inter•noise 2009
innovations in practical noise control
2009 August 23-26
Ottawa, Canada

Perception and environmental impact of wind turbine noise

Kerstin Persson Waye[a]
Occupational and Environmental Medicine
The Sahlgrenska Academy
Gothenburg University
Box 414, 405 30 Gothenburg
Sweden

ABSTRACT

Wind power plays an important role in the ongoing conversion to renewable energy sources and the number of operating wind turbines is growing rapidly. While the public opinion towards wind power is generally favorable, the local community often opposes new wind turbine projects. Noise and visual disturbances are major environmental impacts for residents living nearby, hence important factors to resolve in order to facilitate the expansion of wind power. The overall framework of this paper is the relationships of exposure and human response with focus on the specific challenges inherent for wind turbine noise exposure. Human response and adverse health effects are discussed in relation to physical factors moderating the human response such as visibility of the turbine, audibility of specific sound characteristics and contextual factors such as the individual's expectancy of the living environment. Finally, unresolved aspects related to health and noise exposures will be discussed.

1. INTRODUCTION

Wind power plays an important role in the ongoing conversion to renewable energy sources. The installed effect is increasing with for 2008 an annual growth of almost 29% globally. The global contribution of wind generated electricity is about 1.5%, however the variation between countries is large. The total installed capacity is greatest in Germany, USA and Spain where the installed capacity ranges from 16% (Spain) to 24 % (Germany)[1]. Regarding new installed capacity (2007) USA and Spain but also China belongs to the three top leading countries.

While the public opinion towards wind power is generally favorable, the local community often opposes new wind turbine projects. Noise and visual disturbances are major environmental impacts for residents living nearby, hence important factors to resolve in order to facilitate the expansion of wind power.

[a] Email adress: kerstin.persson.waye@amm.gu.se

2. EARLY STUDIES

When the wind turbine energy production started to take off in the mid of 1990's, there was little knowledge of the environmental impacts. The early down-wind constructions generating low frequency "thumping sounds" gave wind turbines a reputation of being noisy[2]. With the next generation of turbines this problem was largely solved, however mechanical tonal noise from the gearbox was then a source of noise annoyance. Sporadic complaints were also directed to the local health authorities on flickering light and moving shadows but there was no gathered information on the prevalence of the environmental impact.

Early studies carried out in California indicated that visual impacts followed by noise were rated to be serious problems but concluded also that the public acceptance for wind turbines may be facilitated if the public could be more involved in the planning process[3]. Studies carried out in the Netherlands, Germany and Denmark[4] could only find a weak correlation between noise annoyance and A-weighted sound pressure level (A-weighted SPL). The follow-up analyses made in Denmark found though a significant dose-response relationship between annoyance and A-weighted SPL and furthermore that the visual angle, perception of shadows and the attitude to the impact that wind turbines had on the landscape played a role also for noise annoyance[5].

These early studies hence, gave a first insight into the complexity of wind turbines impact on people living nearby, however their results were based on wind turbines of nominal power of 150 kW or less and it was questionable if these results were applicable to modern turbines.

3. SPECIFIC CHALLENGES INHERENT FOR WIND TURBINE NOISE EXPOSURE?

Being a community noise source it would be expected that existing dose-response relationships or noise regulations for stationary noise sources could be applicable also for wind turbines. Some aspects that are specifically inherent for wind turbines may however make this community noise source a specific challenge. Apart from the noise exposure, the visual disturbances are major environmental impacts for residents living nearby and hence important factors to resolve in order to facilitate the expansion of wind power. These factors need to be studied within the context that wind turbines are usually erected, i.e. rural or coastal areas where the background noise level may be low, where recreational factors play a role and where the landscape's scenery is important for the inhabitants. The risk for disturbance could be looked upon as a detection of signals in relation to a baseline. The baseline is an individually formed concept although a substantial part is believed to be generic for a larger population. The individual's baseline can be seen as his/hers expectancy of the living environment (per se influenced by many factors); the visual baseline being a natural unbroken landscape and the aural baseline being lack of intrusive sounds. In the following these aspects will be further explored and their relevance for noise annoyance discussed.

A. Noise annoyance due to sound intrusion

The audibility of a sound source is one obvious factor affecting the response to low and moderate level noise sources. This in turn depends on the sound properties in the source in relation to the level and properties of the ambient sound. It has for instance been found in experimental studies, that the same sound presented in different backgrounds was rated differently with regard to detectability[6] and annoyance[7]. The hypothesis was also confirmed in a field study of air condition noise where the response of the neighbours was best predicted by the signal to noise ration, where the noise was the ambient sound with the air conditioner turned off[8]. One way of reducing the intrusion is by masking the target sound. Due to the broadband frequency characteristics of both wind turbine sounds and natural wind generated sounds, it has repeatedly been suggested that wind turbines would easily be masked by natural sounds. Indeed, recent laboratory results showed an effect of reduced loudness in the order of 5 dB but only as long as the level of the natural sound was in the same order as the wind turbine sound[9]. It is though difficult to predict how this applies to a real situation, especially as the level of natural sounds had to be about 10 dB above that of the wind turbine sound in order to mask the wind turbine sound completely (ibid).

The main issue with modern turbines is the aerodynamic noise produced by the blades moving through the air and passing the tower. The movements of the blades through the wind velocity at different heights and the effect of the wind being slowed down by the tower produce a "broad band" rhythmically varying, i.e amplitude modulated, sound. The frequency of the modulations corresponds to the revolutions and modern wind turbines with three rotor blades usually generate amplitude modulations in the range of 1 to 2 Hz. Amplitude modulations were in studies by Zwicker and Fastl[10] identified as easily perceived sound characteristic. It has then later been confirmed in several studies that amplitude modulations increase the risk for unpleasantness[11] and annoyance[12]. Interestingly, studies using Magnetic Resonance Imaging (MRI) has shown a considerably higher activation in non-primary auditory regions for frequency modulated tones as compared to non-modulated tones indicating a specific central auditory response to this sound characteristic[13]. It was also shown that the response and the place of central auditory region was rather similar between frequency and amplitude modulated sounds indicating a common sensitivity to both frequency and amplitude modulated sounds[14]. When asked, most respondents describe the annoying sound properties from wind turbines as swishing followed by whistling and pulsating/throbbing[15]. The correlation between the perception of swishing and noise annoyance was also seen to be high (r = 0.72), which can be compared to the correlation between noise annoyance and the calculated sound level at each respondents house which was r = 0.35. To see if the perception of the various sound characteristics changed with distance, in this case estimated by the calculated noise level, the respondents' reports of annoyance for a selection of sound characteristics were plotted against their calculated A-weighted SPL at home (Figure 1). The response to swishing can be seen to attenuate rather well with decreasing level, on average about 17% per 5dB interval, while the response to pulsating and low frequency attenuates least with about 6 and 7% per 5dB interval respective.

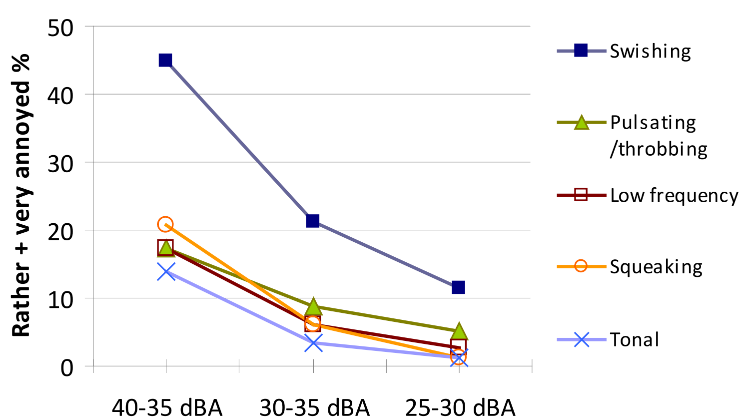


Figure 1. The change of annoyance for some sound characteristics with distance (estimated as a change in calculated A-weighted SPL). Data from Pedersen and Persson Waye 2004[15].

The results from the field study correspond rather well with earlier experimental studies investigating unpleasant characteristics and their relevance for noise annoyance[16-19]. In those series of studies it was first established that wind turbine sounds played back at the same A-weighted sound pressure level were rated differently with regard to annoyance, and awareness[16]. The most annoying acoustic parameters were found to be swishing, lapping and whistling. Subjects were then asked to interactively adjust the most and least unpleasant characteristics in frequency and temporal domain keeping the A-weighted SPL the same. To obtain a pleasant sound, respondents decreased the frequency component above about 1600Hz in relation to the preferred frequency range of 785-1000Hz[17], while the results of the temporal adjustments mainly could be seen as a reduction of loudness over time[18]. Finally subjects were asked to rate annoyance for the modified pleasant sounds, modified with regard to both spectral and temporal aspects, and with the tone at 546 Hz present in the original sound removed (Modified sound without tone) and Modified sound with the tone as well as the Original sound with tone[19]. The results displayed in Figure 2 showed that modified sounds were less annoying compared to Original sound except at 40 dBA where the Modified sound without tone was not significantly different from the Original sound (Wilcoxson sign rank test p=0.077) (ibid). If the data points are fitted to a linear regression, the difference in annoyance between the Modified sound with tone and the Original sound corresponds to a reduction of about 5 dBA in noise level, while there was an even greater difference between the Original and the Modified sound without tone.

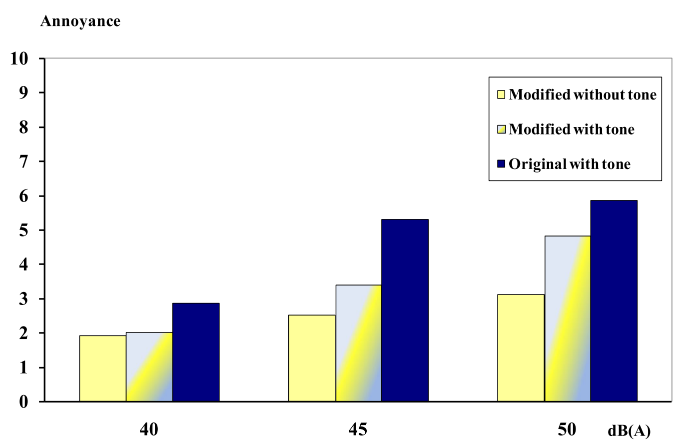


Figure 2. Median levels of annoyance for the three wind turbine sounds at 40, 45 and 50 A-weighted SPL. Modified sound without tone, Modified sound including the original tone and the Original wind turbine sound with tone. Data from Persson Waye and Agge 2000[19].

Efforts in construction and design of modern wind turbines have aimed to minimize the aerodynamic sounds inclusive perception of modulations. Though, as shown by van den Berg 2005[20] the problem with modulations is still a factor of concern for modern tall wind turbines. At meteorological conditions such as stable or very stable atmospheres, measured modulation fluctuation levels typically reach 4-6 dB for single wind turbines producing a clearly perceivable thumping or beating sound.

B. Noise annoyance due to visual intrusion

Vision can influence aural sensation, and vice versa, and by using these cross-modal capabilities our detection of external stimuli can be improved[21]. In studies of community noise it has been found that human response to sounds can be modified by visual stimuli. For example, seeing the noise source usually leads to higher annoyance[22]. Modern wind turbines with a typical hub height of 90m are easily visible in most landscapes. Furthermore, the rotating movements of the blades sometimes connected with moving shadows and/or flicker, make them difficult to ignore visually. This was verified in a study using a qualitative method, where respondents described the constant rotation as annoying and impossible to ignore[23].

It has further been found that sounds are perceived more positive if presented together with pictures of vegetation[24], and that emphasizing the urbanization in pictures increased subjects' negative ratings of sounds[25]. As wind turbines can be looked upon as intruders in a natural landscape[26] and as such contribute to an increased perception of "urbanization" of the landscape, it is possible that also this factor adds to noise annoyance.

The influence of visibility of the wind turbines was tested in a study comprising both complex/hilly and flat terrain[27]. Seeing the wind turbine had a significant impact on the risk for noise perception OR= 2.3 (95%CI 1.51-3.47) and for noise annoyance OR=10.9 (95%CI 1.46-81.92). Although the interpretation of the exact values of the risk has to be done with care, data show that the visibility plays a great role also for noise annoyance.

C. Noise annoyance and individual intrusion

The not in my backyard phenomena (NIMBY) is often mention in connection to peoples' reaction to wind turbines if they are to be erected close to their homes. Over the years the phenomena has been used, with little discrimination, to indicate any objections to wind turbines with or without an implicit knowledge of the underlying basis[28]. In an analysis of the concept Wolsink concludes that the crucial factor in NIMBY is "not egotism, nor any other personality trait, but fair decision making that does not cause any perceived injustice". Significant relationships between perceived fairness of a planning process and acceptance was also found by[29]. Few studies have looked at the connection between the perception of procedural justice and wind turbine annoyance. Some guidance could be found in [22], where the model that emerged from the interviews described a connection between perceived intrusion of wind turbines (visually and aurally) and lack of influence, control, being subjected to injustice and not being believed.

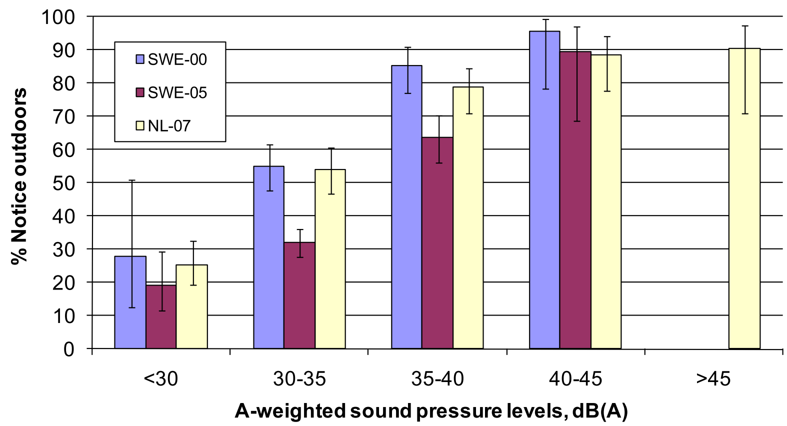
Individual factors that have been shown to be associated to noise annoyance are attitude to wind turbines impact on the landscape, general attitude to wind turbines and noise sensitivity, of those the largest impact has repeatedly been found from visual attitude[15, 27, 30].

4. NOISE ANNOYANCE AND DOSE-RESPONSE RELATIONSHIPS

The results of two cross-sectional studies carried out in Sweden in 2000 (SWE-00) and 2005 (SWE-05)[14, 26] and the latest study carried out in the Netherlands 2007 (NL-07)[30], also cross-sectional, have given a comprehensive understanding on perception and annoyance in relation to noise exposure of wind turbines erected during this period. These studies will be described in more detail and discussed in relation to moderating factors that may be of importance for noise annoyance. Finally factors that are yet to be resolved are outlined.

The two studies carried out in Sweden comprised twelve geographical areas at different locations in Sweden with in total 44 turbines. The majority of the turbines had a nominal power of 500-800 kW. The study areas in SWE-00 were mainly rural, agricultural and flat landscapes, while the areas in SWE-07 had a larger variation in topography and population density including also hilly terrain and suburban sites. The study in the Netherlands comprised a random sample of people all over the country that lived in the vicinity of a nominal power of 500 kW or more in a flat landscape but with different degree of road traffic intensity. For all three studies the responses of the nearby residents were collected using questionnaires and answers were received from 1095 respondents (response rate 61%) in the two Swedish studies and from 725 (response rate 37%) in the Dutch study. The data sets for the three studies have been reanalysed to assure similar treatment of data[31]. A-weighted sound pressure levels corresponding to a down wind condition with wind speed 8 m/s at 10 m height from the turbines were calculated for each respondent, using the Swedish standard for the Swedish study[32] and the ISO-standard for the Dutch study[33] for the sound propagation attenuation. The algorithms have been found to give similar levels for the distances relevant for these studies[30].

The proportions of respondents noticing sounds and annoyed when spending time outdoors from wind turbines are shown in Figure 3.



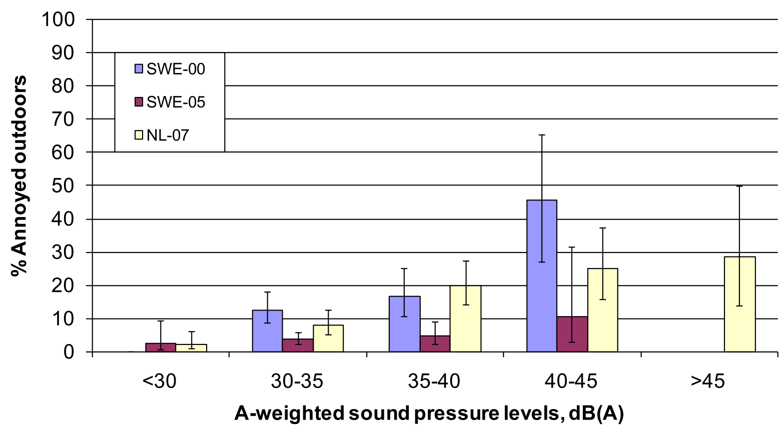


Figure 3. Proportions of respondents (with 95% confidence intervals) who noticed and who were annoyed by, respectively, wind turbine noise outdoors in the Swedish study carried out 2000[15], the Swedish study carried out 2005[27] and the Dutch study (only respondent who did not benefit economically from wind turbines) carried out 2007[30] in relation to 5-dB intervals of A-weighted sound pressure levels.

Figure 3 shows that sounds from wind turbines can be noticed by a majority of respondents from levels as low as 35-40 dBA, and at the sound level interval of 40-45 dBA, all or nearly all,

respondents noticed sounds from wind turbines. It is interesting to note the remarkable good agreement between the SWE-00 and the NL-07, both carried out in a flat landscape.
In all three studies the prevalence of noise annoyance increased with increasing sound levels, although the SWE-05 obtained in hilly terrain generally tended to have a lower prevalence of noise annoyance.

The question is often raised whether wind turbine noise can be seen and estimated as other community noise sources, for example stationary sources from industry. Some complications exist though in making these comparisons, one of the most important being the question on where is noise annoyance assessed, outdoors or indoors? For rural areas and for Nordic countries with a good insulation of the houses, noise from wind turbines are mainly an outdoor problem. While for example when assessing transportation noise, noise annoyance is mainly assessed indoors.

In Figure 4 the prevalence of wind turbine noise annoyance reported outdoor and indoors in SWE-00, SWE-05 and NL-07 are plotted against the curves obtained for stationary noise sources[34].

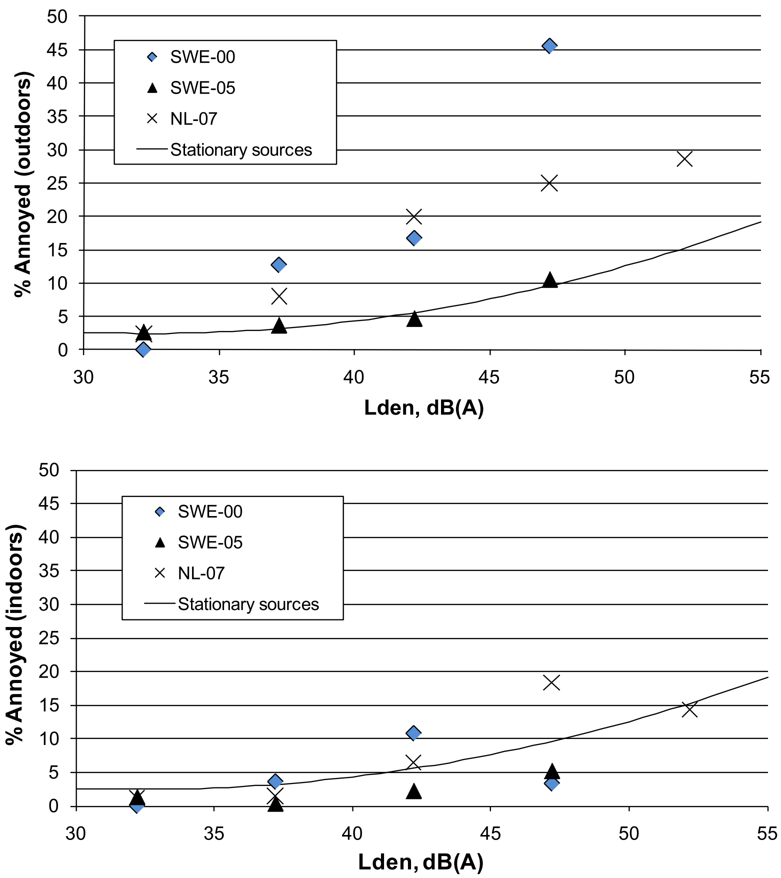


Figure 4. Proportions of respondents annoyed, indoors and outdoors, due to wind turbine noise in the Swedish study carried out 2000[15], the Swedish study carried out 2005[27] and the Dutch study (only respondent who did not benefit economically from wind turbines) carried out 2007[30] in comparison with the dose-response curve for stationary sources[33] at 5-dB(A) intervals of Lden values. Lden values for wind turbine were transformed from A-weighted sound pressure levels in accordance with van den Berg[35].

The figures above illustrate the complexity in answering the question raised above as it very much depend on if noise annoyance outdoor or indoors is of relevance. If we by a good/healthy living environment mean a place that should provide restoration in order to recover from daily stress it is in most cases apparent that also the outdoor environment should be taken into account. This may be especially true for people living in rural areas where recreational values may be an important quality of their living environment. Furthermore it is possible that rural areas attract people who are more sensitive to noise and who would therefore be more negatively affected by the introduction of a new noise source. It was for example found in the Swedish studies[36] that people who had previously lived in cities were significantly more sensitive to noise compared to people who had “always lived there”, the difference being 15% (95% CI: 5.9-25.2).

5. WIND TURBINES A RISK FOR OTHER ADVERSE HEALTH EFFECTS?

Apart from annoyance that is the most observed adverse reaction to community noise, it is well known that noise alone or in combination with other factors may lead to adverse health effects. The association between these effects and noise exposure have however mainly been observed after exposure to higher sound levels and mainly from transportation noise[37, 38]. As regards adverse outcomes from low or moderate level sources less information is available. The question whether wind turbine noise can lead to other health effects is though relevant seen in the light of some respondent’s reports of feelings of stress and lack of restoration when being home[23]. It was also in a subsequent study shown that annoyance to wind turbine noise was significantly correlated with the respondents’ judgement of the possibility for recovery and regaining strength in their current living environment, i.e. subjects that were annoyed did not think of their living environment as a suitable place for recovery (ibid). In today’s society with an increasing load of noise and other stressors, it can not be excluded that inhibited restoration may play a role for the development of ill health[39]. While research in this area is much needed, it has for example been found that exposure to restorative environments facilitates recovery from mental fatigue[40].

To cast some light on this matter data from the three studies (Swe-00, Swe-05 and NL-07) were reanalysed[31]. All data are based on self-reported health and only data that were include in all three studies were considered such as annoyance, chronic diseases (diabetes, high blood pressure, cardiovascular disease, tinnitus, impaired hearing) stress related symptoms (headache, undue tiredness, feeling tense or stressed, feeling irritable) and disturbed sleep (interruption of sleep by any noise source). In the analysis the variables were dichotomized and the associations between A-weighted sound pressure levels (continuous variable) and self-reported health analyzed using binary logistic regression adjusting for age, sex, and in the Dutch study, also for economical benefits. The sleep disturbance was measured differently in the Swedish studies (yes/no) and the Dutch study where the frequency of sleep disturbance was asked for. Sleep disturbance once a month or more often was in the analysis considered as sleep disturbance.

The odds for being annoyed outdoors was as expected significantly associated with sound levels: SWE-00, OR=1.24 (95%CI 1.13-1.36), SWE-05 OR=1.14 (95%CI 1.03-1.27) and NL-07, OR=1.10 (95%CI 1.06-1.15). No other variable measuring health was consistently associated to sound level throughout the three studies. Reports of interruption in the sleep by any source was however associated with sound level in the SWE-00, OR=1.12 (95%CI 1.03-1.22) and in the NL-07, OR=1.03 95%CI 1.00-1.07), while no such association was found in the SWE-05, OR=0.97 (95%CI 0.90-1.05).

The proportions of disturbed sleep by any noise source related to A-weighted sound pressure levels are given in Figure 5.

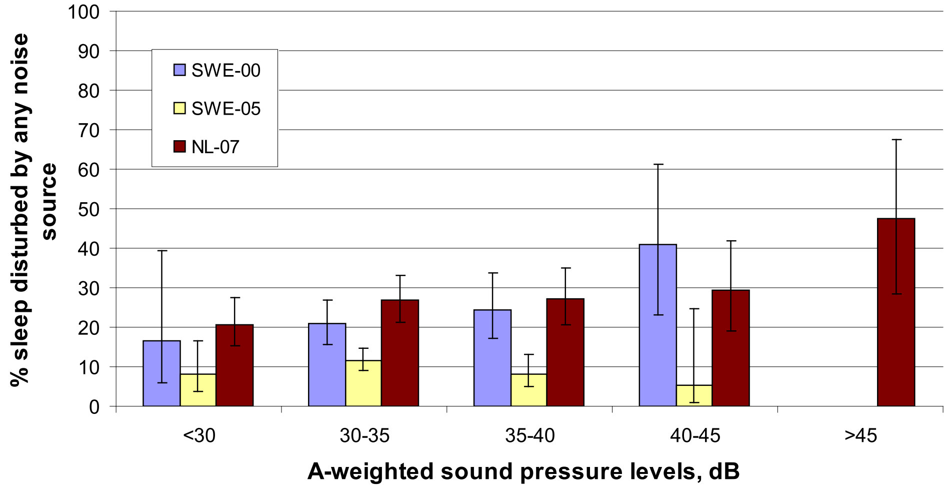


Figure 5. Proportions of respondents (with 95% confidence intervals) who were disturbed in their sleep by noise (any noise source) in the two Swedish studies (binary scale: no/yes) and in the Dutch study (once a month or more often; only respondent who did not benefit economically from wind turbines)[31].

It has previously been suggested that annoyance can act as a mediator between noise exposure and health. In coherence with that hypothesis it was in the analysis found that several of the symptoms of stress were associated with annoyance to wind turbine noise also when adjusting for A-weighted sound pressure levels. Feeling tense or stressed as well as irritable was related to noise annoyance in all three studies, while headache was related to annoyance in two of the studies SWE-00 and NL-07.

6. CONCLUDING COMMENTS

Wind turbine noise is easily perceived and causes annoyance even at low A-weighted SPL. The environmental impact on people is though multifaceted and noise perception and annoyance is moderated by visual, aural and individual perceived intrusions. It is plausible that acceptance and also annoyance would be positively influenced by a greater transparency and fairness of the planning process. The main problem for people living nearby wind turbines is experienced outdoors, where wind turbine sounds may inhibit restoration. The relevance of this for long term health needs to be further resolved. Whether wind turbine noise may disturb sleep is another important factor to pursue, possibly through experimental studies. Finally, the aspects of meteorological influence on the wind turbine sound characteristics should be clarified.

ACKNOWLEDGEMENT

Many thanks to my colleges at the Sound environment research group at Gothenburg University, and especially to Dr Eja Pedersen for providing valuable data analyses.

REFERENCES

[1] World Watch Institute, www.worldwatch.org (2009-05-13).

[2] K. P. Shepherd and H. H. Hubbard, ”Physical characteristics and perception of low frequency noise from wind turbines,” *Noise Control Engineering* **36**, 5-15 (1991).

[3] P. Bosley and K. Bosley, “Public Acceptability of California’s wind energy developments: Three studies,” *Wind Engineering* **12**(5), 311-318 (1988).

[4] M. Wolsink, M. Sprengers, A. Keuper, T.H. Pedersen and C.A. Westra, “Annoyance from windturbine noise on sixteen sites in three countries,” *European Community Wind Energy Conference* (8-12 March, Lübeck-Travemünde, Germany 1993).

[5] T. H. Pedersen and K. S. Nielsen, ”Genvirkning af støj fra vindmøller (Annoyance by noise from wind turbines),” [in Danish] Report 150, DELTA Acoustic &Vibration, Lydtekniske Institut, Copenhagen, Denmark (1994).

[6] S. Fidell, S. Teffeteller, R. Horonjeff and D. M. Green, ”Predicting annoyance from detectability of low-level sounds,” *J. Acoust. Soc. Am.* **66**, 1427–34 (1979).

[7] K. Persson Waye, M. Bjorkman and R. Rylander, “Loudness, annoyance and dBA in evaluating low frequency sounds,” *J. Low Freq. Noise Vib. and Act. Contr.* **9**, 32-45 (1990).

[8] J.S. Bradley, “Subjective disturbance of outdoor air conditioner noise,” In: A. Lawrence (ed) *Inter-noise 91,* (2nd-4th December, Sydney, Australia 1991).

[9] K. Bolin, ”Wind turbine noise and natural sounds - masking, propagation and modeling,” Doctoral thesis, Kungliga Tekniska Högskolan, School of Engineering Sciences, Department of Aronautical and Vehicle Engineering (Stockholm 2009).

[10] E. Zwicker and H. Fastl, ”Psychoacoustics, facts and models,” (Berlin, Heidelberg, New York, Springer Verlag 1999).

[11] J. Bengtsson, K. Persson Waye and K. Kjellberg, “Sound characteristics in low frequency noise and their relevance for the perception of pleasantness,” *Acta Acoustica* **90,** 171-180 (2004).

[12] J. S. Bradley, “Annoyance caused by constant-amplitude and amplitude-modulated sounds containing rumble,” *Noise Control Eng. J.* **42**(6), 203-208 (1994).

[13] D. A. Hall, I. S. Johnsrude, M. P. Haggard, A. R. Palmer, M. A. Akeroyd and A. Q. Summerfield, “Spectral and temporal processing in human auditory cortex,” *Cerebral Cortex* **12**, 140-149 (2002).

[14] H. C. Hart, A. R. Palmer and D. A. Hall, “Amplitude and frequency modulated stimuli activate common regions of human auditory cortex,” *Cerebral Cortex* **13**, 773-781 (2003).

[15] E. Pedersen and K. Persson Waye, “Perception and annoyance due to wind turbine noise: a dose–response relationship,” *J. Acoust. Soc. Am.* **116**, 3460–3470 (2004).

[16] K. Persson Waye and E. Ohrstrom, “Psycho-acoustic characters of relevance for annoyance of wind turbine noise,” *Journal of Sound and Vibration* **250**(1), 65-73 (2002).

[17] K. Persson Waye, E. Ohrstrom and M. Bjorkman, “Sounds from windturbines – can they be made more pleasant?” In: N. Carter and R. F. S. Job (eds), *7th International congress on noise as a public health problem,* pp 531-534 (22-26 nov, Sydney, Australia 1998).

[18] K. Persson Waye, A. Agge and M. Bjorkman, “Pleasant and unpleasant characteristics in wind turbine sounds,” In: D. Cassereau (eds), *Inter-Noise 2000,* (August 27-30, Nice, France 2000).

[19] K. Persson Waye and A. Agge, “Experimental quantification of annoyance unpleasant and pleasant wind turbine sounds,” In: D. Cassereau (eds), *Inter-Noise 2000,* (August 27-30, Nice, France 2000).

[20] G.P. Van den Berg, “The beat is getting stronger: The effect of atmospheric stability on low frequency modulated sound on wind turbines,” *Noise notes* **4**(4), 15-40 (2005).

[21] G. A. Calvert, ”Crossmodel processing in the human brain: insights from functional neuroimaging studies,” *Cerebral Cortex* **11**, 1100-1123 (2001).

[22] Z. Bangjun, S. Lili and D. Guoqing, ”The influence of the visibility of the source on the subjective annoyance due to its noise,” *Applied Acoustics* **64**, 1205-1215 (2003).

[23] E. Pedersen, L. R.-M. Hallberg and K. Persson Waye, “Living in the vicinity of wind turbines - a grounded theory study,” *Quality Research in Psychology* **4**(1-2): 49-63 (2007).

[24] J. L. Carles, I. L. Barrio and J. Vicente de Lucio, ”Sound influence on landscape values,” *Landscape and Urban Planning* **43**, 191-200 (1999).

[25] S. Viollon, C. Lavandier and C. Drake, ”Influence of visual setting on sound ratings in an urban environment,” *Applied Acoustics* **63**, 493-511 (2002).

[26] E. Pedersen. “Human response to wind turbine noise- perception, annoyance and moderating factors”, Doctoral thesis at Occupational and Environmental Medicine, Gothenburg University 2007, ISBN978-628-7149-9 (2007).

[27] E. Pedersen and K. Persson Waye, “Wind turbine noise, annoyance and self-reported health and wellbeing in different living environments,” *Occ. Environ. Med.* **64**, 480–486 (2007).

[28] M. Wolsink, “Wind power implementation: The nature of public attitudes: Equity and fairness instead of backyard motives,” *Renewable and Suistainable Energy Reviews* **11,** 1188-1207 (2007).

[29] J. Zoellner, P. Schweizer-Reis and C. Wemheuer, “Public acceptance of renewable energies: Results from case studies in Germany,” *Energy Policy* **36**, 4136-4141 (2008).

[30] G. P. Van den Berg, E. Pedersen, J. Bouma and R. Bakker, “Visual and acoustic impact of wind turbine farms on residents,” WINDFARM perception, Final report, Specific Support Action, Project no. 044628 (2008).

[31] E. Pedersen, "Effects of wind turbine noise on humans," *Proceedings of Third International Meeting on Wind Turbine Noise* (Aalborg, Denmark, 17–19 June 2009).
[32] Environmental Protection Agency, "Ljud från vindkraftverk (Noise from wind turbines)," *Report 6241* [In Swedish] (Stockholm 2001).
[33] ISO, "Attenuation of sound during propagation outdoors, Part 2: General method of calculation," *International Standard Organization* (1996).
[34] H. M. E. Miedema and H. Vos, "Noise annoyance from stationary sources: relationships with exposure metric day-evening-night level (DENL) and their confidence intervals," *J. Acoust. Soc. Am.* **116**, 334–343 (2004).
[35] G.P. Van den Berg, "Criteria for wind farm noise: Lmax and Lden," *Proceedings of the 7th European Conference on Noise control, EURONOISE, Acoustics"08* (Paris, France 2008).
[36] E. Pedersen and K. Persson Waye, "Wind turbines - low level noise sources interfering with restoration?," *Environ. Research Letter* **3**, 015002 (5pp) (2008).
[37] E. E. van Kempen, H. Kruize, H. C. Boshuizen, C. B. Ameling, B. A. Staatsen and A. E. de Hollander, "The associationbetween noise exposure and blood pressure and ischemic heartdisease: a meta-analysis," *Environ. Health Perspect.* **110**, 307–17 (2002).
[38] W. Babisch, "Transportation noise and cardiovascular risk: updated review and synthesis of epidemiological studies indicate that the evidence has increased," *Noise & Health* **8,** 1–29 (2006).
[39] H. Staats, A. Kieviet and T. Hartig, "Where to recover from attentional fatigue: An expectancy-value analysis of environmental preference," *J. Environ. Psychol.* **23**(2), 147-157 (2003).
[40] M.A Wallenius, "The interaction of noise stress and personal project stress on subjective health," *J. Environ. Psychol.* **24**(2), 167-177 (2004).