University of Salford MANCHESTER

Acoustics Research Centre

Health Impacts of Wind Turbines

s.vonhunerbein@salford.ac.uk

http://www.acoustics.salford.ac.uk/profiles/vonhunerbein/

Report on Health Impacts of Wind Turbines

Prepared for Scottish Government by:

Sabine von Hünerbein, Andy Moorhouse, Dani Fiumicelli, David Baguley

10th April 2013

Contents

1. Executive summary

This report presents the results of a rapid, desk based analysis of peer reviewed UK and international literature from the last four years on the effects of wind turbines on human health. The review covers literature specified by the Scottish government, peer-reviewed original studies and recent peer-reviewed literature reviews.

Recent original studies consist mostly of cross-sectional studies and case studies on the effects of wind turbines on local residents. All studies present evidence for annoyance due to wind turbine noise and most concur that there is evidence for sleep disturbance in the presence of wind farms but not necessarily from noise. Both results are in agreement with the effects of noise from other environmental sources.

Other health effects are increasingly reported in the presence of wind turbines but the reviewed literature does not provide firm scientific evidence of a causal relationship with wind turbines or even more specifically wind turbine noise.

The most widely quoted cross-sectional studies show correlations between annoyance and visual impact, economic benefit and attitude related to wind turbines. Wind turbine sound is reported to be comparatively weakly related to annoyance and inseparable from the other contributing factors.

Literature on low frequency noise and infrasound (LFIS) can be categorised as reviews, sound level measurements around windfarms and discussion of mechanisms of perception and response. A Swedish review finds no evidence to support ‘wind turbine syndrome’ while another concludes that further research is required.

Regarding noise measurements, there are concerns that a new generation of wind turbines will produce a sound with a spectrum shifted down in frequency. However, a study in Australia concluded that infrasound levels near windfarms were no higher than elsewhere and that higher levels in urban areas were probably due to traffic and other human activity rather than wind turbines. Some other studies found measured sound levels near wind farms to conform with a range of criteria for LFIS.

Papers by Salt *et al.* propose that LFIS may differentially stimulate structures in the human inner ear, and may instigate health effects even when inaudible. The authors seek to build a speculative case utilising experimental data gleaned from guinea pigs and some observations on human experiences with specific pathological conditions. Based upon the documents submitted, the proposal is unproven, and would need clear data from hypothesis driven independent research in humans in order to be credible.

A proposal by US consultants that motion sickness-like symptoms reported at one wind farm might be caused by acoustic excitation of the balance organs is not new and has previously been discounted as an explanation for similar reported effects not involving wind turbines. Other evidence on acoustic stimulation of the balance organs has been noted but not reviewed.

Health effects from other wind turbine related sources such as shadow flicker have been reported in several studies and guidelines to be less of a problem. Careful wind farm design and operational restrictions are suggested to be sufficient to minimise the impact.

The mitigation strategies have been found to vary widely internationally with some countries and federal states using fixed noise limits, others using noise limits relative to existing background levels and many like the UK using a combination of both. Set-back distances are also used internationally but have a number of disadvantages.

The relevant UK guideline document ETSU-R-97 aims to provide a reasonable degree of protection to noise sensitive listeners; without unduly restricting the development of wind turbine renewable energy resources. In the international comparison the ETSU-R-97 guidelines tends to result in comparatively low noise limits although direct comparisons between fixed and relative noise limits are difficult. ETSU-R-97 has been criticised for its inconsistent implementation and relative complexity. Good practice guidelines by the Institute of Acoustics which aim to address the implementation issues are due to be published in May.

2. Introduction

A literature review of the health effects from wind turbines (WT) and their mitigation was conducted to aid planning applications. Three widely quoted government reviews in 2009 (AWEA/CANWEA, 2009, Minnesota Department of Health, 2009, Roberts and Roberts, 2009) concluded that there are no direct health effects from WTs. However, health effects have been reported by residents living near wind farms.

The current review aimed to rapidly analyse peer reviewed new UK and international scientific evidence from the last 4 years on the noise effects of WTs on human health to provide an update on recent developments.

The work therefore concentrated on scientific publications in peer-reviewed journals from 2009 providing an overview over new evidence that relates health effects to WTs. For health effects caused by WT operation, recommendations for the planning system have been identified. Planning standards have been compared for international, UK and Scottish legislation.

3. Method

The review focussed on original studies (20 publications) and included literature reviews where published in a peer reviewed journal. A number of publications were reviewed by specific request. They are indicated in the reference list. This restriction of literature was dictated by the tight schedule and reflects the academically most thorough research outputs. The chosen literature is based on a search for publications using the following data bases: Pub med Search, Google Scholar, Google Search Engine and Thomson Reuter's Web of Knowledge. The search terms were: “wind turbine noise and health”, “wind farm noise and health”; “wind, noise, health”, "wind turbine health", "wind turbine annoyance", "wind farm health", "wind farm annoyance", "shadow flicker wind turbine"

Articles from the following conferences were considered but not generally included because of time constraints:

- Third International Conference on Wind Turbine Noise 2009; Aalborg, DK
- Fourth International Conference on Wind Turbine Noise; Rome, It 12-14th April 2011
- 15th International Meeting on Low Frequency Nose and Vibration and its Control, Stratford on Avon UK, 22-24 May 2012,
- 41st Internoise, New York, US, 19 - 22 August 2012

4. Health effects and annoyance from noise

A literature review by the Minnesota Department of Health (2009) identified the most common complaints from WTs as annoyance. The most common health concerns at that time were named to be sleeplessness and headache. A relationship to WT noise was suggested but not proven. Non-noise related health issues have been identified as shadow flicker, electromagnetic radiation (EMF), ice throw, and mechanical failure (Copes and Rideout, 2009). The following section focuses on recent findings on health effects from noise.

4.1 Epidemiological studies and case reports

An overview of recent publications about health related studies in relation to wind farms can be found in Appendix II. It contains publications on eight epidemiological studies, six case studies at particular wind farms, three laboratory studies and a number of additional measurements of noise at noise sensitive receptors[1] both indoors and outdoors.

Three widely quoted cross-sectional epidemiological studies have been reported by a number of authors and publications (Pedersen *et al.* 2009, 2010 and 2011, Bakker *et al.* 2012, Janssen *et al.*, 2011). The main findings from these studies are that the reported perception and annoyance were related to sound pressure levels. Annoyance was also reported to be related to WT visibility and attitude towards visual impact. Like previous studies economic benefit from WTs was found to result in a significant reduction of reported annoyance. Typically reported health effects from WTs included in the Dutch study were sleep interruption, chronic disease, diabetes, high blood pressure, cardiovascular disease, tinnitus, impaired hearing, headache, undue tiredness, tense and stressed, irritability. Of those Pedersen (2011) only finds sleep interruption to be significantly correlated to annoyance indoors whereas outdoors annoyance was also related to stress and irritability. She concluded that stress is associated with annoyance in the vicinity of WTs but that increased stress levels could not be traced back to WT noise directly. She postulated that cognitive stress could be a contributing factor. Sleep interruption was statistically significantly related to noise levels in two of the studies.

[1] *Noise sensitive receptors* include residential properties and residential institutions but exclude workplaces as the occupancy is not 24 hours.

Bakker *et al.* (2012) re-analysed the dataset from the Dutch study and found no direct physiological effects from WT noise but possible annoyance. Bakker *et al.* (2012) suggested that psychological distress and sleep disturbance can result for long term exposure. Quiet areas were found to be more affected than areas with more other background noise. It is also evident from the results tables in those publications that the percentages of annoyed respondents was higher outside the property than inside.

In contrast to the Pedersen claim that a clear dose-response relation was found between WT noise level and annoyance, both Knopper and Ollson (2011) and MDEP (2012) considered the statistical evidence to be insufficient after moderation with the other involved factors visibility and economic benefit. In his literature review on sleep disturbance effects from WTs Hanning (2010) on the other hand interpreted the Pedersen publications as a clear indication of the prevalence of annoyance and health issues in relation to noise level. He proposed that sleep disturbance directly should be more widespread than evident from these reports because brief arousals cannot be remembered and therefore not reported in the epidemiological self-reporting studies. Hanning postulates that the number of brief arousals due to WT noise could be much larger than common in normal sleep physiology.

Shepherd *et al.* (2011) reported on a cross-sectional study in New Zealand with a much smaller number of respondents. He concluded that there is clear evidence for reduced quality of life through wind farms although his results have been criticised (MDEP, 2012) as not providing clear evidence for a causal link between WTs and the reported quality of life.

In another self-reporting study Nissenbaum *et al.* (2012) used Mars Hill and Vinalhaven wind farms to relate sleep disruption to distance from WTs. They found a statistically significant relation but their attempt at deriving sleep index functions as a function of distance to WTs looks unconvincing given the large spread in the responses. MDEP (2012) also comment on the statistical validity of the results.

A number of case studies (e.g. Thorne, 2011, Walker *et al.*, 2012, Rand, 2011) and review papers (Hanning, 2010, Bronzaft, 2011, Horner *et al.,* 2011) report health effects from residents near wind farms with the symptoms listed in the context of the Dutch study often mentioned. However, as both Knopper and Ollson (2011) and MDEP (2012) point out, these reports fail to demonstrate a consistent relation between WTs and direct health effects other than annoyance and possibly sleep disturbance.

Studies from Poland (Mroczek *et al.,* 2012) and Greece (Katsaprakakis, 2012) find no negative impact from wind farms on residents.

4.2 Amplitude modulation

Janssen *et al.* (2011) confirmed previous results from the two Swedish studies and the Dutch study that WT noise is more annoying than other environmental noise at the same noise level. As a contributing factor sound characteristics have been suggested: in particular the amplitude modulated (AM) character as well as its irregular variation in immission level have been mentioned.

To investigate the role of AM Lee *et al.* (2011) have conducted listening tests using synthesised WT sounds based on recordings with the aim of finding a dose-response relation between modulation and annoyance ratings. The results show that AM strength increases annoyance ratings. However, annoyance scales more strongly with overall sound level than AM strength in that study. In this study results on AM strength are not sufficiently consistent to derive a dose-response relation. Audibility of the amplitude modulated sound is analysed both by Petersen *et al.* (2010) and Bolin *et al.* (2012) and find that, while traffic noise masks WT noise insufficiently, more irregular natural background sounds do reduce both audibility and annoyance.

4.3 Recent reviews

In various reviews the authors discuss (Hanning, 2010, Farboud *et al.,* 2013, Punch *et al.*, 2010) the existence of "Wind turbine Noise Syndrome" as defined by Pierpont (2009) based on sub-samples of the studies mentioned above. Pierpont's case study has been reviewed by Knopper and Ollson (2011) and MDEP (2012), both of which raised concerns about the reliability of the findings. These authors do not provide new scientific evidence for the validity of their claims. The reviews by Knopper and Ollson (2011) and MDEP (2012) conclude that there is currently no evidence for significant health effects from WTs.

4.4 Infrasound and Low Frequency noise

Recent work on infrasound and low frequency noise can be classified as:

- Reviews
- Noise level measurements around windfarms
- Discussion of perception and response mechanisms

First, regarding definitions, there is general agreement that, given high enough levels, infrasound is audible and therefore there is no strict delineation between low frequency sound and infrasound. Nevertheless, the label infrasound (IS) is most frequently adopted for sound at frequencies below 20 Hz (some authors also give a lower bound and use 1-20 Hz) and low frequency noise (LFN) for the range 20-200 Hz. In the following it is sometimes appropriate to use a combined category of low frequency and infrasound (LFIS).

4.4.1 Reviews

Bolin *et al.* (2011) with a team made up from Engineering, Environmental Medicine and Psychology departments at Swedish Universities, together with the Swedish national Transport Laboratory, conducted a review of work up to April 2011. They note that WT noise is more annoying than road traffic noise at the same level but argue that explanations other than LFIS are probable. Whilst acknowledging the potential importance of LFIS they conclude that there is no evidence that infrasound contributes to perceived annoyance or other health effects. They report finding no consistent effects on health due to WT noise other than annoyance but acknowledge a statistically significant association between self-reported sleep disturbance and WT noise. They conclude that empirical support is lacking for claims of serious health effects in the form of ‘vibroacoustic disease’, ‘wind turbine syndrome’ or harmful infrasound effects on the inner ear.

Farboud *et al.* (2013) note reports of a range of symptoms including vertigo near wind farms. They conclude that the effects of LFIS require further investigation.

4.4.2 Noise measurements around windfarms

Møller and Pedersen (2011) conducted a thorough analysis of measurements (taken by others) from 44 WTs. Their main aim was to compare LFN from smaller machines with that from more modern larger machines. In an initial review, the authors argue there is no reliable evidence of physiological effects below hearing threshold and argue that IS from upwind WTs is not significant. They conclude that, compared with smaller machines, the noise output from large machines is shifted down in frequency and discuss the possibility of lowering the Danish A weighted noise limit to cater for this increase.

O’Neal *et al.* (2011) conducted a review of criteria from USA, Japan and UK relating to LFN and associated effects: rattling of fixtures, perceptible vibrations (in panels etc), spectrum balance, and mental and physical discomfort. They carried out combined indoor and outdoor measurements on two WT models and found that IS would be inaudible even to sensitive persons at 305 m. They conclude by confirming that at 305 m the WT noise from the chosen sites meets all the relevant national criteria.

Bozcar *et al.* (2012) conducted a measurement survey on a windfarm comprising of 2 MW WTs. Their measurements were conducted in accordance with appropriate standards. They conclude that infrasonic components are present but at levels well below those which would be expected to cause harm. However, their criterion of 102 dB(G) is based on work place noise guidelines which may not be appropriate for residential settings. It is not possible to tell from the results presented whether the more stringent Danish recommendation for IS of 85 dB(G) would have been exceeded.

Evans *et al.* (2013) measured G weighted IS levels in urban and rural locations. Their study is unusual in that they were able to take control measurements at rural locations away from any WT. They found IS levels to be higher in urban than rural locations (not near WT) and that urban levels decreased at night, suggesting traffic and other human sources as the main contributor. IS levels at rural locations near operating WT were no higher than at other rural locations away from WT sites and appear to be controlled by localised wind conditions rather than WT noise. In a planned shutdown, no noticeable increase in IS levels at 1.5 km was observed with the WT running.

A study by Walker *et al.* (2012) is interesting in that a consensus was reached by four US consulting companies with interests in both pro- and anti-wind sectors. Their measurements showed that IS is measurable at frequencies as low as 1.4 Hz inside a dwelling at 335 m, although at levels below the threshold of audibility. At this residence the wife and child reported severe symptoms while the husband was unaffected. Three of the five consultants taking part in the study could not detect any WT noise in any residences and the fourth only faintly at the nearest residence (at 335 m). Four of the five consultants reported no health effects and the fifth, symptoms including sickness.

Following the investigation the team arrived at a consensus that ‘enough evidence and hypotheses have been given herein to classify LFN and infrasound as a serious issue’. The consultants are not explicit about which evidence persuaded them there was a problem when the majority heard or felt no effects themselves and the measurement evidence indicates inaudibility. Presumably, their concerns are based on the subjective reports of resident(s) and that of the consultant who could detect the WT noise. Amongst other things they recommend a blind ‘threshold of perception test’ to confirm or deny claims that residents could detect the WT in operation at sound levels below hearing threshold. They also hypothesise (discussed in the following section) that the reported symptoms are due to stimulation of the labyrinth system by inaudible sound.

In a conference paper, Ambrose *et al.* (2012) aim to ‘confirm or deny the presence of infrasound and low frequency noise (IFLN) [sic]’. However, the ‘presence’ of sound does not indicate much without an assessment of levels. A subjective evaluation was carried out over two days and nights during which the author reported feeling sick particularly at times when the WT power was highest. The authors use ‘threshold’ curves based on the work of Salt *et al.* (see next section) to claim that WT sound below threshold could be perceptible but their use in this manner is questionable . Some measurement results are presented which in the main display expected trends.

4.4.3 Discussion of perception and response mechanisms

Salt et al.

Several papers by Salt *et al.* have generated significant discussion and will be covered in some detail. The 2010 discussion paper (Salt and Hullar 2010) was published in a credible Auditory Neuroscience journal, and consists of reflections and speculation upon previous published material: it does not contain new evidence. The main contention is that low frequency and infra-sound (LFIS) may stimulate neural activity in the human inner ear even at levels below the audible threshold. The basis for this claim is as follows: there are two types of hair cells in the inner ear, inner hair cells (IHC) and outer hair cells (OHC). The IHC, which are primarily responsible for hearing, are only weakly stimulated by LFIS. The authors claim that the OHC are more highly stimulated by LFIS. This claim is based on known differences in the attachment of the two types of hair cells inside the inner ear which causes a theoretical difference in their response to sound-induced fluid movement in the ear. The theoretical differences are supported by experimental results from previous studies on anaesthetised guinea pigs: the claim that OHC are excited to a greater extent than the IHC by LFIS is plausible, though important anatomical differences exist between the species.

Whether this leads to health effects depends on whether:

- the OHC are sufficiently sensitive to convert the excitation into neural activity at lower levels of LFIS than the IHC

- LFIS stimulation of the OHC can change the operating point of the organ of Corti, changing cochlear function at non LF areas
- activity from OHC is then transduced such as to evoke aversive sensations and/ or symptoms.

In addition, if these postulated mechanisms are deemed to be plausible, then one should question whether any effects specific to WTs would result, as other sources of LFIS could also cause the same problems.

Regarding the sensitivity of the OHC, Salt and Hullar cite circumstantial evidence that the OHC are involved increasingly in the ear's response as frequency decreases into the LFIS region. Relative hair cell sensitivity has not however been measured in the LFIS frequency region. Therefore, the author's conclusion that the OHC respond at inaudible levels requires an assumption about OHC sensitivity which is extrapolated from higher frequency behaviour rather than directly demonstrated from measurement. It is also assumed that if responses are evident in guinea pigs that they would be present at the same or lower level in humans. The proposed mechanisms here become speculative, though of interest.

Regarding the potential of harmful effects from LFIS, the authors present detailed speculation on several mechanisms. Responses of guinea pig ears at levels of LFIS below hearing threshold are cited which is said to support the involvement of the OHC. The possibility is also said to exist that certain human medical conditions (endolymphatic hydrops) could increase sensitivity to LFIS, though no empirical evidence is cited. Another medical condition (third window syndrome – Superior Semicircular Canal Dehiscence) is said to increase the possibility that the vestibular labyrinth might respond to LFIS below hearing threshold but this has also not been evidenced. Further discussion on a potential role for mechanisms regulating the amount of endolymph and perilymph fluids in the inner ear does not reach a firm conclusion.

Overall, the argument that the OHC are more strongly excited than the IHC by LFIS is plausible. It is speculated that this additional excitation leads to neural activity below hearing threshold which is supported by some circumstantial evidence and argument. Proposed mechanisms for harmful effects arising from neural activity below threshold are speculative and not supported by direct evidence. The phenomena discussed are not specific to WTs but to LFIS in general.

Salt and Kaltenbach, (2011) present recording of LFIS in a house near WTs in which the inaudible infrasound component is shown to be higher than the audible component. However, the authors do not discount the possibility that the infrasonic component was caused by mechanisms other than the WT, such as wind around the dwelling.

The authors criticise the use of A weighting for evaluation of environmental sounds with a spectrum weighted towards low frequencies. This argument has been made since before the advent of modern WTs, most notably by the WHO in 1999 (Berglund, Lindvall, & Schwela, 1999) and several countries have now adopted specific guidance for situations involving LFS. Such guidelines are generally motivated by the rapid growth of loudness at low frequency i.e. they can be justified on the basis of audible sounds without a need to consider inaudible sounds as proposed here.

The authors plotted WT sound levels against OHC and IHC ‘sensitivity’. On this basis they argued that WT sounds are “too low to stimulate the IHC and cannot therefore be heard but are of sufficient level to stimulate the OHC”. This use of the sensitivity curves effectively as threshold curves requires some assumptions which are not stated.

Generally, the paper draws heavily on the 2010 paper and does not provide significant new evidence.

Salt and Lichtenhan, (2012) presented a conference paper giving new results from measurements on anaesthetised guinea pigs which show that some regions of the inner ear are sensitive to LFIS (not necessarily below hearing threshold) and that the presence of higher frequency sound suppresses the response to LFIS. Thus, the highest electrical responses in a certain region of the inner ear will occur when LFIS dominates in the absence of higher frequencies.

Generally, the authors devote considerable attention to WT as specific sources of LFIS whilst the effects they discuss would apply generally to LFIS irrespective of the source.

The 2012 paper contains the statement: “…the concept of ‘what you can’t hear can’t hurt you’ is false” which echoes a similar statement in an earlier paper. It is scientifically and philosophically impossible to prove this concept ‘true’, however the authors appear to take lack of proof as indication that it is ‘false’.

To summarise the papers by Salt *et al*., these three documents propose that low frequency and infra-sound (LFIS), and specifically LFIS generated by WTs, may differentially stimulate structures in the human inner ear, and may instigate health effects even when inaudible. The authors seek to build a case for what appears to be a prior assumption utilising reflections from laboratory experimental data gleaned from another species (guinea pig), some observations on human experiences with specific pathological conditions (endolymphatic hydrops and superior semi-circular cabal syndrome), conjecture, and speculation.

Based upon the documents submitted, the proposal is unproven, and would need clear data from hypothesis driven independent research in humans in order to be credible.

Other discussion

Leventhall (2009) discusses several effects of LFIS including the rapid growth of annoyance at levels just above hearing threshold. He also investigates alternative mechanisms of perception including body vibration and vestibular effects. The author concludes that vestibular excitation and perceptible vibration may occur at high sound levels but not below hearing threshold. However, some recent publications on vestibular system excitation by sound were not included (see later comments in this section). The author points out that most work on LFIS has been conducted at far higher sound levels than would be found in the environment and suspects this to be the cause of unnecessary public disquiet.

As mentioned earlier, Walker *et al.* (2012), a group of four US consulting firms reached a consensus that a ‘new Threshold of Perception’ was needed and put forward a proposal that inaudible IS is responsible for motion sickness-like symptoms by stimulation of the labyrinth system. Their hypothesis appears to be based on the similarity of the symptoms reported by residents to those in motion sickness tests in a flight simulator carried out by the US Navy. The frequency of worst sickness in those tests (0.2 Hz) also happened to lie in approximately the same region as the fundamental frequency of the WT (0.7 Hz). It should be noted that symptoms of this type have been widely reported for several decades before the advent of modern WT (Leventhall, Pelmear, & Benton, 2003): in some such cases a link to a source or sources of LFN has been confirmed but there remain many cases where no noise could be found that correlated with the reported effects (Leventhall *et al*., 2003; Moorhouse, Waddington, & Adams, 2005; Pedersen, Møller, & Waye, 2008). The involvement of the labyrinth system, as suggested by Walker *et al.*, has often been put forward as a possible cause of the otherwise unexplained disturbance but was discounted by

Leventhall at sound levels below hearing threshold (Leventhall, 2009). A focussed review of recent research into acoustic stimulation of the labyrinth system (e.g. Jones *et al.* 2010) would be required to determine whether this mechanism should be revisited.

Note that the mechanism proposed by Walker *et al.* differs from that put forward by Salt and Hullar (Salt and Hullar, 2010).

4.5 Conclusions on the impact of wind turbine noise on health

In conclusion, annoyance has been clearly identified as an issue related to WT noise (in common with other noise sources). Sleep disturbance in the presence of wind farms is widely, although not universally, accepted. Other symptoms are increasingly reported in the presence of WTs and in some studies, but not others, are associated with annoyance and potentially indirectly with noise. Other factors like visual impact, financial benefit and attitude have been shown to be more strongly related to annoyance than WT noise. There is agreement that careful design of wind farms at the planning stage can minimise their impact.

5. Shadow flicker

Shadow flicker is reported in a number of studies (e.g. Thorne, 2011, Krogh *et al.*, 2011) in the context of annoyance and generally discussed in reviews (Copes and Rideout, 2009, Knopper and Ollson, 2011, MDEP, 2012) in relation to epilepsy. Copes & Riding (2009) summarise that shadow flicker timing is typically short and strongest within 300 m from WT. The main effects are reported to be "dizziness and disorientation when inner ear and visual cues disagree".

Smedley *et al.* (2010) and others before them calculated safe distances to WTs. They concluded that the risk of seizures from single large turbines is low because of their low blade passing frequency. Whereas the Minnesota DoH (2009) report identifies 10 rotational diameters the results by Smedley *et al.* show that a 10x turbine height distance is sufficient to avoid any risk of seizure.

DECC (2011) have confirmed those recommendations and report about successful mitigation measures of shutting individual turbines down for the duration of flicker where problems occur. They conclude that flicker is not a major concern in the UK.

6. Other health concerns

Concerns about electromagnetic radiation (EMF) have not been substantiated as emissions are low from WT compared to other sources (Copes & Ridout, 2009). Ice throw from WT can be an issue in freezing conditions. Safety distances of 200-250 m (Copes & Rideout, 2009) or 1-2 times the tower height (MDEP, 2012) are generally recommended. Additionally, it is recommended to stop WT in icing conditions. Structural failure rates for WTs are reported to be as low as 10^{-4} and 10^{-7} with the highest likelihood in cold weather and recommended set-back distances 150-500 m (Copes & Ridout, 2009). Generally, the set-back distances recommended in this section are shorter than the ones that would be observed in relation to shadow flicker and noise regulations.

7. Proposed measures of mitigation for wind turbine noise

Given that there is no agreement that health effects from WT noise differ from other environmental noise sources various types of noise limits and setback distances are used for mitigation.

7.1 Setbacks

WT setback distances are relatively common in the United States and Canada. Where specified setbacks can provide legislatively approved fixed minimum distances from WTs to noise sensitive receptors. Whilst they provide a reassuringly simple means of control readily understood by all, they do have substantial drawbacks, including:

- Internationally existing set backs are typically in the range 300 to 500 metres (with the exception of Germany and Scotland – where larger set backs are recommended, but routinely put aside in the light of evidence on the appraisal of impacts at shorter distances). These distances are below the minimum for large scale WTs resulting from the use of the ETSU-R-97 methodology in the UK – which typically results in a minimum separation distance of 10 X the hub height i.e. 750 to 850 metres for a modern 2 to 3 MW turbine.

- Different power rated turbines and the same power rated turbines from different manufacturers have different noise characteristics. Consequently any setback would have to be fixed so as to cope with the noisiest turbine; thereby unreasonably prejudicing the use of less noisy turbines. Medical experts such as Hanning (2010) and noise consultants e.g. Shepherd (2011) and Harrison (2011) who raise concerns about health effects, therefore suggested setback distances of 1500-2000 m.
- Use of fixed setbacks would mean there would be no consideration of the existing noise climate which would result in a higher noise impact in quiet environments compared to areas with high background noise.
- Fixed setbacks would also remove the incentive for developers to incorporate consideration of local noise conditions in the selection of an appropriate number of turbines with the relevant noise characteristics for the circumstances.
- Setbacks do not take into account the many factors that influence the magnitude of any impact, including the surrounding topography and local wind shear effects and the number of turbines. Consequently; any setback would have to be fixed so as to cope with the worst case immission scenario i.e. no topographical attenuation, high wind shear and a large number of turbines thereby unreasonably prejudicing schemes where these factors are likely to result in lower noise levels.
- Continued improvements in wind turbine technology are leading to reductions in noise emissions for existing scale turbines; and larger turbines are coming on the market with higher noise immission characteristics. Consequently, any setback regulation would start to become unduly restrictive or obsolete as soon as approved and require regular review and approval.
- They do not take account of the potential to use noise management systems to restrict specific noise impacts under particular wind conditions.

In light of the above it is considered that a more effective means of managing wind turbine noise impacts is to set noise level limits at the noise sensitive receptors likely to be significantly affected, and require these to be met by planning conditions. This presents a practicable means of appropriate case by case assessment and control balanced against the benefit in terms of renewable energy production; as the noise levels for a specific turbine under specific wind conditions in a particular setting can be predicted by experts using validated data on the turbine noise output using established modelling methods.

European states rely on noise level limits which are derived from national and international standards and usually aim to tie in with national regulations on environmental noise. Low frequency noise limits have been adopted in Denmark.

7.2 International comparison of noise guidelines in relation to Scotland

Scotland, like the rest of the UK, uses the ETSU-R-97 relative – comparison method specifically for the rating and assessment of WT noise i.e. subject to lower limits the noise targets are set relative to existing noise conditions at a range of wind speeds. Similar methods are used in Ireland, Australia and New Zealand. Where noise controls exist elsewhere internationally, most set benchmark – absolute fixed noise limits, although only a minority are WT specific and the majority are generic noise controls that apply to a wide range of sources.

Because different indices like $LA_{eq,t}$, $LA_{90,t}$ and $L_{DEN,t}$[2] are used with a variety of averaging times t the comparison of benchmark - absolute fixed noise maximum and minimum limits is not straightforward. Medical experts such as Hanning (2010) and noise consultants e.g. Shepherd (2011) and Harrison (2011) who raise concerns about health effects, suggested fixed 35 dB(A) outdoors night-time noise limits without specifying the averaging times. Whereas others such as Hessler (2010) and Verheijen (2011) tend to propose slightly higher limits in a compromise between the protection of residents and the requirements of wind farm planners and operators.

Comparison of relative – comparison noise methods with benchmark – absolute fixed noise limits is complicated by the variable nature of the former compared to the latter; particularly where the influence of wind speed is taken into account with relative – comparison noise methods. However, the lower limits of ETSU-R-97 are broadly comparable with the bottom end of the range of benchmark – absolute fixed noise limits and the typical range of upper noise levels derived using the ETSU-R-97 methodology is less than the upper range of benchmark – absolute fixed noise limits. Overall, it is considered that the ETSU-R-97 methodology is more stringent than typical controls applied internationally; although a minority of countries take a firmer approach.

[2] For definitions see Appendix I.

The ETSU-R-97 methodology diverges from many of the international noise controls by using the $LA_{90,10\,min}$ noise index to assess turbine noise. ETSU-R-97 makes the case for this by arguing the $LA_{90,t}$ index is less likely to be affected by extraneous noise than the more ubiquitous $LA_{eq,t}$ index; making monitoring easier (although not easy). Arguably the $LA_{eq,t}$ index is more sensitive to the modulating (time varying) nature of WT noise; but shifting to the $LA_{eq,t}$ noise index would require review of the noise limits in ETSU-R-97 as the document includes allowance for the typical difference between turbine noise $LA_{90,t}$ and $LA_{eq,t}$ of 2 dB(A); although this difference can be greater under a minority of conditions where excess amplitude modulation can occur. In steady noise conditions $LA_{90,t}$ and $LA_{eq,t}$ assume the same value. Internationally, regulations to specifically account for amplitude modulation are rare because of the lack of scientific guidance.

Only Denmark has recently adopted low frequency noise limits for WTs; and bases these on its existing controls for industrial noise. Whilst the limit focuses on low frequency noise it still uses the A-weighted decibel and the limit is internal and based on prediction of intrusion of low frequency noise using standardised assumptions about the sound insulation performance of typical Danish housing.

7.3 Rationale for noise limits

Ideally when setting noise limits it is best if information about the subjective response to the noise in question is taken into account. The subjective response to most types of noise is influenced by a range of acoustic factors e.g. decibel level, frequency content and temporal characteristics, and non-acoustic factors such as individual listener personality and attitudes towards the source. An overview over the most common factors influencing response can be found in Appendix IV.

A search of the available literature reveals that most of the research into the subjective response to wind farm noise has been carried out in Scandinavia, the Netherlands and Germany (e.g. Pedersen *et al.* 2009, 2010 and 2011, Bakker *et al.* 2012, Janssen *et al.*, 2011). Transposing these studies to other countries may not be reliable as methodological and analytical issues; and differences in topography, population density and distribution; and variation in societal, language, economic, cultural, environmental and political factors between these countries and elsewhere, militate against the direct transfer of these dose responses.

Extensive research into noise annoyance and disturbance over many decades has shown that although average long-term effects e.g. annoyance, can be determined by asking a representative sample of a population to rate their individual annoyance on a numerical or category scale such as ‘not annoyed, ‘a little annoyed’, ‘moderately annoyed or ‘annoyed very much’, these responses tend to be only weakly linked with the degree of sound exposure (MDEP, 2012). This modest correlation reflects very large differences between individuals’ reactions to the same noise (due to the modifying non-acoustic factors such as attitude to the noise maker, personality traits, perception of control over the noise and noise sensitivity etc.) rather than a failure of experimental design.

The dose responses for WT noise established so far (e.g. Janssen *et al.,* 2011) typically follow this already established pattern for many noise sources i.e. all the derived “curves of best fit” for dose response are smooth with typically lower rates of response at low compared to high noise level and the data on response versus level is widely spread and is different from one study to another (Pedersen, 2011); and the correlation between level and response not particularly strong due to the influence of non-acoustic factors. Consequently, any point on a dose response curve represents the average or typical response, not that of an individual.

These curves show that, as found by many studies for other noise sources, there is no discrete step change in subjective response at any specific noise level or over a narrow range of noise levels that can be reliably used as a suitable threshold of change from acceptable to unacceptable impact. Thus noise limits have to be set to represent a compromise between reducing the level of impact to zero, and the resulting environmental, social, economic, historical and political constraints that are also important. As a result, any guideline or noise limit value for WTs can only sensibly be based on judgment informed by indicative trends in regard to overall subjective response weighed against the benefit of the turbines.

This is what ETSU–R-97 aims to achieve whilst providing a reasonable degree of protection to those who might be affected; without unduly restricting the development of WT renewable energy resources. The guidelines do not aim for the absolute protection of all amenity and all persons in all circumstances at all costs – a standard which is never applied to the control of noise in the UK or anywhere else. This means that inevitably some persons, in some circumstances will not be satisfied by the degree of protection afforded by the ETSU-R-97 method.

Criticism of ETSU-R-97 for inconsistent implementation led to the DECC (2011a) report on the "Analysis of How Noise Impacts are considered in the Determination of Wind Farm Planning Applications". Additionally, Bowdler (2012) pointed out its complexity and proposed changes to ETSU-R-97 in terms of noise limits and assessment method. His proposals would result in much more conservative noise level estimates. A detailed discussion of the proposals can be found in Appendix III. Many of the points Bowdler raises in regard to determining background noise levels will be addressed by the Best Practice Guide for use of ETSU-R-97 being produced in response to the DECC (2011a) report by the Institute of Acoustics and due for release in May 2013.

Where noise problems occur once WTs are in place, operational restrictions are commonly used. For a number of turbine models limitations to blade passing frequency as reported in (Bockstael *et al.* 2012) are possible. Other operational restrictions request shutting down individual turbines for certain periods (Bockstael *et al.* 2012, Pedersen *et al.* 2009).

Using masking sounds at noise sensitive receptors has been largely unsuccessful in the past (Pedersen 2010) but remains the subject of current research (Bolin 2012).

8. Conclusions

- The review shows there to be evidence for annoyance due to WT noise.
- There is also some evidence for sleep disturbance which has found fairly wide, though not universal, acceptance. It should be noted that environmental noise from other sources such as road traffic and aircraft noise is a known causes of annoyance and sleep disturbance so to find these effects from WTs is not unexpected.
- Some authors label these effects as health effects and others do not.
- WT sound, visual impact, economic benefit and attitude have all been identified as contributing factors to annoyance. If low frequency noise and infrasound was an issue an as yet unproven method of human response would have to be involved.
- Universally agreed noise mitigation strategies have not been identified. Generally noise issues can be minimised by conservative noise limits. Set-back distances are also used internationally but have a number of disadvantages.
- The relevant UK guideline document ETSU-R-97 has been derived from research on the response to noise and aims to provide a reasonable degree of protection to noise sensitive listeners; without unduly restricting the development of WT renewable energy resources. Good practice guidelines on the implementation of ETSU-R-97 are due to be published in May.
- Shadow flicker has been reported to be less of a problem and to be controllable in the current planning framework.

9. References

The publications specifically requested to be reviewed are marked by *.

*Ambrose, S. E., Rand, R. W., and Krogh, C. M. E. (2012). "Falmouth, Massachusetts wind turbine infrasound and low frequency noise measurements," in Internoise (New York).

AWEA/CANWEA (2009) W. David Colby, M.D. *et al.*, Wind Turbine Sound and Health Effects, An Expert Panel Review 2009, Prepared for American Wind Energy Association and Canadian Wind Energy Association

Bakker RH, Pedersen E, van den Berg GP, Stewart RE, Lok W, Bouma (2012) Impact of wind turbine sound on annoyance, self-reported sleep disturbance and psychological distress. *J. Sci Total Environ.*

Berglund, B., Lindval, T., Schwela D. H. (1999), Guidelines for community noise, WHO, Geneva, CH, pp. 161

Bockstael, A., Dekoninck, L., Can, A., Oldoni, D., De Coensel, B., and Botteldooren, D. (2012). "Reduction of Wind Turbine Noise Annoyance: An Operational Approach," *Acta Acustica United with Acustica* **98**, 392-401.

Boczar, T., Malec, T., and Wotzka, D. (2012). "Studies on Infrasound Noise Emitted by Wind Turbines of Large Power," *Acta Physica Polonica* A **122**, 850-853.

Bolin, K. Bluhm, G., Eriksson, G. and Nilsson, M. E.; 2011 *Environ. Res. Lett.* 6 035103; Infrasound and low frequency noise from wind turbines: exposure and health effects.

Bolin, K., Kedhammar, A., and Nilsson, M. E. (2012). "The Influence of Background Sounds on Loudness and Annoyance of Wind Turbine Noise," *Acta Acustica United with Acustica* **98**, 741-748.

*Bowdler, D. (2012a). "ETSU-R-97, an alternative view", *Acoustics Bulletin*, **37**,3, 32-36

Bronzaft, A. L. (2011). "The Noise From Wind Turbines: Potential Adverse Impacts on Children's Well-Being," *Bull Sci Tech Soc*. **31**, 291-295.

Copes, R. and K. Rideout. Wind Turbines and Health: A Review of Evidence. Ontario Agency for Health Protection and Promotion 2009. (presentation)

*DECC (2011). Update of UK Shadow Flicker Evidence Base. London, Department of Energy & Climate Change, Report by Parsson & Brinckerhoff

DECC (2011a). "Analysis of How Noise Impacts are considered in the Determination of Wind Farm Planning Applications" Ref HM: 2293/R1 dated 6th April 2011", Report by Hayes McKenzie.

Evans, T. and J Cooper & V Lenchine - Infrasound levels near wind farms and in other environments, South Australia Environment Protection Authority, January 2013.

Farboud, A. and R Crunkhorn, A Trinidade. ‘Wind turbine syndrome’: fact or fiction?; The *Journal of Laryngology & Otology*, 1 of 5. 2012

Fiumicelli, D. (2011). "Wind Farm Noise Dose Response - A literature review," *Acoustics Bulletin*.

Griffiths, I.D. and Raw, G.J., 1986. Community and individual responses to changes in traffic noise exposure. Journal of Sound and Vibration, 111(2), pg 209-217; and,

Griffiths, I.D. and Raw, G.J,. Adaptation to changes in traffic noise exposure. Journal of Sound and Vibration, 132(2), pg 331-336, 1989.

Guski R. How to forecast community annoyance in planning noisy facilities. Noise and Health, Vol 6: pg 59-64, 2004.

*Hanning, C. D. (2010). "Wind turbine noise, sleep and health," edited by S. f. W. Vigilance.

Harrison, J. P.; Wind Turbine Noise; Bull Sci Tech Soc. 31, 4 256-261

Hessler, D. M., and Hessler, G. F., Jr. (2011). "Recommended noise level design goals and limits at residential receptors for wind turbine developments in the United States," Noise Control Engineering Journal **59**, 94-104.

Horner, B., Roy D. Jeffery, Carmen M. E. Krogh (2011); Literature Reviews on Wind Turbines and Health Are They Enough? Literature Reviews on Wind Turbines and Health: Are They Enough? ; *Bull Sci Tech Soc*. 2011 **31**: 399-413

Janssen SA, Vos H, Eisses AR, Pedersen E. (2011) A comparison between exposure-response relationships for wind turbine annoyance and annoyance due to other noise sources. *J Acoust Soc Am.* Dec; **130**(6):3746-53.

Kaldellis, J. K., Garakis, K., and Kapsali, M. (2012). "Noise impact assessment on the basis of onsite acoustic noise immission measurements for a representative wind farm," *Renewable Energy* **41**, 306-314.

Katsaprakakis, Dimitris Al. (2012) A review of the environmental and human impacts from wind parks. A case study for the Prefecture of Lasithi, Crete, *Renewable & Sustainable Energy Reviews* **16**(5), 2850-2863

*Knopper LD, Ollson CA. (2011) Health effects and wind turbines: a review of the literature, *Environ Health*. Sep 14;**10**:78.

Krogh, C, Gillis, L., Kouwen, N., Aramini, J. (2011). WindVOiCe, a Self-Reporting Survey: Adverse Health Effects, Industrial Wind Turbines, and the Need for Vigilance Monitoring. *Bull Sci Tech Soc*. ; **31**: 334

Krogh, C. M. E. (2011). "Industrial Wind Turbine Development and Loss of Social Justice?," *Bulletin of Science, Technology & Society* **31**, 321-333.

Lee, S., Kim, K., Choi, W., and Lee, S. (2011). "Annoyance caused by amplitude modulation of wind turbine noise," Noise Control Engineering Journal 59, 38-46.

Leventhall, G., Pelmear, P., & Benton, S. (2003). A review of published research on low frequency noise and its effects. Defra, London.

Leventhall, G. (2009). "Low Frequency Noise. What we know, what we do not know, and what we would like to know," Journal of Low Frequency Noise Vibration and Active Control 28, 79-104.

*MDEP (Massachusetts Department of Environmental Protection), Massachusetts Department of Public Health; January (2012); Wind Turbine Health Impact Study: Report of Independent Expert Panel .

Maris, E., PJM Stallen, H. Steensma, and R. Vermunt - Evaluating noise in social context: the effect of procedural unfairness on noise annoyance judgments. J Acoust Soc Am. 2007 Dec; 122(6):3483-94.

McMurtry, R. Y. (2011). "Toward a Case Definition of Adverse Health Effects in the Environs of Industrial Wind Turbines: Facilitating a Clinical Diagnosis," Bulletin of Science, Technology & Society 31, 316-320.

Minnesota Department of Health Environmental Health Division; May 22, (2009). - Public Health Impacts of Wind Turbines

Møller, H., and Pedersen, C. S. (2011). "Low-frequency noise from large wind turbines," Journal of the Acoustical Society of America **129**, 3727-3744.

Moorhouse, A., Waddington, D., & Adams, M. (2005). Proposed criteria for the assessment of low frequency noise disturbance. Defra contract no NANR45.

Mroczek B, Kurpas D, Karakiewicz B. (2012) Influence of distances between places of residence and wind farms on the quality of life in nearby areas. *Ann Agric Environ Med.* **19**(4):692-6.

Nissenbaum MA, Aramini JJ, Hanning CD. (2012) Effects of industrial wind turbine noise on sleep and health *Noise Health*. **14**(60):237-43.-.

O'Neal, R. D., Hellweg, R. D., Jr., and Lampeter, R. M. (2011). "Low frequency noise and infrasound from wind turbines," *Noise Control Engineering Journal* **59**, 135-157.

Pedersen, E., (2011) - Health aspects associated with wind turbine noise—Results from three field studies, *Noise Control Eng*. J. **59** (1), Jan-Feb 2011.Pedersen, E., van den Berg, F., Bakker, R., and 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**, 2520-2527.

Pedersen E, van den Berg F, Bakker R, Bouma J. (2009) Response to noise from modern wind farms in The Netherlands *J Acoust Soc Am.* **126**(2):634-43.

Pedersen, C. S., Møller, H., & Waye, K. P. (2008). A Detailed Study of Low-Frequency Noise Complaints. Low Frequency Noise & Vibration and Active Control, 27(1), 1–33. doi:10.1260/026309208784425505

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.

Punch J, James R, Pabst D. Wind turbine noise: what audiologists should know. *Audiology Today* 2010;**22**:20–31

Rand R. W., Ambrose S. E., Carmen M. E. Krogh (2011); Occupational Health and Industrial Wind Turbines - A Case Study; *Bulletin of Science Technology Society* October 2011, **31**,5 359-362.

Roberts M, and Roberts J., (2009) Evaluation of the scientific literature on the health effects associated with wind turbines and low frequency sound. Exponent Inc. Prepared for Wisconsin Public Service Commission Docket No. 6630-CE-302. October 2009.

*Salt, A.N. and T.E. Hullar Responses of the ear to low frequency sounds, infrasound and wind turbines, *Hearing Research* **268** (2010);

Salt, A.N. and Kaltenbach, J. A., Infrasound From Wind Turbines Could Affect Humans, *Bulletin of Science, Technology & Society* August 2011 **31**: 296-302;

*Salt, A. N., and Lichtenhan, J. T. (2012). "Perception-based protection from low-frequency sounds may not be enough," in Internoise (New York, US).

*Shepherd D, McBride D, Welch D, Dirks KN, Hill EM. (2011) Evaluating the impact of wind turbine noise on health-related quality of life *Noise Health*, **54**:333-9.

Smedley, Andrew R. D.; Webb, Ann R.; Wilkins, Arnold J. (2010) Potential of wind turbines to elicit seizures under various meteorological conditions, *Epilepsia*, **51** (7), 1146-1151,

Thorne, B; The Problems With “Noise Numbers” for Wind Farm Noise Assessment; *Bulletin of Science Technology Society* August 2011 **31,** 4 262-290.

Verheijen E, Jabben J, Schreurs E, Smith KB. (2011) Impact of wind turbine noise in the Netherlands. *Noise Health*.;**13**(55):459-63. -.

*Walker, B., Hessler, G. F., Hessler, D. M., Rand, R., and Schomer, P. (2012). "A Cooperative Measurement Survey and Analysis of Low Frequency and Infrasound at the Shirley Wind Farm in Brown County, Wisconsin," edited by C. Wisconsin, p. 51.

10. Appendix I: International comparison of planning guidelines

INTERNATIONAL STANDARDS FOR WIND TURBINE NOISE CONTROL

Perception and Description of Sound

Between the quietest audible sound and the loudest tolerable sound there is a million to one ratio in sound pressure (measured in pascals, Pa). Because of this wide range a noise level scale based on logarithms is used in noise measurement called the decibel (dB) scale. Audibility of sound covers a range of approximately 0 to 140 dB.

The human ear system does not respond uniformly to sound across the detectable frequency range and consequently instrumentation used to measure noise is weighted to represent the performance of the ear. The most commonly used form of weighting is known as the 'A weighting' and annotated as dB(A)

Table 1 below lists typical sound pressure levels in dB(A) for common situations.

Table 1: Noise Levels for Common Situations

Typical Noise Level, dB(A)	Example
0	Threshold of hearing
20-30	Rural area at night, still air
30-40	Public library, Refrigerator humming at 2m
40-50	Quiet office, no machinery, Boiling kettle at 0.5m
50-60	Normal conversation
60-70	Telephone ringing at 2m, Vacuum cleaner at 3m
70-80	General factory noise level
80-90	HGV at pavement, Powered lawnmower at ear
90-100	Pneumatic drill at 5m
100-120	Discotheque - 1m in front of loudspeaker
120-140	Threshold of pain

dB re 20 µPa.

The noise level at a measurement point is rarely steady, even in quiet rural areas, and varies over a range dependent upon the effects of distant and local noise sources. For example close to a busy motorway, where persistent road traffic noise dominates the soundscape, the noise level may vary over relatively small range of only 5 dB(A); whereas in a suburban area this range may increase up to 20 dB(A) and more due to the multitude of noise sources in such areas (cars, dogs, aircraft etc.) and their variable operation; and in rural locations by even more due to the low density of noise sources and often long periods between noise events. Furthermore, the range of night-time noise levels will often be smaller and the levels significantly reduced compared to daytime levels. When considering environmental noise, it is necessary to consider how to quantify the existing noise (the ambient noise) to account for this often very rapid variability.

In order to describe these always changing noise conditions and to provide adequate links to the various effects of noise the science of acoustics has developed a range of noise indices. For example the equivalent continuous A-weighted sound pressure level, LA_{eq}, is the single number that represents the sound energy measured over that period and is equivalent to the total ambient sound during a defined period. It is the sound level of a notionally steady sound having the same energy as the fluctuating sound over a specified measurement period. The $LA_{max,t}$ index is the maximum instantaneous sound pressure level attained during the relevant measurement period. Whilst statistical indices such as the $LA_{90,t}$ and the $LA_{10,t}$ represent the noise level exceeded for a define proportion of a period; in these examples for 90% and 10% of the time t, respectively. Another commonly used index is $L_{DEN,t}$ (Day Evening Night), an LA_{eq} which applies penalties to the evening and night levels to account for greater listener sensitivity during these periods.

Human subjects under normal conditions, and for sounds of a similar temporal and spectral nature, are generally only capable of noticing changes in noise levels of no less than 3 dB(A); although changes of less than this can be detected under controlled conditions or when the change is due to the introduction of a new noise source with different temporal and spectral characteristics into an existing soundscape. It is generally accepted that a change of 10 dB(A) in an overall, steady noise level is perceived to the human ear as a doubling (or halving) of the noise; although because the sensation of loudness grows more rapidly for low frequency sounds, smaller changes in low frequency noise can be perceived as equivalent to greater changes in higher frequency noise.

NOISE ASSESSMENT METHODS

There are broadly three main methods available to assess the likelihood of noise causing a disturbance to residents, as summarised below.

Benchmark Assessment – Absolute (fixed limits)

Benchmark noise impact assessments are made by comparing specific sound levels against established benchmark values defined in existing standards and regulations i.e. does the noise level exceed a specific threshold of acceptability. Should specific sound levels exceed any defined benchmarks this is taken as indicative of negative impacts of the noise under consideration. These type of assessment methods are normally based on established research that is often noise source or type specific so the value of the threshold of acceptability will vary between sources and types of noise and for the effect considered e.g. annoyance or sleep disturbance etc.

Benchmark limits are relatively easy to set and measure, provided there is sufficient headroom with the existing ambient noise levels. Where a noise limit is close to existing noise levels there can be difficulties in reliably establishing the true value of the noise from the source in question due to intrusion of extraneous noise.

Change comparisons – Relative

Relative change comparisons are carried out by comparing specific sound levels before and after a development to describe the difference in specific sound level between the before and after situations. Increases or decreases in relevant specific sound levels or other features are indicative of negative or positive noise impacts of the development respectively.

The simple comparison of noise levels before and after a development is an attractive concept as it is relatively straightforward. However, there can be limitations to such an approach as whilst it is reasonably well suited to assessment of the impacts of changes in the noise level of a particular source, it is less well suited to assessment of the impacts of introducing a new noise source into an existing soundscape.

Crucial to efficient use of change based noise limits is robustly establishing the pre-scheme noise levels. This can require extensive surveying at many sensitive receptors or the results may not be adequately representative of typical conditions.

Context Comparisons – Relative

Context comparisons are carried out by comparing specific sound levels from a source against appropriate indicators of the pre-existing situation before the development takes place. Appropriate indicators of the pre-existing situation may include either or both the ambient and background sound levels. Examples of context comparisons might include comparing specific sound levels of a source against existing ambient or background sound levels without the development.

Noise limits for wind turbines are broadly similar across many countries. Noise limits can vary based on the number and size of wind turbines and the number of nearby residences, but nearly all include consideration of wind speed and the noise sensitivity of the time of day. Generally, noise limits are lower during the night and in rural areas with few residences, and higher during the day and in areas with a greater amount of residences and pre-existing background sound. In several locations the noise limit increases as the wind speed increases because the natural sound from the wind is amplified along with the noise from wind turbines.

Where the limits are set relative to existing noise level, baseline measurements are required in order to determine these limits. The results of baseline noise necessarily depend on what noise occurs during the periods of measurement and, to a certain extent, on the location chosen for the measurements. There may, therefore, be a limit on the precision in such measurements and they should be viewed as providing results which are representative of the conditions prevailing at the time of the measurement(s). Additionally, where relative noise limits are set close to existing noise levels there can be problems reliably establishing the noise level of the source under investigation due to the influence of extraneous noise.

The table below provides an overview of noise control standards applicable to wind energy schemes from 16 different countries. Some are specifically for wind turbines, but many are generic requirements that apply to industrial noise sources or noise of an industrial nature. A substantial proportion are of the benchmark fixed absolute level type, a significant minority are a hybrid of benchmark fixed absolute and context comparison relative type assessments, only one is a pure context comparison relative type assessment; and none are change comparisons – relative type assessments.

Country	Type of Assessment Method	Detail
Australia – Varies from State to State	Mixed Absolute Benchmark – fixed (lower limits) and Context Comparisons – Relative	**South Australia** Wind farm developments in South Australia must comply with the South Australian EPA's Wind farm environmental noise guidelines (2009), which set criteria as: • $LA_{90,t}$ 40 dB(A) or • $LA_{90,t}$ background + 5 dB(A) Whichever is the greater at each integer wind speed from cut-in wind speed to wind speed at rated power. The criteria are set only for the 24 hour period and do not include a separate night time criteria. The 40 dB(A) base limit becomes 35 dB(A) in areas set aside in planning documents for "rural living", e.g. no primary production. Wind farm noise is measured at each integer wind speed using the L90,10min noise level with a regression analysis of data in the downwind direction (±45º) for the measurement location. Tonality criteria are set as 0 dB tonal audibility at the residence, when assessed in

Country	Type of Assessment Method	Detail
		accordance with IEC 61400-11. A 5 dB(A) penalty is applied for any audible tones from the wind farm exceeding the criteria. The penalty is generally applied to the overall measured noise level at the wind speed at which the tone is detected regardless of the frequency of occurrence, although this is not well defined. No specific criteria are defined for amplitude modulation or low frequency noise. **Victoria** Use New Zealand Standard 6808:2010, which set criteria as: • $LA_{90,t}$ 40 dB(A) or • $LA_{90,t}$ background + 5 dB(A) Whichever is the greater at each integer wind speed across a wind speed range including cut-in wind speed to wind speed at rated power as a minimum. Unlike the SA Guidelines, separate criteria are normally determined for both all time periods and for the night time period (10 pm to 7 am). Victorian authorities modify the requirements of the NZ Standard with regard to the application of a “high amenity” limit. Strictly under the NZ Standard the high amenity limit

Country	Type of Assessment Method	Detail
		is intended to only apply in areas that planning documents indicate are of high amenity (e.g. country living / lifestyle areas). However, Victorian authorities currently require that the test for a high amenity limit is undertaken at all receiver locations, regardless of zoning. Under the high amenity criteria, the 40 dB(A) base limit becomes 35 dB(A) at wind speeds of 6 m/s and below. The applicability of the high amenity limit is determined through comparison of the predicted turbine noise to the measured background noise for evening and night time periods. If the average difference is greater than 8 dB(A), then the high amenity limit will apply but only at wind speeds of 6 m/s and below. As for the SA Guidelines, wind farm noise is measured as the average L90,10min noise level. However, unlike the SA Guidelines, all wind directions are considered in the measurement. EPA Victoria is about to release a guideline defining application of NZS 6808:2010 to wind farm noise assessments, including definition of the application of noise character penalties. Penalties are set at 5 dB(A), except for the tonality penalty which can be between 1 and 6 dB(A). Noise character assessment procedures in the Guideline are: • Application of the tonality criteria contained in Annex C of ISO 1996-2:2007. This applies a scaled penalty of up to 6 dB where the tonal audibility exceeds 4 dB.

Country	Type of Assessment Method	Detail
		• Application of impulsiveness criteria contained in AS 1055.1. • Application of the interim objective criteria for amplitude modulation contained in NZS 6808:2010. • Application of the proposed DEFRA criteria for low frequency noise assessment. An assessment of tonality, amplitude modulation, impulsiveness or low frequency noise would only be required where a subjective assessment by an acoustic specialist or representative of the responsible authority has identified the potential for a noise character penalty. A maximum overall penalty of 6 dB(A) is applicable (regardless of the number of noise character penalties applicable to any measurement) and the penalty is added to the individual 10-minute noise level for the period for which the noise character penalty was objectively determined to apply. **New South Wales** Historically, wind farm developments in NSW have had to comply with the 2003 SA Wind farms environmental noise guidelines (refer to Western Australia). However, in late 2011, the NSW Department of Planning and Infrastructure released the Draft NSW Planning Guidelines: Wind Farms for consultation. The Draft NSW Guidelines

Country	Type of Assessment Method	Detail
		received a significant number of submissions and no final version has been released. The noise criteria from the Draft NSW Guidelines are presented here but it is possible that there may be a considerable number of changes in any final version. Noise criteria under the Draft NSW Guidelines are: • $LA_{90,t}$ 35 dB(A) or • $LA_{90,t}$ background + 5 dB(A) Whichever is the greater at each integer wind speed from cut-in wind speed to wind speed at rated power. Criteria are determined separately for day (7 am to 10 pm) and night (10 pm to 7 am) periods. The Leq,10min wind farm noise level must comply with the criteria, measured as the average L90,10min noise level + 1.5 dB(A) in the downwind direction (±45º) for the measurement location. Objective noise character penalties are defined for: • Tonality – 5 dB(A) penalty applied based on simplified assessment procedure from ISO

Country	**Type of Assessment Method**	**Detail**
		1996-2:2007 (comparison of adjacent one-third octave bands). • Amplitude modulation – 5 dB(A) penalty applied where there is excessive amplitude modulation, taken as variation of greater than 4 dB(A) with respect to the blade passing frequency. • Low frequency noise – 60dB(C) external screening level. 5 dB(A) penalty where proposed DEFRA criteria are found to be exceeded. Penalties are applied according to the following procedure: • Single exceedance – occurs when wind farm noise displays a characteristic for a 10-minute averaged period. Penalty is applied to the individual 10-minute period only. • Repeated exceedance – occurs when single exceedance events occur for more than 10% of a day or night time period. In this case, the penalty is applied to the overall measured wind farm noise level for the specific wind directions and speeds under which the characteristic occurs. • Sustained exceedance – occurs when a repeated exceedance occurs for more than 30% of a season. In this case, operation of the wind farm should be modified to ensure that the noise characteristic exceedances are minimised. **Western Australia** Wind farm developments in Western Australia must comply with the South Australian EPA's Wind farm environmental noise guidelines (2003), which set criteria as: • $LA_{90,t}$ 35 dB(A) or • $LA_{90,t}$ background + 5 dB(A)

Country	Type of Assessment Method	Detail
		whichever is the greater at each integer wind speed from cut-in wind speed to wind speed at rated power. On one recent project, the 2009 SA Guidelines have also been applied but the 35 dB(A) base limit has been maintained for all residential receivers. The only substantial difference between the two versions of the SA Guidelines is the replacement of 10 m height wind speeds from the 2003 Guidelines with hub height wind speeds in the 2009 Guidelines. Tonality, amplitude modulation and impulsiveness would likely be assessed against the noise character penalties in the WA EPA Noise Regulations 1997. However, due to the limited number of developments, no details have been provided regarding assessment procedures or how to apply any noise character penalty to a wind farm. **Queensland** No formal criteria have been defined in Queensland, although this may change in the near future. In mid-2012, the Queensland Department of Energy and Water Supply requested submissions on technical issues relevant to wind farm development including

Country	**Type of Assessment Method**	**Detail**
		noise assessment. The small number of proposed and completed wind farm developments in Queensland to date have typically been assessed against the 2003 or 2009 SA Guidelines.
Canada	Absolute Benchmark – Fixed Upper Limits	No Federal guidelines; instead provinces apply their own legislation. **Alberta** The Alberta Utilities Commission Rule 012 (Dec 2012) requires that for wind turbines, noise should be measured when wind speeds are 6-9 meters per second at 15 meters from the most affected residence within 1.5 km. The night noise limits should remain between 40 and 56 dB(A) LA_{eq}, based on the number of other residences and existing infrastructure noise sources. For most wind energy locations, the night noise limits tends to fall between 40 and 46 dB(A) LA_{eq}. The day noise limits are 10 dB(A) above night limits. Low frequency noise should also be measured with C-weighted sound measurements to ensure that low frequency noise is not excessive i.e. where dBC – dB(A) > 20 dB. **Manitoba** Manitoba uses the noise limit scale developed by the Canadian Wind Energy Association, with limits ranging from 40 dB(A) at wind speeds of 4 meters per second (13 feet/second) to 53 dB(A) at 11 meters per second (36 feet/second).

<table>
<tr><th>Country</th><th>Type of Assessment Method</th><th>Detail</th></tr>
<tr><td></td><td></td><td>
New Brunswick
In New Brunswick, noise limits vary with wind speed, ranging from 40 dB(A) at wind speeds below 7 meters per second (23 feet/second), to 53 dB(A) at wind speeds above 10 meters per second
Ontario
<table>
<tr><td>Wind Speed (m/s) at 10 m height</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td></tr>
<tr><td>Rural - LA_{eq},1 hr dB</td><td>40.0</td><td>40.0</td><td>40.0</td><td>43.0</td><td>45.0 0</td><td>49.0</td><td>51.0</td></tr>
<tr><td>Urban - LA_{eq},1 hr dB</td><td>45.0</td><td>45.0</td><td>45.0</td><td>45.0</td><td>45.0</td><td>49.0</td><td>51.</td></tr>
</table>
</td></tr>
<tr><td>Czech republic</td><td>Absolute Benchmark – Fixed Upper Limits</td><td>

No more than 50 dB(A) Leq, t during the day
No more than 40 dB(A) Leq, t at night

To include a 5 DB penalty for tonality where the turbine noise in any 1/3 octave band between 10 and 160 Hz exceeds both the neighbouring 1/3 octave bands by 5 dB.
</td></tr>
<tr><td>Denmark</td><td>Absolute Benchmark – Fixed Upper Limits</td><td>Wind turbines must respect noise limits in accordance with the Statutory Order. The limits are:</td></tr>
</table>

Country	**Type of Assessment Method**	**Detail**
		• For dwellings, summer cottages, etc.: 39 dB (wind speeds of 8 m/s) and 37 dB (wind speeds of 6 m/s) • For dwellings in open country: 44 dB (wind speeds of 8 m/s) and 42 dB (wind speeds of 6 m/s) For both categories of areas the limit for low frequency noise is 20 dB(A) (1/3-octave bands 10 - 160 Hz). The limit for low frequency noise applies to the calculated indoor noise level at both 6 and 8 m/s wind speed
France	Mixed Absolute Benchmark – fixed (lower limits) and Context Comparisons – Relative	No wind farm specific standards Limits external noise to a lower limit of 30 dB(A) LA_{eq} and a above this no more than 5dB(A) $L_{eq,t}$ above ambient $LA_{eq,t}$ noise during the day and 3dB(A) $L_{eq,t}$ above ambient $LA_{eq,t}$ noise at night. And Limits internal noise to no more than 25 dB(A) $L_{eq,t}$ overall and a relative lit of 7 dB in the octave bands 125 Hz and 350 Hz and 5 dB at higher octave bands.
Germany	Absolute Benchmark – Fixed Upper Limits	No wind farm specific standards instead use generic legislation e.g.

<table>
<tr><th>Country</th><th>Type of Assessment Method</th><th>Detail</th></tr>
<tr><td></td><td></td><td>
<table>
<tr><th rowspan="2"></th><th colspan="8">Land Use</th></tr>
<tr><th colspan="2">Commercial</th><th colspan="2">Mixed</th><th colspan="2">Residential</th><th colspan="2">Rural</th></tr>
<tr><td rowspan="2">$LA_{eq,t}$ dB</td><td>Day</td><td>Night</td><td>Day</td><td>Night</td><td>Day</td><td>Night</td><td>Day</td><td>Night</td></tr>
<tr><td>65</td><td>50</td><td>60</td><td>45</td><td>55</td><td>50</td><td>50</td><td>35</td></tr>
</table>

Many German state governments recommend a 1000meter wind turbine setback from residences, but minimum setbacks may be as small as 300 meters and normally the minimum distance is determined by the noise constraint.</td></tr>
<tr><td>Ireland</td><td>Absolute Benchmark – Fixed Upper Limits

Mixed Absolute Benchmark – fixed (lower limits) and Context</td><td>The Planning and Development Regulations 2008 (S.I. 235 of 2008) amended by the Planning and Development Regulations 2001 to 2010 provides an exemption as Class 56(c) for renewable energy technologies for commercial, public, industrial and agricultural buildings where the proposed development complies with the following noise limits:

Noise levels must not exceed 43db(A) during normal operation, as measured from the nearest party boundary.

Where a wind turbine does not qualify for this planning exemption, the application must be made under the Planning and Development Acts 2000 to 2010. Under Category 3(i) of the Fifth Schedule Part II of the Planning and Development Regulations 2001 (S.I. No.</td></tr>
</table>

<table>
<tr><th>Country</th><th>Type of Assessment Method</th><th>Detail</th></tr>
<tr><td></td><td>Comparisons – Relative</td><td>600 of 2001), an environmental impact statement (EIS) is required where the energy production is generated by more than five turbines or having a total output greater than 5 megawatts.
For sub-threshold turbine developments (i.e. less than the threshold of five turbines or having a total output less than 5 megawatts), a local authority may still request an EIS if the development is considered to have potentially significant impacts.

Typically noise assessments must show that the sites will not create unacceptable noise impacts. It must be prepared in accordance with the DoEHLG's document - Wind Farm Planning Guidelines; which provides monitoring requirements and daytime/ night-time compliance limits:
35-40 dB(A) for quiet daytime environments of less than 30 dB(A)
45 dB(A) for daytime environments greater than 30 dB(A)
5 dB(A) above background levels when background is greater than 40 dB(A)</td></tr>
<tr><td>Italy</td><td>Absolute Benchmark – Fixed Upper Limits</td><td>No wind farm specific standards instead use generic legislation e.g.
<table><tr><th rowspan="2">Land Use</th><th colspan="2">$LA_{eq,t}$ dB</th></tr><tr><th>Day</th><th>Night</th></tr><tr><td>Hospital, School, City Park</td><td>50</td><td>40</td></tr></table></td></tr>
</table>

Country	**Type of Assessment Method**	**Detail**
		Residential / 55 / 45; Mixed Use (commercial/residential) / 60 / 50; Intense Activity (railway, harbour, motorway) / 65 / 55; Industrial / 70 / 70
Japan	Absolute Benchmark – Fixed Upper Limits	No wind farm specific standards instead generic legislation covering industrial noise appears to apply e.g.

Residential	55	45
Mixed Use (commercial/residential)	60	50
Intense Activity (railway, harbour, motorway)	65	55
Industrial	70	70

Area	Daytime $LA_{eq,t}$	Morning Evening $LA_{eq,t}$	Night Time $LA_{eq,t}$	Applicable Areas
I	45 - 50 dB	40 - 45 dB	40 - 45 dB	Areas where maintenance of quiet is particularly needed to preserve a good living environment.
II	50 - 60 dB	45 - 50 dB	40 - 50 dB	Areas where quiet is needed for as they are used for residential purposes.
III	60 - 65 dB	55 - 65 dB	50 - 55 dB	Areas used for commercial and

<table>
<tr><th>Country</th><th>Type of Assessment Method</th><th>Detail</th></tr>
<tr><td></td><td></td><td>
<table>
<tr><td></td><td></td><td></td><td></td><td>industrial as well as residential purposes where there is a need to preserve the living environment of local residents.</td></tr>
<tr><td>IV</td><td>65 - 70 dB</td><td>60 - 70 dB</td><td>55 - 65 dB</td><td>Areas mainly serving industrial purposes which are in need of measures to prevent the living environment of local residents from deteriorating.</td></tr>
</table>
</td></tr>
<tr><td>Netherlands</td><td>Absolute Benchmark – Fixed Upper Limits</td><td>Wind turbine noise is restricted to an external L_{den} value of 47 dB(A) and an L_{night} value of 41 dB(A).</td></tr>
<tr><td>New Zealand</td><td>Mixed Absolute Benchmark – fixed (lower limits) and Context Comparisons – Relative</td><td>Noise criteria for wind farms in New Zealand are defined in NZS 6808:2010

Procedures for the application of penalties are the same as that applied in the state of Victoria, Australia; with the exception that there is no explicit consideration of impulsiveness or low frequency noise criteria.

Additionally, application of the $LA_{90,t}$ 35 dB(A) base limit for “high amenity areas” follow the requirements of the standard for the area to be specifically identified in planning documents as one of high amenity, rather than the test being applied at all locations. If the area is identified as such in planning documents, then the high amenity test outlined in NZS 6808:2010 is undertaken to determine whether the $LA_{90,t}$ 35 dB(A) base limit is applicable for wind speeds of 6 m/s and below.</td></tr>
<tr><td>Portugal</td><td></td><td></td></tr>
</table>

<table>
<tr><th>Country</th><th>Type of Assessment Method</th><th>Detail</th></tr>
<tr><td></td><td>Absolute Benchmark – Fixed Upper Limits</td><td>No wind farm specific standards instead use generic legislation e.g.
<table>
<tr><th rowspan="2">Land Use</th><th colspan="2">$LA_{eq,t}$ dB</th></tr>
<tr><th>Day</th><th>Night</th></tr>
<tr><td>Sensitive Area (e.g. hospital and residential)</td><td>55</td><td>45</td></tr>
<tr><td>Mixed Area (e.g. cultural, recreational, commercial)</td><td>65</td><td>55</td></tr>
</table>
</td></tr>
<tr><td>South Korea</td><td>Absolute Benchmark – Fixed Upper Limits</td><td>No wind farm specific standards instead use generic legislation for industrial sources e.g.
<table>
<tr><th>Area</th><th>Daytime dB(A)</th><th>Nightime dB(A)</th></tr>
<tr><td>Industrial</td><td>70</td><td>60</td></tr>
<tr><td>Mixed industrial and residential</td><td>65</td><td>55</td></tr>
<tr><td>Purely residential</td><td>55</td><td>45</td></tr>
<tr><td>Areas with hospitals, resorts etc</td><td>50</td><td>40</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><th>Country</th><th>Type of Assessment Method</th><th>Detail</th></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Spain</td><td>Absolute Benchmark – Fixed Upper Limits</td><td>No wind farm specific standards instead use generic legislation e.g.
<table>
<tr><th rowspan="2">Noise wind farm specific standards instead use generic legislation e.g.
Land Use</th><th colspan="3">$LA_{eq,t}$ dB</th></tr>
<tr><th>Day</th><th>Evening</th><th>Night</th></tr>
<tr><td>Hospitals, Schools, Cultural Buildings</td><td>60</td><td>60</td><td>50</td></tr>
<tr><td>Residential Buildings</td><td>65</td><td>65</td><td>55</td></tr>
<tr><td>Commercial Buildings</td><td>70</td><td>70</td><td>60</td></tr>
<tr><td>Leisure and Sports Buildings</td><td>73</td><td>73</td><td>63</td></tr>
<tr><td>Industrial Buildings</td><td>75</td><td>75</td><td>65</td></tr>
</table>
</td></tr>
<tr><td>Sweden</td><td>Absolute Benchmark –</td><td>Noise recommendations for county and municipal boards for nearby residential and</td></tr>
</table>

Country	Type of Assessment Method	Detail
	fixed (upper limits)	educational facilities are 40 dB(A) day and night, related to a wind speed of 8 m/s at 10 m height It is unclear over what time period these measurements are averaged.
United Kingdom & NI	Mixed Absolute Benchmark – fixed (lower limits) and Context Comparisons – Relative	The technical detail of ETSU-R-97 is important, but in summary this guidance requires the predicted noise levels from the wind turbine under a range of wind speeds to be compared with the background noise level at noise sensitive premises under similar wind conditions. Noise limits are set at a turbine $LA_{90,10\ min}$ noise level no more than 5 dB(A) above the $LA_{90,10\ min}$ background noise level, subject to external lower limits of 43 dB(A) at night and 35 to 40 dB(A) during the day. The turbine noise limits to include a 5 dB(A) penalty for tonality where appropriate.
United States		A nationwide applicable limit for wind turbine noise is not available in the USA. Instead of imposing standard noise limits, the US Environmental Agency (US-EPA) recommends that local governments develop their own noise regulations or zoning ordinances. Some states have developed there own standards, but planning regulation goes down to county and city level which can have their own ordinances or develop standards on a case by case basis via hearings for applications for wind energy scheme permits.
Maine	Absolute Benchmark – fixed (upper limit) – depending on the type of neighbourhood and existing noise level	Routine operations of a proposed wind energy development are limited to $LA_{eq,t}$ 75 dB(A) at any time; to $LA_{eq,t}$ 60 dB(A) during the daytime; and to $LA_{eq,t}$ 50 dB(A) during the night time for non-commercial and non-industrial areas; and to $LA_{eq,t}$ 55 dB(A) daytime and $LA_{eq,t}$ 45 dB(A) night time for areas in which ambient sounds are $LA_{eq,t}$ 45 dB(A) or less daytime and $LA_{eq,t}$ 35 dB(A) or less night time. Therefore, as most wind projects are in

Country	**Type of Assessment Method**	**Detail**
		relatively quiet rural locations they are subject to a $LA_{eq,t}$ 45 dB(A) night time noise limit. These measurements represent an hourly average.
Massachusetts		Massachusetts Dept of Environmental Protection general noise regulation (310 CMR 7.10) provides the following • No increases the broadband sound level by more than 10 dB(A) above ambient, or • Must not Produce a "pure tone" condition – when any octave band centre frequency sound pressure level exceeds the two adjacent centre frequency sound pressure levels by 3 decibels or more. These criteria are measured both at the property line and at the nearest inhabited residence. "Ambient" is defined as the background A-weighted sound level that is exceeded 90% of the time, measured during equipment operating hours. "Ambient" may also be established by other means with consent of the Department.
Michigan	Mixed Absolute Benchmark – fixed (upper limit) – and Context Comparisons – Relative above this.	On Site Use wind energy systems shall not exceed Leq,t 55 dB(A) at the property line closest to the wind energy system. Exceptions for neighbouring property are allowed with the written consent of those property owners. This sound pressure level may be exceeded during short-term events such as utility outages and/or severe wind storms. If the existing ambient sound pressure level exceeds 55 dB(A), the standard shall be ambient Leq,t dB(A) plus 5 dB(A).
State of Oregon	Absolute Benchmark – fixed (upper limit)	No wind farm specific standards instead use generic legislation for industrial sources e.g.

<table>
<tr><th>Country</th><th>Type of Assessment Method</th><th>Detail</th></tr>
<tr><td></td><td></td><td>
<table>
<tr><th></th><th>Day</th><th>Night</th></tr>
<tr><td>LA_{eq}</td><td>55</td><td>50</td></tr>
<tr><td>L10</td><td>60</td><td>55</td></tr>
<tr><td>L1</td><td>75</td><td>60</td></tr>
</table>
</td></tr>
<tr><td>State of Washington</td><td>Absolute Benchmark – fixed (upper limit) – depending on the type of neighbourhood and existing noise level</td><td>
No wind farm specific standards instead use generic legislation e.g.
<table>
<tr><th rowspan="2">Noise Index (dB(A))</th><th colspan="2">Residential/Commercial/Recreational Receiver</th><th>Industrial Receiver</th></tr>
<tr><td>Day</td><td>Night</td><td>Anytime</td></tr>
<tr><td>LA_{eq}</td><td>60</td><td>50</td><td>70</td></tr>
<tr><td>L_{25}</td><td>65</td><td>55</td><td>75</td></tr>
<tr><td>$L_{8.3}$</td><td>70</td><td>60</td><td>80</td></tr>
<tr><td>$L_{2.5}$</td><td>75</td><td>65</td><td>85</td></tr>
</table>
</td></tr>
</table>

11. Appendix II: Overview over original studies since 2009

The following tables summarise recent health related original studies included in the review.

Epidemiological studies	Article included in review	No of respondents	Health effects reported
Sweden 2000	Pedersen (2011)	351	Yes
Sweden 2005	Pedersen (2011)	754	Yes
Netherlands	Pedersen (2009, 2010, 2011), Janssen (2011) Bakker (2012)	725	Yes
Makara Valley, New Zealand	Shepherd (2011)	66	Yes
Lasithi, Crete, Greece	Katsaprakakis(2012)	100	No
Ontario, Canada	Krogh (2011)	96	Yes
Poland	Mroczek (2012)	1277	No
Mars Hill/Vinalhaven, United States	Nissenbaum (2011)	79	Yes

Case Studies/Reports	
Wind Farm	**Article**
Deeping St Nicholas, UK	Thorne (2011)
Falmouth, US	Ambrose (2012)
Shirley, US	Walker (2012)
Te Rere Hau, NZ	Thorne (2011)
Vinalhaven, US	Nissenbaum (2011)
Waubra, AU	Thorne (2011)
Unknown	Rand (2011)

Laboratory studies	Topic
Bolin (2012)	Effectiveness of Masking
Lee (2011)	Amplitude modulation dose-response
Salt (2010, 2011,2012)	Physiological response of ear to LFN and infrasound

12. Appendix III: Remarks on Bowdler (2012)

Bowdler (2012) criticises the current guidelines on assessing the noise from wind turbines, ETSU-R-97 for its inconsistent implementation and relative complexity.

The technical detail of ETSU-R-97 is important, but in summary the guidance requires the predicted noise levels from wind turbines under a range of wind speeds to be compared with the background noise level at noise sensitive premises under similar wind conditions. Noise limits are set at 5 dB(A) above the $LA_{90,10\ min}$ background noise level, subject to a lower limit of 42 dB(A) at night and 35 to 40 dB(A) during the day. The lower limit noise level during the day is less than at night because it is aimed at protecting amenity spaces outdoors; whereas the night time limit is based on preservation of sleep indoors with windows open and where a modest degree of noise attenuation by the building envelope is to be expected.

Bowdler proposes streamlining the planning process by essentially using BS4142, which he claims to be simpler than ETSU-R-97. However, it is difficult to see how using BS 4142 for wind turbine noise would be any simpler than ETSU-R-97 as the latter is derived from the former. Additionally, ETSU-R-97 came about because of difficulties in using BS 4142 for wind turbines. The complication with using either BS 4142 or ETSU-R-97 for wind turbine noise is the need to link varying turbine noise levels at a range of wind speeds to the prevailing background noise level at equivalent wind speeds at noise sensitive receptors, in order to account faster wind speeds leading to more noise from a wind turbine and background noise levels rising as wind speeds increase.

Clearly when using any standard that sets noise limits relative to the existing background noise level it is important to establish what is a suitably representative value for the background noise level. Bowdler rightly points out that background noise levels can vary considerably, so establishing what is a suitably representative background noise level value is often not easy. However, this problem is shared by both BS 4142 and ETSU – R-97; although ETSU-R-97 offers much more comprehensive advice on how to derive representative background noise levels than BS 4142; which is fairly vague on this point, although it does advise that the “typical” background noise level should be used. Bowdler’s suggestion to make a worst case biased assessment by using the best fit curve minus 1 standard deviation would result in the use of $LA_{90,t}$ values that are exceeded for more than 84% of the time (assuming a normal distribution) i.e. they would not be typical. Another problem with using the best fit curve minus 1 standard deviation to derive the background noise level target would be that the resulting +5dB(A) noise limit would be very close to the prevailing background noise level, and almost certainly below the general ambient ($LA_{eq,t}$) noise level; thereby making it very difficult to monitor as separating turbine noise from extraneous noise from measurements of these in combination would be subject to substantial uncertainty; and any planning condition based on this approach most probably unenforceable. Additionally it is worth considering that the Environmental Impact Assessment regulations under which applications for most large scale wind farm schemes are determined, only require that the "likely significant effects" are assessed; not the worst conceivable effects.

Bowdler proposes using the difference between the $LA_{90,t}$ noise index at a receptor from prior to the wind turbine development and after to assess impact. Whilst this difference is an attractively simple proposition there are significant drawbacks, including the following:

- There appears to be no scientific basis or agreed consensus for the proposed matrix of changes and associated semantic descriptors.
- The problem of establishing the existing prevailing background noise level remains.
- Solely using the change in noise level to assess the significance of noise impact; rather than also considering the absolute noise level i.e. how loud the turbine is; makes it harder for the decision maker to weigh the benefits in terms of the public interest in increasing renewable energy supply and dis-benefits in terms of the private interest in protecting the existing amenity of individual property owners; as potentially a change in noise level of > 8 dB(A) is ranked according to Bowdler's matrix as a major level of amenity loss; whereas the resulting noise level may still be substantially less than established thresholds of acceptability.
- The matrix appears to be fixed i.e. the same semantic descriptor applies to the same range of change in noise levels no matter how low the existing prevailing background noise level is or how high the final turbine noise level is. Whereas the subjective rate of response to turbine noise at low levels is low, therefore an apparently large change from very low existing background levels to a higher value is less likely to have as significant an effect as the same change in circumstances where the existing background levels are moderate or high.

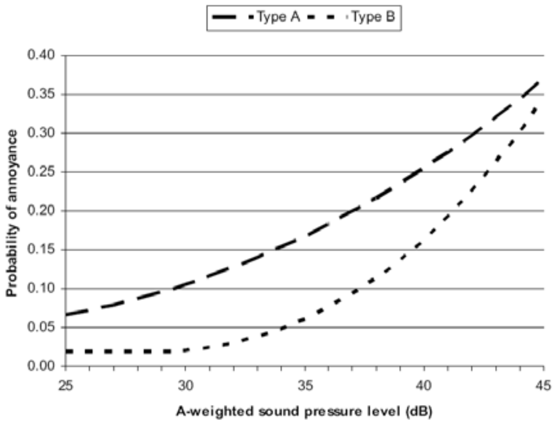
Many of the points Bowdler raises in regard to determining background noise levels will be addressed by the Best Practice Guide for use of ETSU-R-97 being produced by the Institute of Acoustics and due for release in May 2013.

13. Appendix IV: Evidence on the subjective response to wind turbine noise

The subjective response to most types of noise is influenced by a range of acoustic factors e.g. decibel level, frequency content and temporal characteristics, and non-acoustic factors such as individual listener personality and attitudes towards the source; and wind farm noise is no exception to this; for example.

- The type and level of background noise against which the wind turbine noise is heard is important because it can help mask turbine noise and affects the connotation of the wind farm noise and can therefore influence its intrusion and the subjective response (Pedersen *et al.*, 2010, Bolin *et al.*, 2012).

Figure 1: Pedersen, E, Persson Waye, K. Probability of annoyance with wind turbine noise outdoors. Wind turbine noise, annoyance and self-reported health and well-being in different living environments. Occup. Environ. Med. 64, 480–486. (2007)



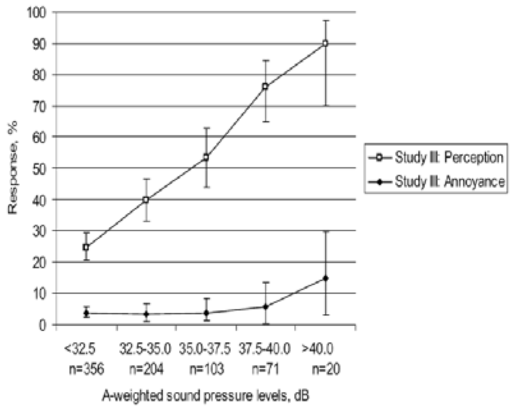
Type A

Rural location, with low background noise levels.

And;

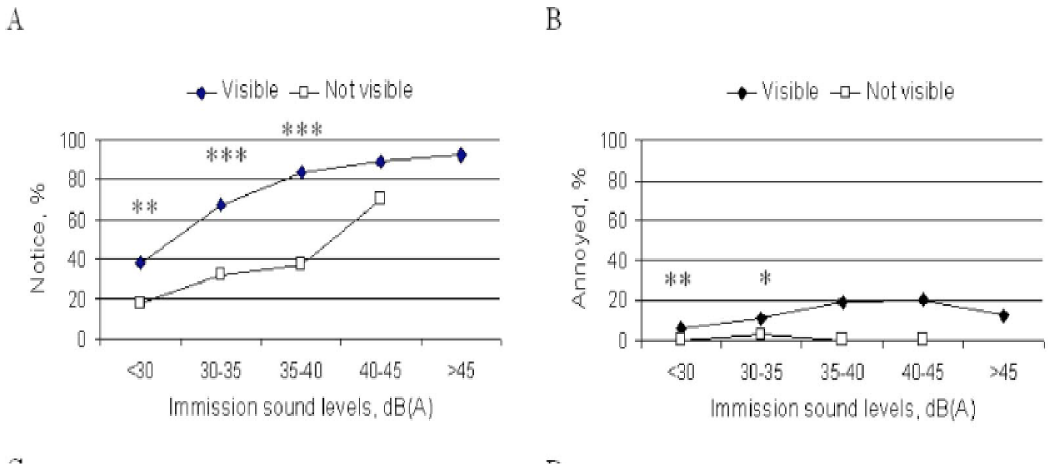
- Although wind turbine noise can be perceived at levels below the existing ambient noise level, the onset of significant levels of community annoyance appears to be at substantially higher levels (Pedersen *et al.*, 2010) i.e. there appears to be a reasonable degree of community tolerance of the audibility of wind turbine noise; although this varies significantly on an individual basis.

Figure 2: Pedersen, E, Persson Waye, K. Probability of annoyance with wind turbine noise outdoors. Wind turbine noise, annoyance and self-reported health and well-being in different living environments. Occup. Environ. Med. 64, 480–486. (2007)



- A low percentage of persons report annoyance at relatively low levels of exposure to wind turbine noise (Pedersen, 2011) and like other noises non-acoustic factors can strongly influence the annoyance response to noise for wind turbines e.g. the visual impact of the wind farms (Pedersen *et al.*, 2009); and real and perceived injustices regarding the development of such schemes (Maris *et al.*, 2007).

Figure 3: Eja Pedersen, Frits Van Den Berg, Roel Bakker & Jelte Bouma; *Response to noise from modern wind farms in The Netherlands*; J. Acoust. Soc. Am. 126 _2_, August 2009.



- Evidence on the direct health effects of wind turbine noise is strongest for annoyance and sleep disturbance (Pedersen *et al.,* 2009, Pedersen, 2011). There is no robust evidence that wind farm and wind turbine noise has other health effects or gives rise to unique syndromes or sets of symptoms different from other noise sources.

- In common with other noise sources, the presence of acoustic features in wind turbine noise such as tonality and the amplitude modulation of aerodynamic noise (AM) and the influence of non-acoustic factors are important in dictating the degree of impact (Guski, 2005, Pedersen *et al.,* 2009, Pedersen, 2011) However, whilst there are various methods which can potentially be used to assess the tonality of noise emissions, there is little guidance regarding the objective rating of effects attributable to other acoustic features, such as AM. If methods of objectively rating the effects of these features can be developed, then it is likely that suitable corrections to take their impact into account are possible.

- Several studies suggest that wind farm noise can be more disturbing than transportation and general industrial noise sources at the same noise level (Pedersen *et al.,* 2009, Janssen *et al.*, 2011).

Figure 4: Janssen *et al.*; A comparison between exposure-response relationships for wind turbine annoyance and annoyance due to other noise sources J. Acoust. Soc. Am. Volume 130, Issue 6, pp. 3746-3753 (2011)

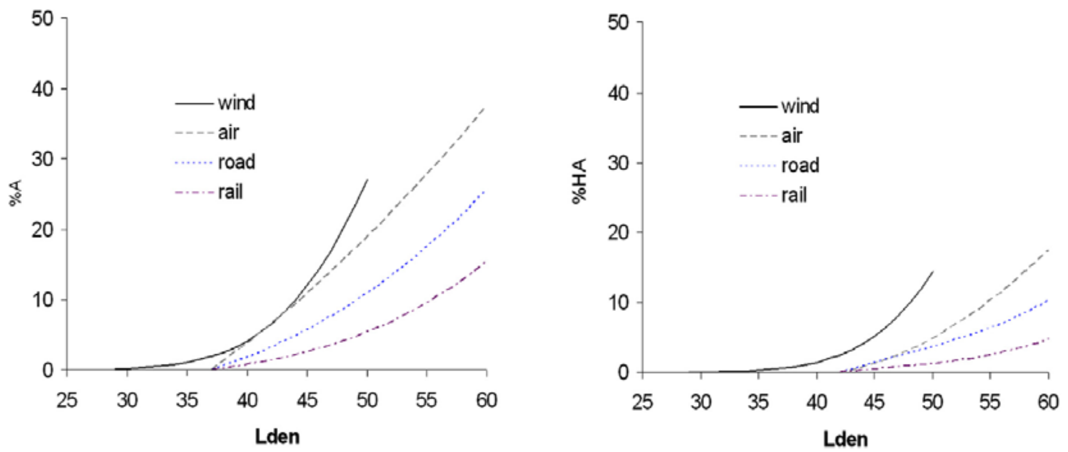


FIG. 3. (Color online) Comparison of the percentage of residents annoyed (%*A*) or highly annoyed (%*HA*) indoors due to wind turbine noise (wind) and due to transportation noise (air, road and rail).

- People who benefit economically from wind turbines have a significantly decreased risk of annoyance, despite exposure to similar sound levels (Janssen *et al.,* 2011).

In practice although non-acoustic factors can have a substantial influence on the response of individuals, sometimes being the majority influence; accounting for the effect of non-acoustic factors on the subjective response to wind turbine noise is impracticable as the prevalence and degree of effect on individual response varies substantially from person to person, and is location and scheme specific and volatile over time. Instead, as is common for many other noise sources, these factors are taken into account by the “averaging” inherent in the development of noise limits aimed at providing protection at a community level. However; this inevitably means that a minority of persons are still likely to be dissatisfied at noise levels equal to or less than such control limits; but this is common for nearly all sources of noise, as controlling to avoid nil impacts at all cost in every situation, whilst benefiting these individuals, has potentially catastrophic consequences for the overall public interest; for example if this approach were to be applied to transportation noise virtually all private and public mass transport would cease.

Figure 5: F. van den Berg, E. Pedersen, R. Bakker, J. Bouma: “Project WINDFARM perception – Visual and acoustic impact of wind turbine farms on residents”, University of Groningen, UMCG and Universiteit Göteborg (2008) n = 1948.

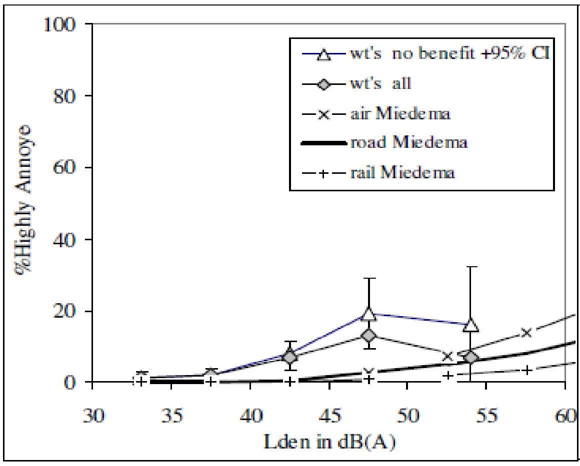


Figure 8.1: relation between sound level Lden and percentage highly annoyed residents exposed to that sound, for three transportation noise sources and for wind turbines; the relation is given for all respondents and for those that have no economical benefit from a wind turbine.

Bars denote 95% confidence interval for non-benefitters.

However, it is important to take into account that, in common with most investigations of the subjective responses to many noise sources, virtually all studies so far on the impact of wind farm noise have been cross-sectional studies of the effects of the noise under steady state conditions i.e. studies of the reaction of a sample of individuals exposed to different wind turbine noise levels; not the reaction of individuals to changing turbine noise levels or the introduction of turbine noise into an existing soundscape without such noise. A cross-sectional approach does not take into account how change due to the introduction of wind turbine noise into an existing soundscape without this noise may aggravate the noise impact; which is a well-established effect, for example for transportation noise (Griffith and Raw, 1986 & 1989). It has been suggested that when analysing possible statistical trends in noise annoyance reactions; even for steady-state noise conditions, and especially for changing soundscape situations, the effects of the change should also be taken into account (Guski, 2004). However methods established in the UK that do take change into account e.g. the Highways Agency's Design Manual for Roads and Bridges, have a higher minimum cut-off limit than the equivalent limit in ETSU–R-97.