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Non-acoustic and acoustic variables associated with wind turbine noise annoyance

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ABSTRACT

BACKGROUND. Previous residential surveys have been conducted in areas involving wind turbines (WTs) less than 3 MW. However, modern WTs are usually larger than 3 MW and the applicability of the previous results must be re-examined. Previous results show that sound level explains only a small portion of noise annoyance in WT areas.

AIM. The purpose was to determine how various non-acoustic factors are associated with WT noise annoyance.

METHODS. The survey was conducted around three areas involving WTs sizing from 3 to 5 MW in Finland. Altogether 318 permanent residents living within 2 km from the WTs answered the survey. The modelled WT noise outside their houses ranged from 27 to 44 dB L_{Aeq}.

RESULTS. The concern for health effects of WT noise was the strongest associate of WT noise annoyance. Other factors were area, noise sensitivity, gender, and general attitude towards wind power as an energy production form. Sound level of WTs had only a weak association with annoyance outdoors, but not indoors.

PRACTICAL IMPLICATIONS. Provision of fact-based information to the residents about the health effects of wind turbines could reduce the health concerns and thereby noise annoyance.

Keywords: Wind turbine noise, Non-acoustic factors, Annoyance

1. INTRODUCTION

Wind energy is a renewable energy form, which, however, produces special type of sound that can be considered as noise, i.e. unwanted sound. Therefore, it can be considered an environmental stressor. Wind turbine noise (WTN) can be perceived annoying by people living nearby and it can also cause subjective sleep disturbances (1). However, the relationship between noise annoyance and sound level is modest (2,3), which means other factors besides sound level play an important role in becoming annoyed by the sound. Previous studies have involved wind turbines of 3 MW at most (3). There is a need to study the noise annoyance caused by larger WTs since modern WTs are usually larger than 3 MW.

Non-acoustic variables related to WTN annoyance can be divided into three categories: personal, situational, and contextual. Personal factors are related to person's characteristics, attitudes, and expectations. Personal factors related to WTN annoyance are, for example, noise sensitivity (2,4), safety concerns (2), and attitudes towards wind turbines (5). Situational factors are related to general situation and environment, as for example, the visibility of wind turbines to the property (4), the ownership of the property (2). Contextual factors are not readily present, but influence attitudes towards WTN, which can be for example benefitting from the wind turbines (2,4), or unfair politics and a siting process that can be reflected to inefficient coping mechanisms and noise annoyance (6).

The purpose was to determine how various non-acoustic factors are associated with WT noise annoyance in three Finnish wind power areas with large wind turbines (3-5 MW). From each participant, we collected the questionnaire data as well as the modeled sound level of WTN outside their houses. We formed models of variables related to WTN annoyance. We expected the sound level to have a small but significant influence on annoyance. Other variables we expected to be related to WTN annoyance were noise sensitivity, attitude towards wind power, visibility of wind turbines and ownership of the house. A more detailed report of the study has been published in Ref. (7) and a

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detailed dose-response relationship of the data used here was published in Ref. (3).

2. METHOD

2.1 Sample

The sample consisted of the residents close to three wind power areas in Finland. Variable *area* describes the area the participants live in (area 1, area 2, and area 3). These areas were chosen to represent different types of WT areas. The *areas* differed from each other in three factors: general resistance (area 1 was the most against), population density (area 3 was the most densely populated), and history of land use (area 1 was located near industrial area, while areas 2 and 3 were in recreational areas). The residents living within 2 km from the nearest WT were invited to participate. The survey was conducted using both face-to-face interviews and in-mail questionnaires.

2.2 Sound level predictions

Outdoor sound pressure level (SPL) in each participants yard was predicted according to international standard (8). The method used in this study was described in more detail by Hongisto et al. (3). The outcome was the A-weighted equivalent SPL, L_{Aeq}, (later: *sound level*) at a height of 4 m from the ground. The predicted *sound level* corresponds to the weather conditions when the WTs operate at their maximum power. The *sound level* predictions were verified in each area using measurements during maximum electric power and the predicted *sound levels* corresponded well with measured sound levels (3). In addition to *sound levels*, 5-dB wide *sound level categories* are used in this study.

2.3 Questionnaire

Table 1 describes the set of questions used in this study and Table 2 their response scales. The questionnaire included a vast set of questions. Here we included only those, which were presented in all three *areas*, and were not correlated with other questions in the set. Questions dealing with sleep were left out because we focus on annoyance. The full set of questions can be found both from Refs. (3) and (7).

2.4 Dependent variables

We used *%A indoors* and *%A outdoors* as the dependent variables in our study. %A means the percentage of annoyed respondents. A participant belongs to the group of *%A indoors*, if he/she responded "4" or "5" to variable *annoyance indoors*. We used similar dichotomization protocol for *%A outdoors*.

2.5 Statistical analysis

Different *areas* were compared with each other using Fisher's exact test for dichotomous variables and analysis of variance for continuous variables. In addition, the response rates from different sound levels were compared using Fisher's exact test. Absolute *sound levels* were used instead of *sound level categories*. The binary logistic regression models were used to get a predictive power of different variables related to *%A indoors* and *%A outdoors*. The final variables in the binary logistic regression model were: *noise sensitivity, health concern, energy attitude, landscape attitude, sound level, visibility,* and the background factors of *gender, age*, and *area*. We used a stepwise model with conditional forward selection with an entry threshold of 0.05 and a removal criterion of 0.10.

Table 1 – Variables, their explanations and response scales. The response scales are defined in Table 2.

Variable name	Question(Q)/explanation	Scale
Annoyance outdoors	Q16a. How annoying do you find the WT sound oudoors in your yard?	A
Annoyance indoors	Q18a. How annoying do you find the WT sound indoors inside your apartment?	A
Noise sensitivity	Sum of questions 10a. (reversed) and 10b.	
	Q10a. I easily get used to most sounds.	B
	Q10b. Sounds annoy me easily.	B
Health concern	Q31. Are you concerned about possible effects of WT sound on your health?	C
Landscape attitude	Q24. The influence on WTs for the scenery is…	D
Change attitude	Q25. Has your opinion changed about the WTs after building it in the area?	D
Community benefit	Q28. Has your community benefited from WTs?	E
Energy attitude	Q30. What is your opinion of the wind power electricity as a form of energy?	F
Trust for operators	Q33a. Do you think the operators of wind farms have done enough to control possible damages?	E
Trust for authorities	Q33b. Do you think the authorities have done enough to control possible damages?	E
Visibility	From Q22 and Q23 if one is yes, WT is visible	E
	Q22. Can you see a WT from your yard?	E
	Q23. Can you see a WT from your window?	E

Table 2 – The response scales of questions.

Scale	Response categories
A	1 Sound not audible. 2 Sound audible, but not annoying. 3 Sound annoys a little. 4 Sound annoys quite much. 5 Sound annoys a lot.
B	1 Disagree strongly, 2 Disagree to some extent, 3 Neither disagree nor agree, 4 Agree to some extent, 5 Agree strongly
C	1 Not at all, 2 Only slightly, 3 To some extent, 4 To a great extent, 5 To a very great extent.
D	1 Clearly positive, 2 Somewhat positive, 3 No influence/neutral, 4 Somewhat negative, 5 Clearly negative
E	0 No, 1 Yes
F	1 I am very positive, 2 I am more positive than negative, 3 I am neutral, 4 I am more negative than positive, 5 I am clearly negative

3. RESULTS

Table 3 describes the samples from different *areas*.

%A indoors was 8.0% and *%A outdoors* was 15.4% in the whole sample. According to Figure 1, *%A indoors* and *%A outdoors* depended on the *area* (*%A indoors* $p<0.001$ and *%A outdoors* $p<0.001$) and *sound level* (*%A indoors* $p=0.001$ and *%A outdoors* $p<0.001$).

We examined with logistic regression which are the most important variables associated with WTN annoyance (Table 4). *Health concern* was the most important variable and *area* was the second-most important variable in both models of *%A indoors* and *%A outdoors*.

The results of logistic regression can be interpreted by the following example: when a participant gave a step higher answer in *health concern*, he/she was 4.5 times more likely to be annoyed by WTN. Other important variables were *energy attitude* and *noise sensitivity*. Women were more often annoyed by WTN indoors than men were. *Sound level* was included in the model only with *%A outdoors*.

4. DISCUSSION

We cannot suggest any causality relationship between the subjective variables involved in our study. However, noise annoyance has been found to be the most usual health effect of WTs (1). Therefore, it was justified to develop a model for *annoyance indoors* and *annoyance outdoors* and not for health concerns.

Table 3 – The description of participants in different areas, in total, and whether the areas differed from each other.

	Area 1	*Area 2*	*Area 3*	**Total**	*p* **-value**
No. of households within 2 km	107	189	457	753	
No. of all respondents	70	91	268	429	
Response rate [%]	65.4	48.1	58.6	57	
Permanent residents [%]	54	41	95	77	
No. of participants (No. of permanent residents)	**30**	**37**	**251**	**318**	
Age [yr]					0.01
Mean (SD)	60 (14)	59 (14)	53 (15)	55 (15)	
Range	24–85	23–85	17–89	17–89	
***Gender*, Females** [%]	56.7	32.4	48.6	47.5	ns
Sound level [dB L_{Aeq}]					<0.001
Mean (SD)	38 (3)	36 (3)	34 (3)	34 (3)	
Range	34–44	32–41	27–46	27–46	
Distance [m]					<0.001
Mean (SD)	1395 (372)	1317 (327)	1542 (244)	1503 (279)	
Range	672– 2005	785– 1901	479– 1996	480– 2005	
Trust in authorities [%]	12.5	66.7	48.6	46.0	0.001
Trust in operators [%]	12.0	66.7	50.8	48.3	<0.001
Community benefit [%]	18.5	51.7	21.8	24.6	0.003

SD=Standard deviation
ns=non-significant

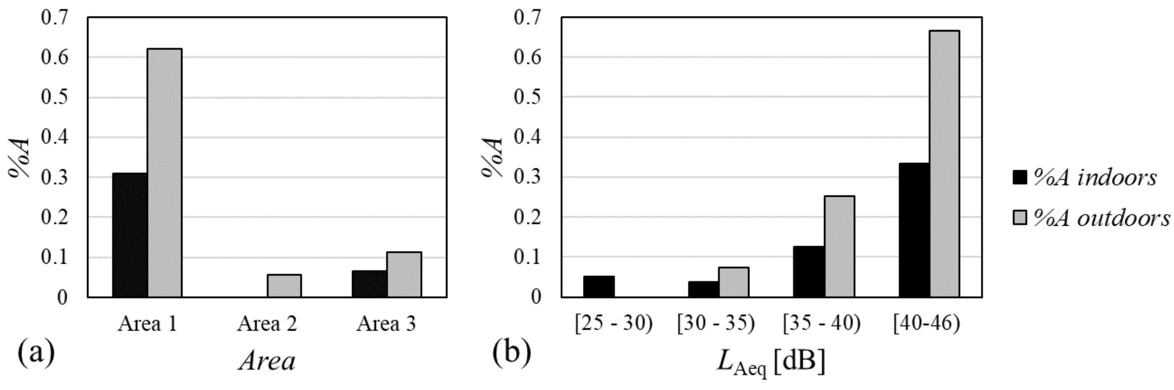

Figure 1 – (a) The percentage of annoyed residents, *%A*, per *area*. (b) The percentage of annoyed residents as a function of *sound level category*, L_{Aeq}.

Table 4 – The logistic regression models for *%A outdoors* and *%A indoors*.

%A outdoors Variable	Groups in the variable[a]	Logistic regression model (N=280, R^2=0.710,[c] H-L,[d] p=0.651)		
		OR (CI)[b]	*p-value*[e]	Order of entry into model: R^2 at each step
Health concern	Scale: 1-5	2.71 (1.78, 4.11)	<0.01	Step 1: 0.43
Area	Area 1	10.32 (2.22, 47.84)	<0.01	Step 2: 0.58
	Area 2	0.29 (0.03, 3.21)	0.31	
	Area 3	Reference	<0.01	
Energy attitude	Scale: 1-5	1.89 (1.24, 2.87)	<0.01	Step 3: 0.63
Noise sensitivity	Scale: 2-10	1.69 (1.23, 1.32)	<0.01	Step 4: 0.67
Sound level [dB]	Continuous	1.41 (1.14, 1.74)	<0.01	Step 5: 0.71

%A indoors Variable	Groups in the variable[a]	Logistic regression model (N=281, R^2=0.667,[c] H-L,[d] p=0.992)		
		OR (CI)[b]	*p-value*[e]	Order of entry into model: R^2 at each step
Health concern	Scale: 1-5	4.46 (2.41, 8.26)	<0.01	Step 1: 0.47
Area	Area 1	5.69 (1.25, 25.97)	0.03	Step 2: 0.55
	Area 2 [f]	0.00 (0.00, 0.00)	1	
	Area 3	Reference	0.08	
Noise sensitivity	Scale: 2-10	1.81 (1.15, 2.84)	0.01	Step 3: 0.60
Gender	Female/Male	8.30 (1.63, 42.19)	0.01	Step 4: 0.63
Energy attitude	Scale: 1-5	1.92 (1.10, 3.35)	0.02	Step 5: 0.67

[a] The reference category in categorical variables is always the last category.

[b] Odds ratio (OR) and 95% confidence interval CI based on the binary logistic regression model; an OR indicates how much the odds of belonging to a dependent group changes with one step of independent variable. OR > 1 indicates that odds of belonging to dependent group were higher relative to the reference group or category and OR < 1 means they were lower.

[c] The Nagelkerke pseudo R^2 gives an estimate of the proportion of deviance explained by the model. Its values are between 0 and 1, 1 indicating perfect fit.

[d] H-L: Hosmer-Lemeshow test, p>0.05 indicates a good fit.

[e] *p-values* indicate whether the variable was significantly contributing to the model.

[f] Area 2 had no-one reporting *annoyance indoors* larger than 3.

Health concern is the most important variable related to both *annoyance indoors* and *annoyance outdoors*. In other words, if a person is concerned that WTN might have an influence on their health, he/she is more likely to be annoyed by the noise. The second variable related to annoyance is *area*. This is somewhat surprising, even though we selected *areas* to represent different types of wind turbine areas. The negative attitude of people in *area 1* is clearly reflected to the annoyance scores of that *area* (62% annoyed outdoors and 31% indoors), whereas in *area 2*, no one belongs to the group of *%A indoors* and only 6% belongs to the group of *%A outdoors*. Table 3 shows that the respondents from different *areas* have also different opinions on whether they *trust the authorities* and *operators* and whether their community has benefited from the WTs. The benefit has been linked to annoyance already earlier, but mainly on a personal level (2,9). In our sample, there were just six persons benefiting personally from WTs. Based on other information we have received, we believe that also differences in land use history are reflected in the attitudes of people from different *areas*.

Other variables related to annoyance were *noise sensitivity* and *energy attitude*. *Noise sensitivity* is reported as a personal variable in previous studies (2,4). *Sound level* was included only in the model of *%A outdoors*. This might reflect the fact that indoors the noise is reduced by building façade and its direct importance is reduced. However, the sound insulation of building façades differs a lot (10) and it may partially explain the variance between respondents. *Gender* was included in the model *%A indoors*. Women reported more annoyance of WTN indoors than men did. A previous study on WTN annoyance did not report a gender difference in annoyance indoors (4).

5. CONCLUSIONS

To reduce annoyance, we suggest that factual knowledge should be used to answer people's concerns. This could reduce people's concern and sensitive people would feel they are being listened to.

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REFERENCES

1. Schmidt JH, Klokker M. Health effects related to wind turbine noise exposure: A systematic review. PLoS One. 2014;9(12).
2. Michaud DS, Keith SE, Feder K, Voicescu SA, Marro L, Than J, et al. Personal and situational variables associated with wind turbine noise annoyance. J Acoust Soc Am. 2016;139(3):1455–66.
3. Hongisto V, Oliva D, Keränen J. Indoor noise annoyance due to 3–5 megawatt wind turbines—An exposure–response relationship. J Acoust Soc Am. 2017;142(4):2185–96.
4. Janssen SA, Vos H, Eisses AR, Pedersen E. A comparison between exposure-response relationships for wind turbine annoyance and annoyance due to other noise sources. J Acoust Soc Am. 2011;130(6):3746–53.
5. Pawlaczyk-Luszczynska M, Dudarewicz A, Zaborowski K, Zamojska-Daniszewska M, Waszkowska M. Annoyance related to wind turbine noise. Arch Acoust. 2014;39(1):89–102.
6. Pohl J, Gabriel J, Hübner G. Understanding stress effects of wind turbine noise – The integrated approach. Energy Policy. 2018;112:119–28.
7. Radun J, Hongisto V, Suokas M. Variables associated with wind turbine noise annoyance and sleep disturbance. Build Environ. 2019;150.
8. ISO. ISO 9613-2: Acoustics -- Attenuation of Sound During Propagation Outdoors -- Part 2: General Method of Calculation. Geneva, Switzerland: International Organization of Standardization; 1996.
9. Pedersen E, van den Berg F, Bakker R, Bouma J. Response to noise from modern wind farms in The Netherlands. J Acoust Soc Am. 2009;126(2):634–43.
10. Keränen J, Hakala J, Hongisto V. The sound insulation of façades at frequencies 5–5000 Hz. Build Environ. 2019;156:12–20.