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Mitigating the Acoustic Impacts of Modern Technologies: Acoustic, Health, and Psychosocial Factors Informing Wind Farm Placement

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Abstract

Wind turbine noise is annoying and has been linked to increased levels of psychological distress, stress, difficulty falling asleep, and sleep interruption. For these reasons, there is a need for competently designed noise standards to safeguard community health and well-being. The authors identify key considerations for the development of wind turbine noise standards, which emphasize a more social and humanistic approach to the assessment of new energy technologies in society.

Keywords

wind turbines, community noise, noise standards, health, sense of place

Introduction

The relationship between individuals or groups and their environment can be assessed from one or more perspectives. One approach is environmental psychology, which examines the effect of environmental parameters on the environment's inhabitants. Typically, the sorts of parameters scrutinized are those that are problematic in some way, and which adversely affect the well-being of those individuals found residing or operating within the confines of the environment. One example of a commonly cited environmental problem is noise (Proshansky, 1987), which traditionally has been judged more of a problem in high-density urban areas than rural or semirural (e.g., greenbelt) areas. In the past decade, a new source of noise has emerged in many rural and semirural areas across the world, noise associated with the operation of wind turbines.

Though considered a "green" source of renewable energy, wind turbines have their own environmental and social impacts and need to be sited with care and consideration in relation to the communities hosting them. Communities opposed to wind turbines argue that their health, amenity, and sense of place are compromised by turbine noise and visual impacts. Wind energy proponents argue that wind turbines provide communities with environment-friendly energy and economic opportunities. In between are the authorities overseeing the consent and compliance processes. There has been considerable public and academic debate over whether wind turbine noise poses a significant health threat to those living in their vicinity. It has been suggested that wind turbines can directly affect health via the emission of low-frequency sound energy (including infrasound), though this is currently an area of controversy (Pierpont, 2009; Salt & Timothy, 2010). Additionally, wind turbines may compromise health by producing sound that is annoying and/or can disrupt sleep. In this respect, turbine noise can be classified as community noise alongside industrial and transportation noise. When erected in rural settings, the visual impact of turbines can interact with turbine noise to exacerbate annoyance reactions (E. Pedersen & Persson Waye, 2004) and potentially reduce amenity (Pheasant, Fisher, Watts, Whitaker, & Horoshenkov, 2010).

Noise, as a social problem, is determined by a number of factors, some of which interact, some of which are acoustically related, and others which are not. This makes it very difficult to predict both individual and group responses to noise, which in turn hampers the development of noise standards. Factors influencing social reactivity to noise include the physical characteristics of the noise itself, the characteristics of the environment exposed to the noise (e.g., rural vs. suburban vs. urban), the type of human activities that the noise interferes with (e.g., rest, recreation, sleep, work), and the traits of the exposed individuals. The notion that living in the vicinity of a busy road, an airport, or a cluster of wind turbines can degrade health is, for some, a ridiculous proposition. For others, the invasion of their personal spaces by intrusive noise constitutes

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an abuse that severely degrades general health and well-being. This variability in response at the human level renders noise level an inadequate metric with which to safeguard community health, and in fact subjective evaluations of noise (e.g., intrusive, unnecessary) constitute a better predictor of aversive response than the noise itself (Flindell & Stallen, 1999). However, the inclusion of the human and social sides of the equation into noise guidelines remains an ongoing challenge (Maris, Stallen, Vermunt, & Steensma, 2007), and this criticism extends to noise standards that have "arguably" been developed to protect society from wind turbine noise. In this monograph, we list a number of points relevant to the placement of wind turbines near inhabited areas. The first cluster of points (Points 1 to 14) is general in nature, whereas the second cluster (Points 15 to 20) relates specifically to noise standards.

1. Wind Turbines Emit Noise

Noise is an unwanted sound that is judged undesirable, irritating, discordant with ones expectations, and/or that interferes with wanted sounds. Annoying or intrusive sound emanating from road, wind turbines, rail and air traffic, industries, construction and public works, or the neighborhood is known as community noise. Community noise is classified by the World Health Organization (WHO; 2011) as a common pollutant and health threat. Whether sited in isolation or in clusters, wind turbines produce audible sound to those living in their close vicinity. What distance defines "close vicinity" has yet to be determined, though Di Napoli (2011) reports that amplitude-modulated turbine noise can be heard up to 4 kilometers away from the source. Irrespective of distance, however, if the sound annoys, or disturbs the sleep of an individual, then the turbine(s) can be classified as noise generator(s).

People respond more negatively to man-made noise than natural noise (Nosulenko, 1990; E. Pedersen & Persson Waye, 2008), though some developers and supporters of wind energy claim that the sound emitted by wind turbines is congruent with natural habitats and is aesthetically pleasing. Sometimes developers and their contracted acousticians will compare wind turbine sounds to rustling leaves, flowing streams, or lapping waves. It follows then from these comparisons that turbine sounds cannot be considered noise in the formal sense as people generally do not find such sounds annoying or disruptive to sleep. In fact, the little research that has been undertaken on the sound properties of wind turbines concludes just the opposite (Pheasant et al., 2010; F. van den Berg, Pedersen, Bouma, & Bakker, 2008). Therefore, it must be acknowledged that wind turbines have the capacity to emit noise.

2. Spectrum Analyzers and Noise-Level Meters Do Not Mimic Human Hearing

Some acousticians mistakenly believe that if a band of acoustic frequencies are not represented in physical measurements of acoustic energy (e.g., on a spectrograph), then those frequencies cannot be perceived. However, for humans hearing is the most acute sense, and in controlled conditions a person with normal hearing can detect vibrations with an amplitude of less than half a nanometer: approximately one tenth the diameter of the hydrogen atom (Green, 1976). The range of sounds a properly functioning human ear can detect is likewise impressive, ranging from the smallest perceptible amplitude to amplitudes that are 10,000,000,000,000 times greater. Pertinently, our hearing processes are finely tuned to extract correlated patterns of acoustic activity from background noise and can far outperform any current technological devices claiming to perform the same function. Thus, wind turbine noise may be audible to a human even when the noise itself is lower than the ambient noise level (R. H. Pedersen, Von-Hunerbein, & Legarth, 2011; Siponen, 2011) and beyond the resolving power of modern equipment. Therefore, the limits of sound measurement apparatus relative to those of the human auditory system need to be acknowledged when judging acceptable limits of exposure to wind turbine noise.

3. The Subjective Nature of Noise

It has long been recognized that what is, and what is not, noise is highly subjective, and one person's noise can be another's music. Thus, noise pollution must be viewed as comparative to a certain extent, with substantial individual differences existing in relation to personal perception, sleep disturbance, annoyance, social context, and perceived control. As with other noise sources, we should expect individual variation with regard to the effects of wind turbine noise. However, it is a fallacy to argue that because only some suffer adverse effects while others do not, those who claim to be suffering effects must be "making them up." In the field of epidemiology, the differential susceptibilities of individuals are known as risk factors, and assuming that individuals of a population can be represented by the average characteristics of the population is known as the ecological inference fallacy. Although the WHO does acknowledge the existence of vulnerable groups, the noise levels presented in its Night Noise Guidelines for Europe (WHO, 2009) nevertheless rest on aggregate data that for the most part do not distinguish vulnerable from non-vulnerable groups. Such an approach, regrettably, constitutes an ecological inference fallacy.

Substantial individual differences are expected, and indeed found, when examining the effects of community noise on humans (Maris et al., 2007), including wind turbine noise (E. Pedersen & Persson Waye, 2008). Unfortunately, for policy makers there is no proportional relationship between annoyance or sleep disturbance and noise level, as these outcome factors will be influenced by characteristics associated with both the noise and the listener (Flindell & Stallen, 1999). Therefore, moderating factors, which include age, noise sensitivity, attitude, social context, coping styles, and mental health, need to be acknowledged and accounted for when judging the appropriateness of wind turbine sites close to residences.

4. Understand the Meaning of Health

Before considering any possible impact of wind turbine noise on health, an acceptable definition of health must be adopted. Such a task is not laborious however, as the WHO did precisely that during its formation in 1948. The WHO (1948) defines health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity."

Thus, health refers not only to illness and "cuts-and-bruises" but also to well-being, quality of life, and amenity. In its 2008 World Health Report, the WHO recommitted itself to the concept of primary health care and acknowledged that good health exists not in the hospital but in society at large. At the social level, good health can be facilitated not only by the pursuit of healthy lifestyles (e.g., exercise and diet) but also by the provision of restful and restorative living environments (e.g., soundscapes). A prominent factor determining the restfulness of a living space is the level of privacy and intrusion by pollutants, including smell, air quality, and noise. In assessing the impacts of wind turbine noise, it is important to not only consider the potential of wind turbine noise to induce poor health but also its potential to compromise good health.

The health of a nation or group may be assessed using morbidity and mortality data and by using health status and health-related quality-of-life (HRQOL) data. The latter two approaches correlate highly with medical morbidity assessment, but instead of diagnosing particular symptoms or classifying health problems as the medical profession would, this approach has the value and advantage of examining factors that cause and/or result from a health disorder(s). These factors include physical health, psychological well-being, social support, and the environment. Such information is important both in the prevention and the treatment of health problems and in the assessment of treatment outcomes. It is now common practice in health research to incorporate measures of HRQOL, such that the U.S. Food and Drug Administration agency, for example, insists on such assessment in appraising all new pharmaceutical products (Glasgow & Emmons, 2007). Therefore, health status and HRQOL instruments would serve well to the studies of the effect of wind turbines on the health and well-being of nearby residents and in many ways are more practical and sensitive measures than those applied in medical appraisals.

5. Avoid the Argumentum Ad Ignorantiam

Wind turbines are a new source of community noise and as such their effects are only beginning to emerge in the literature. The recognition of a new disease, disorder, or threat to health usually follows a set pathway. First, doctors and practitioners attempt to fit symptoms into predefined diagnostic categories or else classify the complaints as psychosomatic. Second, as evidence accumulates, case studies begin to appear in the literature and exploratory research is undertaken to obtain better descriptions of the symptoms/complaints. Third, intensive research is undertaken examining the distribution and prevalence of those reporting symptoms, the factors correlating with the distribution and prevalence of those symptoms, and ultimately to cause-and-effect explanations as to why those reporting symptoms may be doing so.

Currently, the health and amenity impacts of wind turbines are only beginning to be elucidated and is caught somewhere between the first and second stages described above. Case studies (e.g., Harry, 2007; Krogh, Gillis, & Kowen, 2011; Pierpont, 2009) and correlational studies (e.g., E. Pedersen & Persson Waye, 2007; F. van den Berg et al., 2008) have already emerged in relation to the health effects of wind turbine noise, indicating that wind turbine noise, like traffic or aviation noise, has the potential to affect health and well-being. We can expect that, over the next decade, intensive research will be undertaken enabling more certain decisions to be made regarding wind turbine noise and health and the mechanisms that mediate the relationships between the two. Until that research is undertaken, however, an absence of data addressing cause-and-effect mechanisms does not equate to an absence of wind turbine noise impact (viz., *argumentum ad ignorantiam*).

6. Critically Interpret the Research

It is important to note that many studies reporting noise annoyance data are laboratory, as opposed to field, studies. If noise guidelines are informed by research predominantly undertaken in laboratories then they themselves lack ecological validity. That is, what is measured in a laboratory may not concord with measurements made in the actual environment. Additionally, older published data on wind turbine noise may involve turbines that are substantially fewer in number, smaller in size, and less noisy than modern wind turbine set ups, and so present findings that cannot be generalized to contemporary technology. Wind turbine noise research (actually nonsystematic literature reviews) has been conducted by industrial stakeholders in wind energy (e.g., Colby, 2009), which present results that likewise should be interpreted with caution. Wind turbine noise research, then, should be consulted with qualification and critique when considering wind turbine effects and not taken prima facie.

7. Determine Why Turbine Noise Is Especially Annoying

The characteristics of wind turbine noise have been well described from a social perspective (e.g., F. van den Berg et al., 2008, Table 7.23), either as a typical amplitude modulation (i.e., a 3-5 dB modulated "swish," audible in the near field) or an atypical amplitude modulation (i.e., >5 dB modulated "thump," audible in the far field). G. P. van den Berg (2004) shows that wind turbines produce noise with an impulsive character, and although the actual cause of the swishing or thumping has not yet been fully elucidated, it has been demonstrated that this swishing or thumping pattern is common with larger turbines (Stigwood, 2008) and may result from a fluctuating angle of attack between the trailing edge of the rotor blade and wind (Siponen, 2011). Furthermore, lower frequencies, which tend to be judged as more annoying than higher frequencies, become more salient during the transitions from swish to thump. In the far field, the less common two-bladed turbines, it should be noted, have a different noise profile characterized by an alternating thump without the swish.

Because wind is variable and not constant, wind turbine noise levels are also variable and inconsistent. Furthermore, the cyclic action of the turbine rotors serves to modulate noise level across time, producing a noise that can be perceived as repeating itself several times per second. This is unfortunate, as human senses act as contrast analyzers, responding to changes in sound rather than to the absolute level of the sound itself (Laming, 1986). Additionally, we are more sensitive to change in continuous noise (such as impulsive turbine noise) than to discrete auditory events (e.g., a passing car at night). Thus, wind variability will bring about noticeable changes in the level of turbine noise, irrespective of the aggregated level of that noise, and these changes in noise level due to wind speed fluctuations will make the noise more noticeable, especially so at night, when ambient sound levels reduce. Consequently, overall measures of sound level are not in themselves useful in predicting annoyance if those levels are dynamic (i.e., they change over time). In fact, the level of noise only explains 10% to 25% of an individual's response to noise (E. Pedersen & Persson Waye, 2008). When considering acoustical characteristics of turbine noise, however, overall noise level is usually chosen as the metric of importance whereas other aspects of the noise such as periodic amplitude modulation are ignored (Lundmark, 2011). Metrics describing the amplitude modulation characteristics of turbine noise, such as that proposed by T. H. Pedersen et al. (2011), should therefore be considered when judging the appropriateness of turbine placements.

8. Have Experts Working Within Their Field of Expertise

Although the contribution of acousticians can be critical in the measurement of noise at the physical level of description, there has been a noticeable trend in the field of public policy that, when the effects of wind turbine noise on society are being debated, acousticians are adopting the role of health experts. British physician Dr. Amanda Harry (2007) reports the alarming prevalence of acousticians giving evidence with regard to the health effects of sound emitted from wind turbines. She states that their "comments are made outside their area of expertise and should be ignored until proper medical, epidemiological studies are carried out by independent researchers" (p. 21). The message here is that acousticians reporting measured or predicted wind turbine noise levels should withhold commentary on likely health effects unless possessing suitable qualifications and can support their recommendations with quality research. As a corollary, health experts should not be commenting on acoustical matters without relevant qualification and the backing of quality research.

9. Reliance on Oversimplified Models

Though noise level itself explains only a small proportion of the variability found in the response to noise, it invariably carries the greater weighting and emphasis during wind turbine consent processes. Noise level metrics are usually predicted, though on occasion may be reported from other wind farms of a similar nature to that proposed or directly from the manufacturer's testing facilities. In relation to predicted levels, there are a number of factors influencing the predictions, and failing to sufficiently account for these factors can potentially produce either under- or overestimates of turbine noise. For example, depending on terrain and time of day, the effects of meteorological conditions on wind turbine noise can be in the order of 20 to 25 dB, with noise levels typically higher in spring than autumn due to temperature differences (Larsson & Öhlund, 2011). Terrain type is also important, and the predictions between open field and forest areas can differ by as much as 20 dB SPL, due to temperature and wind speed differences (Johansson & Almgren, 2011). Additionally, when the terrain impedes the wind close to dwellings then the wind's masking effect is reduced, and turbines located on higher ground may become more audible (Appelqvist & Almgren, 2011). Turbine noise depends on wind speed, which itself peaks between noon and 2:00 p.m. We can conclude that during this time of day the masking efficacy of wind is at its peak. Furthermore, thermal effects on atmospheric stratification can induce significant variability in wind gradients. Hence, wind speed can differ between ground and turbine hub height. Unfortunately, the most common reference of wind vertical profile used in modeling (IEC 61400-11) is appropriate only for flat terrain containing simple vegetation (Gianni, Bartolazzi, Mariani, & Imperato, 2011). Another important factor affecting noise level is the humidity- and temperature-dependent air absorption coefficient, in which lower values (e.g., 0.003 dB/m) yield more conservative estimates than higher values (e.g., 0.005 dB/m). Though these differences may appear subtle, selecting representative air absorption coefficient values are important as propagation through the air introduces random phase shifts due to atmospheric turbulence, which in turn influences noise levels. Additionally, when selecting an appropriate frequency weightings (e.g., dB(A) vs. dB(C)), one must consider that atmospheric sound absorption is greater for high as opposed to low frequencies (Siponen, 2011).

Current approaches to the modeling of sound propagation between multiple turbines assume statistical independence and sum the individual outputs of turbines in order to profile the impact of groups of turbines. Often this involves using manufacturer's technical data from a single turbine, but does not take into account the fact that multiple deterministic noise sources can add coherently. In the case of wind turbine installations, these noise sources include periodic modulating blade noise, low-frequency pulsations, and tones emanating from mechanical processes (Walker, 2011). The interactive effects of turbines may produce local "hotspots" or "heightened noise zones" (Bakker & Rapley, 2010) in which turbine noise can be amplified (and elsewhere attenuated) due to the superposition of multiple turbine acoustic waves. Hence, when predicting turbine noise levels using mathematical models, model complexity should not be sacrificed to simplify the calculation process.

10. Choosing the Right Metric

Another important factor when measuring or predicting wind turbine noise level is the range of exposure levels, that is, the minimum and maximum levels that are emitted by wind turbines. Noise measures based on energy summation and expressed as averaged values are not always sufficient when examining the health-related effects of noise. The WHO (1999) has repeatedly emphasized the importance of measuring peak values of noise fluctuations rather than averages. The inclusion of maximum levels is important as studies have consistently demonstrated that sleep disturbance is related to peak noise levels rather than aggregated measures (Morrell, Taylor, & Lyle, 1997). Thus, any measured or predicted noise levels used by acoustic experts must be accompanied by maximum levels, as sensitivity to the peaks of modulating noise waves are likely to better predict annoyance (Walker, 2011). Bolin and Karasola (2011), arguing against the use of aggregated measures when undertaking monitoring, claim that in order to present a "worst-case scenario," distributions representing the top 10% of the time average levels measured (i.e., dB LA_{10}) should be generated.

Further debate centers on the type of weighting that should be applied to noise measurements and predictions. Currently, standard practice in the wind turbine industry involves using A-weighted noise level estimates (i.e., dB(A)), though these may underestimate annoyance by failing to account for the degree of temporal variations and low-frequency content the measured noise contains. Siponen (2011), accounting for amplitude modulation and the low-frequency noise components in turbine noise, argues that A-weighted noise predictions underestimate the minimum distance required between wind turbines and inhabited dwellings. Instead, he advocates the use of a C-weighting, or else a corrected level based on the difference between C- and A-weightings.

Prior to the approval of a wind farm, it is common practice to assess the ambient (or background) sound levels and to compare these to, or combine them with, the predicted levels. Even this stage of noise level measurement has issues that require consideration, as extraneous factors such as time of year or equipment type can result in substantial overpredictions of ambient noise levels, up to 17 dBA in one study (Terlich, 2011). Seasonal effects such as insect noise can be lessened using weighting algorithms (Terlich, 2011), while decreasing the averaging time from the 1 minute recommended by IEC 61400-11 to around 10 seconds can help eliminate data contaminated by bird cries, pedestrian noise, or traffic noise (Ishibashi, Imaizumi, Ochiai, Inoue, & Yamada, 2011). Arguably, however, smaller durations around 100 milliseconds should be adopted as best practice, as the time averaged dB(A) levels recommended by the IEC 61400-11 (but see also its Appendix A5) fail to measure the amplitude modulation inherent in turbine noise (Lundmark, 2011).

11. Be Critical of Dose-Response Relationships

Many international standards for acceptable levels of community noise are based on the dose-response curve. This approach to establishing acceptable noise levels lacks validity and has been rightly lambasted by acousticians and health researchers alike (Fidell, 2003). The dose-response curve, constructed from dose-response data, plots (for example) noise annoyance as a function of noise level. Users of a dose-response curve define a level of noise annoyance that they are willing to accept and then, either graphically or numerically, derive a threshold by determining the level of noise that yields this predefined annoyance level. Figure 1A illustrates an actual theoretical dose-response curve produced by the Federal Interagency Committee on Aviation Noise (FICON) in the United States. Figure 1B is the same curve but with a shortened *x*-axis (now from 57 to 68 dB) accompanied by actual measurements of noise annoyance for aircraft noise. Note the incompatibility of the theoretical curve and the empirically derived data (data extracted from Fidell, 2003).

As Figure 1B shows, annoyance reactions to noise vary substantially and do not appear to be correlated with noise level. It can be concluded that the high variability between individuals and groups makes it difficult to model the relationship between noise and annoyance. Even though noise level is not a major determinant of noise-induced annoyance responses, plots such as Figure 2 are still used to determine acceptable noise levels. We can conclude from such data that the concept of a simple stimulus-response relationship is inadequate, and more attention needs to be paid to psychosocial factors when assessing the impact of wind turbine noise.

12. Dose-Response Curves and Criteria of Acceptable Harm

Using dose-response curves entails the establishment of an "acceptable harm" threshold, expressed in physical levels of the stimulus. The question is, at what level of noise does one estimate the threshold? In Australia, the criterion for aircraft noise is set at a point in which no more than 10% of the population would be severely affected. However, such criteria setting reflect a utilitarian approach to public health that is simply not sanctioned by modern society and are often arbitrary. Would we put an additive in the water that would benefit 90% of citizens and make the other 10% ill? These values need to be based on scientific validity and medical evidence but instead

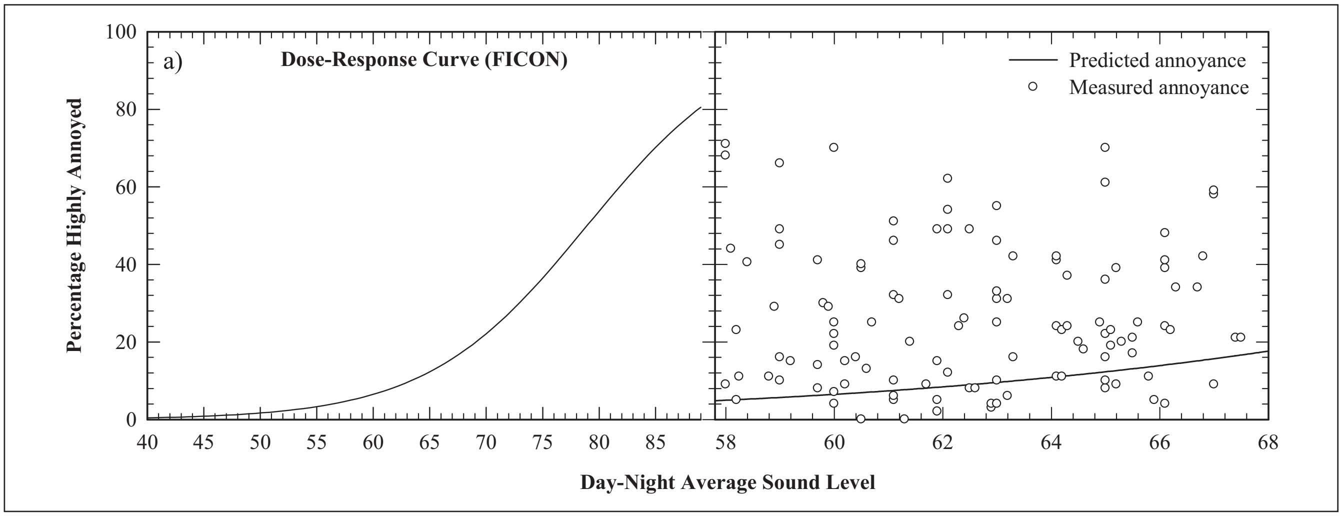

Figure 1. The dose-response function adopted by FICON (1992) to determine acceptable aviation noise levels (A) and actual measurements of aviation noise-induced annoyance in the vicinity of 60 and 65 dB LDN (B)
Note. Data reproduced with permission from Fidell (2003).

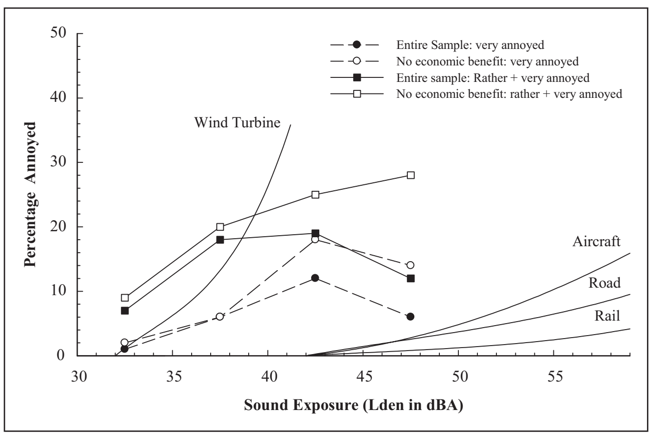

Figure 2. Annoyance plotted as a function of noise level for four theoretical models (rail, road, and air parameters: Miedema & Oudshoorm, 2001; wind turbine parameters: E. Pedersen & Persson Waye, 2004) and four sets of data obtained from Van der Berg et al. (2008, Tables 7.24 to 7.26)
Note. For the data, closed symbols are for the entire sample, whereas open symbols are for those who identified that they had no economic interest. Circles represent the percentage of "very annoyed" responses whereas squares represent the sum of "very annoyed" and "rather annoyed" responses.

are being set to reflect industrial objectives. The notion of acceptable harm then is one that needs to be debated at the societal level and, in relation to wind turbine noise, defined on a case-by-case basis with input from the communities hosting the turbines.

13. Noise Is a Social Problem, So Consider Approaches Other Than Level

Adopting noise level as the sole criterion of health impact makes little sense, given that (a) noise level is a poor predictor of the human response it elicits and (b) there has been a systemic failure in the prediction and measurement of wind turbine noise. In relation to the later, it is apparent that errors of prediction and measurement emerge due to inadequate methodology. For example, many of the wind turbine installations erected in New Zealand's Manawatu region were initially welcomed by residents who supported renewable energy (Martin, 2008). However, this initial enthusiasm was based on reassurances from the developers that turbine noise would not intrude into homes. The resulting lack of concordance between the predicted impacts of the noise and the actual impacts of the noise has since led to a rise in resistance to wind turbines in this region. Further evidence comes from a recent compliance report (Lloyd, 2010) undertaken on the Te Rere Hau wind turbine installation, also in the Manawatu region, that indicates that the complaints made by nearby residents regarding noise exposure are justified on the basis of recent noise level readings. Note that these readings are discordant with those originally predicted and do not comply with the original resource consent conditions. In 2011, court action against the wind farm operator was initiated by the Manawatu District Council.

Because of the discrepancies between predicted and actual noise levels, it may be more prudent to rely on evidence coming from individuals at established wind turbine installations than mathematical models heavily constrained by assumptions (see Points 9 and 10). Additionally, social-based approaches to wind turbine siting have actually been reported in the peer-reviewed literature (e.g., Gross, 2007; Maris et al., 2007), though incorporating these approaches into noise standards remain a challenge. Some countries, including Britain, Germany, and Canada, have negated noise level criteria and have instead adopted minimum setback distances between turbines and residential buildings. At this point in time, however, the use of setback distance is as controversial as the use of noise levels due to the lack of informing data.

14. Public Relations Should Consider the Social and Cultural Context

Invariably, the deployment of wind turbines creates winners (those who economically benefit) and losers (those who do not benefit and see the turbines as pollutants). Thus, it is important that the decision-making processes be perceived by all involved to be fair, or divided communities may ensue resulting in damaged relationships, degraded social well-being, and loss of sense of place. To this end, wind farm developers should not adopt an aggressive approach to decision-making processes, because in the past this has led to pronounced community divisions (Gross, 2007). Nor should they outwardly exploit their economic and political advantages over local opposition, as perceived procedural unfairness lessens social acceptance.

Maris et al. (2007) demonstrate that perceptions of procedural unfairness during the decision-making process, and insensitivity to the social context, can serve to increase subsequent noise-induced annoyance when the noise begins. Thus, public relations between developer and community can critically affect annoyance responses. An example of strained relationships within a community, and between community and wind turbine developer, can be found with the development of the Makara Wind Farm immediately north of Wellington, New Zealand's capital city. As part of the consent process, the developer was required to install a complaints line for the community to call if the noise became excessive. Thousands of calls were received in the first year, but the complaints themselves were never acted upon. A year later the wind turbine developer proposed to increase the wind farm into an adjacent area, which was opposed by the Makara Valley community. At subsequent consent hearings, the developer employed a marketing company to analyze complaints line data and use it against the Makara community. Such behavior resulted in indignation from the Makara community and would have likely increased annoyance to noise produced by the wind turbines already in operation.

The Use and Misuse of Noise Standards

A technical standard is a recognized norm or requirement, usually a formal document describing a standardized criterion, method, process, or practice. Standards may be developed at an international level, in which case they are classified as international standards, or locally by individual nations, in which case they are national standards. The process of agreeing to a technical standard is known as standardization. Standards have been an unqualified success in the field of engineering, science, and commerce. To stipulate a standardized procedure, test, definition, or specification is akin to creating a common language or frame of reference that facilitates communication and understanding between diverse groups. Noise standards exist to protect the public from noise and governments (local or central) from litigation and generally consist of regionally developed standards. That different nations have different noise standards indicates the impact of sociocultural and sociopolitical factors on noise acceptance. Because of their recent introduction, at least relative to other noise sources, wind turbines have developed rapidly in character, and consequently the development of noise standards specific to turbine noise has, for this reason and others besides, lagged.

The existence of a standard does not, unfortunately, presuppose that the standard itself is the correct procedure, test, definition, or specification. Nor does it guarantee that the standard is actually useful or effective. In fact, noise standards are evolving entities that are constantly undergoing review and change. In relation to noise and the public good, the WHO (1999), in identifying the inadequacies of noise emission standards, reports that existing trends in noise pollution are unsustainable. That noise standards are not necessarily definitive is further demonstrated by the lack of agreement that can exist among experts on standards or differences between standards. The differences of opinion surrounding the revision of the New Zealand standard for acceptable wind turbine noise (NZS6808) is testament to this (see, e.g., Chiles, 2010; Dickinson, 2009).

The classification of noise into broad ranges of frequency (e.g., low, medium, and high frequency) likewise illustrates the relative nature of noise standards. There appears to be a lack of universal agreement on this matter, and there are different standards in Germany (DIN 45680:1997), the United States of America (ANSI S12.9), Sweden (SOSFS 1996L17), and both Denmark and Holland. Given that the frequency content of the turbine noise is a contentious issue, and one that acousticians debate with some vigor, it can be argued that a common language is needed in order to advance these debates. In relation to the measurement of low-frequency noise, the international ISO-140-5 and the Swedish SP Info 1996:17 standards predict different noise level differences between outside and inside values (Lindkvist & Almgren, 2011). Thus, although useful, standards should not be treated as definitive authorities on where (or where not) wind turbines can be placed. A number of points relevant to the wind turbine noise standards are now made.

15. Standards Based on Standards

One can often encounter a Russian doll–type situation when examining noise standards, with many noise standards referencing other standards (which in turn may reference other standards) that may themselves not be fit for the purpose. For example, the international standard ISO9613 (Acoustics—Attenuation of sound during propagation outdoors) is used extensively in turbine noise standards (e.g., NZS6808:2010), yet it has been found to be inaccurate when applied to wind turbine noise (Bolin & Karasalo, 2011; Johansson & Almgren, 2011). It is thus of utmost importance to decompose standards into their constituent authorities and to examine each individually. The consequence of a noise standard relying on other inappropriate or ineffectual standards can result in flawed noise level predictions or inaccurate noise level readings during monitoring.

16. Reduce the Lag Between Practice and Reality

Technical and health standards are not updated quickly enough and perpetually lag behind research and technological developments. In England, wind turbine noise is predicted and assessed using standards that were developed for substantially shorter wind turbines (Davis, 2007). The WHO (1999), in their publication "Guidelines for Community Noise," acknowledges that their own noise recommendations are a work in progress and that there is still much to be done. Recently, there were calls from acoustical experts to update current American noise standards (Kryter, 2007), while an investigation by the Department of Health and Aging in Australia (Enhealth, 2004) has called for an immediate review of all noise guidelines, standards, and policies in light of the adverse health outcomes being associated with community noise. Thus, noise standards should have regular reviews in which they are updated, if necessary, to reflect technological advances and the latest findings in the field. For example, the period between the release of the New Zealand wind turbine standard (NZS6808:1998) and its revision (NZS6808:2010) is arguably too lengthy given the volume of research published during this period. Worse still is the British standard ETSU-R-97, which, despite being obsolete and there being repeated calls for a revision, remains in use.

17. Manage Conflicts of Interest

In some countries noise standards can be industry sponsored and as such lack sufficient input from stakeholders, social scientists, and health professionals. Failing to sufficiently declare conflicts of interests of those developing wind turbine noise standards can result in standards being endowed with more credibility than they deserve, or at a later date having their credibility impeached. Thus, all reasonable effort should be made to balance out groups involved with standard development, and all conflicts of interest should be explicitly declared. Wind turbine noise standards containing statements on acceptable noise levels should be developed with input from social organizations concerned with noise levels (e.g., the noise abatement society), and should clearly acknowledge that as a social problem, the mitigation of noise annoyance must necessarily include social factors.

18. The Nonequivalence of Noise Standards

When developing wind turbine noise standards, it is important that preexisting standards developed for other noise sources (e.g., road, rail, aviation) be applied with caution and qualification. For example, the Night Noise Guidelines for Europe developed by the WHO (2009) are based predominantly on road and aviation traffic data, yet are commonly cited in wind turbine consent applications. However, the unique physical characteristics of wind turbine noise (i.e., amplitude modulation), and the characteristics of those communities commonly exposed (i.e., rural and semirural dwellers), dictates that wind turbine noise is consistently judged more annoying than road, rail, or aviation noise (see Figure 2). The data plotted in Figure 2 suggests that the application of noise guidelines derived from aircraft, road, or rail data such as those published by the WHO should be accompanied by a 10 decibel (or more) subtraction in order to normalize it to the turbine context. In Italy, a generic national standard from noise regulation exists (DPCM 1/3/1991) that is not specific to turbine noise and is clearly inadequate to regulate the latest advances in turbine technology.

19. Domain-Specific Expertise

Wind turbine noise guidelines are often developed by teams of acousticians focusing on the physical measurements of noise, who later participate in the drafting of health impact clauses almost as an afterthought. For example, the aforementioned revision of the New Zealand standard (NZS6808:2010) had only a small proportion of health experts, and possibly as a result of this, only a small proportion of the standard was dedicated to health. We suggest that, regardless of noise source, measurement methodologies should be contained within a unique standard separate from those standards assessing health impacts. This would ensure that both measurement and health risk protocols would be developed by the experts in the field, and as such be fit for purpose.

20. Standards Are Not Weapons to Suppress Social Concerns

Noise standards can ironically be used to suppress "unwanted noise" coming from communities dissatisfied with noise levels. Giving a New Zealand example, a major regional newspaper (*The Manawatu Times*, 2005) reported the following statement from the owner of a newly established wind turbine installation: "It's a small number of people making a big noise about nothing" in response to locals complaining of a rumbling sound that "bombarded us with noise and vibration." The wind farm operator justified these comments on the basis of the advice they had received from their employed "health consultants," who were in fact acousticians providing information far beyond their expertise. These consultants justified their judgments by appealing to New Zealand's wind turbine noise standard (NZS6808), which had been sponsored and largely developed by umbrella organizations funded by wind turbine developers, including the owner.

Conclusion

Currently, environmental agencies, planning authorities, and policy makers in many parts of the world are demanding more information on the possible link between wind turbine noise and health in order to legislate permissible noise levels or setback distances. Concurrently, larger and noisier wind turbines are emerging, and consent is being sought for progressively larger wind turbine installations to be placed even closer to human habitats. However, the stimulus-response approach demanded by the bulk of these decision makers is misguided, and neither noise levels nor setback distances used in isolation are likely to be acceptable by society at large. Although noise standards can effectively and fairly facilitate decision-making processes if developed properly, the current standards on offer suffer severe conceptual difficulties. All this points to a need to incorporate social perspectives into the decision-making processes, though how this process itself can be standardized remains a challenge (but see Gross, 2007; Maris et al., 2007).

We have listed a number of important considerations that need to be addressed by environmental agencies currently deciding on the location of wind turbine installations. These various considerations can be grouped into broader categories, such as the credibility of procedures and players involved with standard development, the use of research to inform standards, critique of current approaches inherent in contemporary noise standards, and broader social factors. Ultimately, however, man-made noise is rarely perceived in a social vacuum (Maris et al., 2007), and acceptable levels of wind turbine noise should be a societal, and not a technological, decision one.

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References

Appelqvist, P., & Almgren, M. (2011, June). *Wind turbine noise in sheltered dwelling area*. Paper presented at the Fourth International Meeting on Wind Turbine Noise, Rome, Italy.

Bakker, H. H. C., & Rapley, B. I. (2010). Sound characteristics of multiple wind turbines. In B. I. Rapley & H. H. C. Bakker (Eds.), *Sound, noise, flicker and the human perception of wind farm activity* (pp. 225-251). Palmerston North, New Zealand: Atkinson & Rapley.

Berglund, B., Lindvall, T., & Schwela, D. H. (1999). *Guidelines for community noise*. The World Health Organisation, Geneva.

Bolin, K., & Karasalo, I. (2011, June). *Wind turbine noise exposure in a complex terrain*. Paper presented at the Fourth International Meeting on Wind Turbine Noise, Rome, Italy.

Chiles, S. (2010). NZS6808: 2010 acoustics—Wind farm noise. *New Zealand Acoustics*, *23*(2), 20-22.

Colby, W. D. (2009). *Wind-turbine sound and health effects: An expert panel review*. Retrieved from http://www.canwea.ca/pdf/talkwind/Wind_Turbine_Sound_and_Health_Effects.pdf

Davis, J. (2007, September). *Noise pollution from wind turbines*. Paper presented at the Second International Meeting on Wind Turbine Noise, Lyon, France.

Dickinson, P. J. (2009, November). *Nonsense on stilts*. Paper presented at the Annual Conference of the Australian Acoustical Society, Adelaide, South Australia.

Di Napoli, C. (2011, June). *Long distance amplitude modulation of wind turbine noise*. Paper presented at the Fourth International Meeting on Wind Turbine Noise, Rome, Italy.

EnHealth Council. (2004). *The health effects of environmental noise: Other than hearing loss*. Canberra, ACT: Australian Government, Department of Health and Aging. Retrieved from http://www.health.gov.au/internet/main/publishing.nsf/content/33165540CB3C78CBCA256F1900042E72/$File/env_noise.pdf

Fidell, S. (2003). The Schultz curve 25 years later: A research perspective. *Journal of the Acoustical Society of America*, *114*, 3007-3015.

Flindell, I., & Stallen, P. J. (1999). Non-acoustical factors in environmental noise. *Noise and Health*, *3*, 11-16.

Gianni, M., Bartolazzi, A., Mariani, M., & Imperato, L. (2011, June). *SODAR wind measurements as a mean to refine acoustic analysis of wind projects*. Paper presented at the Fourth International Meeting on Wind Turbine Noise, Rome, Italy.

Green, D. M. (1976). *An introduction to hearing*. Hoboken, NJ: Wiley.

Gross, C. (2007). Community perspectives of wind energy in Australia: The application of a justice and community fairness framework to increase social acceptance. *Energy Policy*, *35*, 2727-2736.

Harry, A. (2007). *Wind turbines, noise and health*. Retrieved from http://www.flat-group.co.uk/pdf/wtnoise_health_2007_a_barry.pdf

Ishibashi, M., Imaizumi, H., Ochiai, H., Inoue, Y., & Yamada, S. (2011, June). *Measuring method of wind turbine noise at residential area-consideration by using various noise indices*. Paper presented at the Fourth International Meeting on Wind Turbine Noise, Rome, Italy.

Johansson, E., & Almgren, M. (2011, June). *Wind turbine sound amplifying forest*. Paper presented at the Fourth International Meeting on Wind Turbine Noise, Rome, Italy.

Krogh, C., Gillis, L., & Kowen, N. (2011). *Wind vigilance for Ontario communities: A self-reporting survey—Adverse health effects with industrial wind turbines and the need for vigilance monitoring*. Retrieved from http://www.healthywindwisconsin.com/Ontario%20Health%20Survey%20Abstract%20Results%20and%20Responses.pdf

Kryter, K. D. (2007). Acoustical, sensory, and psychological research data and procedures for their use in predicting the effects of environmental noises. *Journal of the Acoustical Society of America*, *122*, 2601-2614.

Laming, D. (1986). *Sensory analysis*. London, England: Academic Press.

Larsson, C., & Öhlund, O. (2011, June). *Measurements of sound from wind turbines*. Paper presented at the Fourth International Meeting on Wind Turbine Noise, Rome, Italy.

Lindkvist, P., & Almgren, M. (2011, June). *Low frequency indoor sound from wind turbines*. Paper presented at the Fourth International Meeting on Wind Turbine Noise, Rome, Italy.

Lloyd, N. (2010). *Te Rere wind farm noise compliance assessment for Palmerston North City Council*. Wellington, New Zealand: Acousafe Consulting and Engineering.

Lundmark, G. (2011, June). *Measurement and analysis of swish noise: A new method*. Paper presented at the Fourth International Meeting on Wind Turbine Noise, Rome, Italy.

Manawatu Times. (2005, July 21). Retrieved from http://tvnz.co.nz/content/599657/2591764.xhtml

Maris, E., Stallen, P. J., Vermunt, R., & Steensma, H. (2007). Noise within the social context: Annoyance reduction through fair procedures. *Journal of the Acoustical Society of America*, *121*, 2000-2010.

Martin, M. (2008). *Statement of evidence in chief of Mr Murray Martin in the matter of an appeal under sections 120 and 121 of that Act Between Motorimu Wind Farm Ltd (Appellant) and Palmerston North City Council, Environment Court* (ENV-2007-WLG-000098).

Miedema, H. M. E., & Oudshoorm, C. G. M. (2001). Annoyance from transportation noise: Relationship with exposure metrics DNL and DENL. *Environmental Health Perspectives*, *109*, 409-416.

Morrell, S., Taylor, R., & Lyle, D. (1997). A review of the health effects of aircraft noise. *Australian and New Zealand Journal of Public Health*, *21*, 221-236.

Nosulenko, V. N. (1990). *Problems of ecological psychoacoustics*. Paper presented at the proceedings of the Sixth Annual Meeting of the International Society of Psychophysics, Wurzburg, Germany.

Pedersen, E., & Persson Waye, K. (2004). Perception and annoyance due to wind turbine noise: A dose-response relationship. *Journal of the Acoustical Society of America*, *116*, 3460-3470.

Pedersen, E., & Persson Waye, K. (2007). Wind turbine noise, annoyance and self-reported health and well-being in different living conditions. *Occupational Environmental Medicine*, *64*, 480-486.

Pedersen, E., & Persson Waye, K. (2008). Wind turbines: Low level noise sources interfering with restoration? *Environmental Research Letters*, *3*, 1-5.

Pedersen, T. H., Von-Hunerbein, S., & Legarth, S. (2011, June). *Methods for assessment of the characteristics of wind turbine noise*. Paper presented at the Fourth International Meeting on Wind Turbine Noise, Rome, Italy.

Pheasant, R. J., Fisher, M. N., Watts, G. R., Whitaker, D. J., & Horoshenkov, K. V. (2010). The importance of auditory-visual interaction in the construction of "tranquil space." *Journal of Environmental Psychology*, *30*, 501-509.

Pierpont, N. (2009). *Wind turbine syndrome: A report on a natural experiment*. Santa Fe, NM: K Selected.

Proshansky, H. M. (1987). The field of environmental psychology: Securing its future. In D. Stokols & I. Altman (Eds.), *Handbook of environmental psychology* (Vol. 2, pp. 1467-1488). New York, NY: Wiley.

Salt, A. N., & Timothy, E. H. (2010). Responses of the ear to low frequency sounds, infrasound and wind turbines. *Hearing Research*, *268*, 12-21.

Siponen, D. (2011, June). *The assessment of low frequency noise and amplitude modulation of wind turbines*. Paper presented at the Fourth International Meeting on Wind Turbine Noise, Rome, Italy.

Stigwood, M. (2008). *Evidence to the public enquiry into the proposed North Dover Wind Park*. PINS Ref: APP/X2220/A/08/2071880/NWF.

Terlich, M. (2011, June). *The case for spectral measurements of ambient noise levels in the assessment of wind farms*. Paper presented at the Fourth International Meeting on Wind Turbine Noise, Rome, Italy.

van den Berg, F., Pedersen, E., Bouma, J., & Bakker, R. (2008). *Visual and acoustic impact of wind turbine farms on residents*. Retrieved from http://docs.wind-watch.org/wfp-final-summary-1.pdf

van den Berg, G. P. (2004, August-September). *Do wind turbines produce significant low frequency sound levels?* Paper presented at the 11th Meeting on Low Frequency Noise and Vibration and its Control, Maastricht, Netherlands.

Walker, B. E. (2011, June). *Coherence issues in wind turbine noise assessment*. Paper presented at the Fourth International Meeting on Wind Turbine Noise, Rome, Italy.

World Health Organization. (1948). *Constitution of the World Health Organization*. Retrieved from http://whqlibdoc.who.int/hist/official_records/constitution.pdf

World Health Organization. (2008). *World health report 2008: Primary health care*. Retrieved from http://www.who.int/whr/2008/whr08_en.pdf

World Health Organization. (2009). *Night noise guidelines for Europe*. Copenhagen, Denmark: Author.

World Health Organization. (2011). *Burden of disease from environmental noise*. Copenhagen, Denmark: Author.

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