

Noise annoyance caused by large wind turbines – a dose-response relationship

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ABSTRACT

The purpose was to determine a dose-response-relationship of large wind turbines with nominal power of 3-5 MW. A cross-sectional survey was conducted around three wind power areas in Finland. The sample involved all households within 2 km from the nearest turbine. Altogether 400 households out of 753 reported the annoyance indoors. The dose-response relationship was determined between the predicted noise exposure, L_{Aeq} , outdoors and the percentage of highly annoyed by wind turbine noise indoors.

The percentage of highly annoyed, %HA, was less than 3 %, and relatively even below 40 dB L_{Aeq} . %HA started to increase when the level exceeded 40 dB.

The dose-response relationship was compared to a previous study (Janssen et al. 2011 JASA) involving smaller turbines (0.15-1.5 MW). The relationships differed slightly from each other above 40 dB. However, suggestions about the possible effect of wind turbine size on noise annoyance cannot be made.

INTRODUCTION

The annoyance of wind turbine noise became an issue in Finland in 2012 when an increasing number of large wind power areas were erected. Thereafter, the capacity of wind power has nearly doubled every two years being 1.5 GW in the end of 2016. New noise regulations for wind turbine noise were published in Finland in August 2015 according to which the immission sound pressure level (*SPL*) should not exceed 45 dB L_{Aeq} during day-time (07-22) and 40 dB L_{Aeq} during night-time (22-07). The numbers are less demanding, 55 and 45/50 dB, for other types of environmental noise. Although the tighter target values have been applied already since 2012 in most wind power areas, noise and infrasound are still the most usual reasons to oppose wind turbines in Finland, both around existing wind power areas and around areas of planned wind power.

Dose-response-relationship for wind turbine noise is defined in this study as the association of the percentage of highly annoyed indoors by wind turbine noise, %HA, and noise exposure outdoors. The relationship defined in that way is very relevant for the estimation of possible health effects of noise because people spend most of their time at home indoors. Noise exposure, expressed in L_{Aeq} , can be predicted with reasonable accuracy in outdoor conditions.

However, the noise exposure is nearly impossible to determine indoors due to the lack of façade sound insulation information and the variation of levels between living rooms.

Dose-response relationships, as they were defined above, have been published in several studies, such as Refs. [1-3]. %HA means the percentage of respondents reporting high level of annoyance. The abovementioned studies have involved wind turbines with a nominal electric power within 0.15 – 3.0 MW. In Finland, the nominal power of new installed wind turbines is usually 3.0 MW or larger. The abovementioned studies obtained for 0.15 - 3 MW turbines might not be represent turbines larger than 3 MW. Therefore, authorities, operators, researchers, consultant and citizens active in this field are willing to know about the dose-response relationship of large wind turbines.

The purpose was to determine a dose-response-relationship of large wind turbines with nominal power of 3-5 MW.

MATERIALS AND METHODS

A cross-sectional survey was conducted around three wind power areas in Finland. The sample involved all households within 2 km from the nearest turbine. The addresses were received from the municipal office. Altogether 429 households out of 753 responded to the questionnaire or participated in the interview made at their homes. One respondent per household participated in the survey. The questionnaire involved several questions. This study reports only the results of noise annoyance indoors.

The independent variable is the noise exposure. It refers to the A-weighted immission sound pressure level, L_{Aeq} , which takes place during downwind situation when the wind speed normalized to 10 meter height is 8 m/s. In such conditions, the electric power output and sound emission are usually at maximum or very close to it.

Noise exposure in each respondents' yard was predicted using a commercial software (CadnaA version 4.0.135, DataKustik GmbH). The sound power level values of the wind turbines were received from the operators of each wind power area. The values represent the guaranteed values, that is, the values involve a safety margin (uncertainty margin) so that there is only a 5% probability that the guaranteed value is exceeded. The prediction was made in 1/1-octave bands 31.5 – 8000 Hz. The topographic information of the areas were taken into account. Ground absorption was set to 0.40 according to the Finnish guidelines [4].

The dependent variable is noise annoyance indoors. Noise annoyance was measured using a question: How annoying do you find the following sound indoors? A list of various environmental sounds was presented, including wind power noise. The same 5-point verbal response scale was used as in three previous studies [1, 5, 6]: 1 Do not notice, 2 Notice, but not annoying, 3 Slightly annoying, 4 Rather annoying, 5 Very annoying.

Table 1. Description of the three wind power areas.

	Wind power area		
	A	B	C
Number of wind turbines in the area	12	11	3
Nominal electric power of the turbines	4.5	3.0 / 3.3	5.0
Sound power level of the turbines, L_{WA} [dB]	108.8	106.7 / 107.6	109.6
Time of deployment	Dec 2013	Dec 2012	Dec 2014
Time of the survey	Jan 2015	May 2015	Sept 2015
Location	Pori, Peitto	Ii, Olhava	Salo, Märynummi
Nr of households within 2 km	107	189	457
Nr of responding households	70	91	268
Nr of respondents reporting annoyance	64	78	258

The dose-response relationship was determined between the predicted noise exposure L_{Aeq} outdoors and the perceived noise annoyance indoors. In order to do this, the annoyance responses and related noise exposure from three wind power areas was combined into one file.

The total number of respondents was 429. The mean age of respondents was 55.3 years ranging from 17 to 89 years. Nearly all respondents, 398, reported the perceived annoyance of wind turbine noise indoors. Thus, the response rate of noise annoyance is 53.1%. Dose-response relationship was derived using 5-dB-wide noise exposure categories within 25 dB and 45 dB L_{Aeq} . The total number of respondents in category 40-45 dB was only 15. Therefore, the 95% confidence intervals are reported.

The dose-response relationship was compared to the relationship of Janssen et al. [2]. Their figure 1 reported the percentage of highly annoyed, %HA, as a function of the predicted noise exposure outdoors. They used the day-evening-night sound level, L_{den} , as a measure of noise exposure. It takes into account the annual variation of wind turbine noise and the 5-dB penalty for evening hours and 10-dB penalty for night hours. L_{den} is not used in many national noise regulations, including Finland. Therefore, L_{den} was converted to the measure used in our study, L_{Aeq} , using the equation $L_{Aeq} = L_{den} - 4.7$ dB. The data of Jansen et al. [2] was based on three independent studies conducted in The Netherlands [1] and Sweden [5, 6]. However, Refs. [5, 6] did not report the annoyance responses indoors so that Janssen et al. [2] reported also new data in this respect. Noise annoyance was inquired in our study using a similar question as in Refs. [1, 2, 5, 6]. The dose-response relationship for %HA was calculated using the same mathematical procedure described on page 3748 (left panel) of Ref. [2] so that %HA represents the responses exceeding the cut-off value of 72% when the annoyance responses are distributed on a range of 0-100 using equally spaced intervals. The final dose-response relationship was formed by fitting a third-order polynomial over the give data points (%HA vs. noise exposure category).

RESULTS

The distribution of the noise annoyance ratings in different noise exposure values are described in Figure 1. The Pearson's correlation coefficient between noise annoyance and non-categorized noise exposure was $R_p = 0.33$ ($p < 0.001$). The dose-response relationship is presented in Figure 2.

DISCUSSION

The dose-response relationship of our study concerned wind turbines having a nominal electric output of 3.0-5.0 MW. Janssen et al. [2] had much larger number of respondents (1827) and much smaller wind turbine sizes (0.15 – 1.5 MW) than our study. The mean value of %HA in our study seems to be at a slightly higher level (larger turbines) than in Janssen's study (smaller turbines) when the noise exposure exceeds 40 dB L_{Aeq} . However, we cannot suggest that larger turbines might cause larger annoyance than smaller turbines at the same noise exposure because the curve of Janssen et al. is within the 95% confidence intervals of our study. Our study suffered from too small number of respondents in category 40-45 dB: one respondent corresponds to 6.7% in Figure 1. It is very difficult to increase the number of respondents in this region because noise exposures exceeding 40 dB L_{Aeq} are avoided in Finland. In addition, Michaud et al. [3] have shown that different areas in Canada resulted in different dose-response relationships. Differences were also found between the Refs. [5] and [6] conducted in different parts of Sweden. Therefore, it is not possible to suggest that the minor difference of the curves in Figure 2 is solely explained by wind turbine size.

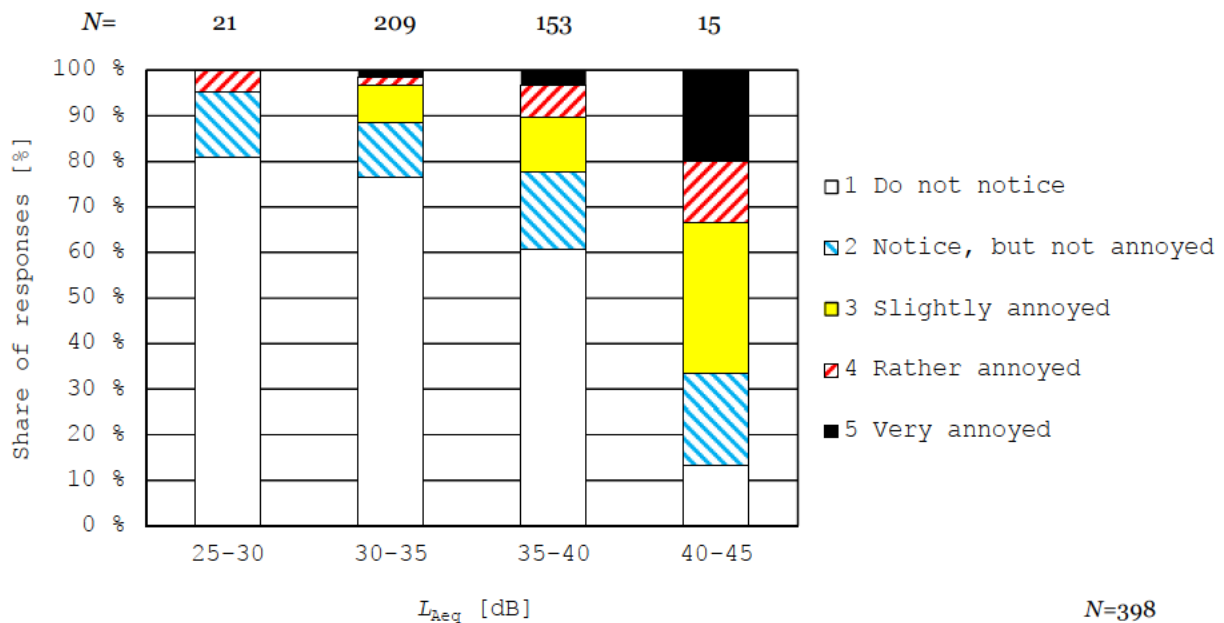


Figure 1. The distribution of annoyance responses as a function of noise exposure, L_{Aeq} .

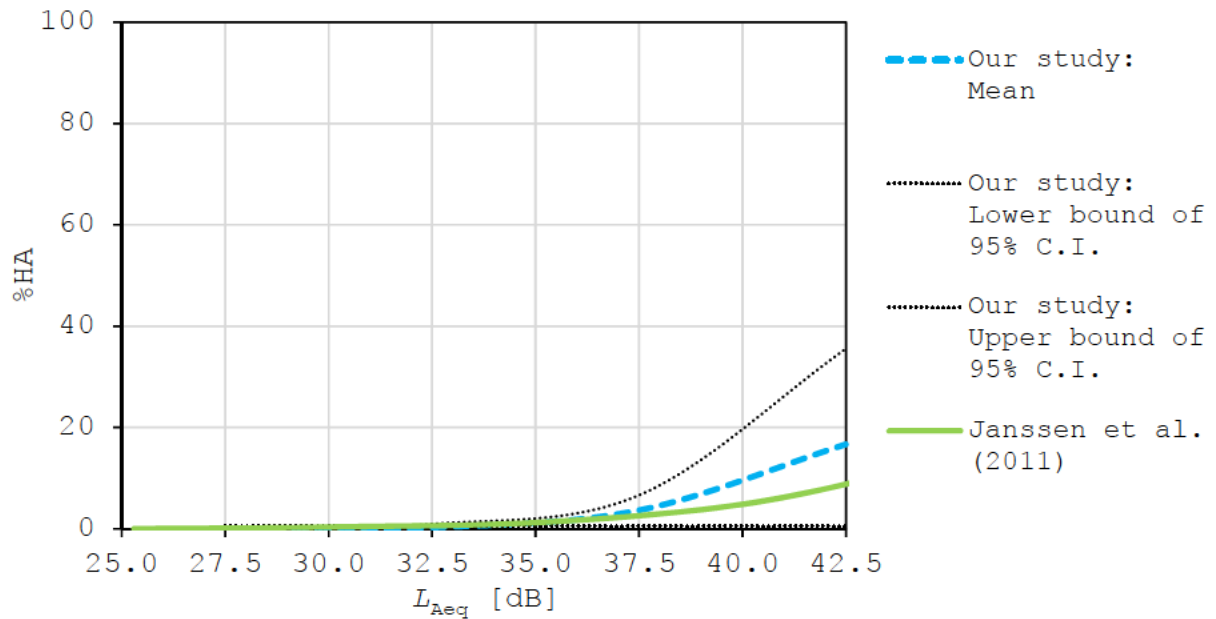


Figure 2. Comparison of the dose response relationships of our study and Janssen et al. [2]. L_{Aeq} is the equivalent sound pressure level outdoors. %HA is the percentage of highly annoyed respondents indoors.

CONCLUSIONS

A dose-response relationship was determined for large wind turbines sizing 3.0-5.0 MW in Finland. The relationship describes the noise annoyance of wind turbine noise indoors as a function of the A-weighted sound pressure level outdoors. The relationship was compared to the previous study published by Janssen et al. [2] involving turbines sizing 0.15-1.5 MW. The relationships differed slightly from each other above 40 dB. However, suggestions about the possible effect of wind turbine size on noise annoyance cannot be made.

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