Building and Environment 150 (2019) 339–348

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Variables associated with wind turbine noise annoyance and sleep disturbance

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ARTICLE INFO

Keywords:
Wind turbine noise
Non-acoustic factors
Environmental noise
Psychological effects
Annoyance
Sleep disturbance

ABSTRACT

Wind turbine noise (WTN) increases the risk of WTN annoyance and self-reported sleep disturbance, which in turn can influence people's well-being. However, the sound level explains only a small fraction of WTN annoyance. The purpose of our study was to determine how acoustic and various non-acoustic variables are associated with WTN annoyance indoors, WTN annoyance outdoors, and sleep disturbance due to WTN. 318 permanent residents living within 2 km of the nearest wind turbine in three different areas of Finland responded to the questionnaire. The turbines were relatively large, within 3 and 5 megawatts. The explanatory models were developed using binary logistic regression. The models predicting WTN annoyance had the predictive strengths of 67% for indoor and 71% for outdoor WTN annoyance. The concern for health effects was the most important factor related to both WTN annoyance and sleep disturbance due to WTN. Other factors explaining WTN annoyance were area, noise sensitivity, and general attitude towards wind power as a form of energy production. Sound level explained also outdoor annoyance and sleep disturbance related to WTN. Furthermore, women were more annoyed indoors and reported more sleep disturbance due to WTN than men. We believe that the health concerns and WTN annoyance could be reduced by providing the residents with more fact-based information about wind power and more interactive and transparent communication concerning the planning and building processes.

1. Introduction

Wind energy is a clean and renewable form of energy that has begun to replace conventional sources of energy production. However, it produces a special kind of sound that can be perceived as noise, i.e. unwanted sound, among some people who live nearby. Wind turbine noise (WTN) increases the risk of WTN annoyance and self-reported sleep disturbance, but there is no conclusive evidence of other health effects [1]. However, the relationship between noise annoyance and sound level is modest. For example, in a large Canadian study, the wind turbine (WT) sound level was attributed only to 9% of high noise annoyance [2]. Similarly, Hongisto, Oliva, and Keränen [3] reported that other factors than the WT sound level explained even 92% of variance behind high annoyance indoors in a Finnish sample of people with a permanent or vacation residence near WTs. Our study examines those other factors behind WTN annoyance in the Finnish sample of permanent residents on which the exposure-response relationship was previously reported by Hongisto et al. [3].

WTN annoyance has been related to psychological distress and sleep disturbance [4,5]. WTN annoyance is also associated with feeling tired and tense in the morning [5]. When thinking about WTs, annoyed residents felt resigned, violated, strained, and tired [5]. In general, sleep disturbance can cause insomnia, which is related to a substantial impairment in a person's quality of life, increased occurrence of accidents, decreased work productivity, and an association with psychiatric disorders such as depression and anxiety [6]. Therefore, it is important to examine the factors that cause WTN annoyance and possible WTN induced sleep disturbance.

Non-acoustic factors related to WTN annoyance can be classified into *personal*, *situational*, and *contextual* factors [7]. *Personal factors* are related to a person's characteristics, attitudes, and expectations [7]. They include, for example, noise sensitivity [2,8], physical safety concerns [2], and current mental health status [9]. Attitudes related to WTN annoyance are, for example, negative attitude towards WTs [9] and a negative attitude towards the visual landscape impacts of WTs [10]. They are direct attitudes towards WTs. A general attitude towards

Abbreviations: WTN, wind turbine noise; WT, wind turbine; SPL, sound pressure level; %A indoors, proportion annoyed indoors; %A outdoors, proportion annoyed outdoors; %SleepD, proportion sleep disturbed; SD, standard deviation

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https://doi.org/10.1016/j.buildenv.2018.12.039
Received 6 June 2018; Received in revised form 13 December 2018; Accepted 18 December 2018
Available online 26 December 2018

landscape littering has also been related to WTN annoyance [9]. Furthermore, a Finnish study showed that different expectations can influence attitudes related to WTs even within the same area. Free-time residents (i.e. of summer houses or vacation homes where people do not live permanently) had more negative attitudes towards wind power than permanent residents, possibly largely due to their different expectations for the area [11].

Situational factors are related to the general situation and environment [7]. For example, the visibility of a WT from a property has been related to annoyance [5,8,10,12]. However, it might be that WT visibility is not only related to WTN annoyance, but also to the visual annoyance of blinking lights and the perception of vibration [2], although vibration levels have not exceeded the limits of perception [1,13]. Therefore, either the visual disturbance caused by WTs or the constant reminder of them through the window is a factor connected with general annoyance caused by WTs. Furthermore, WTN might annoy more in rural areas than in urban areas, which was assumed to be due to the lack of background noise in rural areas and due to different expectations between urban and rural lifestyles [5]. Pedersen & Persson Waye [5] found also that in a rural setting WTN might annoy more in hilly or rocky terrain than in flat areas. On the other hand, the difference could be explained also by the general finding that the level of WTN annoyance can depend on the area [2,10]. In addition, people who owned their property [2] and those who could not hear road traffic noise were more likely to be annoyed by WTN [2,10].

To fully understand the annoyance related to WTN, we must still consider the *contextual factors*. Contextual factors describe factors not readily present, but which influence attitudes towards WTN, such as participation, the decision-making process, siting procedure, and procedural justice. These are probably factors contributing to area differences in WTN annoyance, which have been reported, for example, between provinces in Canada [14], but might be also related to attitudes among different groups living in the same area [11]. The experience of unfair politics and a poor siting process for WTs can be reflected in inefficient coping mechanisms [15]. Furthermore, feelings towards the fairness of the planning phase might manifest later on as annoyance towards WTN [15]. In a Polish study, the quality of life was found to be the highest among people living closest to WTs and the lowest among those living in the area where the turbines were planned but the construction had not yet begun [16]. However, many studies have also reported that those who benefit personally from WTs are not annoyed even by high WT sound levels [2,8,10]. The wind energy business also applies different practices in different countries. For example, in Denmark and the Netherlands, locals are often given the possibility of sharing the ownership of local WTs, whereas in Finland wind power areas are mainly owned by companies that do not share ownership with locals.

A review on WTN health effects [1] as well as a meta-analysis on cross-sectional studies on WTN effects on sleep and quality of life [17] concluded that WTN increases the risk of self-reported sleep disturbance. However, a recent review concluded that there is only limited evidence that WTN affects sleep [18]. The relationship between sleep and WTN has been suggested to be associated with WTN annoyance, which can lead to sleep disturbance and psychological distress [4] or lowered sleep quality [5].

Besides cross-sectional studies [e.g. Refs. [4,5,12]], sleep quality related to WTN has also been studied in residential dwellings. Jalali et al. [19] compared sleep quality before and after the wind turbines started functioning using polysomnography. They found worse subjective sleep quality after the exposure started. Lane et al. [20] compared groups exposed and non-exposed to WTN using actigraphs and sleep diaries. They did not find any significant effects [20]. However, both of these studies [19,20] suffered from small sample sizes. Michaud et al. [21] measured sleep quality with actigraphs in several WTN areas using a large sample size. They reported that factors other than WT sound levels were related to sleep quality in general —for example, the use of sleep medication, other health conditions (including sleep disorders), and annoyance caused by the blinking lights of WTs [21]. Their questionnaire did not involve a question on WTN induced sleep disturbance.

A recent laboratory study measured the effects of WTN on sleep with different WTN characteristics [22]. The night with WTN lowered many aspects of subjective sleep quality [22]. Also other objective results were reported, but the sample size was too modest in the study to make clear conclusions [22].

Some studies have reported a possible relationship between sleep disturbance and WTN when WTN exceeds 40 dB L_{Aeq} outdoors [12]. Furthermore, WTs can run overnight while most other environmental sounds have reduced levels during the nighttime. The impact is that WTN has been suggested to be the most annoying during the night [12]. As sleep disturbance influences the quality of life [6], it is important to study the relationship between WTN and sleep disturbance.

Although the number of studies examining the role of non-acoustic factors and WTN annoyance has increased recently, more research in this field is definitely needed since WT production is increasing and the WT technology is developing faster than in many older areas of industry. Previous studies have involved different methodologies related to the selected subjective measures, the number of areas, and the statistical analysis methods. Most importantly, the typical size of continental WTs is nowadays 3–5 megawatts (MW), while previous studies, except Hongisto et al. [3], have involved WTs of 3 MW at most. The relative proportion of low-frequency sound emitted from the WT increases with the increasing size of the WT [23]. Furthermore, atmospheric attenuation reduces with the reducing frequency of sound [24]. Despite this, Hongisto et al. [3] reported a dose-response relationship for large WTs that did not significantly differ from the one obtained for smaller WTs sizing 0.15–1.5 MW [8]. It is important to investigate also how the non-acoustic factors are associated with noise annoyance and WTN induced sleep disturbance caused by modern large WTs.

The purpose of our study was to determine how acoustic and various non-acoustic variables are associated with WTN annoyance indoors, WTN annoyance outdoors, and WTN induced sleep disturbance. Various personal, situational, and contextual factors were investigated. Our study involves only large wind turbines (3–5 MW), while previous studies referred to in the Introduction have involved WTs of 3 MW at most. It should be noted that Hongisto et al. [3] have already reported the dose-response-relationship and our study does overlap with it. Our study examines the acoustic and non-acoustic factors related to WTN annoyance. The main focus will be non-acoustic factors and their relation to WTN, which has not been reported for this data before.

2. Methods

2.1. General design

Our study is a cross-sectional study that involves both physical independent variables and subjective variables measured by a questionnaire. Our study has three independent variables: *area*, *sound level*, and *distance*. Even though Hongisto et al. [3] demonstrated that *distance* explained only 4% of *indoor sound annoyance*, it was included as an independent variable because *distance* is commonly used in discussions on this topic. The study was conducted around three independent wind farms, which explains the reason for the variable *area*. *Sound level* [dB] means the A-weighted equivalent sound pressure level (SPL) caused by the WTs in the resident's yard when electricity production is at the maximum level (See Section 2.3). *Distance* [m] means the physical horizontal distance from the resident to the root of the nearest WT.

The main dependent variables are *annoyance indoors*, *annoyance outdoors*, and *sleep disturbance*. All of these are related to WTN. Binary logistic regression was applied so that dichotomized versions (outcome variables) of these three variables were used in the final analyses.

The other variables were various non-acoustic factors that were expected to be associated with the main dependent variables.

Table 1
Definitions and response scales of the variables measured by the questionnaire as well as the range of scales. See scales in Table 2.

Variable name	Question(Q)/explanation	Scale	Range
Annoyance outdoors	Q16a. How annoying do you find the WT sound outdoors in your yard?	A	1–5
Annoyance indoors	Q18a. How annoying do you find the WT sound indoors inside your apartment?	A	1–5
Sleep disturbance	Q20a. Has the sound from the WT woken you up or kept you awake during the night?	C	1–6
Noise sensitivity	Sum of questions 10a. (reversed) and 10b.		2–10
	Q10a. I easily get used to most sounds.	D	1–5
	Q10b. Sounds annoy me easily.	D	1–5
Cognitive coping	Q9. When you find yourself in a situation where environmental sounds annoy you, do you feel you can control the feeling of annoyance?	E	1–5
Health concern	Q31. Are you concerned about the possible effects of WT sound on your health?	F	1–5
Landscape attitude	Q24. The influence on WTs for the scenery is …	G	1–5
Energy attitude	Q30. What is your opinion of the wind power electricity as a form of energy?	H	1–5
Change attitude	Q25. Has your opinion about WTs changed after building them in the area?	G	1–5
Change experience WT	Q14. How do you feel about the changes that building WTs has produced in the area near you?	H	1–5
Community benefit	Q28. Has your community benefited from WTs?	B	0/1
Trust in operators	Q33a. Do you think the operators of wind farms have done enough to control possible damage?	B	0/1
Trust in authorities	Q33b. Do you think the authorities have done enough to control possible damage?	B	0/1
Visibility	From Q22 and Q23 if one is yes, WT is visible	B	0/1
	Q22. Can you see a WT from your yard?	B	0/1
	Q23. Can you see a WT from your window?	B	0/1
Hearing disability	Q10c. Do you have a hearing disability confirmed by a physician? (*Area 1* missing)	I	1–3
Health status	Q10d. How do you experience your general health status at the moment? (*Area 1* missing)	J	1–5
Comfortability of environment	Q14Ii. How comfortable do you find your current living environment? (*Area 1* missing)	K	0–10
Information WT	Q30. Have you received enough information about nearby WTs and about their construction? (*Area 1* missing)	F	1–5
Personal benefit	Q32Ii. Do you receive any direct economic benefit from the wind turbines near you? (*Area 1* missing)	B	0/1

2.2. Sample

The sample consisted of households near three wind power areas in Finland. They were located more than 10 km from the nearest city center, but reasonably close (0.3–10 km) to the nearest main highway. The areas were flat and the WTs were in the middle of a forest. We chose these three areas because they were reasonably or highly populated wind power areas compared to the mean population surrounding Finnish wind power areas. The areas differed from each other in three factors: general resistance against turbines (strong complaints from *area* 1 according to the media), population density (*area* 3 was more densely populated than *areas* 1 and 2), and history of land use (*area* 1 was located around an existing industrial area, while *areas* 2 and 3 were located in recreational areas). The areas were far away from each other with little interaction between the residents. We consider the sample to be representative of modern Finnish wind power areas. Detailed information about the areas is presented in Table 3 and in Hongisto et al. [3].

All households located within 2 km of the WTs were invited to take part in the survey. The survey was conducted mainly using face-to-face interviews at participants' homes in *areas* 1 and 2 and if they declined the interview, they were asked to respond to an in-mail questionnaire and if they declined this, a short interview via phone was made. In *area* 3, mainly in-mail questionnaires were used. Detailed information about the survey methods is presented in Hongisto et al. [3]. The study procedure was in conformance with general ethical principles [25].

The full sample described by Hongisto et al. [3] involved a large proportion of vacation homes (free-time residents). We wanted to examine only permanent residents who are exposed to WTN almost daily. Furthermore, permanent and free-time residents have shown to differ in their expectances and attitudes towards wind power in South East Finland [11]. Therefore, the sample for our study represents people permanently living within 2 km of the closest WT, in three different wind power areas in Finland.

2.3. Sound level predictions

Outdoor SPL in each participant's yard was predicted according to an international standard [24]. The method was presented in detail by Hongisto et al. [3]. The prediction was conducted in octave bands from 31.5 Hz to 8000 Hz. 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. This takes place when the wind speed at a height of 10 m exceeds 8 m/s. The accuracy of the predictions was checked by eight measurements during downwind conditions in the abovementioned wind speed. The predicted sound levels were verified by measurements in each area and the predicted sound levels corresponded well with the measured sound levels [3].

Sound level was classified into four *sound level categories*: [25–30), [30–35), [35–40), and [40–46] dB to be taken into account in further analyses.

2.4. Questionnaire

Table 1 defines the variables that were collected using the questionnaire. The response scales are described in Table 2.

2.5. Defining outcome variables

The main dependent variables (outcome variables) of our study were *%A indoors*, *%A outdoors*, and *% SleepD,* where % means *proportion* and *A* means *annoyed* and *SleepD* means *sleep disturbed*. A participant was assigned as annoyed outdoors (*A outdoors*) if the response to the variable *annoyance outdoors* was either “4” or “5”, which means they were rather or very annoyed. The same method was used for *A indoors*. The number of participants reporting alternative “5” was very small so that we had to set the limit for *annoyed* between alternatives “3” and “4”. A similar limit has been used by Pedersen et al. [10,26]. Following the same logic, we classified people as *sleep disturbed* (*SleepD*) if they reported sleep disturbance due to WTN at least a few times a month (responses “3”, “4”, “5” or “6”). An almost similar classification was used by Bakker et al. [4] examining the relationship between noise annoyance and sleep.

2.6. Statistical analysis

Fisher's exact test was used for examining the responses of dichotomous variables in different *areas* and *sound level categories*. The effect size was reported using Cramer's V. The differences between areas in

Table 2
Response scales of Table 1.

Scale	Response categories
A	1 Do not notice, 2 Notice but not annoyed, 3 Slightly annoyed, 4 Rather annoyed, 5 Very annoyed
B	0 No, 1 Yes
C	1 Never, 2 A few days a year, 3 A few days a month, 4 A few days a week, 5 Almost every day, 6 Every day
D	1 Disagree strongly, 2 Disagree to some extent, 3 Neither disagree nor agree, 4 Agree to some extent, 5 Agree strongly
E	1 Not at all (Feels annoyance takes me over), 2 Only slightly, 3 To some extent, 4 To a great extent, 5 To a very great extent (I can aim my attention at other things and forget my annoyance)
F	1 Not at all, 2 Only slightly, 3 To some extent, 4 To a great extent, 5 To a very great extent
G	1 Clearly positive, 2 Somewhat positive, 3 No influence/neutral, 4 Somewhat negative, 5 Clearly negative
H	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
I	1 Yes, I have a hearing disability approved by a physician. 2 No, but I suspect myself that my hearing has deteriorated. 3 No, and I think my hearing is normal.
J	1 Good, 2 Quite good, 3 Neither good nor bad, 4 Quite poor, 5 Poor
K	0 Very uncomfortable, 10 Very comfortable

age, *sound level,* and *distance* were examined with ANOVA because these variables were somewhat normally distributed.

The differences between the groups in different *sound level categories* were examined using the Kruskal-Wallis test and the pairwise comparisons between these groups using Dunn's pairwise tests that were adjusted by the Bonferroni corrections for multiple tests. The Kruskal-Wallis test was conducted using original response scales, not dichotomized variables, and it was used instead of the Univariate ANOVA because the variables were not normally distributed. The response scales (A, C, D, E, F, G, H, J, and K) are used as continuous since they are conceptually ordinal and have at least 5 steps [27,28]. The results of Kruskal-Wallis test are reported using H in Sec 3.

The variable *personal benefit* is not included in the analysis because only six participants reported receiving any economic personal benefit. They lived in *sound level categories* between 30 and 40 dB. These participants are included in the further analyses because they were only a few and they did not belong to *sound level categories* with only a few participants. Furthermore, these participants were not all from the same area.

Binary logistic regression was used to get an estimation of different variables' predictive power in relation to *%A outdoors, %A indoors*, and *%SleepD*. Binary logistic regression examines the probability of a participant being annoyed or sleep disturbed given the values of explanatory variable. Analysis also gives the odds ratio to describe the relationship between the variables.

In the Supplementary material, we show the logistic regression

Table 3
Description of the participants in the three *areas* investigated and in total.

	area 1	*area* 2	*area* 3	Total
Number of WTs in the area	12	11	3	
Nominal electrical power of each turbine	4.5	3.0/3.3	5.0	
Hub height [m]	140	140	140	
Sound power level of each turbine L_{WA} [dB]	108.8	106.7/107.6	109.6	
Locality	Pori, Peittoo	Ii, Olhava	Salo, Märy-nummi	
Time of deployment	Dec 2013	Dec 2012	Dec 2014	
Time of our survey	Jan 2015	May 2015	Sept 2015	
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' propotion of respondents [%]	54	41	95	77
No. of participants (No. of permanent residents)	**30**	**37**	**251**	**318**
Response style: Interview/short interview/questionnaire)	28/0/2	26/5/6	35/0/216	89/5/224
***Age* [yr]**				
Mean (SD)	60 (14)	59 (14)	53 (15)	55 (15)
Range	24–85	23–85	17–89	17–89
***Gender*, Female [%]**	56.7	32.4	48.6	47.5
***Building type* [%]**				
Single-family house	100	100	71.7	77.7
Row house			16.7	13.2
Apartment building			11.6	9.1
***Education* [%]**				
Ground school (mandatory levels)	21.4	32.3	20.3	21.6
Professional or upper secondary school	60.7	54.8	45.8	48.1
Applied or scientific university (highest level)	17.9	12.9	33.9	30.3
***Sound level* [dB L_{Aeq}]**				
Mean (SD)	38 (3)	36 (3)	34 (3)	34 (3)
Range	34–44	32–41	27–46	27–46
***Distance* [m]**				
Mean (SD)	1395 (372)	1317 (327)	1542 (244)	1503 (279)
Range	672–2005	785–1901	479–1996	480–2005
%A outdoors [%]	62.1	5.6	11.4	15.4
%A indoors [%]	31.0	0.0	6.5	8.0
%SleepD [%]	37.9	0.0	9.2	10.9
Trust in authorities [%]	12.5	66.7	47.6	46.0
Trust in operators [%]	12.0	66.7	50.8	48.3
Community benefit [%]	18.5	51.7	21.8	24.6

SD = Standard deviation.

Table 4
The count and the proportion of participants' responses to the dichotomous variables. N is the total number of responses. The count and the proportion of responses is also depicted for each outdoor *sound level category*.

Variable (referred category)	N	Total	*Sound level category* L_{Aeq} [dB]			
			[25–30)	[30–35)	[35–40)	[40–46]
		Count (%)	Count (%)	Count (%)	Count (%)	Count (%)
%A outdoors (annoyed) **	307	48 (15.6)	0 (0.0)	12 (7.3)	28 (25.2)	8 (66.7)
%A indoors (annoyed) **	307	25 (8.1)	1 (5.0)	6 (3.7)	14 (12.6)	4 (33.3)
%SleepD (disturbed) **	308	34 (11.0)	0 (0.0)	11 (6.6)	17 (15.6)	6 (50.0)
Visibility (visible) **	308	184 (59.7)	1 (5.0)	68 (41.5)	102 (92.7)	13 (100.0)
Community benefit (yes)	269	65 (24.2)	5 (28.0)	34 (24.3)	24 (23.8)	2 (20.0)
Trust in authorities (yes) **	233	106 (45.5)	7 (50.0)	67 (56.3)	31 (34.4)	1 (10.0)
Trust in operators (yes) **	236	113 (47.9)	9 (64.0)	69 (58.0)	34 (37.0)	1 (9.1)

** The main difference between *sound level categories* was significant at level $p < 0.001$.

models of single variables (Tables S.3, S.4, and S.5). However, the aim was to get predictive models with many independent variables using binary logistic regression to determine which variables together give the best prediction of belonging to groups *%A outdoors, %A indoors*, and *%SleepD*. For the models, we chose variables not having many missing values and not correlating strongly with each other. Spearman's correlation coefficients are presented in Table 6. The criterion for strong correlation here was set to $r = 0.50$, which is often used as a limit for large effect of correlation coefficients [29].

One of the two objective variables *distance* and *sound level* had to be selected since they correlated strongly with each other ($r = -0.86$). We chose *sound level* over *distance* because it had higher correlations with *annoyance indoors*, *annoyance outdoors*, and *sleep disturbance* (Table 6), and Hongisto et al. [3] suggested that distance is not as appropriate a variable for the assessment of health effects as sound level since the former does not consider the total sound power level of the wind farm.

Even though the variable *change experience WT* was the best single predictor for all three outcome variables (see Supplementary material), we excluded it from the model for two reasons: 1) it correlated strongly with *energy attitude, landscape attitude,* and *health concern*, and 2) it is a retrospective attitude towards the change. It is feasible to expect that if the participant is annoyed or sleep disturbed, the participant probably experiences the change adversely. Therefore, even though *change experience WT* might be a good predictor of our outcome variables, we considered that it mostly described the participant's experience towards WTs and there was a risk of circular reasoning. However, the model with *change experience WT* and without *health concern* and general attitudes is included in the Supplementary material.

Cognitive coping correlated strongly with *noise sensitivity* and it was excluded from the models. We chose *noise sensitivity* because the literature suggests it is an important variable when explaining WTN annoyance [2,8].

The questionnaire was slightly modified after the data collection from *area* 1 and we do not have the responses from all the participants to all the questions (see Table 1). Due to missing values, we included only variables that were collected from all three *areas*. In addition, we excluded three variables with many missing values, although they were measured in all three *areas*: *trust in operators* (n = 238), *trust in authorities* (n = 235), and *community benefit* (n = 267).

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*. Only the participants with data from all variables were included in the analysis. The final number of participants in the models (N) is reported for each model. We used the stepwise model with conditional forward selection with an entry threshold of 0.05 and a removal criterion of 0.10.

Table 5
The means, the standard deviations (SD), and the number of responses (N) for the ordinal variables in total and for each outdoor *sound level category*.

Variable	Total		*Sound level category* L_{Aeq} [dB]							
			[25–30)		[30–35)		[35–40)		[40–46]	
	Mean (SD)	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)	N
Annoyance outdoors **	2.3 (1.1)	307	1.8 (0.7)	20	2.0 (0.9)	164	2.7 (1.1)	111	4.0 (1.0)	12
Annoyance indoors **	1.6 (1.1)	307	1.3 (0.7)	20	1.4 (0.8)	164	1.9 (1.2)	111	3.3 (1.3)	12
Sleep disturbance **	1.3 (0.8)	308	1.1 (0.2)	21	1.2 (0.6)	166	1.5 (0.9)	109	2.7 (1.9)	12
Change attitude **	3.3 (1.0)	306	2.8 (1.1)	21	3.1 (0.9)	165	3.6 (1.0)	108	4.3 (0.9)	12
Change experience WT **	2.9 (1.2)	311	2.5 (0.9)	21	2.6 (1.1)	168	3.3 (1.2)	109	4.5 (1.1)	13
Cognitive coping *	3.8 (1.0)	306	3.7 (1.1)	21	3.9 (1.0)	164	3.8 (1.0)	108	3.0 (1.1)	13
Control of change[a]	1.3 (0.6)	276	1.2 (0.5)	20	1.2 (0.6)	143	1.3 (0.7)	100	1.2 (0.6)	13
Comfortability of environment[a]	8.3 (1.4)	275	8.6 (1.5)	21	8.3 (1.5)	159	8.3 (1.3)	91	8.3 (1.3)	4
Energy attitude	2.1 (1.3)	301	2.0 (1.4)	20	1.9 (1.1)	161	2.3 (1.4)	107	2.9 (1.7)	13
Health status[a]	1.8 (0.9)	244	1.8 (0.9)	21	1.9 (0.9)	149	1.8 (0.9)	70	1.5 (0.6)	4
Health concern **	1.7 (1.2)	306	1.3 (0.7)	21	1.6 (1.1)	165	1.9 (1.3)	109	2.9 (1.4)	11
Information WT[a] *	2.6 (1.1)	278	2.9 (1.0)	21	2.8 (1.0)	161	2.4 (1.2)	92	1.8 (0.5)	4
Landscape attitude **	3.0 (1.2)	309	2.6 (1.2)	21	2.7 (1.1)	165	3.3 (1.1)	110	4.6 (0.7)	13
Noise sensitivity[b]	4.7 (1.8)	302	4.3 (1.8)	21	4.8 (1.9)	164	4.7 (1.7)	105	4.9 (1.7)	12

* or ** The main difference between *sound level categories* was significant at levels $p < 0.05$ or $p < 0.001$, respectively.
[a] The data collected only from Areas 2 and 3.
[b] The values range from 2 to 10.

Table 6
Spearman's correlation coefficients between different variables related to *annoyance indoors*, *annoyance outdoors*, and *sleep disturbance*. These coefficients concern the original variables of Table 1 without dichotomization.

	A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*	*L*
A Sound level	1.00											
B Distance	−0.86**	1.00										
C Annoyance outdoors	0.46**	−0.38**	1.00									
D Annoyance indoors	0.35**	−0.27**	0.62**	1.00								
E Sleep disturbance	0.33**	−0.25**	0.54**	0.72**	1.00							
F Noise sensitivity	0.08	−0.06	0.34**	0.31**	0.37**	1.00						
G Cognitive coping	−0.11*	0.10	−0.27**	−0.28**	−0.32**	−0.60**	1.00					
H Health concern	0.23**	−0.21**	0.62**	0.57**	0.61**	0.43**	−0.35**	1.00				
I Landscape attitude	0.32**	−0.24**	0.47**	0.34**	0.37**	0.24**	−0.22**	0.48**	1.00			
J Energy attitude	0.16**	−0.09	0.42**	0.31**	0.35**	0.28**	−0.23**	0.41**	0.46**	1.00		
K Change attitude	0.34**	−0.27**	0.60**	0.47**	0.44**	0.26**	−0.26**	0.60**	0.62**	0.48**	1.00	
L Change experience WT	0.39**	−0.31**	0.62**	0.54**	0.47**	0.32**	−0.32**	0.58**	0.65**	0.57**	0.68**	1.00

* or ** Correlation is significant at the 0.05 or 0.01 level, respectively (2-tailed).

3. Results

3.1. Participants

The information about the response rates, areas, and participants is presented in Table 3. More background information is presented in Hongisto et al. [3]. Since we do not have the information on residential status among non-respondents, Table 3 reports first the number of all residents, including free-time residents, for the estimation of response rate. Then, the number of participants in our study, i.e. permanent residents, is reported: altogether 318 participants.

The difference in education level between the areas was close to significant ($p = 0.053$, $V = 0.12$), whereas the proportion of men and women did not differ between the areas ($p = 0.11$, $V = 0.12$). The average *distance* from the WTs was longer in *area* 3 than in other two *areas* ($F(2,292) = 10.3$, $p < 0.001$, $\eta^2 = 0.08$) and the *sound levels* were the highest in *area* 1 and the lowest in *area* 3 ($F(2,292) = 45.5$, $p < 0.001$, $\eta^2 = 0.24$). The *areas* differed in the building type participants lived in ($p < 0.001$, $V = 0.20$) and in the response style ($p < 0.001$, $V = 0.51$). *Age* was also significantly different ($F(2,292) = 4.42$, $p = 0.01$, $\eta^2 = 0.03$). The *areas* differed in *%A outdoors* ($p < 0.001$, $V = 0.42$) and in *%A indoors* ($p < 0.001$, $V = 0.28$), and in *%SleepD* ($p < 0.001$, $V = 0.29$). The fewest number of people trusted the authorities and operators in *area* 1 (*trust in authorities*: $p = 0.001$, $V = 0.25$; *trust in operators*: $p < 0.001$, $V = 0.27$). A larger proportion of participants reported their community benefits from the WTs in *area* 2 than in the other two *areas* ($p = 0.003$, $V = 0.22$).

3.2. Dependent variables vs. sound level category

The percentage of participants annoyed by noise both indoors, *%A indoors*, and outdoors, *%A outdoors*, in different *sound level categories* is shown in Table 4. The responses to the variables *annoyance indoors*, *annoyance outdoors,* and *sleep disturbance* in different *sound level* and *distance categories* are presented in Fig. 1 and in the Supplementary material. There was an association between *sound level categories* and the proportions of participants reporting annoyance (*%A outdoors*: $p < 0.001$, $V = 0.38$; *%A indoors*: $p = 0.001$, $V = 0.24$). To examine the results of the main outcome variables more deeply, we also examined the scale variables of *annoyance indoors* and *annoyance outdoors* in more detail in different *sound level categories* (Table 5). *Annoyance outdoors* increased when the *sound level category* was higher ($H(3) = 58.6$, $p < 0.001$). Only the values in the two lowest *sound level categories* did not differ from each other ($p = 1.00$), whereas all the other groups did ($p < 0.05$). Also *annoyance indoors* increased with the *sound level category* ($H(3) = 39.6$, $p < 0.001$). *Annoyance indoors* did not differ in the lowest *sound level category* from the two next *sound level categories* ([25–30) dB vs. [30–35) dB and [25–30) dB vs. [35–40) dB, $p > 0.05$), but all other *sound level categories* differed from each other significantly ($p < 0.01$).

%SleepD depended on the *sound level category* ($p < 0.001$, $V = 0.30$) (see Fig. 2). The examination of the scale variable *sleep disturbance* shows that the frequency of *sleep disturbance* increased with higher *sound level category* ($H(3) = 27.2$, $p < 0.001$). This is understandable considering that even in the *sound level category* [35–40) dB more than half of the participants did not even notice WTN indoors

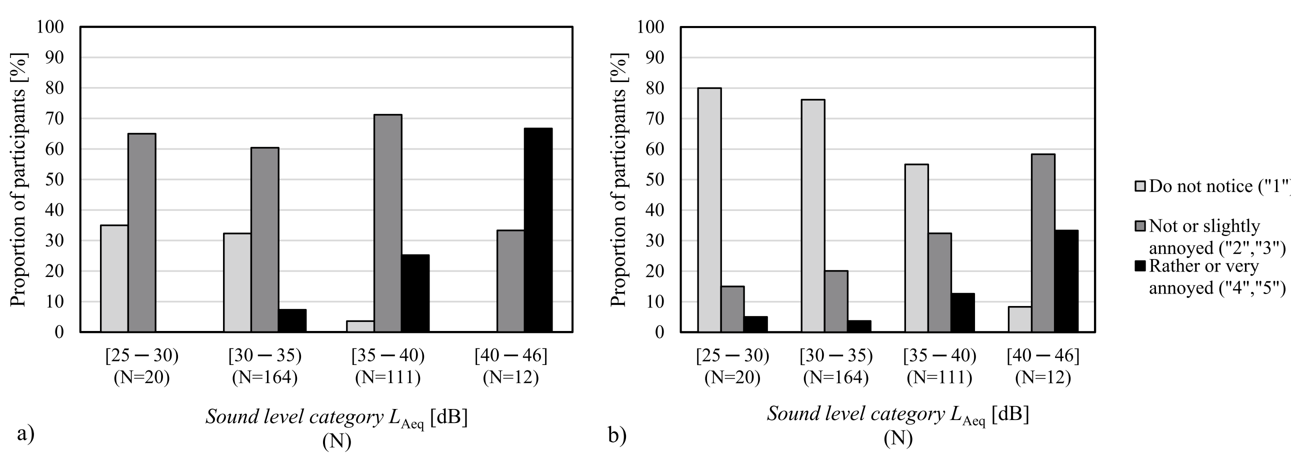

Fig. 1. The proportion of participants reporting different levels of annoyance for variables *annoyance outdoors* (a) and *annoyance indoors* (b) in different outdoor *sound level categories*, L_{Aeq}. The number of participants, N, responding the question in each category is also reported.

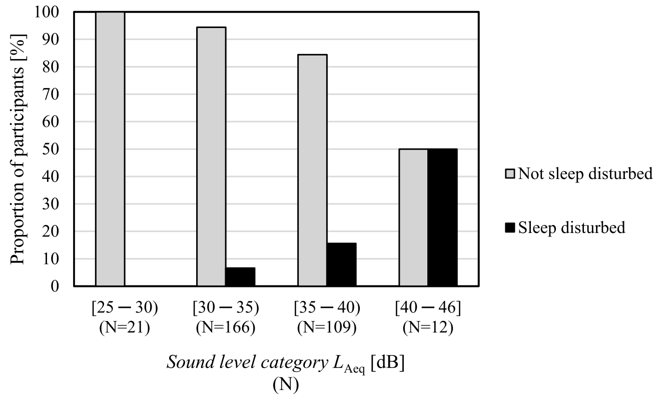

Fig. 2. The proportion of participants reporting sleep disturbance *%SleepD* in different outdoor *sound level categories*, L_{Aeq}. The number of participants, N, responding the question in each category is also reported.

(Fig. 1b and Supplementary material Table S.1). On the other hand, 50% of participants belonging to the highest *sound level category* belonged to the group of *%SleepD*. This result must be interpreted with caution because of the small number of participants in the group (N = 12). *%SleepD* in the highest *sound level category* differed statistically significantly from all the other *sound level categories* ($p < 0.01$). In addition, the values of *sound level categories* [30–35) dB and [35–40) dB differed significantly ($p = 0.023$). The lowest *sound level category* differed only from the highest category ($p < 0.001$), but not from other categories ($p > 0.05$).

The proportion and the count of participants' responses to dichotomous variables (Table 4) and the means and standard deviations for ordinal variables (Table 5) are also presented in total and for each *sound level category*. In the higher *sound level categories*, the participants saw the WTs more often ($p < 0.001$, $V = 0.59$), they were more concerned with the possible health impacts of sound (*health concern*: $H(3) = 20.1$, $p < 0.001$), they considered the change of bringing WTs into the area more negatively (*change experience WT*: $H(3) = 45.0$, $p < 0.001$), their opinions towards the WTs had changed to more negative direction (*change attitude*: $H(3) = 35.4$, $p < 0.001$) than in the lower *sound level categories*. In addition, the influence of WTs on the scenery was considered more negatively in the higher *sound level categories* than in the lower (*landscape attitude*: $H(3) = 39.5$, $p < 0.001$). The attitude towards wind power as an energy form did not depend on *the sound level category* (*energy attitude*: $H(3) = 7.3$, $p = 0.06$). The *cognitive coping* with annoyance caused by noise was considered a bit lower in the highest *sound level category* ($H(3) = 9.3$, $p < 0.03$). Furthermore, the higher *the sound level category,* the less participants felt they had received sufficient information about WTs (*information WT*: $H(3) = 10.9$, $p < 0.01$) and the less participants had *trust in operators* ($p = 0.001$, $V = 0.27$) and *trust in authorities* ($p = 0.001$, $V = 0.26$).

The variables describing the general characteristics of participants or their environment did not depend on the *sound level category*, such as *control of change* ($H(3) = 0.4$, $p = 0.94$)*, comfortability of environment* ($H(3) = 1.4$, $p = 0.71$)*, community benefit* ($p = 0.687$, $V = 0.03$), *noise sensitivity* ($H(3) = 1.5$, $p = 0.69$), and *health status* ($H(3) = 0.8$, $p = 0.85$).

3.3. Simple correlations between the variables

Spearman's correlation coefficients between different variables are presented in Table 6. It includes only the scale variables that were collected from all three areas. *Sound level* correlated strongly with *distance*. *Change experience WT* correlated with different attitudes and *health concern*. *Cognitive coping* correlated strongly with *noise sensitivity*.

3.4. Binary logistic regression

The results of the binary logistic regression models with a stepwise method is shown in Table 7 for *%A outdoors*, *%A indoors,* and *%SleepD*. The results for single variables for *%A outdoors, %A indoors*, and *% SleepD* are presented in the Supplementary material. In addition, the model with *change experience WT* and without *health concern* is presented in the Supplementary material.

The most important variable predicting the three outcome variables was *health concern* (Table 7). The other important variables predicting *%A outdoors* and *%A indoors* were the *area*, *noise sensitivity,* and *energy attitude*. *Sound level* was predicting *%A outdoors* and *gender %A indoors* with women more likely to be annoyed than men. Women were also more likely to belong to *%SleepD*. In addition, *sound level* and *noise sensitivity* predicted belonging to *%SleepD*.

4. Discussion

4.1. Factors related to WTN annoyance

Our best model could reach predictive strengths of 67% for *%A indoors* and 71% for *%A outdoors*. Previous studies on WTN annoyance have reached the predictive strengths of only 58% [2] and 55% [9]. *Health concern* was the first variable included in both models and it explained 43–48% of the two main outcome variables. This is in line with previous results, where concern for physical safety predicted WTN annoyance [2].

In both models of annoyance, the next variable included was *area*. This is somewhat unexpected since the area has not been considered as a variable in several previous studies [5,8,9,12,26]. When comparing the results between the Netherlands and Sweden, Dutch people not benefiting from WTs were more annoyed in the sound level category of (35–40] dB [10]. The hypothetical reasons were taller WTs or the fact that in the Netherlands, the neighbors of people in this comparison received an economic benefit from WTs and while the participants involved in the model of Ref. [10] did not, which might create possible resentment against neighbors. In the Health Canada study, province was defined as a modifier factor that together with sound level gave an 11% prediction strength for noise annoyance [2]. The three areas in our study were selected to reflect different types of wind power areas in terms of resistance towards wind power, land use history, and population density. A recent study has connected feelings towards the fairness of the planning phase with the annoyance that people feel towards WTN after the launching of the wind farm [15]. We believe that the area differences in our study are related to different land use histories.

Noise sensitivity is a personal variable that has been found to be associated with WTN annoyance [2,8]. It was also an important predictor of our main outcome variables. In addition, belonging to the groups of *%A outdoors* and *%A indoors* was less probable if the *energy attitude* was positive. The models of *%A outdoors* and *%A indoors* differed in whether the *sound level* and *gender* were included. The probability of belonging to *%A outdoors* increased with higher *sound level category*. This was not the case for *%A indoors.* This might be explained by the fact that the values of *%A outdoors* were twofold compared to the values of *%A indoors* in the three largest *sound level categories* (Table 5). The explanatory power of the *sound level* is expected to reduce when the prevalence of the explained variable is reduced. The twofold difference may also be explained by the sound insulation of the building façade. The sound insulation of Finnish façade constructions have been recently explored [30] and the sound insulation performance does not significantly differ from, for example, Danish façades. The role of *gender* was important in the model of *%A indoors*. Indoors, women were more often annoyed by WTN than men. For example, Janssen et al. [8] did not find that *gender* would explain *%A indoors*. Further research on the role of *gender* is therefore justified.

Interestingly, the variables related to the *visibility* of WTs and the

Table 7
Binary logistic regression models for *%A outdoors*, *%A indoors,* and *%SleepD*. Variables that were included in the model in the stepwise analysis are reported. Step 1 describes the predictive power of a single most important variable. Last step describes the best possible model.

%A outdoors		Logistic regression model (N = 280, R^2 = 0.710,[c] H-L,[d] p = 0.651)		
Variable	Groups in the variable[a]			
		OR (Cl)[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		Logistic regression model (N = 281, R^2 = 0.667,[c] H-L,[d] p = 0.992)		
Variable	Groups in the variable[a]			
		OR (Cl)[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)	1.00	
	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
%SleepD		Logistic regression model (N = 283, R^2 = 0.554,[c] H-L,[d] p = 0.905)		
Variable	Groups in the variable[a]			
		OR (Cl)[b]	*p-value*[e]	Order of entry into model: R^2 at each step
Health concern	Scale: 1-5	2.89 (1.97, 4.22)	< 0.01	Step 1: 0.44
Sound level [dB]	Continuous	1.38 (1.16, 1.65)	< 0.01	Step 2: 0.50
Noise sensitivity	Scale: 2-10	1.45 (1.06, 1.99)	0.02	Step 3: 0.53
Gender	Female/Male	2.97 (1.03, 8.54)	0.04	Step 4: 0.55

[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.

impact they have for the scenery (*landscape attitude*) were not present in the final models of *%A outdoors* and *indoors.* The *visibility* of WTs was strongly associated with outdoor noise annoyance in the Swedish and Dutch samples [5,10]. Earlier studies have related the negative attitude towards the visual impact of wind turbines on the landscape [10] and general sensitivity to landscape littering [9] to annoyance. *Landscape attitude* alone had the predictive strength of 30% and above (see Supplementary material).

It should be noted that the self-reported *health status* did not depend on the *sound level category*. This is in agreement with earlier studies [5,9,31].

4.2. Factors related to sleep disturbance

In the *sound level category* [35–40) dB, 15.6% of participants reported some sleep disturbance due to WTN. The model of sleep disturbance, i.e. *%SleepD*, had the predictive strength of 55%. This is less than with the models for *%A indoors* and *%A outdoors*. This is logical since sleep disturbance is often not considered to be directly connected to WTN, but through noise annoyance. In our study, the correlation coefficient between *%A indoors* and *%SleepD* was 0.72 (Table 6). *Health concern* explained *%SleepD* the most followed by *sound level.*

It is notable that many earlier studies have not found a direct connection between WTN induced sleep disturbance or sleep disturbance in general and WT sound level [4,21]. Jalali et al. [19] measured sound levels in the bedroom instead of the typical convention of outdoor measurement. They did not find a difference in measurements before and after the WTs started their operation in the area. However, a meta-analysis on cross-sectional studies with 2433 participants suggested an association between the exposure to WTN and sleep problems [17]. The importance of *sound level* in our study can be emphasized because we asked how often sleep is disturbed by WTN, whereas the other studies have used general questions about sleep disturbance and sleep quality without the relationship to WTN (e.g. Refs. [2,4]). Therefore, we can suggest that WTN induced sleep disturbance could increase with an increasing sound level, when the sound level is within 25 and 46 dB L_{Aeq}.

Noise sensitivity is the third variable included in the model, and the last is *gender,* showing that women were more likely to report sleep problems due to WTN than men. This finding suggests that women and noise sensitive people should be especially taken into account during the local public communication concerning the wind farm planning process. Listening to concerns about wind power and responding to them with fact-based information might reduce concerns about health effects and increase the acceptability of wind power in the area. *Area* was not included in the model of *%SleepD*, which means that other variables were more important, even though *%SleepD* differed between *areas*.

4.3. Strengths and limitations

The strength of our study is that the uncertainty of outdoor *sound level* is expected to be small. This was explained carefully in Hongisto et al. [3]. Most of the previous studies in this field have not presented quantitative data about the uncertainty of *sound level*. This is a serious shortage since sound level is still the most important variable for the selection of the setback distances of WT areas: sound level requirements are given in national regulations while the non-acoustic factors cannot be regulated. Therefore, the exact knowledge of the sound level has a strong importance. The presence of sound level in two final models of Table 7 further emphasizes the importance of sound level. *Distance* had a noticeably lower significance and correlation to annoyance than *sound level* and its meaning is discussed more deeply in Hongisto et al. [3].

Our study had a very small percentage of those who benefited economically from the nearby WTs. For example, in the Netherlands, 13.8% of people responding to the questionnaire reported an economic benefit from WTs, and the proportion was the highest in the highest *sound level category* with 67% of participants receiving an economic benefit [10]. This makes our sample different from samples from some other countries (e.g. from the studies [2,10]), since they have indicated that annoyance is almost absent among economic benefiters [10]. It is very important to conduct studies also in WT areas where wind power companies have not offered residents the possibility of ownership. In addition, our study is the first to include only large WTs of 3–5 MW. Previous studies have involved WTs with electrical power of 3 MW at most. Therefore, our study may be very useful for the design of new wind power areas.

The main limitations of our study are the small number of respondents, minor differences between the questionnaire and survey methods in different areas, the small number of respondents in the *sound level categories* of [25–30) dB and [40–46] dB, and the lack of some important non-acoustic variables. The three *areas* had a different number of participants, because *areas* 1 and 2 were less densely populated and had many free-time residents compared to *area* 3. The *areas* were selected to obtain a good coverage of different area types in Finland. The fact that 79% of participants were from *area* 3, might bias the results. However, the responses of participants from *areas* 1 and 2 were typically more extreme than responses from *area* 3. In addition, the participants of *areas* 1 and 2 were mainly interviewed face-to-face, while 86% of participants filled the questionnaire in *area* 3. Face-to-face interviews can produce more socially desirable answers, but mainly with questions on highly sensitive personal behavior [32], which we did not have in this questionnaire. Furthermore, the answers from the *areas* 1 and 2 show differences to opposite directions, *area* 1 being the most and *area* 2 the least annoyed. In addition, when examining the answers from *area* 3, where we had both response types, there was no difference in our main outcome variables between the response types of face-to-face interviews and questionnaires.

4.4. Conclusions

A cross-sectional survey was conducted in three wind power *areas*. The aim was to find the relationship between various subjective and objective variables and three outcome variables describing the adverse effects of wind power: *%A outdoors* (percentage of respondents annoyed by wind turbine noise outdoors), *%A indoors* (percentage of respondents annoyed by wind turbine noise indoors), and *%SleepD* (percentage of respondents reporting sleep disturbance due to wind turbine noise). The most important variable predicting the three outcome variables was *health concern* (concern about health effects of WT sound). This variable alone explained 43–47% of the three outcome variables. The second variable related to *%A outdoors* and *%A indoors* was the *area*. Three areas included in the study differed in the history of bringing wind power to the area. Personal factors, *noise sensitivity* and *energy attitude* (general attitudes towards wind power energy) are also important. *Sound level* also predicted *%A outdoors* and *%SleepD*. Special care should be paid to the reduction of the concern for possible health effects in the public communications. This could be done by offering sufficient information based on reliable studies and involving local people in the process of planning and local politics. A significant part of information distribution could concentrate on answering people's own concerns with factual knowledge. This could reduce the concern and therefore annoyance, and sensitive people could also feel their concerns are being listened to.

Declaration of interest

None.

Acknowledgements

This study was mainly funded by Business Finland [Anojanssi project, grant 828/31/2015]. Other funders were Turku University of Applied Sciences, the Ministry of the Environment, the Ministry of Social Affairs and Health, the Finnish Wind Power Assoc., TuuliWatti Ltd., Environmental Pool c/o Adato Energy Ltd., Kone Ltd., Nokian Tyres Ltd., Wärtsilä Finland Ltd., and APL Systems Ltd. Greatest thanks belong to Johanna Varjo and Annu Haapakangas for their assistance during the questionnaire survey, and David Oliva for conducting the sound level predictions.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.buildenv.2018.12.039.

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Supplementary material

Radun J., Hongisto V., & Suokas M. (2018). ”Variables associated with wind turbine noise annoyance and sleep disturbance”.

Table S.1. The description of the participants as well as their answers to main output variables in different *sound level categories* and in total.

	Sound level category L_{Aeq} [dB]					
	[25 – 30)	[30 – 35)	[35 – 40)	[40 – 46)	Total	Total [%]
Female participants [%]	42.9	54.4	39.6	38.5	47.8	
Mean *age* [yr]	58.3	53.6	54.8	55.1	55.4	
Age range [yr]	34 – 77	17 – 86	23 – 88	37 – 85	17 – 88	
Annoyance outdoors						
Total no. of responses	20	164	111	12	307	100.0
1. Do not notice	7	53	4	0	64	20.8
2. Notice, but not annoyed	10	74	59	1	144	46.9
3. Slightly annoyed	3	25	20	3	51	16.6
4. Rather annoyed	0	10	19	3	32	10.4
5. Very annoyed	0	2	9	5	16	5.2
Annoyance indoors						
Total no. of responses	20	164	111	12	307	100.0
1. Do not notice	16	125	61	1	203	66.1
2. Notice, but not annoyed	3	20	21	2	46	15
3. Slightly annoyed	0	13	15	5	33	10.7
4. Rather annoyed	1	4	9	1	15	4.9
5. Very annoyed	0	2	5	3	10	3.3
Sleep disturbance						
Total no. of responses	21	166	109	12	306	100.0
1. Never	20	147	82	5	254	82.5
2. Few days a year	1	8	10	1	20	6.5
3. Few days a month	0	9	10	3	22	7.1
4. Few days a week	0	2	7	1	10	3.2
5. Almost every day	0	0	0	0	0	0
6. Every day	0	0	0	2	2	0.6

Table S.2. The description of the participants as well as their answers to main output variables in different *distance categories* and in total.

	Distance categories [m]				Total	Total [%]
	1600-2000	1200-1600	800-1200	<800		
Annoyance outdoors						
Mean (SD)	1.9 (0.9)	2.6 (1.0)	2,9 (1.2)	3.4 (1.1)	2.4 (1.1)	
Total no. of responses	125	133	37	5	300	100.0
1. Do not notice	46	10	3	0	59	19.7
2. Notice, but not annoyed	56	71	14	1	142	47.3
3. Slightly annoyed	16	24	9	2	51	17.0
4. Rather annoyed	4	22	5	1	32	10.7
5. Very annoyed	3	6	6	1	16	5.3
Annoyance indoors						
Mean (SD)	1.4 (0.8)	1.8 (1.1)	2,1 (1.3)	2.8 (1.5)	1.7 (1.1)	
Total no. of responses	125	133	37	5	300	100.0
1. Do not notice	98	79	17	1	195	65.0
2. Notice, but not annoyed	13	26	7	1	47	15.7
3. Slightly annoyed	8	14	9	2	33	11.0
4. Rather annoyed	5	9	1	0	15	5.0
5. Very annoyed	1	5	3	1	10	3.3
Sleep disturbance						
Mean (SD)	1.8 (1.3)	1.8 (1.4)	1.4 (0.9)	1.1 (0.4)	1.4 (0.8)	
Total no. of responses	129	132	35	5	301	100.0
1. Never	119	101	24	3	247	82.1
2. Few days a year	6	10	3	1	20	6.6
3. Few days a month	4	15	3	0	22	7.3
4. Few days a week	0	6	3	1	10	3.3
5. Almost every day	0	0	0	0	0	0
6. Every day	0	0	2	0	2	0.7

SD=Standard deviation

Table S.3. The binary logistic regression values explaining the percentage of annoyed participants outdoors (*%A outdoors)* for each variable separately. The larger the Nagelkerke pseudo R^2 value is, the stronger the variable explained the risk for belonging to the group of annoyed participants outdoors. However, since it is pseudo R^2, it cannot be used to directly compare the predictability of variables, especially, when the number of participants changes in the models. N is the number of participants who responded to the question.

Variable	N	H-L, p-value [a]	OR(Cl)[b]	*p-value* [c]	$R^{2,\ d}$
Change experience WT	307	0.90	10.89 (5.82, 19.97)	<0.01	0.60
Change attitude	303	0.21	6.15 (3.91, 9.68)	<0.01	0.45
Health concern	305	0.03	3.31 (2.46, 4.46)	<0.01	0.44
Landscape attitude	306	0.93	4.08 (2.76, 6.02)	<0.01	0.37
Energy attitude	301	0.49	2.40 (1.85, 3.11)	<0.01	0.28
Trust in operators (yes)[e]	235	.	0.07 (0.02, 0.19)	<0.01	0.27
Trust in authorities (yes)[e]	232	.	0.07 (0.03, 0.21)	<0.01	0.25
Sound level [dB]	308	0.71	1.45(1.28, 1.64)	<0.01	0.24
Noise sensitivity	300	0.91	1.75 (1.45, 2.12)	<0.01	0.21
Area 1	311	1.00	12.74 (5.46, 29.72)	<0.01	0.21
Area 2			0.46 (0.10, 2.01)	0.30	
Area 3			reference	<0.01	
Comfortability of environment [f]	273	0.09	0.54 (0.42, 0.68)	<0.01	0.20
Cognitive control	303	0.01	0.45(0.33, 0.63)	<0.01	0.14
Community benefit (yes)[e]	267	.	0.05 (0.01, 0.38)	<0.01	0.13
Visibility (visible)[e]	305	.	7.08 (2.71, 18.44)	<0.01	0.13
Information WT [f]	276	0.59	0.47 (0.31, 0.71)	<0.01	0.11
Distance [km]	300	0.60	0.11 (0.04, 0.32)	0.05	0.09
Hearing disability (no) [f]	277	1.00	reference	0.13	0.04
Hearing disability (suspects) [f]			0.19 (0.03, 1.45)	0.11	
Hearing disability (diagnosed) [f]			1.73 (0.65, 4.63)	0.28	
Age	300	0.36	1.00 (0.97, 1.02)	0.60	0.00
Health status [f]	242	0.96	1.02 (0.63, 1.67)	0.93	0.00
Gender (female)	311	.	0.92 (0.50, 1.71)	0.79	0.00

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

[b] Odds ratio (OR) and 95% confidence interval 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] *p-values* of Wald test indicate whether the variable was significantly contributing to the model.

[d] 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.

[e] Hosmer Lemeshow test does not give values to these variables, because some of their cells in the test have frequency below 5.

[f] Variables that were collected only from Areas 2 and 3.

Table S.4. The binary logistic regression values explaining the percentage of annoyed participants indoors (*%A indoors*) for each variable separately. The larger the Nagelkerke pseudo R^2 value is, the stronger the variable explained the risk for indoor annoyance. However, since it is pseudo R^2, it cannot be used to directly compare the predictability of variables, especially, when the number of participants changes in the models. N is the number of participants who responded to the question.

Variable	N	H-L, p-value [a]	OR(Cl)[b]	*p-value* [c]	$R^{2, d}$
Change experience WT	307	0.42	8.54 (4.19, 17.38)	<0.01	0.48
Health concern	305	0.59	3.77 (2.56, 5.54)	<0.01	0.48
Change attitude	303	0.43	6.05 (3.31, 11.07)	<0.01	0.37
Landscape attitude	306	0.62	4.03 (2.44, 6.67)	<0.01	0.30
Trust in operators (yes) [e]	235	.	0.04 (0.01, 0.27)	<0.01	0.22
Trust in authorities (yes) [e]	232	.	0.04 (0.01, 0.30)	<0.01	0.21
Noise sensitivity	300	0.38	1.81 (1.42, 2.32)	<0.01	0.19
Energy attitude	301	0.38	2.14 (1.57, 2.92)	<0.01	0.19
Comfortability of environment [f]	273	0.00	0.58 (0.44, 0.77)	<0.01	0.14
Area 1	311	1.00	6.47 (2.54, 16.49)	<0.01	0.14
Area 2 [g]			0.00	1.00	
Area 3			reference	<0.01	
Sound level [dB]	308	0.37	1.30 (1.14, 1.48)	<0.01	0.12
Cognitive control	303	0.12	0.48 (0.32, 0.71)	<0.01	0.10
Visibility (visible) [e]	306	.	8.57 (1.98, 37.06)	0.04	0.10
Information WT [f]	276	0.77	0.46 (0.26, 0.80)	0.01	0.09
Community benefit (yes)[e]	267	.	0.11 (0.02, 0.86)	0.04	0.07
Distance [km]	300	0.72	0.21 (0.05, 0.81)	0.02	0.04
Gender (female)	311	.	2.48 (1.04, 5.93)	0.04	0.03
Hearing disability (no) [f]	277	1.00	reference	0.62	0.01
Hearing disability (suspects) [f]			0.36 (0.05, 2.80)	0.33	
Hearing disability (diagnosed) [f]			0.97 (0.21, 4.54)	0.97	
Age	300	0.10	0.99 (0.96, 1.02)	0.38	0.01
Health status [f]	242	0.64	0.95 (0.50, 1.81)	0.88	0.00

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

[b] Odds ratio (OR) and 95% confidence interval 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] *p-values* of Wald test indicate whether the variable was significantly contributing to the model.

[d] 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.

[e] Hosmer Lemeshow test does not give values to these variables, because some of their cells in the test have frequency below 5.

[f] Variables that were collected only from Areas 2 and 3.

[g] Area 2 had no-one reporting annoyance indoors.

Table S.5. The binary logistic regression values explaining the percentage of sleep disturbed participants (*%SleepD*) for each variable separately. The larger the Nagelkerke pseudo R^2 value is, the stronger the variable explained the risk for sleep disturbance. However, since it is pseudo R^2 it cannot be used to directly compare the predictability of variables, especially, when the number of participants changes in the models. N is the number of participants who responded to the question.

Variable	N	H-L, p-value [a]	OR(Cl)[b]	*p-value* [c]	$R^{2,d}$
Change experience WT	311	0.00	5.96 (3.52, 10.11)	<0.01	0.44
Health concern	309	0.16	3.31 (2.41, 4.55)	<0.01	0.44
Change attitude	307	0.63	4.34 (2.75, 6.86)	<0.01	0.31
Landscape attitude	309	0.59	2.88 (1.96, 4.23)	<0.01	0.23
Trust in operators (yes)[e]	237	.	0.05 (0.01, 0.23)	<0.01	0.23
Trust in authorities (yes)[e]	234	.	0.06 (0.01, 0.25)	<0.01	0.22
Sound level [dB]	309	0.12	1.38(1.21, 1.56)	<0.01	0.19
Comfortability of environment [f]	277	0.08	0.55 (0.43, 0.71)	<0.01	0.18
Energy attitude	300	0.38	1.86 (1.42, 2.43)	<0.01	0.14
Area 1	311	1.00	6.03 (2.54, 14.31)	<0.01	0.14
Area 2 [g]			0.00	1.00	
Area 3			reference	<0.01	
Noise sensitivity	303	0.31	1.58 (1.29, 1.93)	<0.01	0.13
Information WT [f]	280	0.76	0.46 (0.29, 0.74)	<0.01	0.10
Distance [km]	301	0.18	0.10(0.03, 0.34)	<0.01	0.09
Cognitive control	307	0.00	0.52 (0.37, 0.73)	<0.01	0.09
Community benefit (yes)[e]	270	.	0.08 (0.01, 0.63)	0.02	0.09
Visibility (visible)[e]	307	.	5.80 (1.99, 16.90)	<0.01	0.09
Gender (female)	311	.	1.85 (0.89, 3.85)	0.10	0.02
Hearing disability (no) [f]	281	1.00	reference	0.83	0.00
Hearing disability (suspects) [f]			0.78 (0.22, 2.77)	0.70	
Hearing disability (diagnosed) [f]			0.67 (0.15, 3.03)	0.60	
Age	304	0.25	0.99 (0.97, 1.02)	0.44	0.00
Health status [f]	246	0.84	1.02 (0.61, 1.73)	0.93	0.00

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

[b] Odds ratio (OR) and 95% confidence interval 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] *p-values* of Wald test indicate whether the variable was significantly contributing to the model.

[d] 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.

[e] Hosmer Lemeshow test does not give values to these variables, because some of their cells in the test have frequency below 5.

[f] Variables that were collected only from Areas 2 and 3.

[g] Area 2 had no-one reporting sleep disturbances.

Table S.6. Binary logistic regression models for *%A outdoors*, *%A indoors* and *%SleepD*. The variables included in the stepwise analysis were *noise sensitivity*, *change experience WT, sound level, visibility,* and background variables *gender, age* and *area*. Only the significant variables are reported in the table. Step 1 tells how much the model would explain, if only the variable with best predictive strength was included and the last step describes the best possible model with all variables.

%A outdoors Variable	Groups in the variable[a]	Logistic regression model (N=288, R^2=0.715,[c] H-L,[d] p=0.713)		
		OR(Cl)[b]	*p-value*[e]	Order of entry into model: R^2 at each step
Change experience WT	Scale: 1-5	9.71(4.61, 20.44)	<0.01	Step 1: 0.60
Noise sensitivity	Scale: 2-10	1.96(1.40, 2.74)	<0.01	Step 2: 0.67
Area	Area 1	5.82 (1.36, 24.97)	0.02	Step 3: 0.72
	Area 2	0.21 (0.02, 2.44)	0.19	
	Area 3	Reference	0.01	

%A indoors Variable	Groups in the variable[a]	Logistic regression model (N=289, R^2=0.612,[c] H-L,[d] p=0.643)		
		OR(Cl)[b]	*p-value*[e]	Order of entry into model: R^2 at each step
Change experience WT	Scale: 1-5	10.20(4.26, 24.42)	<0.01	Step 1: 0.50
Noise sensitivity	Scale: 2-10	1.85(1.28, 2.67)	<0.01	Step 2: 0.57
Gender	Female/Male	5.12 (1.45, 18.04)	0.01	Step 3: 0.61

%SleepD Variable	Groups in the variable[a]	Logistic regression model (N=291, R^2=0.518,[c] H-L,[d] p=0.398)		
		OR(Cl)[b]	*p-value*[e]	Order of entry into model: R^2 at each step
Change experience WT	Scale: 1-5	6.07(3.36, 10.94)	<0.01	Step 1: 0.45
Noise sensitivity	Scale: 2-10	1.48(1.12, 1.94)	0.01	Step 2: 0.49
Gender	Female/Male	3.18 (1.18, 8.55)	0.02	Step 3: 0.52

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

[b] Odds ratio (OR) and 95% confidence interval 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 good fit.

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