Canada [Master of Science in Health Studies and Gerontology] University of Waterloo, Canada

⁶⁹ Health Canada 2014 Wind Turbine Noise and Health Study: Summary of Results

⁷⁰ Krogh C and McMurtry R 2014 Health Canada and Wind Turbines: too little too late CMAJ Blogs

5.67 Children

There are no controlled studies on the effects of wind turbine noise on children but the potential clearly exists for harm (Bronzaft 2011⁷¹). There are a number of anecdotal reports of which the best described are from Pierpont's case control study (Pierpont 2009⁷²). She states "During exposure, young Justin, a healthy 2½ -year-old, pulled on his ears and got cranky at the same times that adults in the family noticed more headache and tinnitus. His language development was good before, during, and after exposure, but his mother noticed during exposure that the child began to confuse T with K sounds and W with L sounds, which he had not done before. This sound confusion was ongoing six weeks after exposure ended, when I interviewed the parents."

- 5.68 She reports that 7 out of the 10 school-age children and teens did worse in school during exposure to turbine noise, compared to before or after, including unexpected problems in reading, mathematics, concentration, and test performance noticed by both teachers and parents. Teachers sent notes home asking what was wrong with the children.
- 5.69 As noted in Appendix A, children are at least as sensitive to noise pollution during sleep as adults. The long term consequences for children of sleep impairment during development have been widely documented in WHO publications. To subject children to what constitutes an unregulated experiment in wind turbine noise exposure in the light of the evidence presented is neither in the public interest nor that of the children.
- 5.70 Children and young people with Autistic Spectrum Disorders (ASD) are especially vulnerable to harm from wind turbines because of their sensitivity to noise and fixation with rotating objects. In a survey of over 17,000 children with ASD, over 40% were hypersensitive to sounds (Cortesi 2011⁷³, Stiegler and Davis 2010⁷⁴). This does not seem to be due to any physical changes in hearing but due to an increased perception of loudness, a psychoemotional-behavioural difference; a fear of sound stimuli, accompanied by hyper-reactive avoidance behaviours. Avoidance behaviours include covering the ears, crying, tantrums, fleeing the area, humming or vocalising, trembling, increased muscle tone, hyperventilation (over breathing) and self-injury in the form of blows to the ears. Individual responses vary but it is quite clear that a significant proportion of subjects with ASD have a reaction to environmental sounds that is distressing and potentially harmful.
- 5.71 Some subjects with ASD have an abnormal and distressing fixation with rotating objects. This is recognised as a diagnostic feature of ASD and can therefore be presumed to be common. Several UK planning inquiries took account of such subjects in their decisions to refuse consent such as Penpell⁷⁵, Flixborough⁷⁶ and Caduscott Farm⁷⁷. The author has been involved with two cases locally at Ketton and Somerby with children with identical symptoms where planning consent was properly refused.

⁷¹ Bronzaft AL 2011 The noise from wind turbines: potential adverse effects on children's well-being Bull Sci Tech Soc. 31:291

⁷² Pierpont N 2009 Wind Turbine Syndrome: A Report on a Natural Experiment K Selected Publications Santa Fe, New Mexico

⁷³ Cortesi F et al 2011 Sleep in children with autistic spectrum disorder Sleep Medicine 11:659-664

⁷⁴ Stiegler L and Davis R 2010 Understanding sound sensitivity in individuals with autism spectrum disorders *Focus on Autism and Other Developmental Disabilities, 20* (10), 1–9

⁷⁵ Planning Inquiry Penpell Farm dismissed R D Hiscox 17 Jan 2007

⁷⁶ Planning Inquiry Flixborough Grange Farmhouse dismissed J Braithwaite 19 April 2010

⁷⁷ Planning Inquiry Caduscott Farm dismissed Neil Pope 15 April 2014

5.72 A recent case from County Clare, Ireland, serves to demonstrate that this concern is real (Danaher 2012⁷⁸). The mother of a 23yr old man with ASD claimed that a wind turbine had had a devastating impact on her son, affecting his sleep and causing great distress. The rated power of the turbine is not stated but from the information given, would seem to be 20kW. The turbine, which has a blade diameter of about 9m is installed about 120m from the young man's bedroom.

5.73 Conclusions

It is abundantly clear that wind turbine noise adversely effects sleep and health at the setback distances and noise levels permitted in UK by ETSU. There is no reliable evidence at all that wind turbines are safe at these distances and noise levels, not a single study. In contrast there is an increasing volume of studies outlined here to the contrary.

⁷⁸ Danaher D 2012 Family "demented" by wind turbine noise *The Clare Champion* 14 February 2012

Appendix A – Effects of noise on sleep and health

1.1 Sleep, sleep physiology and the effects of noise

Sleep is a universal phenomenon. Every living organism contains, within its DNA, genes for a body clock which regulates an activity-inactivity cycle. In mammals, including humans, this is expressed as one or more sleep periods per 24 hours. Sleep was previously thought to be a period of withdrawal from the world designed to allow the body to recuperate and repair itself. However, modern research has shown that sleep is primarily by the brain and for the brain. The major purpose of sleep seems to be the proper laying down and storage of memories, hence the need for adequate sleep in children to facilitate learning and the poor memory and cognitive function in adults with impaired sleep from whatever cause.

- 1.2 Inadequate sleep has been associated not just with fatigue, sleepiness and cognitive impairment but also with an increased risk of obesity, impaired glucose tolerance (risk of diabetes), high blood pressure, heart disease, cancer, depression and impaired immunity as shown by susceptibility to the common cold virus. Sleepy people have an increased risk of road traffic accidents. Sleepiness, as a symptom, has as much impact on wellbeing as epilepsy and arthritis. It is not insignificant.
- 1.3 Humans have two types of sleep, slow wave (SWS) and rapid eye movement (REM). SWS is the deep sleep which occurs early in the night while REM or dreaming sleep occurs mostly in the second half of the night. Sleep is arranged in a succession of cycles, each lasting about 90 minutes. We commonly wake between cycles, particularly between the second and third, third and fourth and fourth and fifth cycles. Awakenings are not remembered if they are less than 30 seconds in duration. As we age, awakenings become more likely and longer so we start to remember them.
- 1.4 Even while deeply asleep, the brain is processing sounds and deciding whether they merit awakening either because the sound has meaning or constitutes a threat. For example, at the same noise level, awakening is more likely when one's name is called rather than a nonspecific noise. Similarly, a mother will wake when her baby cries but not for a passing car.
- 1.5 Noise interferes with sleep in several ways. Firstly, it may be sufficiently audible and annoying to prevent the onset of sleep or the return to sleep following an awakening. It is clear also that some types of noise are more annoying than others. Constant noise is less annoying than irregular noise which varies in frequency and loudness, for example, snoring, particularly if accompanied by the snorts of sleep apnoea (breath holding). The swishing or thumping impulsive noise (EAM) associated with wind turbines seems to be particularly annoying as the frequency and loudness varies with changes in wind speed and local atmospheric conditions and the character of the noise may be perceived as threatening.
- 1.6 Secondly, noise experienced during sleep may arouse or awaken the sleeper. A sufficiently loud or prolonged noise will result in full awakening which may be long enough to recall. Short awakenings are not recalled as, during the transition from sleep to wakefulness, one of the last functions to recover is memory (strictly, the transfer of information from short term to long term memory). The reverse is true for the transition from wakefulness to sleep. Thus only awakenings of longer than 20-30 seconds are subsequently recalled. Research that relies on recalled awakenings alone will therefore underestimate the effect.

- 1.7 Noise insufficient to cause awakening may cause an arousal. An arousal is brief, often only a few seconds long, with the sleeper moving from a deep level of sleep to a lighter level and back to a deeper level. Because full wakefulness is not reached, the sleeper has no memory of the event but the sleep has been disrupted just as effectively as if wakefulness had occurred. It is possible for several hundred arousals to occur each night without the sufferer being able to recall any of them. The sleep, because it is broken, is unrefreshing resulting in sleepiness, fatigue, headaches and poor memory and concentration (Martin 1997⁷⁹), many of the symptoms in fact of "wind turbine syndrome". Arousals are associated not just with an increase in brain activity but also with physiological changes, an increase in heart rate and blood pressure, which are thought to be responsible for the increase in cardiovascular risk.
- 1.8 A clear relationship between high blood pressure and aircraft noise exposure has been shown by the HYENA consortium (Jarup 2008⁸⁰) and between traffic noise and high blood pressure for adults (Barregard 2009⁸¹) and, worryingly, for preschool children (Belojevic 2008⁸²). The MESA study has suggested a link between exposure to traffic and alterations in heart function (Van Hee 2009⁸³) and Selander et al 2009⁸⁴ have suggested a link with myocardial infarction (heart attack) but neither could separate noise effects from pollution. Arousals occur naturally during sleep and increase with age (Boselli 1998⁸⁵), as do awakenings which may make the elderly more vulnerable to wind turbine noise. Arousals may be caused by sound events as low as 32 dB(A) and awakenings with events of 42dB(A) (Muzet and Miedema 2005⁸⁶). Arousals in SWS may trigger a parasomnia (sleep walking, night terrors etc.). Pierpont 2009⁷² notes that parasomnias developed in some of the children exposed to turbine noise in her study group.
- 1.9 Arousals are caused by aircraft, railway and traffic noise. In one study of aircraft noise, arousals were four times more likely to result than awakenings and resulted in daytime sleepiness (Basner 2011⁸⁷). Freight trains are more likely to cause arousals than passenger trains, presumably because they are slower, generating more low frequency noise and taking longer to pass (Saremi 2008⁸⁸). The noise of wind turbines has been likened to a "passing train that never passes" which may explain why wind turbine noise is prone to cause sleep disruption. A recent study of over 18000 subjects has shown a link between exposure to traffic noise and "the risk of getting up tired and not rested in the morning (de Kluizenaar 2009⁸⁹). This study, together with that of Basner 2011⁸⁷ confirms that excessive

⁸⁵ Boselli M et al 1998 Effect of age on EEG arousals in normal sleep Sleep, 21 (4): 351-357

⁷⁹ Martin SE et al 1997 <u>The effect of nonvisible sleep fragmentation on daytime function</u> *American Journal of Respiratory and Critical Care Medicine,* 155 (5): 1596-1601

⁸⁰ Jarup L et al 2008 Hypertension and Exposure to Noise Near Airports: the HYENA Study *Environmental Health Perspectives* 116:329–333

⁸¹ Barregard L, Bonde E and Ohrstrom E 2009 Risk of hypertension from exposure to road traffic noise in a population based sample *Occup Environ Med* 66:410-415

⁸² Belojevic G et al 2008 Urban road traffic noise and blood pressure and heart rate in preschool children *Environment International* 34:226-231

⁸³ Van Hee VC et al 2009 Exposure to traffic and left ventricular mass and function The Multi-ethnic study of atherosclerosis (MESA) *Am J Respir Crit Care Med.* 179:827-834

⁸⁴ Selander J et al 2009 Long term exposure to road traffic noise and myocardial infarction *Epidemiology*. 20:272-279

⁸⁶ Muzet A, Miedema H 2005 Short-term effects of transportation noise on sleep with specific attention to mechanisms and possible health impact. Draft paper presented at the Third Meeting on Night Noise Guidelines, WHO European Center for Environment and Health, Lisbon, Portugal 26-28 April 2005

⁸⁷ Basner M, Muller U and Elmenhorst E 2011 Single and combined effects of air, road, and rail traffic noise on sleep and recuperation. *Sleep* 34:11-23

⁸⁸Saremi M et al 2008 Sleep related arousals caused by different types of train Journal of Sleep Research 17:Supplement 1;P394

⁸⁹ De Kluizenaar Y et al 2009 Long-term road traffic noise exposure is associated with an increase in morning tiredness *J Acoust Soc Am* 126:626-33

noise disturbs sleep sufficiently to impair its restorative properties and adds credence to the anecdotal reports of those living near wind turbines.

- 1.10 Noise character is an important factor in determining whether an arousal occurs. Solet et al ²¹ in a study of the effects of noise on hospital inpatients determined the likelihood of an arousal at different sound levels for a range of sounds from telephone, intravenous fluid pump alarm, conversation, door closing, a jet aircraft passing and a helicopter landing (Fig 6, Appendix C). Those sounds with an impulsive quality (telephone and alarm) were much more likely to cause an arousal than steadier noises such as conversation. The noise least likely to cause an arousal was the jet aircraft. Note that for the most arousing noises, at 40dBLA_{eq10sec}, 80-90% of the stimuli caused an arousal. It is evident that arousals will still occur at noise levels well below 35dBA.
- 1.11 Studies of different alarm signals have shown that arousals and awakenings occur at lower sound levels with low frequency sounds than those of higher frequency (Bruck 2009). Repeated short beeps of 400-520Hz were most intrusive, leading to arousal and awakening. Wind turbine noise often has a considerable low frequency component and has an impulsive nature which may, in part, explain its adverse effect on sleep. A recent laboratory study of the effects of air, road and rail traffic noise on sleep showed that the differences were explained by sound pressure level rise time, faster rises being more likely to arouse (Basner 2011⁸⁷). A characteristic of wind turbine noise is the rapid rise time which may explain, in part its propensity to disturb sleep.
- 1.12 While it is widely accepted that LFN disturbs sleep (WHO 1999²⁵), the mechanism remains unknown. Salt et al (Salt and Lichtenhan 2014⁹⁰) have demonstrated that the ear may detect inaudible sound and stimuli received by this route could causes arousals and awakening. It is probable that internally generated "sensations" (Cooper 2014⁶¹) would have a similar effect.
- 1.13 It is often claimed that continual exposure to a noise results in habituation, i.e. one gets used to the noise. There is no research to confirm this assertion, indeed there is anecdotal evidence that sensitisation to LFN occurs (Cooper 2014⁶¹). A recent small study (Pirrera et al 2009⁹¹) looking at the effects of traffic noise on sleep efficiency suggests that habituation does not occur. Griefahn et al 2008⁹² have found that the increases in heart rate with traffic noise induced arousals show no habituation.
- 1.14 Sleep spindles are short bursts of high frequency oscillation seen in the brain's electrical activity (electroencephalogram, EEG) during SWS and are a marker of sleep stability. Recent research has shown that subjects with a higher spindle rate are less likely to show an arousal in response to a transient noise than a subject with a lesser rate and are less likely to report that noise disturbs their sleep (Dang-Vu et al 2010⁹³). The spindle rate decreases with age, explaining the vulnerability of the elderly to noise induced sleep disruption. Insomniacs, when asleep, have reduced spindle counts, thus suggesting that sensitivity to noise while asleep is not purely psychological but has a physical basis thus confirming the finding that noise sensitivity is, to a large degree, inherited.

⁹⁰ Salt A and Lichtenhan J 2014 How does wind turbine noise affect people? Acoustics Today. Winter 2014:20

⁹¹ Pirrera S, De Valck E, Cluydts R 2009 Nocturnal road traffic noise and sleep quality: Habituation effects assessed in a test-retest field situation *Sleep* 32:A422

⁹² Griefahn B et al 2008 Autonomic arousals related to traffic noise during sleep *Sleep* 31:569-577

⁹³ Dang-Vu et al 2010 Spontaneous brain rhythms predict sleep stability in the face of noise Current Biology 20:R626-7

1.15 A plot of sound level against the probability of stable sleep is presented (Fig 7, Appendix C). This is effectively an inverted dose-response curve of log(sound pressure) against the likelihood of an arousal. Dang-Vu's study only examined noise stimuli of 40-70dB(A), however it is reasonable to extrapolate to lower noise levels. For subjects with a low spindle rate, at a stimulus level of 35dB(A) there would be an approximate 50% probability of an arousal. The subjects were 26.3 (± 7.5) years of age. Older subjects would be expected to have even fewer spindles and to be even more sensitive to noise. This study confirms the findings of Solet²¹ that sleep disturbance can occur at audible sound levels below 35dBA.

1.16 Psychological factors and noise sensitivity

There is considerable interaction between the psychological response to noise and sleep disturbance, each worsening the other. It is well recognised that psychological factors and personality traits influence the response to noise. Approximately 15% of the population are noise sensitive and have both a lowered annoyance level and an enhanced cortisol response, a physiological marker of stress. Noise sensitivity is considered to be a stable, partly heritable, personality trait; the noise sensitive being at one end of a continuum with the noise tolerant at the other. It is often implied that those who are highly annoyed by noise, including wind turbine noise, are motivated simply by a dislike of the noise source or are psychologically disturbed in some way. This is simply not the case, the response of the noise sensitive being as normal a reaction as that of the noise tolerant.

- 1.17 The noise sensitive are more likely to have stress related disorders, anxiety, headaches and poor sleep than the average. They are more likely to be found in the countryside where noise disturbance is less. Pedersen (2004) reported that 50% of her rural subjects were rather or very noise sensitive. Noise sensitivity is more likely in those with brain injury, psychological disorders such as dyslexia and Autistic Spectrum Disorder and increased community noise may exacerbate depression in susceptible individuals.
- 1.18 Flindell and Stallen 1999⁹⁴ listed factors influencing the degree of annoyance to noise:
 - 1 Perceived predictability of the noise level changing
 - 2 Perceived control, either by the individual or others
 - 3 Trust and recognition of those managing the noise source
 - 4 Voice, the extent to which concerns are listened to
 - 5 General attitudes, fear of crashes and awareness of benefits
 - 6 Personal benefits, how one benefits from the noise source
 - 7 Compensation, how one is compensated due to noise exposure
 - 8 Sensitivity to noise
 - 9 Home ownership, concern about plummeting house values
 - 10 Accessibility to information relating to the noise source

To which may be added:

- 11 Perceived value of the noise source
- 12 Expectation of peace and quiet
- 13 Visual impact

⁹⁴ Flindell IH Stallen PM 1999 Non-acoustical factors in environmental noise Noise Health;1:11-6

- 1.19 Disempowerment and loss of control is a common theme from reports of those subjected to excessive wind turbine noise. The impulsive character of the noise is perceived as threatening and cannot be escaped within the home, the usual source of refuge and quiet "to permit restoration" (Pedersen 2008⁴⁶), a considerable loss of amenity. The end result is fear and anger at loss of control over the living environment with increased stress responses including increased difficulty in initiating and maintaining sleep. The increased wakefulness at night and the lower quality sleep increase the impact of nocturnal turbine noise on sleep, increasing the daytime fatigue and stress and so on in a reinforcing cycle.
- 1.20 The psychological response to noise and noise sensitivity is a complex area and an excellent review is given by Shepherd, a psychoacoustician (Shepherd 2010⁹⁵).
- 1.21 The "nocebo" hypothesis has been advanced recently suggesting that symptoms reported by thousands of subjects complaining of adverse effects from wind turbine noise are an example of a mass psychogenic illness (MPI) (Rubin 2014⁹⁶, Chapman 2013⁵⁵). Chapman claims that reports of adverse effects do not predate the earliest published papers, particularly the Pierpont case series (Pierpont 2009⁷²), and the ensuing publicity, and that the complaints are restricted to those wind farms where opposition groups were active in the planning stage. This hypothesis is falsified by the observations that adverse reports predate the Pierpont book by over 20 years (Kelley 1985²⁶), many wind farms reporting adverse effects had no opposition groups and occur in places where the residents initially welcomed the turbines, including wind turbine hosts (Mortimer 2012⁹⁷). Stigwood et al 2013⁹⁸ note "This (the "nocebo" hypothesis) is contrary to our own direct evidence where many communities and individuals either did not object to the development, positively supported the development or moved near to the wind farm in the belief that it would not adversely affect them". Several experienced acousticians who could reasonably be expected to be immune to such suggestions have reported adverse effects (Ambrose et al 2012⁹⁹, Stigwood 2013⁹⁸, Cooper 2014⁶¹). McMurtry 2013¹⁰⁰, Laurie 2013¹⁰¹ and Hartman 2013¹⁰² have analysed the Chapman⁵⁵ papers in depth, detailing their bias and logical fallacies. Hartman concludes that the Chapman papers "fail to meet credible standards of professionalism to be taken seriously". I concur with this conclusion.
- 1.22 Chapman cites a laboratory based study in support of his hypothesis (Crichton 2013¹⁰³).
 Punch, an audiologist (Punch 2013¹⁰⁴), and Swinbanks, an acoustician (Swinbanks 2013¹⁰⁵),

⁹⁵ Shepherd D 2010 Wind turbine noise and health in the New Zealand context In: Rapley BI and Bakker HHC Sound, Noise, Flicker and the Human Perception of Wind Farm Activity Atkinson & Rapley Consulting Ltd, Palmerston

⁹⁶ Rubin G J, Burns M, Wessely S 2014 Possible psychological mechanisms for "wind turbine syndrome" On the windmills of your mind Noise Health;16:116-22

⁹⁷ Mortimer D 2012 Statement to the Victorian Civil and Administrative Appeals Tribunal No 2910 of 2012

⁹⁸ Stigwood M et al 2013 Audible amplitude modulation - results of field measurements and investigations compared to

psychoacoustical assessment and theoretical research 5th International Conference on Wind Turbine Noise Denver 2013
 ⁹⁹ Ambrose SE, et al 2012. Wind turbine acoustic investigation: Infrasound and low frequency noise – a case study. *Bull Sci Tech Soc.* 32:128

¹⁰⁰ McMurtry R 2013 Commentary on Chapman "nocebo" paper

¹⁰¹ Laurie S 2013 A critical analysis of the "complaints" data from the Chapman et al "nocebo" research

¹⁰² Hartman R 2013 The adverse health impacts of industrial wind turbines: A scientific response to "It's all in your head" Evidence to the Charleston, Rhode Island Zoning board

¹⁰³ Crichton F et al (2013) Can expectations produce symptoms from infrasound associated with wind turbines? *Health Psychology*, Advance online publication doi:10.1037/a0031760

¹⁰⁴ Punch J 2013 Review of Crichton et al ¹⁰³ (Can expectations produce symptoms from infrasound associated with wind turbines?)

¹⁰⁵ Swinbanks M 2013 Review of Crichton et al¹⁰³ (Can expectations produce symptoms from infrasound associated with wind turbines?)

found the experiment itself, and its conclusions, to be seriously flawed, doubting that the volunteers were even exposed to infrasound. Government and industry accepts that adverse symptoms such as those described by Pierpont are due to turbine noise (Colby 2009³³). Adverse effects are found in children and animals who would not be susceptible to psychological factors.

- 1.23 In clinical medicine, a psychogenic explanation for reported symptoms is not entertained until possible physical explanations are excluded. There is a clear physical cause for the symptoms reported by those exposed to wind turbine noise. Nissenbaum and Paller's studies (Nissenbaum 2012⁶³, Paller 2014⁶⁸) show a clear dose-response between distance and effects. Cooper's recent research (Cooper 2014⁶¹) at Cape Bridgewater demonstrate a clear trend and dose response relationship of symptoms with concurrently measured levels of wind turbine infrasound inside homes. These are all clear evidence of a causal relationship between wind turbine noise and effects on humans which would not be present for a psychogenic cause.
- 1.24 In short the "nocebo" hypothesis has no merit.

1.25 Children

Many authorities hold that children are at least as vulnerable as adults to the adverse effects of night time noise (van Kamp 2013¹⁰⁶). A WHO fact sheet (WHO 2013¹⁰⁷) states "As children spend more time in bed than adults, they are more exposed to night noise" and "Impairment of early childhood development and education caused by noise may have lifelong effects on academic achievement and health. Studies and statistics on the effects of chronic exposure to aircraft noise on children have found:

- *1* consistent evidence that noise exposure harms cognitive performance;
- 2 consistent association with impaired well-being and motivation to a slightly more limited extent; and
- 3 moderate evidence of effects on blood pressure and catecholamine hormone secretion."
- 1.26 Stansfeld and Matheson 2003¹⁰⁸ note "It is likely that children represent a group which is particularly vulnerable to the non-auditory health effects of noise. They have less cognitive capacity to understand and anticipate stressors and lack well-developed coping strategies. Moreover, in view of the fact that children are still developing both physically and cognitively, there is a possible risk that exposure to an environmental stressor such as noise may have irreversible negative consequences for this group...."
- 1.27 Ising and Ising 2002¹⁰⁹ compared the sleep of children exposed to high traffic noise levels (26-53 dB L_{Amax}, 55-78 dB L_{Cmax}) and those exposed to lower levels (20-43 dB L_{Amax}, 35-54 dB L_{Cmax}). The maximum level of low frequency noise was correlated with increased cortisol production in the first half of the night, impaired sleep, memory and ability to concentrate.

¹⁰⁶ van Kamp IV et al 2013 The effects of noise disturbed sleep on children's health and cognitive development Presented to ICA 2013, Montreal

¹⁰⁷ World Health Organization 2013 Noise Facts and Figures

¹⁰⁸ Stansfeld S and Matheson M 2003 Noise pollution: non-auditory effects on health *British Medical Bulletin* 68:243–257

¹⁰⁹ Ising H, Ising M Chronic cortisol increases in the first half of the night caused by road traffic noise *Noise Health* 2002;4:13-21

1.28 Long term sleep disturbances in children causes neuronal loss and cognitive impairment (Jan et al 2010¹¹⁰) with serious consequences for long term health and wellbeing.

1.29 Consequences of sleep disturbance

Humans need sleep adequate in quality and quantity. Sleep disturbance and impairment of the ability to return to sleep is not trivial as almost all of us can testify. The elderly may be more vulnerable, not just because they have more spontaneous awakenings than the young but because their high frequency hearing loss may remove some of the masking of the lower frequency noise characteristic of wind turbines. In the short term, the resulting deprivation of sleep results in daytime fatigue and sleepiness, poor concentration and memory function. Accident risks increase. In the longer term, sleep deprivation is linked to depression, weight gain, diabetes, high blood pressure and heart disease.

1.30 A distinction is often made by those seeking to minimise the effects of wind turbine noise between "direct" and "indirect" effects with the implication that "indirect" effects through annoyance and sleep disruption are either of lesser import or the receptors' "fault". The following graphic from the WHO 2009¹⁰ Noise Guidelines for Europe demonstrates that the consequences are identical whatever the means of causation.



1.31 There is a very large body of literature on the consequences of noise exposure, but please see the 2009 WHO/EU Night Noise Guidelines for Europe (WHO 2009¹⁰) for a fuller consideration.

¹¹⁰ Jan JE et al 2010 Long term sleep disturbances in children: a cause of neuronal loss

Appendix B – The Author

Dr Christopher Hanning, Honorary Consultant in Sleep Disorders Medicine to the University Hospitals of Leicester NHS Trust, based at Leicester General Hospital, having retired in September 2007 as Consultant in Sleep Disorders Medicine. In 1969, he obtained a First class Honours BSc in Physiology and, in 1972, qualified in medicine, MB, BS, MRCS, LRCP from St Bartholomew's Hospital Medical School. After initial training in anaesthesia, he became a Fellow of the Royal College of Anaesthetists by examination in 1976 and was awarded a doctorate from the University of Leicester in 1996. He was appointed Senior Lecturer in Anaesthesia and Honorary Consultant Anaesthetist to Leicester General Hospital in 1981. In 1996, he was appointed Consultant Anaesthetist with a special interest in Sleep Medicine to Leicester General Hospital and Honorary Senior Lecturer to the University of Leicester.

His interest in sleep and its disorders began over 30 years ago and has grown ever since. He founded and until retirement ran the Leicester Sleep Disorders Service, one of the longest standing and largest services in the country. The University Hospitals of Leicester NHS Trust named the Sleep Laboratory after him as a mark of its esteem. He was a founder member and President of the British Sleep Society and its Honorary Secretary for four years and has written and lectured extensively on sleep and its disorders and the effects of wind turbine noise (e.g. Hanning and Evans 2012¹¹¹) and continues to be involved in research. He chaired the Advisory panel of the SOMNIA study and sat on the Advisory panel for the Medicated Sleep and Wakefulness study, both major projects investigating sleep quality in the elderly, and sat on Advisory panels for several companies with interests in sleep medicine. He was an Associate Member of the General Medical Council, chairing Investigation Committee hearings, until 2014. In 2010, he was invited to join the Board of the Society for Wind Vigilance.

His expertise on the effects of wind turbine noise has been accepted by the civil, criminal and family courts. He has been accepted as an expert on sleep disturbance related to wind turbine noise by the Ontario High Court and Environmental Review Tribunal and at planning inquiries in the UK, Canada and Ireland. He has given evidence on wind turbine noise and its effects to the Irish Parliament and Australian Senate.

He lives in Ashby Magna, Leicestershire, UK within 1km of the Low Spinney Wind Farm.

¹¹¹ Hanning C and Evans A 2012 Wind turbine noise *BMJ* 344:e1527

Appendix C – Figures and Tables

Fig 1 Sound level and annoyance for different noise sources (van den Berg⁸)



Fig 2 Sound level and annoyance for different noise sources (Pedersen E and Persson Waye 2004⁹)



Fig 3 Relationship between A-weighted sound pressure levels (equivalent levels at wind speed 8 m/s, 10 m over the ground) and proportion of respondents disturbed in the sleep by noise in three studies: SWE00 (n = 341), SWE05 (n = 746) and NL07 (only respondents that did not benefit economically from wind turbines; n = 593). (Pedersen 2009a⁴⁸)



Fig 4 Sleep disturbance and distance from turbines. Fig 9F Morris 2012⁵²



Figure 9F Is your household's sleep disturbed? 0 – 10 km

Fig 5 Sleep disturbance and distance from turbines. Question 9 Schneider 2012⁵³.



Question 9. Is your households sleep disturbed?

Fig 6 Arousal probability threshold curve for non-REM2 (light sleep). X axis signifies A-weighted equivalent sound level measured over 10-seconds. From Solet 2010²¹.



Fig 7 Spindle rate and sleep stability. From Dang-Vu et al 2010⁹³. Observations were pooled among subjects in the lower and upper halves of the spindle rate distribution (ranges 4.57-5.44 and 5.58-6.14 spindles/min respectively) based on EEG lead C3 during stage N2. Corresponding sleep survival curves were derived from each pool in stage N2 using the Kaplan-Meier (product-limit) method.

Backward extrapolation of the response curve for low spindle rate subjects shows only a 50% likelihood of stable sleep at noise levels of 35 dB(A) and 75% likelihood for those with high spindle rates.



Table I Recommendations for setback of residential properties from industrial wind turbines

- Note 1 The 2km limit from edges of towns and villages seems to have been set more for visual than noise reasons
- Note 2 Dixsaut et al (2008¹¹²) report a review of this recommendation by AFSSET. They concluded that the 1.5km setback was "not relevant" and would compromise wind park development.

Authority	Year	Notes	Recommendation	
			Miles	Kilometres
Frey & Hadden	2012	Scientists. Turbines >2MW	>1.24	>2
Frey & Hadden	2012	Scientists. Turbines <2MW	1.24	2
Harry	2007	UK Physician	1.5	2.4
Pierpont	2008	US Physician	1.5	2.4
Welsh Affairs Select Committee	1994	Recommendation for smaller turbines	0.93	1.5
Scottish Executive	2007	See note 1.	1.24	2
Adams	2008	US Lawyer	1.55	2.5
Bowdler	2007	UK Noise engineer	1.24	2
French National Academy of Medicine	2006	French physicians See note 2	0.93	1.5
The Noise Association	2006	UK scientists	1	1.6
Kamperman & James	2008	US Noise engineers	>.62	>1

¹¹² Dixsaut G et al 2008 Wind turbines and noise: is there a minimal siting distance? Epidemiology 19(6) Supplement S216

Kamperman	2008	US Noise engineer	>1.24	>2
Bennett	2008	NZ Scientist	>0.93	>1.5
Acoustic Ecology Institute	2009	US Noise engineer	0.93	1.5
NSW General Purpose Standing Committee	2009	Legislators	1.24	2
Thorne	2010	Aus/NZ acoustician	1.24	2
Horonjeff	2010	US acoustician	1.5-2	2.4-3.2
Shepherd	2011	Psychoacoustician	1.24	2
Cox et al	2012	UK engineer	1.24	2

Table IIResponse to wind turbine noise outdoors or indoors, proportion of respondents (n=708) according to 5-dB(A) sound
level intervals, and 95% confidence intervals (95%CI). (From Pedersen 2009a)

Predicted A-weighted sound pressure levels dB(A)

	<30	30–35	35–40	40–45	>45
Outdoors n	178	213	159	93	65
Do not notice (%) (95%Cl)	75 (68–81)	46(40–53)	21(16–28)	13 (8–21)	8(3–17)
Notice, but not annoyed (%) (95%CI)	20 (15–27)	36(30–43)	41(34–49)	46 (36–56)	58(46–70)
Slightly annoyed (%) (95%Cl)	2 (1-6)	10(7–15)	20 (15–27)	23 (15–32)	22(13–33)
Rather annoyed (%) (95%Cl)	1 (0-4)	6(4–10)	12 (8–18)	6 (3–13)	6(2–15)
Very annoyed (%) (95%CI)	1 (0-4)	1(0-4)	6 (3–10)	12 (7–20)	6(2–15)
Indoors, n	178	203	159	94	65
Do not notice (%) (95%Cl)	87 (81–91)	73(67–79)	61(53–68)	37 (28–47)	46(35–58)
Notice, but not annoyed (%) (95%CI)	11(7–17)	15(11–20)	22 (16–29)	31(22–31)	38(28–51)
Slightly annoyed (%) (95%Cl)	1 (0-4)	8(5–12)	9 (6–15)	16 (10–25)	9(4–19)
Rather annoyed (%) (95%Cl)	0 (0–2)	3(1-6)	4 (2–8)	6 (3–13)	5(2–13)
Very annoyed (%) (95%Cl)	1 (0-4)	1(0-4)	4 (2–8)	10 (5–17)	2(0-8)

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