Wind Farm Noise Dose Response

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INTRODUCTION

A literature search reveals most wind farm noise dose response studies have been carried out in Scandinavia, the Netherlands and Germany. Transposing these studies to other countries may not be reliable as methodological and analytical issues, and differences in topography, population density and distribution, as well as variation in societal, language, cultural, environmental and political factors between these countries and elsewhere, militate against the direct transfer of these dose responses. However, these studies make a useful contribution to trying to understand wind farm noise dose response overall.

Review of dose response research

A substantial review of wind farm noise dose response was produced in 2003 by Eja Pedersen[1] on behalf of the Swedish Environmental Protection agency. As a starting point this study looked at work done by Wolsink et al (1993) in the early 1990's, which is summarised below.

1. In all, 13.5% of the study respondents were exposed to turbine noise in the range <25 to 30 dB(A) , 70% of the study respondents were exposed to turbine noise in the range 30 to 40 dB(A), and 16.4% were exposed to turbine noise above 40dB(A);
2. The proportion of persons indicating any noise annoyance is low at only 6.5% of the survey sample;
3. The degree of annoyance is only slightly related to noise level;
4. *'The fact that someone was complaining was mainly determined by the personality of the individual';*
5. *'The conclusions must not be misunderstood. The fact that sound level is not predicting annoyance does not mean that people are not really annoyed when they are reporting it.'*

Importantly, the Wolsink et al (1993) study sounds a note of caution regarding interpretation of its results as 'There are a number of methodological problems involved in the project'.

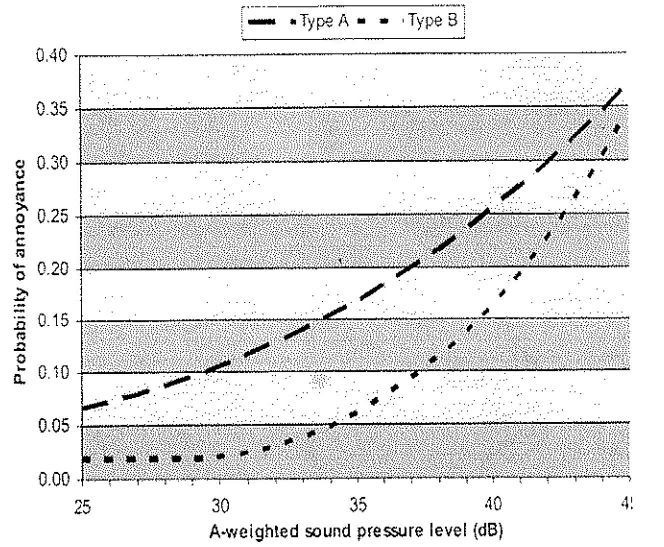
The Swedish study

Another more recent (2007) field study has been carried out in Sweden[2] (referred to hereafter as 'the Swedish study'). This study consisted of multiple phases, including cross-sectional social surveys to derive a dose-response relationship. Subjective responses were obtained from 1,288 respondents across the different phases of the study. The first phase was carried out in an area of flat terrain in a mainly quiet rural area, whereas the later phase was carried out in areas with different types of terrain (flat or complex) and different degrees of urbanisation and higher ambient noise levels.

Overall the Swedish study found a greater probability of the perception of wind turbine noise in quieter rural areas compared with noisier suburban locations; and a greater annoyance response rate in quieter compared to noisier locations.

The Swedish study also considered the impact of visual factors by comparing responses from respondents who could see wind turbines with those who could not see wind turbines. The study found that 'being negative towards the visual impact of wind turbines on the landscape scenery, rather than towards wind turbines as such, was strongly associated with annoyance.'

Dose-response relationships were found in the Swedish study both for perception of noise and for noise annoyance in relation to turbine A-weighted sound levels derived in accordance with the Swedish Environmental Protection Agency (2001) Guidelines†. Two dose-response relationships were presented: one for rural areas (Type A) and the other for suburban areas (Type B) and these are reproduced here in Figure 1.



Type A Rural location, with low background noise levels

Type B Suburban location with higher background noise levels

Figure 1

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

However, caution is advised when considering the masking effect of other noises, as the distinctive temporal and frequency characteristics of wind turbine noise may mean that it is not completely masked until other noises eg road traffic noise, are at A-weighted levels least 20dB greater than the turbine noise[3]. However, as the Pedersen and Persson Waye (2007) work referred to above shows, when making decisions on wind turbine noise policy or in regard to specific developments, complete masking so that the turbine noise is not audible is not required in order to manage the impact of turbine noise. As with most other noise sources, there is generally a substantial gap between the proportion of persons who can perceive wind turbine noise at a particular noise level, and the much smaller proportion of persons reporting annoyance, as will be shown shortly in this review. In line with most other noises, this suggests that whilst the overall community response of the relevant proportion of a population reacting adversely to turbine noise at specific levels may ultimately be capable of prediction, the wide variability of human response to noise and the influence of non-acoustical factors typically makes precise prediction of the reaction of individuals to wind turbine noise impracticable.

The graphs in Figure 2 are from the Swedish study and show the proportion of respondents who noticed and/or were annoyed by wind turbine noise in Phases I and III. Care should be taken when comparing the two studies as Phase III was not intended to replicate Phase I:the studies were in different landscapes with different geographical characteristics, and Phase III included questions about evaluation of the environment and feelings invoked by wind turbines and coping strategies

* The paper is unclear as to what noise index applies, but it is assumed that the $L_{Aeq,t}$ is relevant as it is applied to wind turbine noise in all the countries in the study.

† The text this report suggests that the dose responses use the $L_{Aeq,T}$ noise index. Whilst in the UK ETSU-R-97 advises use of the statistical method (L_{A90}) for the measurement of noise from wind farms, most other countries in Europe use the equivalent continuous noise index ($L_{Aeq,T}$). Most other EU countries have fixed limits, the lowest being Sweden and Ireland (40dB(A) $L_{Aeq,T}$ and the highest being Spain (65dB(A) $L_{Aeq,T}$ – although care should be taken when comparing advice from different countries as noise index, time period and definition of night and day periods can vary substantially.

that were not asked in Phase I. The two phases show clear differences in the degree of response, which suggests that amongst other variables the response rate is influenced by location specific factors.

Both phases of the Swedish study reinforce that mere perception of wind turbine noise is not sufficient to provoke annoyance in most of the respondents, as there is a significant difference in the percentage perceiving the wind farm noise and those who are annoyed, with a smaller differential at lower noise levels compared to higher values.

Both Phases I and III of the Swedish study have in common the general trends that:

- annoyance increases with increasing noise level;
- sleep disturbance was associated with annoyance (although only Phase I showed an association between noise level and sleep disturbance);
- Descriptors of the turbine noise characteristics including 'swishing', 'whistling', pulsating/throbbing' and 'resounding' were highly correlated with noise annoyance in both Phase I and Phase III.

Recent developments

More recently (2009), work[4] has been published that considers two surveys in Sweden and one in the Netherlands on wind farm noise dose response compared with industrial noise. This concluded that:

- *'At outdoor exposure levels higher than 40dB(A), the expected percentage of annoyed persons indoors due to wind turbine noise is higher than due to industrial noise from stationary sources at the same exposure level;*
- *Besides noise exposure, various individual and situational characteristics were found to influence the level of annoyance;*
- *Having economic benefit from the use of wind turbines, or being able to see one or more wind turbines from within the home are two particularly influential situational factors [with positive and negative effects respectively];*
- *The economic benefit factor is reminiscent of earlier findings that being employed at the noise source (eg airport or industry) attenuates the annoyance reported;*
- *Also, visibility from the home (eg living room, bedroom) has been reported earlier to affect annoyance from stationary sources;*
- *In addition, noise sensitivity and age had similar effects on [increasing] annoyance to those found in research on annoyance by other noise sources.'*

The chart in Figure 3 (taken from the Netherlands study) illustrates that wind turbine noise measured using Lden in dB(A) appears to have a higher annoyance rate than industrial noise.

Also in 2009 further work[5] concluded that:

- *'A dose-response relationship between calculated A-weighted sound pressure levels and reported perception and annoyance was found;*
- *Wind turbine noise was more annoying than transportation noise or industrial noise at comparable levels (see Figure 4), possibly due to specific sound properties such as a 'swishing' quality, temporal variability, and lack of night time abatement. High turbine visibility enhances negative response, and having wind turbines visible from the dwelling significantly increased the risk of annoyance;*
- *Annoyance was strongly correlated with a negative attitude toward the visual impact of wind turbines on the landscape;*
- *People who benefit economically from wind turbines have a significantly decreased risk of annoyance, despite exposure to similar sound levels.'*

The Janssen, Eisses and Pedersen (2009) study compared the Dutch

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study results with results from the Swedish study‡ and concluded the following;

- *'The study confirms that wind turbine sound is easily perceived and;*
- *Compared with sound from other community sources, relatively annoying, and;*
- *Annoyance with wind turbine noise is related to a negative attitude toward the source and to noise sensitivity, and;*
- *In that respect it is similar to reactions to noise from other sources, and;*
- *This may be enhanced by the high visibility of the noise source, the swishing quality of the sound, its unpredictable occurrence, and the continuation of the sound at night.'*

The importance of acoustic features

G P van den Berg[6] (2005) has investigated the possibility that uneven

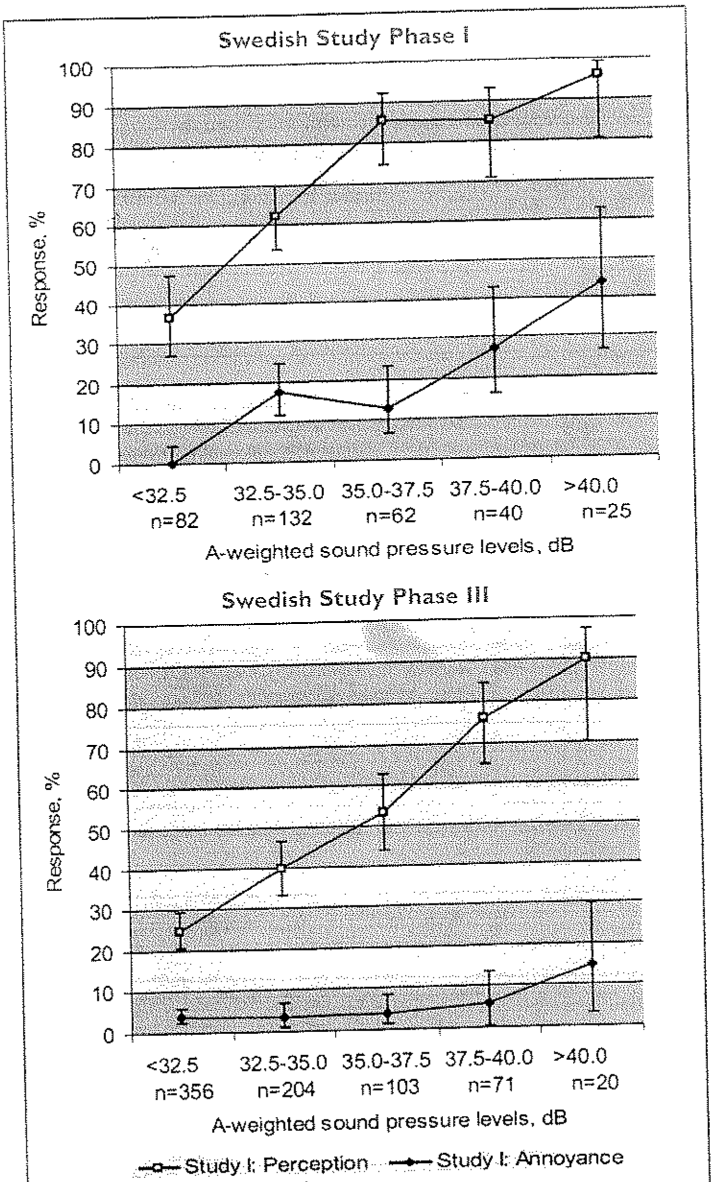

Figure 2

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

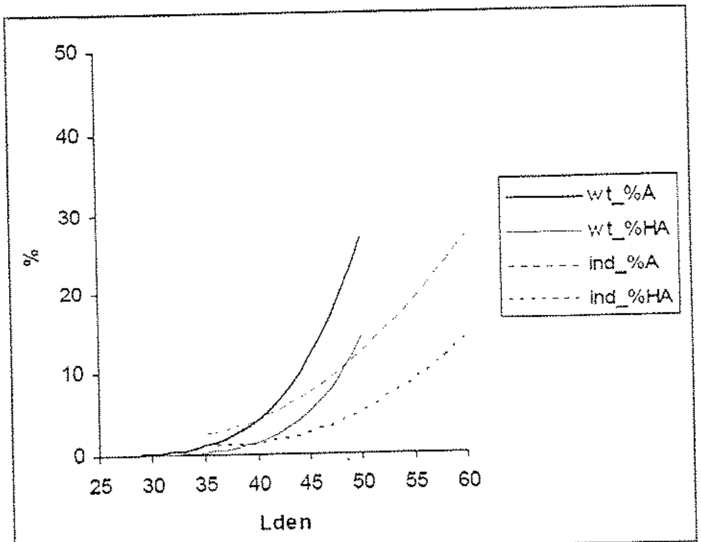

Figure 3

Comparison of the percentage annoyed and highly annoyed persons indoors (%A indoors and %HA indoors) due to wind turbine noise (wt) and industrial noise (ind). Janssen, Eisses and Pedersen, Exposure-response relationships for annoyance by wind turbine noise: a comparison with other stationary sources, EURONOISE 2009, Edinburgh.

wind speed across the rotor plane may cause fluctuations in noise emission and has suggested that in stable atmospheric conditions the difference in wind speed between the top and bottom of the rotor of a large turbine is relatively high. This may contribute to a cyclical variation in the noise level, which may be characterised as a 'beating' – an effect referred to as amplitude modulation of aerodynamic noise (AM). This type of noise is of interest, as it is likely that a modulated noise will be more annoying than a non-modulated noise at the same sound pressure level. In regard to this point, it has recently (2009) reported that:

> *'Acoustically this may be due to the diurnal course of the noise and the rapid fluctuation in level related to the rotation, which are not usual features of most transportation and industrial noise sources. It can also be a result of non-acoustic factors such as visual intrusion and the perceived distribution of benefits and adverse effects.'*[7]

As wind farm noise typically includes a degree of modulation it will normally be appropriate to include assessment of this factor when assessing dose response. However, aerodynamic modulation of the aerodynamic noise emitted by wind turbines is not well understood and there are presently no peer reviewed and validated models available through which the occurrence of aerodynamic modulation can be reliably predicted. Additionally, there is currently little understanding of the factors that influence how modulation of the turbine noise may affect its impact, or any established thresholds of modulation beyond which the impact is clearly unacceptable.

In 2002 in a laboratory study[8] 25 subjects were exposed to five wind turbine noises of different character, but all at the same noise level of 40dB $L_{Aeq,t}$, in order to see if differences between the noises with regard to annoyance could be found. The most annoying noises were predominantly described as 'swishing', 'lapping' and 'whistling'. These descriptors could all be regarded as related to the aerodynamic noise and as descriptions of a time varying (modulated) noise with high frequency content.

In another laboratory study[9] (2007) 20 subjects were asked to rate recordings of wind turbine noise with different acoustic features, principally tonal components and aerodynamic noise from the rotating blades. The rated tonality of the stimuli did not correlate well with the metric developed for the prominence of tones - ΔLta. However a metric for calculating 'swishing sound' was developed ie fluctuation strength, which is a measure of amplitude and frequency modulation. This was measured in the 350 – 700 Hz band, and correlated well with the ratings on 'swishing sound' in the sound played to the test subjects. The frequency band between 350 and 700 Hz was chosen because it

‡ Again the study is unclear as to the noise index or the measurement time period, but the propagation model used (ISO 9613) suggests $L_{Aeq,T}$.