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Annoyance from wind turbine noise – What can we learn from different assessment methods?

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Abstract

The literature on recent original studies that relate wind turbine noise to annoyance is reviewed with the aim of providing an overview of the validity of each approach in answering current questions of policy. It is shown that the most useful types of study design for policy making are cross-sectional studies and listening tests. However, one important study design, that is the longitudinal study has so far not been used.

1. Introduction

Doubts have been raised in various publications (e.g. Hanning, 2010, Shepherd *et al.* 2011, Nissenbaum *et al.* 2012) that current noise regulations are not adequate for wind turbine noise because of its special characteristics such as omnipresence, periodic nature, patterns of random occurrence and low frequency content. Adverse health effects are reported.

On the other hand, widely cited literature reviews such as Knopper and Olson (2011) and MDEP (2012) conclude that the statistical evidence for health effects and annoyance from wind turbine noise is insufficient.

In reviewing literature on recent original studies on health effects and annoyance from wind turbines this article discusses the source of the gap between these contradictory findings.

2. Perception and affective response

When studying the response to wind turbine noise it is important to understand the conceptual path from the noise source to the response by the listener as illustrated in Figure 1 (Pedersen, 2007). The sound with its physical, measurable properties enters the ear, which acts as a filter resulting in the perceived stimulus. The perceived stimulus is processed by the brain at which point a second filter process occurs when non-acoustical factors like mood, state of health, context, emotion and background, influence the response to the perceived stimulus. There are three measurement “points” identified in the schematic, M1 would be a microphone measuring the physical properties of the sound, M2 would be conducted in the form of listening tests in a laboratory. Examples for perception parameters are loudness, fluctuation strength and tone audibility. M3 can be assessed through various study designs as detailed in the following section.

At this point it is important to note though that annoyance is an attitudinal response in this model and as such will always be influenced by all the involved factors. However, to arrive at

meaningful noise regulations some objective measure has to be found on how certain aspects of the noise tend to influence annoyance.

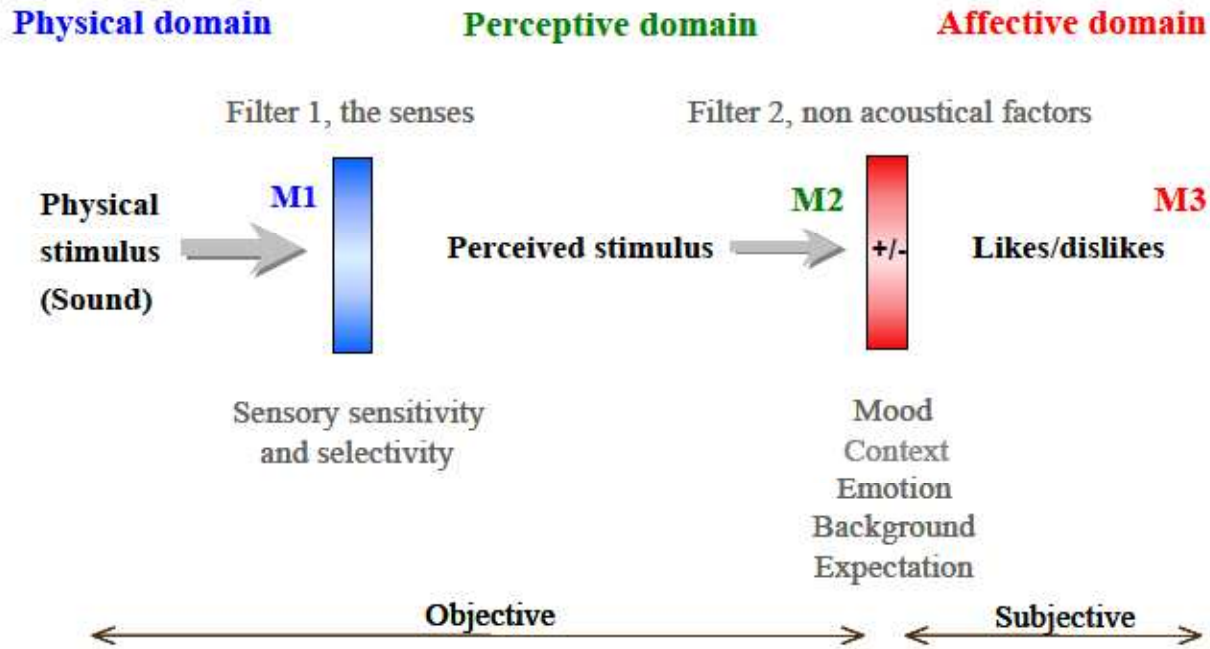


Figure 1 – From Pedersen (2007): The filter model of the sound path from source to response. Filter 1 denotes the ear and filter 2 the brain. M1 –M3 denote the three measurement/assessment points.

3. Types of studies applied to WTN

The recent original studies on annoyance and health effects from wind turbines listed in Tab 1 can be categorised into epidemiological (cross-sectional) studies, case studies and reports, and laboratory studies.

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

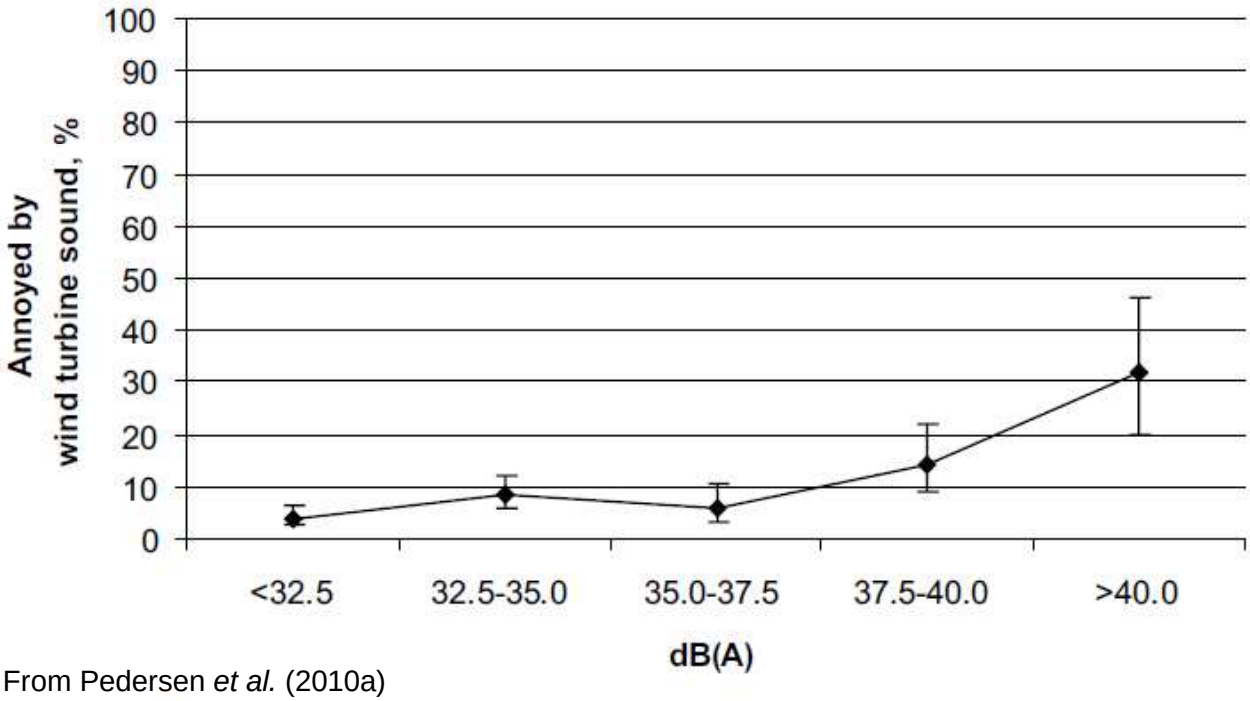
Case Studies/Reports	
Wind Farm	**Article**
Deeping St Nicholas, UK	Thorne (2011)
Falmouth, US	Ambrose (2012)
Shirley, US	Walker (2012)
Te Rere Hau, NZ	Thorne (2011)
Vinalhaven, US	Nissenbaum (2011)
Waubra, AU	Thorne (2011)
Unknown	Rand (2011)

Laboratory studies	Topic
Lee (2011)	Amplitude modulation dose-response
Legarth (2007)	Auralization and Assessments of Annoyance from Wind Turbines
von Hünerbein (2010)	Perception of noise from large wind turbines

Table 1 – Recent original studies on health effects and annoyance from wind turbine noise (adapted from von Hünerbein *et al.* (2013).

Epidemiological/social studies are typically questionnaire based postal studies which are often designed to include (all) affected residents as well as an unaffected control group to make the results comparable and objective. To avoid attitudinal bias (i.e. responses that are heavily influenced by opinion or emotion) the topic under investigation is frequently disguised in a more general questionnaire such as a "Quality of Life" questionnaire when the study is about the health effects from wind turbines. It is judged to be advantageous that the questionnaire will be completed in the respondent's own environment as the non-acoustic factors detailed in Fig. 1 will be typical.
These types of studies are often criticised for not providing accurate information about the noise environment. Concerns have been raised about a statistical skew of the results from potential over-reporting by affected residents (MDEP, 2012). It is important to remember that these types of studies are a snapshot in time. Where historical questions are asked the information might be unreliable because of the respondent's inability to accurately recall events.

These studies typically attempt to derive dose-response relations measured as the percentage of people annoyed/affected as a function of exposure (see an example in Fig. 2, Pedersen, 2010a). Even very well designed studies are frequently criticised on the basis of over-reporting bias and low statistical significance after moderation with other non-acoustical factors (e.g. MDEP, 2012).



From Pedersen *et al.* (2010a)

Figure 2. The proportions of respondents who were rather or very annoyed by noise from wind turbines in relation to sound levels at the dwelling, with 95% confidence intervals (n = 1095)

Another approach is the case study/report. These are often conducted in response to complaints and examples can be found in Tab. 1. Different methodologies can be used but often in-depth interviews are conducted at the respondent's premises and sometimes there are even noise measurements reported (e.g. Ambrose, 2012). As in the cross-sectional studies the information is provided in the respondent's home environment and therefore case studies often result in detailed information on a particular site/respondent. In some cases the studies have been conducted over a period of time but not before the wind turbines were built.

These studies are not designed to provide statistical information on the prevalence of annoyance or health effects from wind turbine. They are quoted to be useful for awareness raising of possible effects of wind turbines. These studies are often criticised for providing insufficient evidence for a causal relation between the noise source and health effects (e.g. Knopper & Ollsen 2011). Recruitment methods are also questioned (MDEP, 2012).

Only a small number of listening tests relating to affective response from wind turbine noise have been published recently (Lee *et al.*, 2011, Legarth, 2007, von Hünerbein *et al.* 2010, Vos *et al.,* 2010). Listening tests have the advantage of a closely controlled environment both in terms of the presented sound stimuli and a reproducible listening environment. Systematic investigations of different aspects of a sound are possible. The topic under investigation can in principle be disguised (e.g. as an environmental noise study) to avoid attitudinal bias. The participants can be chosen to be a representative sample of the population. Listening tests can either request listeners for absolute ratings for annoyance or perceptual parameters like loudness. They can also be comparative. An example of a comparative listening test would be to adjust the volume of a reference sound to be as annoying as a test stimulus.

When interpreting the results of listening tests it is important to keep in mind that the listeners have been taken out of their usual context. Therefore absolute annoyance ratings are not comparable to ratings that would be expected in their own home environment. However, results can be compared in relation to each other. Fig. 3 shows an attempt by Lee *et al.* (2009) to derive a dose-response relation for amplitude modulated wind turbine noise. Statements can be made about the relative influence of the two different parameters on annoyance.

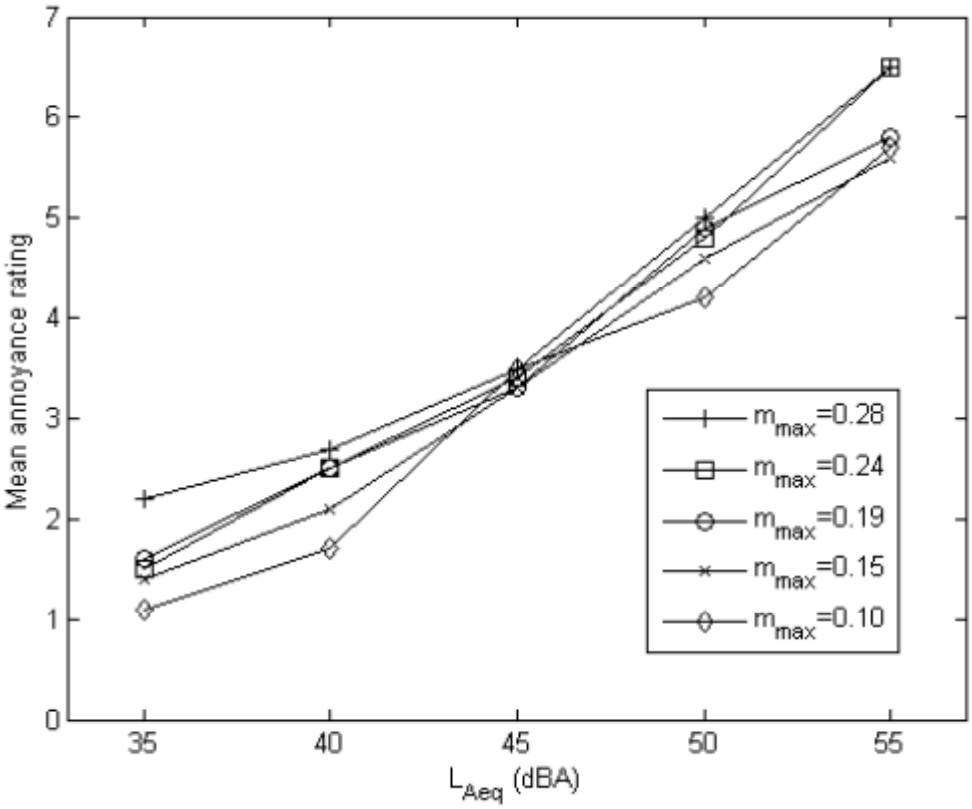


Figure 3 – From Lee *et al.* (2009): Absolute annoyance ratings for stimuli with varying L_{Aeq} and modulation depth.

A common approach in defining regulations for wind turbines is to set absolute or relative noise limits and where special noise characteristics like tonal noise occurs to add a "penalty" to the measured noise. Comparative listening tests can be useful to establish the size of these

penalties. The example in Fig. 4 compares annoyance of tones at different frequencies to the annoyance of a tone at a "reference" frequency of 180 Hz in an attempt to establish whether penalties for tonal components of wind turbine noise should be frequency dependent. It has been found that comparative studies are often harder to interpret than studies that use absolute ratings.

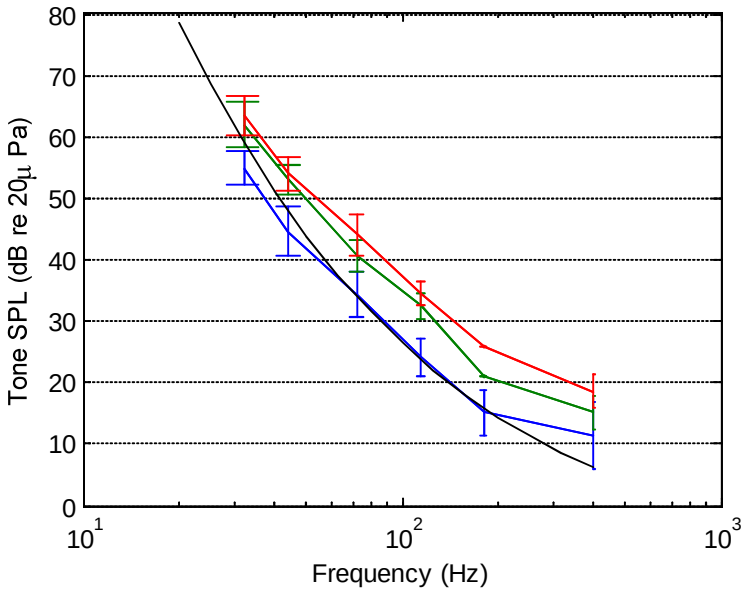


Figure 4 – From von Hünerbein *et al.* (2010): Audibility threshold of tones at 6 different frequencies (blue), equal annoyance to a 180 Hz reference tone at 5 dB audibility (green) and 10 dB audibility (red) of low frequency tones. Black solid line: Hearing threshold according to ISO 389-7 (2005).

A restriction of listening tests is the time participants spend in the laboratory, which typically ranges from half an hour to a few hours at most. Long testing times in the laboratory can result in fatigue bias unless very carefully controlled. Effects resulting from realistic long term exposure to wind turbine noise can also not be assessed.

Another difficulty lies in the study of effects of random exposure patterns that can occur in situations of strong meteorological variability. To date, the lack of a sufficiently large data base of recordings precludes the creation of a representative set of stimuli. The stimuli would also have to be considerably longer than the typical 20 second to 1 minute stimuli used in Lee *et al.* (2009) and von Hünerbein *et al.* (2010).

In contrast to cross-sectional studies and case studies, the control over the noise parameters in listening tests allows to compare the correlation of different metrics with annoyance. The most common metrics used for sound level in relation to wind turbines are L_{Aeq} and L_{A90}. L_{DEN} is also used in some countries. Other measures are used for other sources of environmental noise such as aircraft noise. It is still unclear whether these metrics based on the physical properties of sound correlate better with annoyance than perception parameters such as loudness or fluctuation strength, although a study by King (2012) has found that different loudness models disagree significantly for the non-stationary wind turbine sound. It can therefore be speculated that loudness would not be a suitable parameter.

4. Conclusions

Currently used study methods to evaluate the annoyance from wind turbine noise have been compared with the aim of informing the discussion on policy making.

Cross-sectional studies have so far given the best available estimates of the percentage of population with different degrees of annoyance in response to wind turbine noise and of the

percentage of . They have therefore been widely quoted in the discussion on the adequacy of noise limits. Case studies and reports are useful as an indication of which effects can occur. Listening tests also have the potential of addressing a number of special noise characteristics of wind turbine noise in an attempt to find relevant noise limits. To be representative these studies need a much larger database of wind turbine noise recordings than is currently available. The rationale in obtaining such a larger data base would be especially to answer questions of the influence of amplitude modulation and source directivity.

A study type that has not been applied to wind turbines is the longitudinal (long term) study that compares the responses of affected residents before and after wind turbines were built. These types of studies have been conducted for other noise sources but they tend to be very expensive. However, they have the potential of establishing a causal relation between the introduction of wind turbines and annoyance as well as health effects.

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