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Health effects of wind turbine noise and road traffic noise on people living near wind turbines

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A B S T R A C T

Very few surveys have investigated the health effects of both wind farms and road traffic so that the public health effects of environmental stressors are broadly understood. This case-control study examined the influences of both wind turbine noise and road traffic noise on self-reported symptoms and diseases close to wind turbines and in a control area. Wind turbine sound levels 17–39 dB L_{Aeq} met new national regulation (40 dB). Daytime road traffic noise levels were 32.5–63.5 dB, sometimes exceeding the regulation (55 dB). Altogether 676 residents responded to a masked living environment questionnaire. Higher wind turbine sound level was only associated with more likely reporting wind turbine noise annoyance and not with reporting of other symptoms or chronic diseases. On the other hand, higher road traffic sound level was associated with increased odds for road traffic noise annoyance, migraine or headache, dizziness, impaired hearing, pressure in ears, tachycardia or heart palpitations, and heart disease. Road traffic exposure seems to deserve attention especially if daytime levels exceed 55 dB. The health effects of wind farms seem to be limited to noise annoyance in areas where all residents are exposed to sound levels under 40 dB.

1. Introduction

Possible adverse health effects of wind turbine noise on humans are one of the most challenging factors affecting the social acceptability of wind power. High noise annoyance is the most usual adverse health effect of environmental noise. High noise annoyance means coarsely that if the resident is given an annoyance response scale, e.g., from 0 (Not at all) to 10 (Extremely much), the resident responds a value from 8 to 10. There is plenty of evidence from exposure−response studies that high noise annoyance increases with increasing wind turbine noise level [1–5]. Mainly due to these evidences, World Health Organization (WHO) [6] recommends an upper limit of 45 dB L_{den} (day-evening-night level) for wind turbine noise, even though the evidence related to wind turbine noise health effects was estimated to be of low quality or even lacking. Therefore, new research in this field is highly justified. During the progress of this recommendation, many countries already tightened mandatory noise regulations of wind turbine noise. Exceedance of 40 dB L_{Aeq} during nighttime hours (07–22) and 45 dB L_{Aeq} during daytime hours was prohibited in Finland already in 2015 [7]. This means the same as 48.2 dB L_{den}. However, in Finland, daytime relief in noise emission is never applied by wind farm operators so 40 dB is applied also during daytime (46.4 dB L_{den}). Similar regulation as in Finland is applied in Wallonia, Belgium [8]. In some countries, the regulations are stricter, for example 35 dB in purely residential areas in Germany and 39 dB in Flanders, Belgium and Denmark [8]. There is a need to investigate the operability of these new regulations from a health perspective, since most previous studies on health effects have concentrated on wind turbine areas involving sound levels that are higher than the new regulation allows (e.g. Refs. [1,2]).

The investigation of wind turbine areas meeting the tightened noise regulations is highly important, since other factors have been found to explain annoyance of wind turbine noise better than wind turbine sound level itself (e.g. Ref. [9]). The factors related to wind turbine noise annoyance are, for example, concern of one's physical health [9,10],

Abbreviations: %A, percentage of respondents reporting noise annoyance; ANOVA, analysis of variance; CI, 95% confidence interval; Ctrl, Control area; Exp(B), exponentiated logistic coefficient; FPRC, The Finnish Population Register Centre; $L_{Aeq,WT}$, wind turbine sound level; $L_{Aeq,07\text{-}22,RT}$, road traffic sound level during the day; $L_{Aeq,22\text{-}07,RT}$, road traffic sound level during the night; RTN, road traffic noise; RTSL, road traffic sound level; SD, standard deviation; SPL, sound pressure level; SWL, sound power level; WHO, World Health Organization; WT area, wind turbine area; WTN, wind turbine noise; WTSL, wind turbine sound level.; WT syndrome, wind turbine syndrome; %, percentage; %SleepD, percentage of respondents reporting sleep difficulties.

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receiving economic benefit [10,11], and planning fairness [12]. These factors contribute to the regional differences of wind turbine noise annoyance [9,10]. Furthermore, if the noise level is high, this might elevate opposition among people living closest to the turbines. This might, among other things, be reflected to attitudes of also other people living farther away in the same area. Therefore, examining noise annoyance in wind turbine areas where the regulated sound level is fulfilled among the whole population is important and highly topical. In other words, studying a wind turbine area where a minority of residents is exposed to high wind turbine noise levels, which are no longer accepted in new areas due to stricter regulations, might bias the responses of the whole area and the outcome would not represent the outcome in (new) areas where such minority does not exist.

On the other hand, the most common environmental noise in Western Europe is road traffic noise [13]. It has higher sound levels common in residential areas than wind turbine noise and clear health effects related to it [6]. In the European region, WHO recommends values below 53 dB L_{den} for road traffic noise, because above this level there is strong evidence of adverse health effects [6]. During night time, the values should to be below 45 dB L_{night} (equivalent A-weighted sound pressure level (SPL) during hours 22–07), because higher levels are associated with disturbed sleep [6]. In Finland, new living areas shall be planned so that the sound level of road traffic is under 55 dB $L_{\mathrm{Aeq,07\text{-}22}}$ during daytime and under 45 dB $L_{\mathrm{Aeq,22\text{-}07}}$ during nighttime in the yard and balcony [14]. These limits are, however, often exceeded in the residential yards near large roads and busy streets especially in areas built before 1992. Maula et al. [15] reported values up to 75 dB L_{Aeq}. Road traffic noise exposure is nearly always present close to wind turbine areas since they are placed close to existing infrastructures. Therefore, adverse health effects caused by road traffic noise can exist also in wind turbine areas.

Only few studies have investigated the effects of wind turbine noise and road traffic noise in parallel although it is self-evident that people close to wind farms are also exposed to road traffic noise. Some studies have asked symptoms people associate to road traffic and wind turbine noise [12] and others have included general background noise as a factor [16]. Hearing road traffic noise was related to less probable wind turbine noise annoyance [10]. However, studies examining the sound exposures of both road traffic and wind turbine noise are rare. Road traffic sound was connected with decreased wind turbine noise annoyance, but only if wind turbine sound level was moderate (35–40 dB) and road traffic sound level was 20 dB higher than that [17]. Most cross-sectional studies concerning the health effects of wind turbines solely focus on wind turbine noise. From the public health perspective, focusing only on wind turbine noise can be a limitation since road traffic is the dominant noise source around many wind turbine areas. Wind turbines are usually built close to existing large roads since their erection and maintenance requires large transport vehicles. Therefore, to set the wind turbine noise into right perspective regarding public health, it is very important to examine all potential environmental stressors and their health effects simultaneously.

The non-auditory effects of noise have two routes: direct and indirect route [18]. Direct route means the non-conscious physiological stress, which is known to disturb sleep already at low levels of noise [19]. The indirect route means that noise causes emotional stress reaction among awake person due to perceived discomfort [18]. The first symptom of indirect route is noise annoyance, which can be followed by a stress response causing activation in autonomic nervous system and stress hormone secretion [20,21]. If this reaction is prolonged, it might cause a chronic imbalance in the body. This imbalance can lead to different stress-related symptoms and, in the end, to chronic diseases.

There are claims that wind turbine noise exposure is related to a certain combination of symptoms called wind turbine syndrome [22,23], where a wide list of symptoms occurs on the vicinity of wind turbines [24]. Large controlled studies on a population level do not support the claims for relations between wind turbine noise and other self-reported health effects [1,2,25] or subjective and objective stress-symptoms [26], or subjective and objective measures of sleep [27]. In addition, an examination of people's noise exposure and health register data showed no association between long-term nighttime exposure to wind turbine noise and risk for diabetes [28] nor short-term nighttime wind turbine noise and cardiovascular events [29]. Current reviews are not in agreement whether noise annoyance is the only health effect of wind turbine noise. Two reviews suggest a connection between wind turbine noise and annoyance as well as sleep disturbance, but no conclusive evidence for other health effects [30,31]. Another recent review described noise annoyance to be the only clear consequence of wind turbine noise exposure with no conclusive findings concerning stress and biophysical variables of sleep and heterogeneous findings concerning sleep disturbance, quality of life, and mental health problems [32]. Due to the uncertainty in the conclusions, the examination of health effects related to wind turbine noise is essential.

Furthermore, noise exposure-response relationships of wind turbine noise have been commonly investigated by selecting participants having at least three groups, i.e., small, moderate, and large noise exposure (cross-sectional design) without a control group. Cross-sectional design has weaker power to suggest health effects than case-control design, since the WTs can still be visible in the group with the smallest noise exposure (depending on terrain and hub height). Turbine visibility is one factor associated with wind turbine noise annoyance [17], which makes using the group with small noise exposure as a control group not feasible. The health effects of an environmental stressor can be most reliably investigated by using a between-group design, where the other group is exposed to the stressor and the other group is not (case-control design). There are very few studies [25,33] inspecting the health effects of wind turbines which apply case-control design and which also have determined the noise exposures of participants.

On the other hand, various health effects have been related to the most common environmental noise, road traffic noise. Increased road traffic sound level is associated with increased risk of cardiovascular disease in general [19], and more specifically with both ischemic heart disease [34], and increased risk of hypertension [35]. There are some indications for the association between transportation noise and stroke [34], diabetes [34,36], obesity [34], and disturbed sleep [37]. Disturbed sleep is associated with cortical awakenings and self-reported sleep disturbances, when the noise source is specified, but not to self-reported sleep disturbances in a general level [37]. Some studies suggest an association between road traffic noise and respiratory mortality in elderly [38], and depression [39,40]. In general a connection between road traffic noise and mental health has been rated to be very low [41], though a connection has been suggested to exist among people reporting poor sleep in general [42].

The aim of this study was to examine the health effects of wind turbines close to a highly populated area near a wind farm, where the wind turbine sound levels were in accordance with tightened noise regulations and adopted design policies (<40 dB both daytime $L_{\mathrm{Aeq,22–07}}$ and night-time $L_{\mathrm{Aeq,07–22}}$). This enables the examination of the phenomena in an area that represents the situation in modern wind farm around which the whole population is protected by the tightened noise regulations. This kind of setting is highly topical since the pressure of increasing the proportion wind power exists in many countries, but the increment requires that the health effects of wind farms meeting the current noise legislations must be properly known. First question was whether the residents with wind turbine noise exposure differ from the residents with no wind turbine noise exposure (control area) in their self-reported health reports. The second question was whether road traffic noise constitutes a larger risk to health than a well-regulated wind turbine noise. The self-reported health effects include annoyance, chronic diseases, and different stress-related symptoms. To minimize response bias, we developed and applied a masked questionnaire where our primary purpose of studying the health effects of wind turbine noise was hidden.

2. Materials and methods

2.1. General design

This is a case-control study, which was conducted in a wind turbine area (WT area) close to wind turbines and in a Control area far away from wind turbines. Selected residents were invited to fill a "living environment questionnaire" once. The independent exposure variables were wind turbine sound level ($L_{Aeq,WT}$) and road traffic sound level ($L_{Aeq,07\text{-}22,RT}$). The dependent variables were the self-ratings obtained from the questionnaire. The ethical committee of Turku University of Applied Sciences approved the study (statement 2018–099).

2.2. Study areas

The study areas are elucidated in Fig. 1. Fig. S1 illustrates WT area in more detail. WT area, which met the Finnish noise regulations for wind turbine noise, was chosen as our case area. The Finnish regulations for wind turbine noise set the highest allowed level to 45 dB L_{Aeq} during the day and 40 dB L_{Aeq} during the night [7]. Due to efficiency reasons, the areas are planned in Finland so that the wind turbines can produce full power 24 h per day. Therefore, 40 dB L_{Aeq} is not exceeded in residential yards nearby Finnish wind farms, which are built after 2015. This approach was also applied in the WT area of this study.

WT area included residents living near wind turbines near one Finnish town having 20.000 inhabitants (Hamina). The WT area contained three subareas having slightly different types and ages of wind turbines (Table 1). These subareas were together called as WT area. The sample around this WT area included a small-town center, suburbs, and peaceful countryside. All residential buildings within 2.5 km from these wind turbines were identified from the maps of National Land Survey of Finland. This specific cluster of three nearby, but separate wind turbine areas was chosen for this study because the settlement was very versatile, the study area was large (approximately 8 × 6 km), and the population density was among the highest in Finland close to wind turbines. Furthermore, the new Finnish noise policy [7] had been followed due to local policies although the wind turbines were built before 2015. These conditions (both high population and agreement with new noise regulations) are not fulfilled in other communities in Finland.

The criteria during the identification of the control area were similar residential profile, similar socioenonomic status, and essentially similar road traffic noise level distribution as in the WT area but the distance to any wind turbine shall be larger than 6 km making them inaudible and not visible. A single Control area (an Eastern part of Kotka city) was selected to be enable easier determination of the sound level outside the residential houses. The distance of the Control area to the nearest wind turbines was within 6.8–8.0 km. Residential buildings in the Control area were selected from the maps of National Land Survey of Finland. While selecting the Control area, the socioeconomic comparability to WT area was examined through the prices of houses and apartments,

Table 1
Descriptions of three subareas, which together form the WT area of our study. The number of questionnaires sent describes the distribution of the potential participants in relation to their nearest wind turbine subareas.

Descriptor	Subarea		
	1	2	3
Name	Harbor	Summa	Mäkelänkangas
No. of WTs	2	3	4
Start of operation (year)	2015	2010	2012
WT manufacturer and type	Enercon E−101	Winwind WWD3	Hyundai HG2000
No. of questionnaires sent	1403	731	426

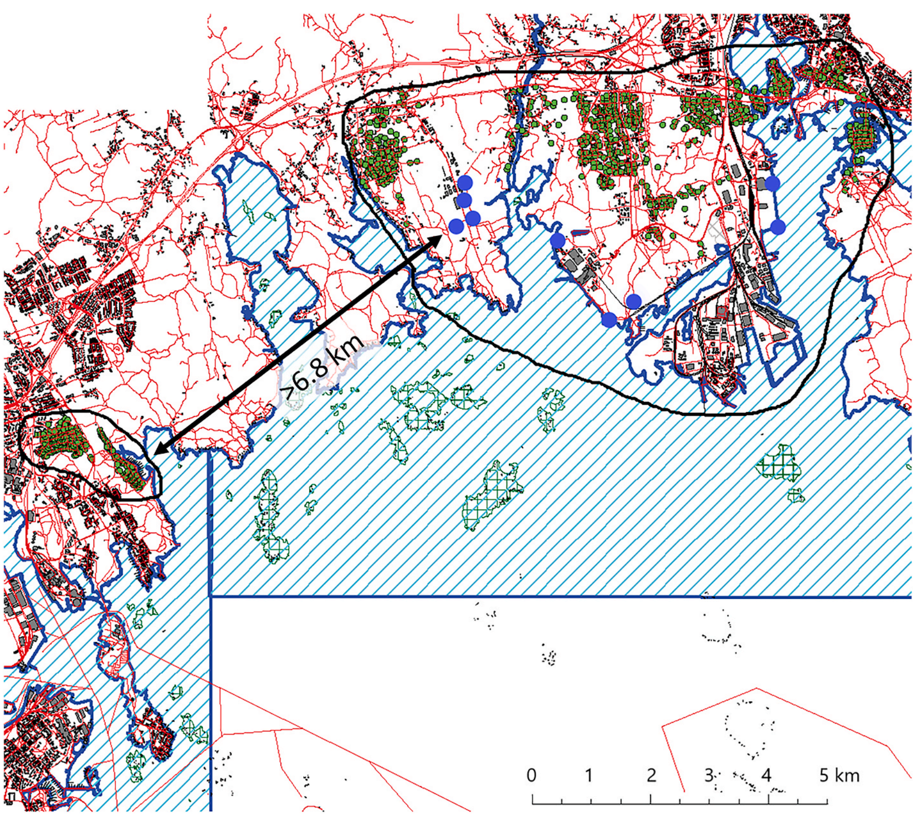

Fig. 1. A map involving both WT area (right) and Control area (left). Both areas are indicated with black contour lines. Wind turbines are marked with large blue dots. Small green dots represent the residential buildings to which the questionnaire was sent. Some buildings involved several potential participants. Red lines on the ground denote roads.

which corresponded to each other in these areas. There was a wind power area of three turbines in the south-west direction from the Control area, but they were not visible and farther from the Control area than the closest wind turbines of the studied WT area.

2.3. Questionnaire

The questionnaire is available in Supplementary Material 2. It is well-known that another questionnaire study was conducted in subareas 2 and 3 in 2015 [43]. The questionnaire was named a "Living environment questionnaire". It included ten and half pages of questions concerning living environment, attitudes, quality of life, and health. To avoid response bias, all attempts were made to mask the purposes of the questionnaire to avoid, e.g., the expectation that the study focuses on wind turbines. Wind turbines or wind turbine noise were mentioned 19 times while road traffic or factors related to road traffic noise were mentioned 18 times. Table 2 defines the health-related variables that were collected using the questionnaire. The response scales are described in Table 3. The annoyance questions were formulated by taking the recommendations of ISO TS 15666 standard [44] into account. Stress was measured using 10-item Perceived Stress Scale [45], which describes, e.g., life control, anger, and stress experienced during the past month. All dichotomized variables are marked by %. %A means the percentage of respondents being annoyed by noise. That is, they reported the annoyance to be 5 or more on an 11-step response scale from 0 to 10. The list of different symptoms and diseases are presented in more detail in Tables 6–10. The list of symptoms and diseases were chosen using previous literature on wind turbine noise [1] and taking into account WT syndrome's claimed symptoms [22] and also to cover symptoms related to prolonged stress reaction as well as to long term effects of environmental noise [13].

2.4. Selection of sample

The Finnish Population Register Centre (FPRC) provided information about the residents in the selected buildings. The data gained from FPRC included only permanent addresses so that free-time residences such as summer cottages were excluded. FPRC provided information for altogether 3058 households, of which 2560 resided in WT area and 498 in Control area. FPRC provided name, contact information, the year of birth of one adult living in each household, the number of people and minors living in the same address, and the mother tongue. Some buildings contained several households (e.g., terraced houses, block of flats). FPRC also selected the adult for whom the questionnaire was addressed randomly from adults living in each household considering the gender and age of the person. People having an order of non-disclosure or a non-disclosure for direct marketing could not be included. The proportion of such people in the target population is not known.

Certain background questions were categorized. Question of building time was dichotomized to show the building time before and after 1990, since the new rules requiring a better façade sound insulation came into force in 1992 [14]. Building type was dichotomized to show difference between block of flats and other type of buildings (detached house, semi attached house, and terraced house).

2.5. Implementation of the survey

The questionnaire was sent in the end of September 2018 to 3058 people's home addresses. The reminder was sent to all of them in mid-November 2018. People were requested to answer within four weeks from receiving the letter. The paper questionnaire and invitation letter were sent in Finnish. If the mother tongue was Swedish, an additional invitation letter was included in Swedish. If the mother tongue was not Swedish nor Finnish, an additional invitation letter was included in English. Everyone had a possibility to respond also online in Finnish,

Table 2
Definitions and response scales of the health-related variables measured with the questionnaire as well as the range of scales. The scales are defined in Table 3 and the whole questionnaire is presented in Supplementary material 2.

Variable/Variable type name	Question(Q)/explanation	Scale	Range
Annoyance indoors question	Q18. How much do the following environmental factors disturb, bother, or annoy you when you spend time indoors at home? Think about the situation in the past 12 months.		
WTN annoyance indoors	Q18c. Noise from the wind farm	A	0–10
RTN annoyance indoors	Q18a. Road traffic noise	A	0–10
%A WTN indoors	Percentage of respondents reporting 5 or more to *WTN annoyance indoors* (Q18c.)	B	0/1
%A RTN indoors	Percentage of respondents reporting 5 or more to *RTN annoyance indoors* (Q18a.)	B	0/1
Annoyance outdoors question	Q19. How much do the following environmental factors disturb, bother, or annoy you when you spend time outside in the garden, balcony, or terrace of your home? Think about the situation in the past 12 months.		
WTN annoyance outdoors	Q19c. Noise from the wind farm	A	0–10
RTN annoyance outdoors	Q19a. Road traffic noise	A	0–10
%A WTN outdoors	Percentage of respondents reporting 5 or more to *WTN annoyance outdoors* (Q19c.)	B	0/1
%A RTN outdoors	Percentage of respondents reporting 5 or more to *RTN annoyance outdoors* (Q19a.)	B	0/1
%Stress (PSS)	Percentage of respondents classified as stressed. Values > 16 on Cohen's Perceived Stress Scale	B	0/1
Sleep difficulties in general	Q58. How much have you experienced sleep problems all in all in the past 12 months? Sleep problems include difficulty falling asleep, waking up in the middle of the night, poor quality of sleep and waking up too early in the morning.	A	0–10
%SleepD in general	Percentage of respondents reporting 5 or more to *Sleep difficulties in general* (Q58.)	B	0/1
Sleep difficulties due to noise	Q59. How often is your sleep disturbed by the sounds from your environment?	C	1–5
%SleepD due to noise	Percentage of respondents reporting 3 or more to *Sleep difficulties due to noise* (Q59) (at least once a month or more often)	B	0/1
Sleep difficulties due to environmental factors	Q60. How much have the following factors disturbed your sleep in the past 12 months?	A	0–10
%SleepD due to environmental factors	Percentage of respondents reporting 5 or more to *Sleep difficulties due to environmental factors* (Q60.)	B	0/1
Stress symptoms question	Q70. In the last 12 months, how often have you experienced … (Symptom)	D	1–5
%Symptoms	Percentage of respondents reporting 3 or more (almost every month or more often) to Stress symptoms question (Q70.)	B	0/1
%Diseases	Percentage of respondents reporting yes to Q71. In the past 12 months, have you experienced … (Disease)	B	0/1

Table 3
Verbal descriptors of the response ranges for scales of Table 2.

Scale	Descriptors of the response range
A	0 = not at all, 10 = very much
B	0 = no, 1 = yes
C	1 = less than once a year, 2 = at least once a year, 3 = at least once a month, 4 = at least once a week, 5 = nearly every day
D	1 = never, 2 = a few times, 3 = every month or almost every month, 4 = every week or almost every week, 5 = every day or almost every day

Swedish, or English. Ten 100-euro gift vouchers were drawn among willing respondents to increase the response rate.

2.6. Noise modelling

Wind turbine noise. The studied WT area contained three subareas and three wind turbine types. The sound power level (SWL, emission) of each wind turbine type was determined by measurements on site by the researchers because manufacturer data was not available for every wind turbine type and we wanted to verify them all. The measurements were conducted according to the national instructions [46] which is largely based on IEC 61400-11 standard for octave bands from 31.5 to 8000 Hz [47]. The standard allows the determination of SWL at different wind speeds. We reported the SWL only for wind speed of 8 m/s at the height of 10 m since the maximum rotation speed and electricity production is achieved at this condition. This maximum emission must be used in land use design as well as health effect studies. The wind speed at hub height was obtained from the electric power versus wind speed curve of the wind turbine. This curve was obtained from the operators. The electric power versus national time during the noise emission measurement was obtained from the operators of the wind turbines who were informed about the measurements. The time of sound level meter was also calibrated to the national time. Background noise caused by vegetation prevented the determination of A-weighted SWL for every 1/1-octave band. This is typical for frequency bands 31.5–63 Hz and 4000–8000 Hz, which have, fortunately, almost negligible impact on A-weighted total SWL within 31.5–8000 Hz. Because the 1/1-octave band SWLs were needed for the modeling, a typical spectrum shape of large wind turbines reported by Møller and Pedersen [48] and Danish Ministry of Environment [49] was used at those bands. The SWLs used in the modeling represent the maximum noise emission of all nine turbines. The SWLs exclude the wind and vegetation noise prevailing during the SWL measurements because background noise correction was made.

Modelling of noise exposure at residential areas (immission), i.e., the A-weighted equivalent SPL (L_{Aeq}), was conducted in a similar way as by Hongisto et al. [5] within 31.5–8000 Hz according to the ISO 9613 standard [50]. A commercial calculation software (CadnaA 4.0.135, DataKustik GmbH, Germany) was used. Calculation was conducted using the above mentioned SWLs during the maximum emission condition. The maximum emission takes place less than 10% of time annually in Finland. Despite of this, it is the practice in epidemiological surveys that the noise immission calculations represent this worst-case scenario. The topographical information was downloaded from the open database of the National Land Survey of Finland and further

Table 4
Description of the participants in different *Groups* and in total. SD denotes standard deviation.

	Groups				Total	*p*-value[a]	Categories that differ significantly from Control area[b]
	Control area	[17—25] dB	(25—30] dB	(30—40] dB			
Households identified	498	557	1301	702	3058		
Number of respondents	121	122	282	159	684		
Response rate [%]	24.3	21.9	21.7	22.6	22.4	0.676	
Gender, Female [%]	47.0	66.1	57.9	60.5	58.1	**0.025**	**[17—25] dB**
Age [years]						**0.027**	**[17—25] dB**
Mean (SD)	60 (14)	65 (16)	63 (16)	61 (14)	62 (15)		
Range	20—87	20—89	20—94	19—86	19—94		
Education [%]						**0.012**	**[17—25] dB**
Elementary	8.5	25	17.3	15.8	16.8		
Secondary level degree	43.2	31.7	32.7	45.6	37.4		
Lower tertiary level degree	40.7	32.5	40.6	31.6	37.1		
Higher tertiary level degree or higher	7.6	10.8	9.4	7.0	8.8		
Work situation [%]						**0.025**	**[17—25] dB**
Full time job	34.7	15.8	24.7	31.0	26.4		
Retired	55.9	69.2	63.8	55.7	61.5		
Other	9.3	15.0	11.5	13.3	12.1		
Building type, Block of flats [%]	17.8	67.5	33.8	13.8	32.3	< **0.001**	**[17—25] dB, (25—30] dB**
Building time, After 1990 [%]	21.4	10.8	31.4	21.4	23.6	< **0.001**	**[17—25] dB**
Ownership, Owners [%]	57.6	22.5	47.1	60.4	47.7	< **0.001**	**[17—25] dB**
Community benefit, No [%]	86.6	56.0	61.6	58.7	64.2	< **0.001**	**[17—25] dB, (25—30] dB, (30—40] dB**
***Distance* to nearest wind turbine** [m]						–	
Mean	7450	2120	1771	1411	1811		
Range	6821—7984	1461—2744	1207—2674	866—1834	866—7984		
$L_{Aeq,07\text{-}22,RT}$ [dB]						< **0.001**	**[17—25] dB, (25—30] dB**
Mean (SD)	44.9 (4.8)	47.8 (6.1)	47.6 (6.6)	44.4 (5.2)	46.4 (6.1)		
Range	35.6—53.8	32.9—59.5	34.9—63.5	32.5—60.6	32.5—63.5		
$L_{Aeq,22\text{-}07,RT}$ [dB]						< **0.001**	**[17—25] dB, (25—30] dB**
Mean (SD)	38.0 (4.8)	40.9 (6.1)	40.7 (6.6)	37.5 (5.2)	39.5 (6.1)		
Range	28.7—47.0	26.0—52.6	28.1—56.7	25.6—53.7	25.6—56.7		

[a] *p*-value denotes the significance of the main effect of *Group*.
[b] Shows the *WTSL categories* that differ from Control area in the pairwise comparisons. This is performed only if the main effect of *WTSL categories* is significant.

Table 5
Noise annoyance, stress, and sleep disturbances, and their association with *Groups*. The results are based on binary logistic regression. The *WTSL categories* are compared to the Control area (Ctrl). Variables are explained in Table 2. Significant associations ($p < 0.05$) are marked with bold.

Variable	Comparison	Exp(B)	CI
%A WTN indoors	Ctrl vs. [17–25] dB	2.03	(0.18, 23.20)
	Ctrl vs. (25–30] dB	1.80	(0.20, 16.49)
	Ctrl vs. (30–40] dB	**11.06**	**(1.42, 86.48)**
%A WTN outdoors	Ctrl vs. [17–25] dB	3.13	(0.31, 31.19)
	Ctrl vs. (25–30] dB	2.27	(0.26, 19.89)
	Ctrl vs. (30–40] dB	**10.09**	**(1.29, 79.13)**
%A RTN indoors	**Ctrl vs. [17–25] dB**	**2.06**	**(1.02, 4.15)**
	Ctrl vs. (25–30] dB	0.94	(0.49, 1.80)
	Ctrl vs. (30–40] dB	0.94	(0.45, 1.95)
%A RTN outdoors	Ctrl vs. [17–25] dB	1.96	(0.96, 4.02)
	Ctrl vs. (25–30] dB	1.24	(0.64, 2.39)
	Ctrl vs. (30–40] dB	1.21	(0.58, 2.49)
%Stress (PSS)	Ctrl vs. [17–25] dB	1.16	(0.68, 1.99)
	Ctrl vs. (25–30] dB	1.27	(0.81, 2.01)
	Ctrl vs. (30–40] dB	1.46	(0.88, 2.41)
%SleepD in general	Ctrl vs. [17–25] dB	1.64	(0.88, 3.05)
	Ctrl vs. (25–30] dB	0.95	(0.54, 1.65)
	Ctrl vs. (30–40] dB	1.19	(0.66, 2.15)
%SleepD due to noise	**Ctrl vs. [17–25] dB**	**2.25**	**(1.19, 4.23)**
	Ctrl vs. (25–30] dB	1.40	(0.79, 2.46)
	Ctrl vs. (30–40] dB	1.35	(0.73, 2.51)

Model is controlled for *age*, *gender*, and $L_{Aeq,07\text{-}22,RT}$.

processed in CadnaA. The interval of the contour lines was 2.5 m. Building height were read from National Land Survey laser scanning database at an interior point of each building. The building evaluation function of CadnaA was used to determine the L_{Aeq} for a residential building. Building evaluation is an operation scanning the vertical façades of a building for the maximum SPL falling on it. The highest value on the façade was assigned to all households located in that building. Buildings were modelled as non-reflecting objects and with zero acoustic transparency. The following requirements given by the Finnish Ministry of the Environment [51] were used to provide better agreement with measurements. The ground absorption was 0.4 (mixed porous/hard ground) and 0.0 for water. The values of temperature and relative humidity were set to 15 °C and 70%, respectively. Our results represent well the conditions used in the political decision making because our L_{Aeq} maps were in perfect agreement with the maps created recently by independent Finnish acoustic consultants for the same WT areas.

Wind turbine sound level (WTSL) is described by the A-weighted equivalent SPL, abbreviated by $\boldsymbol{L_{Aeq,WT}}$. It represents the hypothetic condition when all nine wind turbines are operating at maximum power. For further analysis, $\boldsymbol{L_{Aeq,WT}}$ was used to classify the respondents into *WTSL categories*. ***WTSL categories*** are defined in the results.

Road traffic sound level (RTSL) was modelled using the same software and topographical information as above. Calculations were carried out according to the joint Nordic prediction method for road traffic noise [52] embedded in the software. To accomplish the calculations, roads and streets were split into homogenous sections with

Table 6
Symptoms' association with *Groups*. The results are based on binary logistic regression. The *WTSL categories* are compared to the Control area (Ctrl). Variables are explained in Table 2. Significant associations ($p < 0.05$) are marked with bold.

%Symptoms	Comparison	Exp(B)	CI
Migraine or headache including nausea, vomiting, and sensitivity to light and sound	Ctrl vs. [17–25] dB	0.45	(0.16, 1.31)
	Ctrl vs. (25–30] dB	0.85	(0.38, 1.90)
	Ctrl vs. (30–40] dB	0.87	(0.36, 2.11)
Dizziness	Ctrl vs. [17–25] dB	0.82	(0.33, 2.03)
	Ctrl vs. (25–30] dB	0.96	(0.45, 2.05)
	Ctrl vs. (30–40] dB	0.62	(0.25, 1.53)
Ringing, whistling or other sounds in your ears that have no actual source (e.g. tinnitus)	Ctrl vs. [17–25] dB	1.19	(0.59, 2.40)
	Ctrl vs. (25–30] dB	1.24	(0.68, 2.26)
	Ctrl vs. (30–40] dB	0.78	(0.39, 1.58)
Impaired hearing	**Ctrl vs. [17–25] dB**	**2.11**	**(1.00, 4.44)**
	Ctrl vs. (25–30] dB	1.40	(0.70, 2.77)
	Ctrl vs. (30–40] dB	1.07	(0.49, 2.34)
Blocked ears or a sense of pressure in your ears	Ctrl vs. [17–25] dB	0.66	(0.26, 1.63)
	Ctrl vs. (25–30] dB	0.77	(0.36, 1.62)
	Ctrl vs. (30–40] dB	0.97	(0.43, 2.18)
Rash or itchy skin	Ctrl vs. [17–25] dB	1.17	(0.58, 2.38)
	Ctrl vs. (25–30] dB	1.23	(0.68, 2.24)
	Ctrl vs. (30–40] dB	0.93	(0.48, 1.83)
Back pain or backache	Ctrl vs. [17–25] dB	1.18	(0.67, 2.07)
	Ctrl vs. (25–30] dB	1.44	(0.90, 2.31)
	Ctrl vs. (30–40] dB	1.35	(0.80, 2.25)
Regular stomach problems	Ctrl vs. [17–25] dB	1.62	(0.78, 3.39)
	Ctrl vs. (25–30] dB	1.58	(0.83, 3.02)
	Ctrl vs. (30–40] dB	1.36	(0.67, 2.75)
Blurred vision	Ctrl vs. [17–25] dB	1.50	(0.48, 4.74)
	Ctrl vs. (25–30] dB	1.91	(0.70, 5.21)
	Ctrl vs. (30–40] dB	0.87	(0.26, 2.95)
Tachycardia or heart palpitations	Ctrl vs. [17–25] dB	0.97	(0.45, 2.08)
	Ctrl vs. (25–30] dB	1.09	(0.57, 2.09)
	Ctrl vs. (30–40] dB	0.91	(0.44, 1.89)
Problems in concentrating or remembering things	Ctrl vs. [17–25] dB	0.70	(0.35, 1.39)
	Ctrl vs. (25–30] dB	1.11	(0.65, 1.91)
	Ctrl vs. (30–40] dB	1.17	(0.65, 2.11)
Panic attacks or similar sensations	Ctrl vs. [17–25] dB	1.01	(0.21, 4.86)
	Ctrl vs. (25–30] dB	1.08	(0.28, 4.16)
	Ctrl vs. (30–40] dB	1.68	(0.42, 6.73)

Model is controlled for *age*, *gender*, and $L_{Aeq,07\text{-}22,RT}$.

constant traffic density (vehicles/hour) and speed limit. Each section was fed separately into the program. The percentage of heavy vehicles was given, as well as a separate speed limit for heavy traffic where applicable. The traffic counts used were averages over entire week and all seasons (i.e., full year averages). The counts and percentages of heavy vehicles were obtained from Finnish Transport Infrastructure Agency and were based on year 2016 traffic census. The daily traffic counts were divided into daytime (07–19), evening (19–22), and nighttime (22–07) hours using the recommendation of the data provider. This recommendation divides the traffic counts values so that the 78% is allocated to daytime, and 11% for both evening and nighttime. The road and street surfaces were asphalt throughout. The modeling was conducted without studded tires as the survey was conducted in autumn.

All SPLs of our study are valid only outdoors. Indoor SPLs were not measured nor predicted since the variation of façade sound insulation is extremely large in Finland as shown by the sound insulation survey of Keränen et al. [53]. Determination of indoor SPLs would require the measurement of every respondent's façade, which is not feasible. **RTSL** is expressed by the A-weighted equivalent SPL caused by road traffic noise during daytime and evening hours, abbreviated by $\boldsymbol{L_{Aeq,07\text{-}22,RT}}$. It is a continuous variable. Nighttime levels, i.e., $\boldsymbol{L_{Aeq,22\text{-}07,RT}}$, were calculated and reported in Table 4 for different *WTSL categories*, but were not used in other the analyses. $L_{Aeq,07\text{-}22,RT}$ was further categorized into variable ***RTSL category*** and is defined in the results.

2.7. Statistical analyses

The statistical analyses were performed with IBM SPSS version 25 (Armonk, NY, USA). The limit of significance was $p < 0.05$.

For the respondents, the *Groups* were compared with χ^2 -test for categorical and ANOVA for continuous variables. If the main effect of *Group* was significant, Control area was compared with *WTSL categories*. For categorical variables, this was performed using the pairwise comparisons for each pair with Benjamini-Hochberg correction. For continuous variables, the comparison between Control area and *WTSL categories* was performed with contrasts. For χ^2 -test the effect size was marked with Cramer's V and for ANOVA with η^2.

Since *WTN annoyance indoors* and outdoors and *RTN annoyance indoors* and outdoors were not normally distributed, Wilcoxon Signed Ranks Test was used with *r* as effect size measure ($r = Z{\cdot}N^{-0.5}$).

Binary logistic regression analyses were performed to examine the relation between environmental noise exposure and health variables. It gives an estimate of the relationship between independent variables and a dichotomous dependent variable. Exponentiated logistic coefficient Exp(B) reflects the changes in odds when the independent variable changes one unit. A 95% confidence interval (CI) reflects the statistical significance of this relationship. If Exp(B) is above 1.00 and CI's lower value is also above 1.00, the relationship is positive, i.e., the increase in independent variable increases the odds of belonging to the predicted group of the dependent variable. If Exp(B) is below 1.00 and the higher value of CI is also below 1.00, the relationship is negative, i.e., the increase in independent variable decreases the odds of belonging to the predicted group of dependent variable. In other cases, the relationship is not significant. The dichotomous health variables are described in Table 2 and marked with %, which denotes percentage.

The prevalence of self-reported health variables between Control area and *WTSL categories* was tested with a model adjusted for *age*, *gender,* and road traffic noise exposure $L_{Aeq,07\text{-}22,RT}$. $L_{Aeq,07\text{-}22,RT}$ was included since the *Groups* differed in the exposure to road traffic noise. The same examination with only *age* and *gender* as effect modifiers can be found in Supplementary material 1.

To further examine the health effects related to $L_{Aeq,WT}$ and $L_{Aeq,07\text{-}22,RT}$, a logistic regression analysis was performed with both $L_{Aeq,WT}$ and $L_{Aeq,07\text{-}22,RT}$ as continuous variables and adjusted for *age* and *gender*. $L_{Aeq,WT}$ values were not associated to the Control area since the wind turbines were inaudible. Therefore, the number of respondents in this part of the study was 558. The multicollinearity of the independent variables ($L_{Aeq,WT}$, $L_{Aeq,07\text{-}22,RT}$, *age*, and *gender*) was estimated with linear regression analysis between the independent variables and the variance inflation factor (VIF) was <2 in all variable combinations. The conservative cutoff value for acceptable VIF is < 3 [54]. Therefore, there is no multicollinearity between the independent variables.

3. Results

3.1. Background examination

3.1.1. Noise exposure of the respondents

From the 3058 questionnaires sent, 684 answers were received. Therefore, the response rate was 22.4%.

$L_{Aeq,WT}$ of the respondents ranged from 17.3 to 39.2 dB in WT area. These values were used to divide the respondents into *Groups*: Control area, and *WTSL categories* [17—25) dB, [25—30) dB, and [30—40] dB (Fig. S2 in Supplementary material 1). The division was made using unequal decibel ranges to ensure a more balanced number of residents in each *WTSL category*. Because our purpose is not to determine the exposure−response relationship, unequal ranges are not causing a problem. The response rate did not differ in these G*roups* ($\chi^2(3) = 1.53$, $p = 0.676$, $V = 0.022$) (Table 4).

$L_{Aeq,07\text{-}22,RT}$ ranged from 32.5 to 63.5 dB (Table 4). $L_{Aeq,07\text{-}22,RT}$ was categorized into variable *RTSL category* with the following categories: [32—40] dB, (40—45] dB, (45—50] dB, (50—55] dB, (55—64] dB (Fig. S3 in Supplementary material 1). The comparison of respondents and non-respondents is presented in Supplementary material 1.

$L_{Aeq,WT}$ of the respondents in the Control area was on average 15 dB which is inaudible. In general, WTSLs under 20 dB cannot be distinguished during windy weather because of the masking noise caused by wind and vegetation.

3.1.2. Comparison of groups

Eight respondents returned questionnaires with only partial or inconsistent answers and these participants were removed from further examination. Therefore, the final number of respondents was **676**. The descriptive variables from the respondents in the Control area and in different *WTSL categories* was tested to examine the differences between the *Groups* (Table 4). The influence of *Group* was significant in all these descriptive variables except response rate. However, only one descriptive variable showed a difference and it occurred between Control area and the *WTSL category* (30–40] dB: community benefit ($\chi^2(3) = 30.7$, $p < 0.001$, $V = 0.22$). Respondents living near wind turbines considered they benefited more from wind turbines than respondents living in the Control area did. Personal benefit was also asked, but less than 15 respondents reported gaining personal financial benefit from wind turbines, so this variable was not further analyzed. The exact number cannot be given due to ethical reasons. The *%SleepD factors* and *Groups* was examined and is reported in Supplementary Material Table S1.

3.1.3. Noise annoyance

Since our main interest was to study the health effects related to both wind turbine and road traffic sound levels, the relation between wind turbine noise annoyance and *WTSL category* as well as road traffic noise annoyance and *RTSL category* was further examined (Fig. 2). Wind turbine noise annoyance was the highest in the category (30—40] dB: *%A WTN indoors* was 8.2% and *%A WTN outdoors* was 7.7%. It is notable that Fig. 2 suggests that the prevalence of annoyance was at the same level both indoors and outdoors. However, statistical tests revealed that this was not the case. When examining *WTN annoyance indoors* and *outdoors*, participants rated the *WTN annoyance outdoors* higher than *WTN annoyance indoors* ($Z = -3.8$, $p < 0.001$, $r = -0.164$). In 52 cases annoyance outdoors was rated higher and in 19 cases lower than annoyance indoors. For the highest *RTSL category* (55—64] dB, *%A RTN outdoors* and *%A RTN indoors* were 38.1% and 33.3%, respectively. For

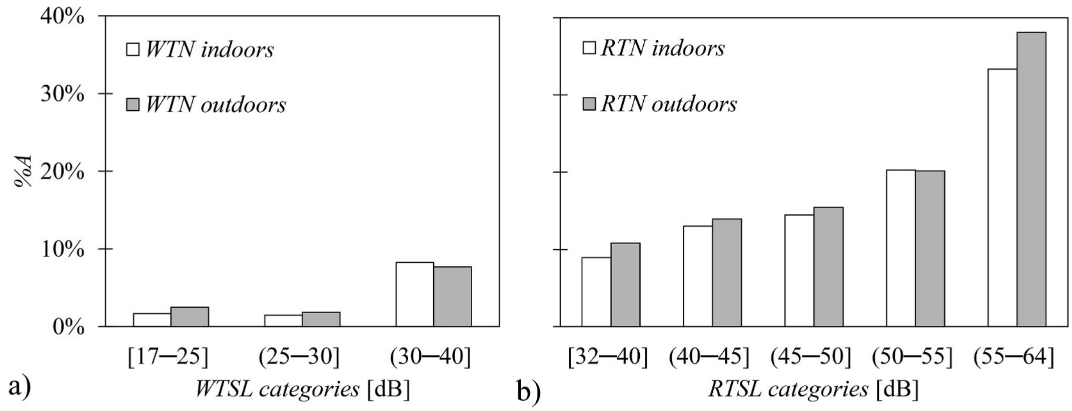

Fig. 2. Proportion of annoyed respondents (%A) as a function of (a) WTSL category and (b) *RTSL category*, which describe the sound level outside respondents' homes.

RTN annoyance indoors and outdoors, participants rated the *RTN annoyance outdoors* higher than indoors ($Z = -4.1$, $p < 0.001$, $r = -0.158$). In 166 cases, annoyance outdoors was rated higher and in 89 cases lower than annoyance indoors. The annoyance distributions are presented in detail in Tables S2–S6 in Supplementary material 1.

3.2. Comparison of WTSL categories to control area

Table 5 examines the most common health effects connected with environmental noise: annoyance, stress, and sleep difficulties. The *WTSL category* (30—40] dB had more respondents who were annoyed by wind turbine noise indoors (*%A WTN indoors*) than the Control area ($p = 0.022$). The odds of being annoyed by wind turbine noise indoors was 11.1 times higher in the *WTSL category* (30—40] dB than in the Control area. The *WTSL category* [17—25] dB was related to higher odds of disturbed sleep due to noise (*%SleepD due to noise*) than the Control area ($p = 0.012$). The *WTSL category* [17—25] dB differed also from the Control area in road traffic noise annoyance indoors (*%A RTN indoors*), which means that respondents belonging to this category had higher odds of being annoyed by road traffic noise indoors than respondents in the Control area ($p = 0.044$). Table 6 examines symptoms and Table 7 examines diseases. Table 6 shows that the only significant difference is the higher odds of *impaired hearing* in the *WTSL category* [17—25] dB than in the Control area ($p = 0.049$). Prevalence of diseases showed no significant differences between the Control area and the three *WTSL categories*.

3.3. Health effects related to wind turbine sound level and road traffic sound level

The influence of $L_{Aeq,WT}$ and $L_{Aeq,07\text{-}22,RT}$ on self-rated health in the WT area was examined (Tables 8–10). The Control area was not included in the analysis, since the wind turbine noise was inaudible there. $L_{Aeq,WT}$ and $L_{Aeq,07\text{-}22,RT}$ were continuous variables. *Age* and *gender* were effect modifiers. Likewise for the comparison of the *WTSL categories* and the Control area, increasing $L_{Aeq,WT}$ increased the probability of being annoyed by wind turbine noise indoors (*%A WTN indoors*, $p = 0.021$) and outdoors (*%A WTN outdoors*, $p = 0.034$) (Table 8). Increasing $L_{Aeq,WT}$ decreased the probability of being annoyed by road traffic noise indoors (*%A RTN indoors*, $p < 0.001$) and outdoors (*%A RTN outdoors*, $p < 0.001$). For example, the increment of $L_{Aeq,WT}$ by 1 dB increased the odds of being annoyed by wind turbine noise indoors by 21% (i.e., probability of reporting 5 or more to *WTN annoyance indoors* question) and decreased the odds of being annoyed by road traffic noise indoors by 14%. In addition, increasing $L_{Aeq,WT}$ decreased the odds of experiencing sleep difficulties due to noise (*%SD due to noise*, $p = 0.020$) (Table 8).

Increasing $L_{Aeq,07\text{-}22,RT}$ increased the odds of being annoyed by road traffic noise indoors (*%A RTN indoors*, $p < 0.001$) and outdoors (*%A RTN outdoors*, $p < 0.001$) (Table 8). $L_{Aeq,07\text{-}22,RT}$ was statistically significantly associated with the prevalence of many symptoms and diseases unlike $L_{Aeq,WT}$. Increasing $L_{Aeq,07\text{-}22,RT}$ showed increasing odds for migraine or headache ($p < 0.001$), dizziness ($p = 0.015$), impaired hearing ($p = 0.035$), blocked ears and sense of pressure in ears ($p = 0.021$) and tachycardia or heart palpitations ($p = 0.044$) (Table 9).

Increasing $L_{Aeq,07\text{-}22,RT}$ showed increasing odds for heart disease ($p = 0.029$) but not any other inquired chronic disease (Table 10).

4. Discussion

4.1. General summary

Our study examined the self-reported health effects associated with the sound levels of wind turbine noise and road traffic noise close to a wind turbine area, where the wind turbine sound level meets the current national design policy according to which wind turbine noise exposure shall not exceed 40 dB L_{Aeq} during daytime or nighttime in residential yard (see Sec. 1). In this respect, the WT areas of the current study represent a modern Finnish wind turbine area, which meets the regulated sound levels.

Wind turbine noise exposure increased the odds of being annoyed by wind turbine noise, since respondents in *WTSL category* (30—40] dB more likely reported annoyance of wind turbine noise (*%A WTN indoors* and *%A WTN outdoors*) than respondents in the Control area and $L_{Aeq,WT}$ was positively associated with the same variables. This agrees with our expectations based on previous literature [1,2]. However, the *WTSL category* [17—25] dB differed from the Control area in the probability of road traffic annoyance indoors (*%A RTN indoors*) and sleep difficulties due to noise (*%SleepD due to noise*). Increase in $L_{Aeq,WT}$ was related to decreased probability of road traffic annoyance indoors (*%A RTN indoors*) and sleep difficulties due to noise (*%SleepD due to noise*). This means that the odds of being annoyed by road traffic noise were higher when people lived farther from the wind turbines and they more likely reported sleep difficulties due to environmental noise. However, it seems that noise causing sleep difficulties was not road traffic noise, since the relation between $L_{Aeq,07\text{-}22,RT}$ and *%SleepD due to noise* was not significant (Table 8). These differences between Control area and *WTSL category* [17—25] dB were most likely not due to wind turbine noise, but related to other factors, such as other nighttime activities in town center. Respondents in this area reported, for example, that the sound of motorcycles and mopeds often annoyed them (Table S1). Therefore, the only health effect related to wind turbine noise exposure was the elevated odds for wind turbine noise annoyance both indoors and outdoors.

Contrary to this, $L_{Aeq,07\text{-}22,RT}$ was associated with the raised

Table 7
Chronic diseases association with *Groups*. The results are based on binary logistic regression. The *WTSL categories* are compared to the Control area (Ctrl). Variables are explained in Table 2. Significant associations ($p < 0.05$) did not exist.

%Diseases	Comparison	Exp(B)	CI
Chronic pain	Ctrl vs. [17—25] dB	1.18	(0.67, 2.07)
	Ctrl vs. (25—30] dB	1.10	(0.68, 1.77)
	Ctrl vs. (30—40] dB	1.21	(0.72, 2.04)
Asthma	Ctrl vs. [17—25] dB	0.80	(0.36, 1.76)
	Ctrl vs. (25—30] dB	0.85	(0.44, 1.66)
	Ctrl vs. (30—40] dB	0.82	(0.39, 1.73)
Joint inflammation	Ctrl vs. [17—25] dB	1.14	(0.63, 2.06)
	Ctrl vs. (25—30] dB	0.93	(0.56, 1.56)
	Ctrl vs. (30—40] dB	1.16	(0.67, 2.03)
Cancer	Ctrl vs. [17—25] dB	0.67	(0.21, 2.07)
	Ctrl vs. (25—30] dB	0.90	(0.35, 2.30)
	Ctrl vs. (30—40] dB	0.45	(0.14, 1.48)
Depression	Ctrl vs. [17—25] dB	0.89	(0.44, 1.81)
	Ctrl vs. (25—30] dB	0.77	(0.42, 1.40)
	Ctrl vs. (30—40] dB	0.95	(0.50, 1.81)
Elevated blood pressure	Ctrl vs. [17—25] dB	1.73	(0.97, 3.07)
	Ctrl vs. (25—30] dB	1.57	(0.96, 2.57)
	Ctrl vs. (30—40] dB	1.39	(0.81, 2.38)
Bronchitis, pulmonary emphysema or chronic obstructive pulmonary disease	Ctrl vs. [17—25] dB	0.95	(0.37, 2.42)
	Ctrl vs. (25—30] dB	1.31	(0.61, 2.83)
	Ctrl vs. (30—40] dB	1.12	(0.48, 2.60)
Diabetes	Ctrl vs. [17—25] dB	1.08	(0.52, 2.24)
	Ctrl vs. (25—30] dB	0.57	(0.29, 1.11)
	Ctrl vs. (30—40] dB	0.61	(0.29, 1.29)
Heart disease	Ctrl vs. [17—25] dB	0.50	(0.21, 1.17)
	Ctrl vs. (25—30] dB	0.55	(0.27, 1.14)
	Ctrl vs. (30—40] dB	0.84	(0.38, 1.82)
Sleep problems, including sleep apnea and insomnia	Ctrl vs. [17—25] dB	1.58	(0.92, 2.70)
	Ctrl vs. (25—30] dB	1.03	(0.65, 1.62)
	Ctrl vs. (30—40] dB	1.37	(0.84, 2.24)
Restless legs syndrome	Ctrl vs. [17—25] dB	1.70	(0.90, 3.21)
	Ctrl vs. (25—30] dB	1.09	(0.62, 1.93)
	Ctrl vs. (30—40] dB	0.91	(0.48, 1.71)

Model is controlled for *age*, *gender*, and $L_{\text{Aeq,07-22,RT}}$.

probability of many different health effects. Increase in $L_{\text{Aeq,07-22,RT}}$ increased the odds of being annoyed by road traffic noise indoors and outdoors, reporting migraine or headache, dizziness, impaired hearing, blocked ears or feeling pressure in the ears, tachycardia or heart palpitations, and heart disease. Different maximum values of $L_{\text{Aeq,WT}}$ and $L_{\text{Aeq,07-22,RT}}$ can partly explain these results: the maximum values were 39.2 dB for $L_{\text{Aeq,WT}}$ and 63.5 dB for $L_{\text{Aeq,07-22,RT}}$. However, the noise exposures of our study represent the general noise exposure in wind turbine areas very well. Therefore, our finding benefits those who want to understand the total or aggregate risks of all noise sources on public health around wind turbine areas. The exposure to wind turbine noise in such levels, which meet the national regulations set for wind turbine noise, was not related to other health effects than noise annoyance, whereas road traffic noise exposure could be related to several health effects. It should be noted that the $L_{\text{Aeq,07-22,RT}}$ exceeded the Finnish regulated limit of 55 dB $L_{\text{Aeq,07-22}}$ outside many residential buildings of our study areas [14]. The limit concerns the yard and the balcony of residential houses. This is a general situation in Finland: almost 600.000 people were exposed to road traffic sound level equal to or above 55 dB L_{den} in 2017 [55]. For most roads, L_{den} is a couple of decibels higher than $L_{\text{Aeq,07-22,RT}}$. Our study shows that noise exposure caused by wind energy is much better controlled than the noise exposure of road traffic at least in this specific area. It is expected that the situation is the same also around other wind turbine areas in Finland where road traffic noise is present.

An important difference between road traffic and wind turbine noise is that road traffic noise diminishes during the night and is the highest in the morning and afternoon, while wind turbine sound depends on the wind speed and is not constant. However, during the night, wind turbine sound might be the only sound heard. Therefore, the direct comparison of road traffic sound levels and wind turbine sound levels is not justified when annoyance effects are assessed. However, Fig. 2 shows that annoyance ratings seem not to be clearly influenced by the characteristic difference.

Table 8
Association between noise annoyance, stress, and sleep disturbance with continuous sound level variables $L_{\text{Aeq,WT}}$ and $L_{\text{Aeq,07-22,RT}}$. The results are based on binary logistic regression. Variables are explained in Table 2. Significant associations ($p < 0.05$) are marked with bold.

Variable	$L_{\text{Aeq,WT}}$		$L_{\text{Aeq,07-22,RT}}$	
	Exp(B)	CI	Exp(B)	CI
%A WTN indoors	**1.21**	**(1.04, 1.40)**	0.97	(0.90, 1.06)
%A WTN outdoors	**1.16**	**(1.01, 1.33)**	0.98	(0.91, 1.06)
%A RTN indoors	**0.86**	**(0.81, 0.93)**	**1.07**	**(1.03, 1.11)**
%A RTN outdoors	**0.87**	**(0.82, 0.94)**	**1.07**	**(1.03, 1.11)**
%Stress (PSS)	1.02	(0.97, 1.07)	0.99	(0.96, 1.02)
%SleepD in general	0.96	(0.90, 1.01)	1.01	(0.97, 1.04)
%SleepD due to noise	**0.94**	**(0.89, 0.99)**	1.01	(0.98, 1.04)

Model included $\boldsymbol{L_{\text{Aeq,WT}}}$, $\boldsymbol{L_{\text{Aeq,07-22,RT}}}$, *age*, and *gender*.

Our study suggests that very little improvements can be obtained in public health if wind turbine noise is controlled more than nowadays. Instead, our study suggests that public health improves if road traffic noise exposure is reduced. Our estimation is that attention should be paid to road traffic noise control especially when 55 dB $L_{\text{Aeq,07-22,RT}}$ is exceeded in the residential yards.

4.2. Wind turbine noise

Our result regarding wind turbine noise exposure's association with

Table 9
Association between the prevalence of symptoms and continuous sound level variables $L_{Aeq,WT}$ and $L_{Aeq,07\text{-}22,RT}$. The results are based on binary logistic regression. Variables are explained in Table 2. Significant associations ($p < 0.05$) are marked with bold.

%Symptoms	$L_{Aeq,WT}$		$L_{Aeq,07\text{-}22,RT}$	
	Exp(B)	CI	Exp(B)	CI
Migraine or headache including nausea, vomiting, and sensitivity to light and sound	1.06	(0.96, 1.18)	**1.12**	**(1.06, 1.18)**
Dizziness	0.97	(0.89, 1.06)	**1.06**	**(1.01, 1.11)**
Ringing, whistling or other sounds in your ears that have no actual source (e.g. tinnitus)	0.97	(0.91, 1.03)	1.01	(0.97, 1.04)
Impaired hearing	0.94	(0.88, 1.00)	**1.04**	**(1.00, 1.08)**
Blocked ears or a sense of pressure in your ears	1.04	(0.95, 1.14)	**1.05**	**(1.01, 1.10)**
Rash or itchy skin	0.97	(0.91, 1.03)	0.99	(0.95, 1.02)
Back pain or backache	1.01	(0.96, 1.06)	1.02	(0.99, 1.05)
Regular stomach problems	0.97	(0.91, 1.03)	1.01	(0.97, 1.04)
Blurred vision	0.92	(0.84, 1.01)	1.02	(0.97, 1.07)
Tachycardia or heart palpitations	0.99	(0.92, 1.06)	**1.04**	**(1.00, 1.08)**
Problems in concentrating or remembering things	1.06	(1.00, 1.13)	1.01	(0.98, 1.05)
Panic attacks or similar sensations	0.98	(0.85, 1.12)	1.07	(1.00, 1.14)

Model included $\boldsymbol{L_{Aeq,WT}}$, $\boldsymbol{L_{Aeq,07\text{-}22}}$, *age,* and *gender.*

Table 10
Association between the prevalence of chronic diseases and continuous noise exposure variables $L_{Aeq,WT}$ and $L_{Aeq,07\text{-}22,RT}$. The results are based on binary logistic regression. Variables are explained in Table 2. The significant association ($p < 0.05$) is marked with bold.

%Diseases	$L_{Aeq,WT}$		$L_{Aeq,07\text{-}22,RT}$	
	Exp(B)	CI	Exp(B)	CI
Chronic pain	0.99	(0.94, 1.04)	1.00	(0.97, 1.03)
Asthma	0.99	(0.92, 1.06)	1.01	(0.97, 1.06)
Joint inflammation	0.99	(0.94, 1.05)	1.00	(0.97, 1.03)
Cancer	0.93	(0.84, 1.03)	0.97	(0.91, 1.03)
Depression	0.99	(0.92, 1.06)	1.03	(0.99, 1.07)
Elevated blood pressure	0.98	(0.93, 1.03)	1.01	(0.98, 1.04)
Bronchitis, pulmonary emphysema or chronic obstructive pulmonary disease	1.00	(0.92, 1.08)	0.97	(0.93, 1.02)
Diabetes	0.93	(0.87, 1.00)	0.97	(0.93, 1.01)
Heart disease	1.03	(0.95, 1.12)	**1.05**	**(1.00, 1.09)**
Sleep problems, including sleep apnea and insomnia	0.97	(0.92, 1.02)	0.99	(0.96, 1.01)
Restless legs syndrome	0.95	(0.89, 1.00)	1.00	(0.97, 1.03)

Model included $\boldsymbol{L_{Aeq,WT}}$, $\boldsymbol{L_{Aeq,07\text{-}22,RT}}$, *age,* and *gender.*

health effects is in line with epidemiological studies, which conclude that the only clear relation is found between wind turbine sound level and annoyance, while the relation with other self-reported health effects is non-existing or less clear [1,2]. In these studies, the maximum exposures to wind turbine noise were higher than in our study. For example, Michaud et al., [1] got 234 responses from wind turbine noise category [40–46] dB. In Finland, very few people are exposed to levels higher than 40 dB L_{Aeq}. For example, [5] conducted a survey in three Finnish WT areas known to involve households exposed to levels higher than 40 dB $L_{Aeq,WT}$. However, the number of such yards was only 35, when also free-time residences were included. Besides annoyance, self-reported sleep disturbances are sometimes related to wind turbine noise exposure, but usually at higher levels than in our study. For example, sleep disturbances due to noise were related to wind turbine noise sound levels above 35 dB L_{Aeq} [3] or general sleep disturbances to wind turbine noise sound levels above 40 dB L_{Aeq} [25,33]. However, Michaud et al. [27] found no association between wind turbine noise exposure and subjectively estimated or objectively measured sleep disturbances. In our study, the frequency of the self-reported sleep difficulty did not differ between the Control area and the *WTSL categories*, when asked to rate sleep disturbances in general. However, when asking sleep difficulties due to environmental noise, the WTSL category [17—25] dB differed from the Control area and the probability of reporting sleep difficulties due to noise deceased with increasing $L_{Aeq,WT}$. This noise disturbance seemed to arise from other sources as people belonging to the WTSL category [17—25] dB reported more often that their sleep was more disturbed by motorcycles and mopeds and by other sounds typical for the area than people from the other *WTSL categories* (Table S1). Therefore, our study did not show an influence of wind turbine noise exposure on sleep disturbance (*%SleepD in general* or *%SleepD due to noise)*.

The perceived stress did not differ between the *WTSL categories* and the Control area nor was there a significant relation between $L_{Aeq,WT}$ and stress (*%Stress)*. An earlier study found no association between wind turbine noise exposure and stress using the same perceived stress scale PSS as in our study and using objective measures of stress including hair cortisol analysis, heart rate, and blood pressure [26]. Therefore, our study was in accordance with their findings. WHO recommends the wind turbine sound level to be below 45 dB L_{den} (World Health Organization, 2018). This corresponds to 38.6 dB $L_{Aeq,24h}$ if the sound emission is constant 24 h a day. 40 dB L_{Aeq} is the nightime limit according to Finnish regulations for wind turbine sound level [7]. In our study, the $L_{Aeq,WT}$ was below that in all residential yards. Wind turbine noise exposure in our study represents the situation nearby wind turbine areas in Finland very well, since the exposure is in accordance with national regulations. Further, our study shows that wind turbine noise does not cause other health effects than noise annoyance at these sound levels. Therefore, our work represents the state of the art in wind turbine areas where tight regulations for wind turbine noise, which are increasingly set in many countries, are already obeyed.

It should be noted that even though no association between wind turbine noise exposure and symptoms were found in our study, there can be people, who intuitively associate their symptoms to wind turbine noise [12,56], but this approach is outside the scope of this study.

4.3. Road traffic noise

$L_{Aeq,07\text{-}22,RT}$ was associated with multiple self-reported health effects. The reason for finding such effects is that $L_{Aeq,07\text{-}22,RT}$ ranged from 32 to 64 dB while $L_{Aeq,WT}$ ranged from 17 to 40 dB. The probability of reporting heart disease and tachycardia or heart palpitations rose when $L_{Aeq,07\text{-}22,RT}$ increased, which is in line with road traffic sound level's association with the increased risk of ischemic heart disease [34] and cardiovascular disease in general [19]. However, our study did not show an association between hypertension and $L_{Aeq,07\text{-}22,RT}$. Hypertension is a cardiovascular disease and a meta-analysis examining 27 studies suggested an association between road traffic sound level and hypertension [35] and an association between subjective reports on hypertension and road traffic sound level has been reported as well [57]. However, the subjective reports in our study and Bluhm et al. [57] were different; they asked for the existence of hypertension diagnosis by a physician during past five years, whereas our questionnaire asked the experience of elevated blood pressure during past 12 months (see Supplementary material 2). Therefore, our finding is not necessarily in disagreement with the abovementioned studies.

No association between $L_{Aeq,07\text{-}22,RT}$ and depression was found. Earlier studies have suggested a connection between road traffic noise and depression in a 5-year follow-up study [39], as well as in a case-control study [40].

The relation between road traffic sound level and self-reported sleep disturbance has been suggested to appear, when the sleep question refers to noise [37], but our results did not confirm that.

The direct effects of noise can be related to different auditory effects, like hearing loss and tinnitus. Our study showed that increased $L_{Aeq,07\text{-}22,RT}$ was associated with experiences such as impaired hearing and sense of pressure in ears. In general, long term exposure with SPLs higher than 75–85 dB are thought to cause noise-induced hearing loss [18]. Therefore, our result was unexpected and must be considered with reservations.

In addition, our study showed an association between $L_{Aeq,07\text{-}22,RT}$ and symptoms of migraine, or headache, and dizziness. So far, only few studies have reported a relation between road traffic noise and migraine or headache. Öhström et al. [58] examined the connection between road traffic noise exposure and the stress related effects, including headache, sadness and depression, and stomach discomfort. They found no difference between different road traffic noise sound level categories, but found a connection with more general stress related symptoms, like annoyance, sleep disturbance, tiredness, feeling stressed or irritated, and angry. Feeling stressed, irritated, and angry were not separately asked in our questionnaire, but Perceived Stress Scale (PSS) contained questions on these, and it showed no association with $L_{Aeq,07\text{-}22,RT}$.

4.4. Strengths and limitations

This epidemiological study has many strengths: the inclusion of a modern WT area involving large 2–3 MW wind turbines, agreement of tightened wind turbine noise regulations among the whole population in the area, inclusion of a control area, masked questionnaire, and the inclusion of both wind turbine and road traffic sound levels outdoors. For public health research, focusing only on wind turbine noise would be a limitation since road traffic is the dominant noise source around many wind turbine areas: wind turbines are usually built close to existing infrastructures. Therefore, to set the wind turbine noise into right perspective, it was very important to examine also road traffic noise stressor simultaneously. In addition, the respondents from the Control area were very similar to the respondents in the *WTSL category* with the highest wind turbine sound level, which strengthens our conclusions.

The limitation is the low response rate, which is most likely caused by long questionnaire asking sensitive questions about one's health and personal life. A second reason may be that residents were satisfied with their residential area and the appearance of this questionnaire did serve as an important means to express concerns. To increase the response rate both a reminder and a lottery were used. Another limitation is that the respondents were slightly older than the whole sample. However, also generally the municipality in our sample has a larger proportion of people over 65 year old (29% in year 2019) than is the average in whole Finland (22%) [59]. This might mean that the effects found can describe better older population.

Another limitation, or statistical inconvenience, is that only ten respondents were exposed to SPLs above 35 dB $L_{Aeq,WT}$. The response rate sample was 22.6% within 35–40 dB, which is similar to the response rate of the whole sample (22.4%). That is, most respondents were exposed to SPLs below 35 dB $L_{Aeq,WT}$. However, this is the situation in most wind turbine areas in Finland.

The socioeconomic status was not directly asked from the respondents to avoid the collapse of response rate, but the education level and work situation were asked. Only the lowest WTSL category [17—25] dB differed in these variables from the Control area. This shows that, with these measures, the other *WTSL categories* might be comparable to the Control area.

5. Conclusions

A major epidemiological health survey was conducted which applied the case-control design to study the health effects of both wind turbine noise and road traffic noise. The case group involved residents who lived close to a wind turbine area. Wind turbine noise outdoors met the tightened noise regulations being under 40 dB L_{Aeq} among the whole population. The control group was located farther away from wind turbines. Increased wind turbine noise level was associated with an increased probability of noise annoyance, but no other associations with health effects were found. However, increased road traffic noise level was associated with an increased probability of various self-reported health effects, for example, heart disease and related symptoms, road traffic noise annoyance, and different stress related symptoms like, migraine, headache, and dizziness as well as ear related problems of impaired hearing and blocked ears or pressure in ears. These associations were found although the sound level of road traffic noise was only moderate (under 65 dB L_{Aeq} during daytime from 07 to 22). The findings of our study are expected to be applicable also to other wind turbine areas, where wind turbine sound level is under 40 dB among the whole population. If this sound level is met, it seems to be more important to control road traffic noise in these residential areas. Previous epidemiological field studies have not found other health effects related to wind turbine sound level than annoyance and sleep disturbance. Our results suggest that when the level of wind turbine noise is under 40 dB L_{Aeq}, noise annoyance is the only health effect and the prevalence of annoyance is very low. Our results provide very important evidence for wind energy policy developers since noise is among the most usual factors that reduce the social acceptability of wind turbines. Our study is the first epidemiological case-control study, which was conducted in a wind turbine area where all residents were protected by new noise regulations. Further research is still warranted since the health effect studies among wind turbines are still rare compared to many other sources of environmental noise.

Credit author statement

Jenni Radun: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review and editing, Visualization; Henna Maula: Conceptualization, Methodology, Investigation, Data curation, Writing - review and editing; Jukka Keränen: Methodology, Validation, Formal analysis, Writing - review and editing; Pekka Saarinen: Methodology, Validation, Formal analysis, Writing review and editing; Visualization; Reijo Alakoivu: Investigation, Writing - review and editing; Valtteri Hongisto: Conceptualization, Methodology, Resources, Writing - review and editing, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rser.2021.112040.

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Supplementary material 1: Health effects of wind turbine noise and road traffic noise on people living near wind turbines

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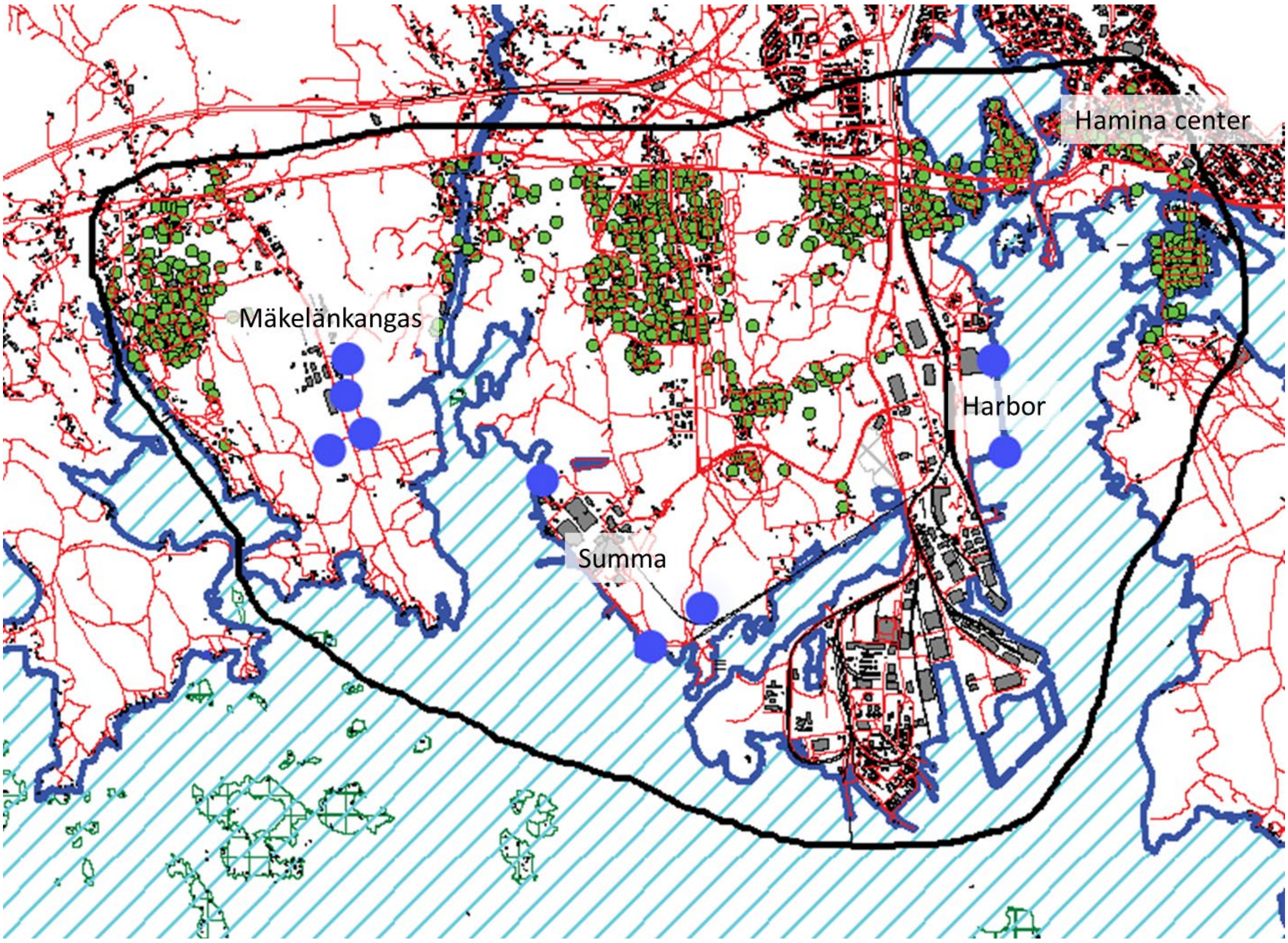

Fig. S1. A map of the WT area including nine wind turbines. All nine turbines are located in the city of Hamina locating in the South-Eastern coast of Finland. Wind turbines are marked with blue dots. Green dots represent the residential buildings, where the questionnaire was sent. Roads are marked with red lines. Black contour line defines the WT area. The topographical information was downloaded from the open database of the National Land Survey of Finland and further processed in CadnaA 4.0.135.

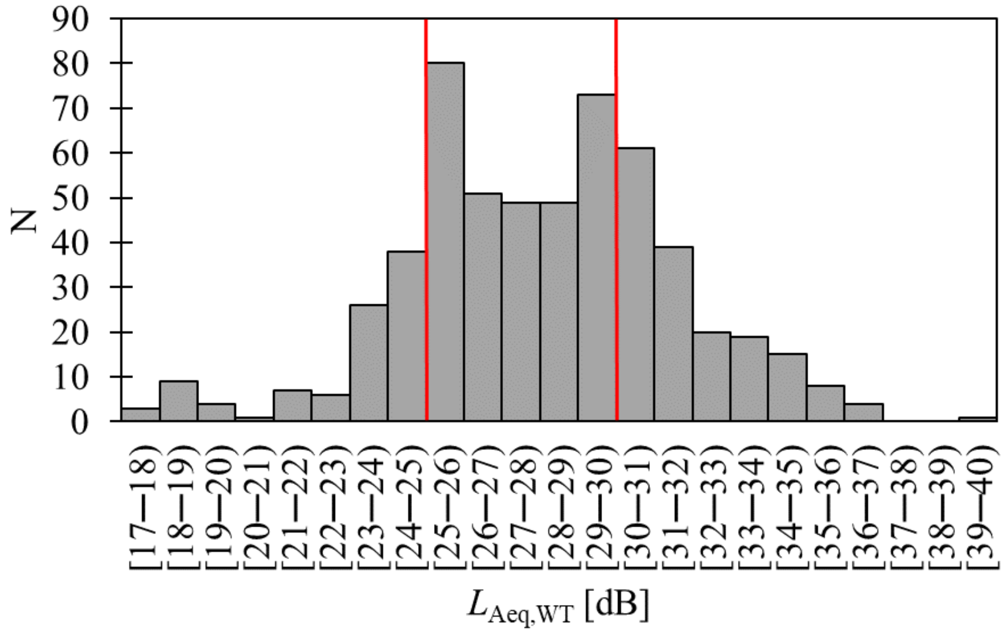

Fig. S2. The number of participants per 1-dB category of $L_{Aeq,WT}$. Vertical lines show the division into three *WTSL categories* used in the statistical analyses.

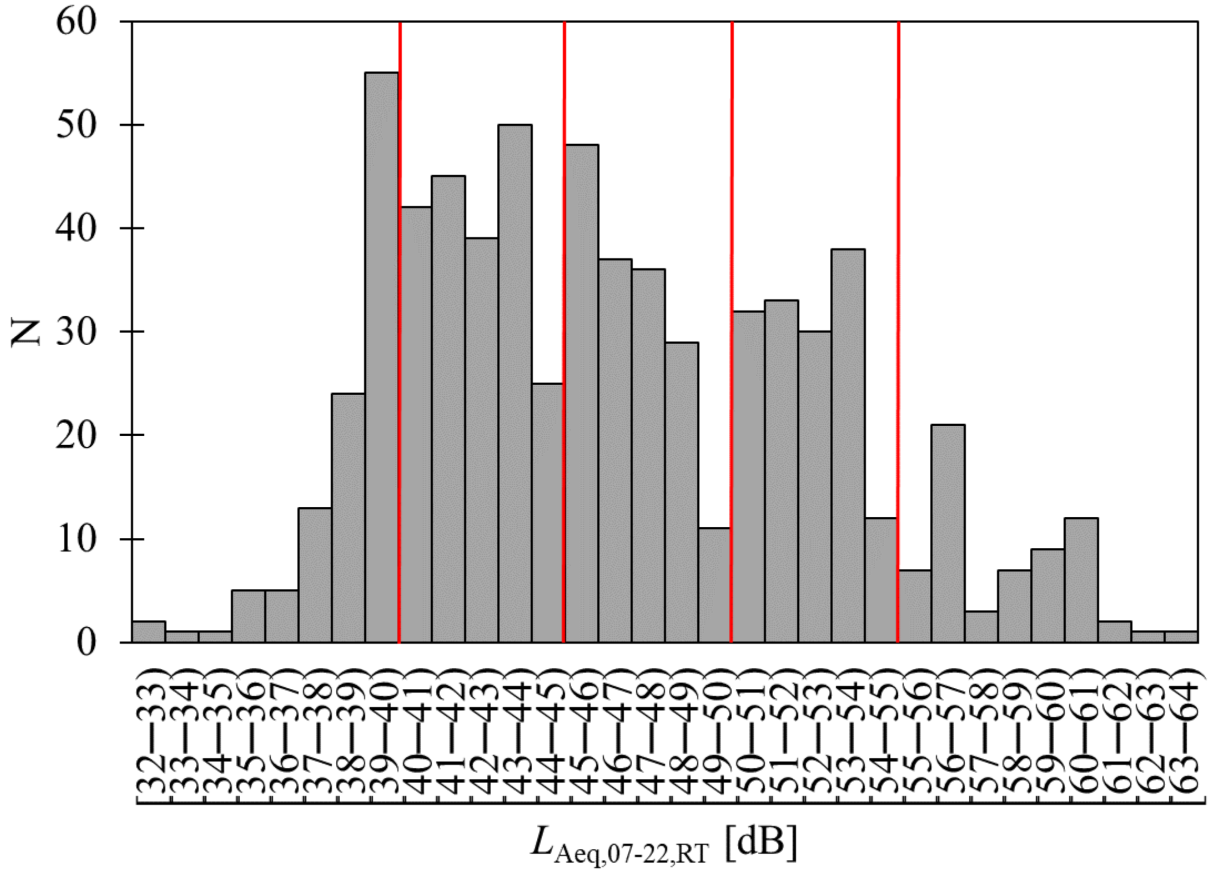

Fig. S3. The number of participants per 1-dB category of $L_{Aeq,07-22,RT}$. Red vertical lines show the division into *RTSL categories* used in statistical analysis.

Comparison of respondents and non-respondents

Method

The respondents and non-respondents were compared with χ^2 -test for categorical and analysis of variance (ANOVA) for continuous variables. For $L_{Aeq,WT}$ analysis, the examination was done only for the *WTSL categories* and without Control area, since for Control area, the $L_{Aeq,WT}$ was below hearing threshold. With other variables, all respondents were included.

Results

The respondents and non-respondents did not differ from each other in $L_{Aeq,WT}$ ($F(1, 2558)=0.25$, $p=0.553$, $\eta^2=0.000$), wind turbine distance ($F(1, 2553)=0.11$, $p=0.740$, $\eta^2=0.000$), and $L_{Aeq,07\text{-}22,RT}$ ($F(1, 3048)=3.21$, $p=0.073$, $\eta^2=0.001$). However, the respondents were older (mean 62.7 y, standard deviation 15.2 y) than the non-respondents (mean 55.6 y, standard deviation 19.4 y) ($F(1, 3056)=77.44$, $p<0.001$, $\eta^2=0.025$). In addition, women responded more often than men did ($\chi^2(1)=11.69$, $p=0.001$, $V=0.062$): the proportion of responded women was 24.9% (men: 19.7%).

Table S1. The proportion of respondents [%] reporting sleep difficulties due to environmental factors (*%SleepD due to environmental factors*) in *Groups*. *P*-values denote whether the proportion depends on the *Group*.

	Group				
%SleepD due to environmental factors	Control area	[17 - 25] dB	(25 - 30] dB	(30 - 40] dB	*p* -value[a]
Road traffic noise	6.9	16.4	10.8	5.7	0.019
Railway noise	0.0	0.9	1.4	0.6	—
Noise from the wind farm	0.0	0.0	1.1	0.6	—
Noise from the port and industry	0.9	0.0	0.7	1.3	—
Noise from mopeds and motorbikes	23.3	45.7	21.7	19.7	<0.001
Noise from next-door neighbours	7.8	15.7	7.2	4.5	0.008
Odours or dust	6.1	14.0	7.3	5.7	0.055
Noise made by your own family members	7.8	6.9	6.2	7.6	0.913
Other noise typical to the area	0.9	8.6	2.9	1.9	—

[a] The χ^2-test between the groups. "—" denotes that factor does not fulfill the χ^2-test requirements, which are the expected frequency for each cell is <1 or 80% of cells have the expected frequency of at least 5.

Table S2. Distribution of *WTN annoyance indoors* responses among 5 dB WTSL categories and Control area.

WTN annoyance	*Group*					
indoors	Control	(17─20] dB	(20─25] dB	(25─30] dB	(30─35] dB	(35─40] dB
0 = Not at all	116	13	100	247	108	6
1	0	2	1	12	10	0
2	0	0	1	4	8	1
3	0	0	1	2	9	0
4	0	0	0	4	3	0
5	0	1	0	1	3	0
6	0	0	0	0	4	2
7	0	0	0	3	0	0
8	0	0	0	0	2	1
9	0	0	0	0	1	0
10 = Extremely	1	0	1	0	0	0

Table S3. Distribution of *WTN annoyance outdoors* responses among 5 dB WTSL categories and Control area.

WTN annoyance	*Group*					
outdoors	Control	(17─20] dB	(20─25] dB	(25─30] dB	(30─35] dB	(35─40] dB
0 = Not at all	116	14	98	238	100	4
1	0	1	2	11	13	0
2	0	0	1	8	12	1
3	0	0	0	8	4	2
4	0	0	1	1	8	0
5	0	1	1	1	2	0
6	0	0	0	2	2	0
7	0	0	0	0	1	1
8	0	0	0	2	3	1
9	0	0	0	0	0	1
10 = Extremely	1	0	1	0	1	0

Table S4. Distribution of *RTN annoyance indoors* responses among 5 dB RTSL categories and Control area.

RTN annoyance	*Group*						
indoors	(32─35] dB	(35─40] dB	(40─45] dB	(45─50] dB	(50─55] dB	(55─60] dB	(60─64] dB
0 = Not at all	4	50	93	67	59	12	9
1	0	17	29	37	19	5	2
2	0	18	34	17	19	3	3
3	0	8	12	8	10	3	1
4	0	5	6	1	7	4	0
5	0	3	9	3	15	6	0
6	0	1	8	5	3	6	0
7	0	2	4	5	3	3	0
8	0	3	2	5	4	4	1
9	0	0	0	1	2	0	0
10 = Extremely	0	1	3	3	2	1	0

Table S5. Distribution of *RTN annoyance outdoors* responses among 5 dB RTSL categories and Control area.

RTN annoyance	*Group*						
outdoors	(32─35] dB	(35─40] dB	(40─45] dB	(45─50] dB	(50─55] dB	(55─60] dB	(60─64] dB
0 = Not at all	4	50	86	63	51	12	6
1	0	15	36	24	21	4	3
2	0	14	28	21	23	5	4
3	0	10	17	13	9	3	1
4	0	6	6	5	7	1	0
5	0	4	9	4	12	3	0
6	0	1	7	5	4	2	0
7	0	4	4	5	6	4	0
8	0	2	1	6	2	4	0
9	0	0	3	1	0	5	2
10 = Extremely	0	1	4	2	4	4	0

Comparison of Control area and WTSL categories

Logistic regression analysis

For *WTSL categories*, the relation between exposure and health variables was tested examining whether the reported prevalence of health variables differs between Control area and *WTSL categories*. This model reported here was adjusted for *age* and *gender* without road traffic noise $L_{Aeq,07\text{-}22,RT}$. The results of the final model adjusted for *age*, *gender*, and road traffic noise $L_{Aeq,07\text{-}22,RT}$ is reported in the article Tables 5-7.

Results

Table S5 shows an expected result that the *WTSL category* (30─40] dB had more respondents who were annoyed by wind turbine noise indoors (*%A WTN indoors*) than Control area (p=0.021). *WTSL category* [17─25] dB was related to higher odds of disturbed sleep due to noise (*%SD due to noise*) than Control area (p = 0.008). *WTSL category* [17─25] dB differed also from Control area in road traffic noise annoyance indoors (*%A RTN indoors*), which means that respondents belonging to this category had a higher odds of being annoyed by road traffic noise indoors than respondents in Control area (p = 0.009). Similarly, road traffic noise annoyance outdoors had higher odds in the *WTSL category* [17─25] dB than in Control area ($p = 0.016$), but this was no longer significant, when $L_{Aeq,07\text{-}22,RT}$ was also included in the analysis ($p = 0.066$) (see Table 5 in the main article). Table S6 examined symptoms and Table S7 examined diseases. Table S6 shows that the only significant difference was the larger proportion of respondents with *impaired hearing* in the *WTSL category* [17─25] dB than in Control area ($p = 0.026$). Prevalence of diseases showed no significant differences between Control area and three *WTSL categories*.

Table S5. Health effects related to noise annoyance, stress, and sleep, and their association with *Groups.* The results are based on binary logistic regression. *WTSL categories* are compared to Control area. Variables are explained in Table 2. Significant associations (p<0.05) are marked with bold. Control area is abbreviated by Ctrl.

Variable	Comparison	Exp(B)	CI
%A WTN indoors	Ctrl vs. [17─25] dB	1.95	(0.17, 22.13)
	Ctrl vs. (25─30] dB	1.70	(0.19, 15.49)
	Ctrl vs. (30─40] dB	**11.18**	**(1.43, 87.31)**
%A WTN outdoors	Ctrl vs. [17─25] dB	3.05	(0.31, 30.13)
	Ctrl vs. (25─30] dB	2.20	(0.25, 19.11)
	Ctrl vs. (30─40] dB	**10.15**	**(1.29, 79.59)**
%A RTN indoors	**Ctrl vs. [17─25] dB**	**2.48**	**(1.25, 4.92)**
	Ctrl vs. (25─30] dB	1.16	(0.61, 2.20)
	Ctrl vs. (30─40] dB	0.91	(0.44, 1.88)
%A RTN outdoors	Ctrl vs. [17─25] dB	**2.38**	**(1.18, 4.81)**
	Ctrl vs. (25─30] dB	1.52	(0.80, 2.90)
	Ctrl vs. (30─40] dB	1.17	(0.57, 2.40)
%Stress (PSS)	Ctrl vs. [17─25] dB	1.14	(0.67, 1.94)
	Ctrl vs. (25─30] dB	1.25	(0.80, 1.96)
	Ctrl vs. (30─40] dB	1.46	(0.89, 2.41)
%SleepD in general	Ctrl vs. [17─25] dB	1.70	(0.92, 3.13)
	Ctrl vs. (25─30] dB	0.98	(0.57, 1.70)
	Ctrl vs. (30─40] dB	1.18	(0.65, 2.13)
%SleepD due to noise	**Ctrl vs. [17─25] dB**	**2.35**	**(1.26, 4.4)**
	Ctrl vs. (25─30] dB	1.46	(0.83, 2.56)
	Ctrl vs. (30─40] dB	1.34	(0.72, 2.48)

Model is controlled for *age*, and *gender*.

Table S6. Symptoms' association with *Groups*. The results are based on binary logistic regression. *WTSL categories* are compared to Control area. Variables are explained in Table 2. Significant associations (p<0.05) are marked with bold. Control area is abbreviated by Ctrl.

%Symptoms	Comparison	Exp(B)	CI
Migraine or headache including nausea, vomiting, and sensitivity to light and sound	Ctrl vs. [17─25] dB	0.65	(0.23, 1.82)
	Ctrl vs. (25─30] dB	1.13	(0.52, 2.45)
	Ctrl vs. (30─40] dB	0.86	(0.36, 2.07)
Dizziness	Ctrl vs. [17─25] dB	0.95	(0.39, 2.32)
	Ctrl vs. (25─30] dB	1.12	(0.54, 2.33)
	Ctrl vs. (30─40] dB	0.62	(0.25, 1.52)
Ringing, whistling or other sounds in your ears that have no actual source (e.g. tinnitus)	Ctrl vs. [17─25] dB	1.23	(0.61, 2.47)
	Ctrl vs. (25─30] dB	1.29	(0.71, 2.33)
	Ctrl vs. (30─40] dB	0.78	(0.39, 1.56)
Impaired hearing	**Ctrl vs. [17─25] dB**	**2.31**	**(1.10, 4.83)**
	Ctrl vs. (25─30] dB	1.58	(0.80, 3.09)
	Ctrl vs. (30─40] dB	1.05	(0.48, 2.28)
Blocked ears or a sense of pressure in your ears	Ctrl vs. [17─25] dB	0.76	(0.31, 1.86)
	Ctrl vs. (25─30] dB	0.92	(0.44, 1.90)
	Ctrl vs. (30─40] dB	0.95	(0.42, 2.13)
Rash or itchy skin	Ctrl vs. [17─25] dB	1.15	(0.57, 2.31)
	Ctrl vs. (25─30] dB	1.21	(0.67, 2.18)
	Ctrl vs. (30─40] dB	0.94	(0.48, 1.84)
Back pain or backache	Ctrl vs. [17─25] dB	1.21	(0.69, 2.11)
	Ctrl vs. (25─30] dB	1.47	(0.92, 2.35)
	Ctrl vs. (30─40] dB	1.34	(0.80, 2.24)
Regular stomach problems	Ctrl vs. [17─25] dB	1.63	(0.79, 3.39)
	Ctrl vs. (25─30] dB	1.59	(0.84, 3.02)
	Ctrl vs. (30─40] dB	1.36	(0.67, 2.74)
Blurred vision	Ctrl vs. [17─25] dB	1.54	(0.49, 4.82)
	Ctrl vs. (25─30] dB	1.96	(0.72, 5.31)
	Ctrl vs. (30─40] dB	0.86	(0.26, 2.92)
Tachycardia or heart palpitations	Ctrl vs. [17─25] dB	1.08	(0.51, 2.29)
	Ctrl vs. (25─30] dB	1.22	(0.64, 2.30)
	Ctrl vs. (30─40] dB	0.89	(0.43, 1.84)
Problems in concentrating or remembering things	Ctrl vs. [17─25] dB	0.73	(0.37, 1.44)
	Ctrl vs. (25─30] dB	1.15	(0.67, 1.96)
	Ctrl vs. (30─40] dB	1.17	(0.65, 2.09)
Panic attacks or similar sensations	Ctrl vs. [17─25] dB	1.34	(0.29, 6.20)
	Ctrl vs. (25─30] dB	1.37	(0.37, 5.10)
	Ctrl vs. (30─40] dB	1.65	(0.41, 6.57)

Model is controlled for *age*, and *gender*.

Table S7. Chronic diseases association with *Groups*. The results are based on binary logistic regression. WTSL categories are compared to Control area. Variables are explained in Table 2. Significant associations ($p<0.05$) are marked with bold. Control area is abbreviated by Ctrl.

%Diseases	Comparison	Exp(B)	CI
Chronic pain	Ctrl vs. [17–25] dB	1.17	(0.67, 2.05)
	Ctrl vs. (25–30] dB	1.09	(0.68, 1.75)
	Ctrl vs. (30–40] dB	1.21	(0.72, 2.04)
Asthma	Ctrl vs. [17–25] dB	0.83	(0.38, 1.82)
	Ctrl vs. (25–30] dB	0.89	(0.46, 1.71)
	Ctrl vs. (30–40] dB	0.82	(0.39, 1.71)
Joint inflammation	Ctrl vs. [17–25] dB	1.13	(0.63, 2.04)
	Ctrl vs. (25–30] dB	0.93	(0.56, 1.54)
	Ctrl vs. (30–40] dB	1.17	(0.67, 2.03)
Cancer	Ctrl vs. [17–25] dB	0.64	(0.21, 1.98)
	Ctrl vs. (25–30] dB	0.85	(0.33, 2.14)
	Ctrl vs. (30–40] dB	0.46	(0.14, 1.51)
Depression	Ctrl vs. [17–25] dB	1.00	(0.50, 1.99)
	Ctrl vs. (25–30] dB	0.85	(0.47, 1.54)
	Ctrl vs. (30–40] dB	0.94	(0.49, 1.79)
Elevated blood pressure	Ctrl vs. [17–25] dB	1.73	(0.98, 3.07)
	Ctrl vs. (25–30] dB	1.57	(0.96, 2.56)
	Ctrl vs. (30–40] dB	1.39	(0.81, 2.38)
Bronchitis, pulmonary emphysema or chronic obstructive pulmonary disease	Ctrl vs. [17–25] dB	0.92	(0.36, 2.33)
	Ctrl vs. (25–30] dB	1.26	(0.59, 2.69)
	Ctrl vs. (30–40] dB	1.12	(0.48, 2.61)
Diabetes	Ctrl vs. [17–25] dB	1.05	(0.51, 2.16)
	Ctrl vs. (25–30] dB	0.54	(0.28, 1.05)
	Ctrl vs. (30–40] dB	0.62	(0.29, 1.30)
Heart disease	Ctrl vs. [17–25] dB	0.55	(0.23, 1.28)
	Ctrl vs. (25–30] dB	0.66	(0.32, 1.32)
	Ctrl vs. (30–40] dB	0.81	(0.37, 1.77)
Sleep problems, including sleep apnea and insomnia	Ctrl vs. [17–25] dB	1.53	(0.90, 2.61)
	Ctrl vs. (25–30] dB	1.00	(0.64, 1.57)
	Ctrl vs. (30–40] dB	1.38	(0.84, 2.25)
Restless legs syndrome	Ctrl vs. [17–25] dB	1.67	(0.89, 3.14)
	Ctrl vs. (25–30] dB	1.07	(0.61, 1.88)
	Ctrl vs. (30–40] dB	0.91	(0.48, 1.71)

Model is controlled for *age*, and *gender*.

Supplementary material 2: Health effects of wind turbine noise and road traffic noise on people living near wind turbines

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LIVING ENVIRONMENT QUESTIONNAIRE

Instructions
Give your response by **crossing the box next to the suitable alternative**: ☒
The responses will be processed automatically. It is important that you cross the box and not, for example, the number above the box. If you wish to change your response, fill in the box fully and put a cross in the box you want.
An example of correcting a mistake in your response:

How many persons are living in your household?

1	2	3	4	5	6	7	8	9
☐	☐	■	☒	☐	☐	☐	☐	☐

BACKGROUND INFORMATION

Date of filling in this questionnaire: [ ] day [ ] month **2018** Instructions: Write the numbers within the boxes

1. What is your highest education level?

☐ Primary school or comprehensive school
☐ Junior secondary level
☐ Upper secondary vocational school or similar
☐ Upper secondary school (Matriculation examination)
☐ Vocational college diploma
☐ Bachelor's degree (e.g. UAS, polytechnic)
☐ Master's degree or doctorate

2. What is your employment situation at the moment? You can select several options.

☐ Full-time employee
☐ Part-time employee
☐ Retired
☐ Unemployed
☐ Student
☐ On parental leave
☐ Study or job alternation leave
☐ Other

3. Do you work...

...shifts?	☐ Yes	☐ No
...night shifts (more than 3 hrs between 23–08)?	☐ Yes	☐ No

4. Is the dwelling to which this questionnaire was sent to...

☐ …detached house?
☐ …semi-detached house?
☐ …block of flats or gallery-access building?
☐ …terraced house?

5. When was the building built where you live in?

- ☐ Before 1930
- ☐ 1930s or 1940s
- ☐ 1950s or 1960s
- ☐ 1970s or 1980s
- ☐ 1990s or 2000s
- ☐ 2010 or later

6. How long have you been living in your current apartment? years ☐☐

7. The tenure category of your home?

- ☐ Owner-occupied (owned by yourself or family member)
- ☐ Rented accommodation
- ☐ Employer-provided accommodation
- ☐ Right-of-occupancy or owner-occupied
- ☐ Sheltered housing, rehabilitation home or retirement home

8. How well do the following statements describe you in general?	Agree strongly					Disagree strongly
a. I get used to most noises without much difficulty.	☐	☐	☐	☐	☐	☐
b. I get annoyed if my neighbours are noisy.	☐	☐	☐	☐	☐	☐
c. I find it hard to relax in a place that’s noisy.	☐	☐	☐	☐	☐	☐
d. I get mad at people who make noise that keeps me from falling asleep or getting work done.	☐	☐	☐	☐	☐	☐
e. I am sensitive to noise.	☐	☐	☐	☐	☐	☐

LIVING ENVIRONMENT

9. Rate how satisfied you are with the different features of your area.	Strongly dissatisfied	Somewhat dissatisfied	Not satisfied nor dissatisfied	Somewhat satisfied	Strongly satisfied
a. Services	☐	☐	☐	☐	☐
b. Transport connections	☐	☐	☐	☐	☐
c. Green areas/ facilities for outdoor activities	☐	☐	☐	☐	☐
d. Clean air	☐	☐	☐	☐	☐
e. Peaceful surroundings	☐	☐	☐	☐	☐
f. Neighbours	☐	☐	☐	☐	☐
g. Safety	☐	☐	☐	☐	☐
h. Landscape	☐	☐	☐	☐	☐

10. Can you see from the windows of your home...	No	Yes
...busy roads?	☐	☐
..built-up area?	☐	☐
...railway?	☐	☐
...port?	☐	☐
...wind turbine?	☐	☐
...power lines, pylons or masts?	☐	☐
...fields, meadows, forests or parks?	☐	☐
...sea, lake or river?	☐	☐
...untidy or neglected plots and buildings?	☐	☐
...industrial plant?	☐	☐

11. Can you see from your garden/balcony...	No	Yes
...busy roads?	☐	☐
..built-up area?	☐	☐
...railway?	☐	☐
...port?	☐	☐
...wind turbine?	☐	☐
...power lines, pylons or masts?	☐	☐
...fields, meadows, forests or parks?	☐	☐
...sea, lake or river?	☐	☐
...untidy or neglected plots and buildings?	☐	☐
...industrial plant?	☐	☐

12. Have you gained financially from the following projects that have taken place in your area (e.g. you have gained through sale or rent or you are a partner in a project)?	No.	Yes
a. Local road or transport building	☐	☐
b. Industrial building or warehouse	☐	☐
c. Wind farm	☐	☐
d. Office or commercial building	☐	☐
e. Agricultural building	☐	☐

13. Do you feel that your local community benefits from the projects carried out in your area?	Not at all	To some degree	Signific-antly
a. Local road or transport building	☐	☐	☐
b. Industrial building or warehouse	☐	☐	☐
c. Wind farm	☐	☐	☐
d. Office or commercial building	☐	☐	☐
e. Agricultural building	☐	☐	☐

14. In your opinion, how do the functions in your area affect the value of your property?	Decreases considerably	Somewhat decreases	Not relevant	Somewhat increases	Increases considerably	The function does not exist nearby
a. Busy road	☐	☐	☐	☐	☐	☐
b. Railway	☐	☐	☐	☐	☐	☐
c. Urban centre with services	☐	☐	☐	☐	☐	☐
d. Industrial plant	☐	☐	☐	☐	☐	☐
e. Wind farm	☐	☐	☐	☐	☐	☐
f. Agricultural building	☐	☐	☐	☐	☐	☐
g. Landfill or recycling centre	☐	☐	☐	☐	☐	☐

15. Have there been significant changes in your living area or are significant changes expected in your living area in the near future? ☐ Yes ☐ No

If yes, please

specify:____

____

If necessary, continue in the comment field on the final page.

16. Indicate how much you agree or disagree with the following statements regarding the decision-making on land use in your home municipality.	Strongly agree	Agree to some extent	Neither agree nor disagree	Disagree to some extent	Strongly disagree
a. I trust the authorities' expertise.	☐	☐	☐	☐	☐
b. I have the opportunity to influence the decision-making concerning my area.	☐	☐	☐	☐	☐
c. The local authorities and elected officials aim to work towards what is best for the entire municipality.	☐	☐	☐	☐	☐
d. The decision-making in the municipality is transparent.	☐	☐	☐	☐	☐
e. I have received sufficient information about changes that have taken place or are planned to take place close to my living area.	☐	☐	☐	☐	☐

17. Rate how much you agree with the following statements regarding energy production.	Strongly agree	Agree to some extent	Neither agree nor disagree	Disagree to some extent	Strongly disagree
a. I think solar energy is not a sufficiently profitable form of energy production this far in the north.	☐	☐	☐	☐	☐
b. The use of fossil fuels imported from abroad should be decreased because of energy self-sufficiency.	☐	☐	☐	☐	☐
c. I am concerned about the adverse effects of air pollutants created by the use of fossil fuels.	☐	☐	☐	☐	☐
d. I think electricity produced by wind power is a positive thing.	☐	☐	☐	☐	☐
e. Wind farms have a positive impact on the landscape.	☐	☐	☐	☐	☐
f. I am concerned about the impact of wind farms on the animals.	☐	☐	☐	☐	☐
g. I think electricity produced by nuclear power is a positive thing.	☐	☐	☐	☐	☐
h. When operating normally, nuclear power causes no health hazards and is therefore a safe form of energy production.	☐	☐	☐	☐	☐

18. How much do the following environmental factors disturb, bother or annoy you when you spend time <u>indoors</u> at home? Think about the situation in the past 12 months.

	Not at all 0	1	2	3	4	5	6	7	8	9	Very much 10
a. Road traffic noise	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
b. Railway noise	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
c. Noise from the wind farm	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
d. The lights and flicker from the wind farm	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
e. Noise from the port and industry	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
f. Noise from mopeds and motorbikes	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
g. Odours or dust	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
h. Noise from the nearby neighbours	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
i. Other noise typical in the area	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

19. How much do the following environmental factors disturb, bother or annoy you when you spend time <u>outside</u> in the garden, balcony or terrace of your home? Think about the situation in the past 12 months.

	Not at all 0	1	2	3	4	5	6	7	8	9	Very much 10
a. Road traffic noise	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
b. Railway noise	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
c. Noise from the wind farm	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
d. The lights and flicker from the wind farm	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
e. Noise from the port and industry	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
f. Noise from mopeds and motorbikes	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
g. Odours or dust	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
h. Noise from the nearby neighbours	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
i. Other noise typical in the area	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

20. Rate how much you agree with the following statements regarding possible disturbances in your area.	Strongly agree	Agree to some extent	Neither agree nor disagree	Disagree to some extent	Strongly disagree	This disturbance does not exist here
a. The road traffic sound affects how often I keep my windows open.	☐	☐	☐	☐	☐	☐
b. The sound from the wind farm affects how long I keep my windows open.	☐	☐	☐	☐	☐	☐
c. The road traffic sound affects how much time I spend in my garden or on the balcony.	☐	☐	☐	☐	☐	☐
d. The sound from the wind farm affects how much time I spend in my garden or on the balcony.	☐	☐	☐	☐	☐	☐
e. I am concerned about the possible adverse health effects of road traffic sound.	☐	☐	☐	☐	☐	☐
f. I am concerned about the possible adverse health effects of wind farm sound.	☐	☐	☐	☐	☐	☐
g. I am concerned about the health effects of particle emissions from road traffic.	☐	☐	☐	☐	☐	☐
h. I avoid moving in the area of the wind farm because wind farms are not safe.	☐	☐	☐	☐	☐	☐
i. Not enough is done about road traffic noise abatement.	☐	☐	☐	☐	☐	☐
j. I am concerned about the possible adverse health effects of the infrasound produced by wind farms.	☐	☐	☐	☐	☐	☐

21. How annoying do you find the following sounds while indoors at your home? Think about the situation in the past 12 months.	Do not notice	Notice but not annoyed	Slightly annoyed	Rather annoyed	Very annoyed
a. Road traffic noise	☐	☐	☐	☐	☐
b. Noise from the wind farm	☐	☐	☐	☐	☐
c. Other noise typical to the area	☐	☐	☐	☐	☐

WELL-BEING

Read every question and estimate how you feel.

	Very poor	Poor	Neither poor nor good	Good	Very good
22. How would you rate your quality of life?	☐	☐	☐	☐	☐

	Very dissatisfied	Dissatisfied	Neither satisfied nor dissatisfied	Satisfied	Very satisfied
23. How satisfied are you with your health?	☐	☐	☐	☐	☐

The following questions ask about how much you have experienced certain things **in the last four weeks**.

	Not at all	A little	A moderate amount	Very much	An extreme amount
24. To what extent do you feel that physical pain prevents you from doing what you need to do?	☐	☐	☐	☐	☐
25. How much do you need any medical treatment to function in your daily life?	☐	☐	☐	☐	☐
26. How much do you enjoy life?	☐	☐	☐	☐	☐
27. To what extent do you feel your life to be meaningful?	☐	☐	☐	☐	☐

	Not at all	A little	A moderate amount	Very much	Extremely
28 How well are you able to concentrate?	☐	☐	☐	☐	☐

	Not at all	A little	A moderate amount	Very much	Extremely
29. How safe do you feel in your daily life?	☐	☐	☐	☐	☐

	Not at all	A little	A moderate amount	Very much	Extremely
30. How healthy is your physical environment?	☐	☐	☐	☐	☐

The following questions ask about how completely you experience or were able to do certain things **in the last four weeks**.

	Not at all	A little	Moderately	Mostly	Completely
31. Do you have enough energy for everyday life?	☐	☐	☐	☐	☐
32. Are you able to accept your bodily appearance?	☐	☐	☐	☐	☐
33. Have you enough money to meet your needs?	☐	☐	☐	☐	☐
34. How available to you is the information that you need in your day-to-day life?	☐	☐	☐	☐	☐
35. To what extent do you have the opportunity for leisure activities?	☐	☐	☐	☐	☐

	Very poor	Poor	Neither poor nor good	Good	Very good
36. How well are you able to get around?	☐	☐	☐	☐	☐

The following questions ask about how satistied you have been with different parts of your life **in the last four weeks**.

	Very dissatisfied	Dissatisfied	Neither satisfied nor dissatisfied	Satisfied	Very satisfied
37. How satisfied are you with your sleep?	☐	☐	☐	☐	☐
38. How satisfied are you with your ability to perform your daily living activities?	☐	☐	☐	☐	☐
39. How satisfied are you with your capacity for work?	☐	☐	☐	☐	☐
40. How satisfied are you with yourself?	☐	☐	☐	☐	☐
41. How satisfied are you with your personal relationships?	☐	☐	☐	☐	☐
42. How satisfied are you with your sex life?	☐	☐	☐	☐	☐
43. How satisfied are you with the support you get from your friends?	☐	☐	☐	☐	☐
44. How satisfied are you with the conditions of your living place?	☐	☐	☐	☐	☐
45. How satisfied are you with your access to health services?	☐	☐	☐	☐	☐
46. How satisfied are you with your transport?	☐	☐	☐	☐	☐

The following question refers to how often you have felt or experienced certain things **in the last four weeks**.

	Never	Seldom	Quite often	Very often	Always
47. How often do you have negative feelings such as blue mood, despair, anxiety, depression?	☐	☐	☐	☐	☐

The questions in this scale ask you about your feelings and thoughts **during the last month**. In each case, you will be asked to indicate how often you felt or thought a certain way.

In the last month, how often have you…	Never	Almost never	Sometimes	Fairl y often	Very often
48. … been upset because of something that happened unexpectedly?	☐	☐	☐	☐	☐
49. … felt that you were unable to control the important things in your life?	☐	☐	☐	☐	☐
50. … felt nervous and “stressed”?	☐	☐	☐	☐	☐
51. … felt confident about your ability to handle your personal problems?	☐	☐	☐	☐	☐
52. … felt that things were going your way?	☐	☐	☐	☐	☐
53. … found that you could not cope with all the things that you had to do?	☐	☐	☐	☐	☐
54. … been able to control irritations in your life?	☐	☐	☐	☐	☐
55. … felt that you were on top of things?	☐	☐	☐	☐	☐
56. … been angered because of things that were outside of your control?	☐	☐	☐	☐	☐
57. … felt difficulties were piling up so high that you could not overcome them?	☐	☐	☐	☐	☐

58. How much have you experienced sleep problems all in all in the past 12 months? Sleep problems include difficulty falling asleep, waking up in the middle of the night, poor quality of sleep and waking up too early in the morning.

Not at all 0	1	2	3	4	5	6	7	8	9	Very much 10
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

59. How often is your sleep disturbed by the sounds from your environment?

Less than once a year	At least once a year	At least once a month	At least once a week	Nearly every day
☐	☐	☐	☐	☐

60. How much have the following factors disturbed your sleep in the past 12 months?

	Not at all 0	1	2	3	4	5	6	7	8	9	Very much 10
a. Road traffic noise	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
b. Railway noise	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
c. Noise from the wind farm	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
d. Noise from the port and industry	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
e. Noise from mopeds and motorbikes	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
f. Noise from next-door neighbours	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
g. Odours or dust	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
h. Noise made by your own family members	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
i. Other noise typical to the area	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

61. How often do you have beer, wine or other drinks containing alcohol? Please also include the times, when you drank only small amounts, e.g. a bottle of beer or a sip of wine.

☐ Never → Go to question 64.
☐ monthly or less
☐ 2-4 times a month
☐ 2-3 times a week
☐ 4 times a week or more

62. How many drinks containing alcohol do you have on a typical day when you are drinking? One portion is a 0,33 l bottle of beer, cider or long drink, 12 cl of table wine, or 4 cl of spirits.

☐ 1-2 drinks
☐ 3-4 drinks
☐ 5-6 drinks
☐ 7-9 drinks
☐ 10 drinks or more

63. How often do you have 6 or more drinks on an occasion when you are drinking?

☐ Never
☐ Less than monthly
☐ Monthly
☐ Weekly
☐ Daily or almost daily

64. How many cigarettes per day do you smoke?

☐ I don't smoke. → Go to question 66.
☐ 10 or less.
☐ 11-20
☐ 21-30
☐ 31 or more

65. How soon after you wake up do you smoke your first cigarette?

☐ Within 5 minutes
☐ 6 to 30 minutes
☐ 31 to 60 minutes
☐ After 60 minutes

66. How many caffeinated drinks do you consume in a day on average? One caffeinated drink is a normal cup of caffeinated coffee, tea, soft drink, or energy drink.

☐ Not at all.
☐ 1 or 2 drinks.
☐ 3 to 4 drinks.
☐ 5 drinks or more.

67. How much do you move while at work?

☐ Only a little, I mainly sit or stand at work.
☐ To some degree.
☐ A lot, my job is physically strenuous.

68. How often do you move <u>other than at work</u> 20 minutes or longer at a time so that you get slightly breathless and break a sweat?

☐ Never.
☐ Less than once a week.
☐ 1–3 times per week.
☐ 4 times per week or more.

In the following, we will ask questions about your diagnosed illnesses and symptoms. Note that all information provided by you will be strictly confidential and such data will not be published at any stage that could be linked to you personally.

69. Do you suffer from a chronic illness? (For example, diabetes, high blood pressure, tinnitus, cardiovascular diseases, migraine...) ☐ Yes ☐ No

If yes, please specify:____

70. In the last 12 months, how often have you experienced...	Never	A few times	Every month or almost every month	Every week or almost every week	Every day or almost every day
... migraine or headache including nausea, vomiting, and sensitivity to light and sound?	☐	☐	☐	☐	☐
... dizziness?	☐	☐	☐	☐	☐
... ringing, whistling or other sounds in your ears that have no actual source (e.g. tinnitus)?	☐	☐	☐	☐	☐
... impaired hearing?	☐	☐	☐	☐	☐
... blocked ears or a sense of pressure in your ears?	☐	☐	☐	☐	☐
... rash or itchy skin?	☐	☐	☐	☐	☐
... back pain or backache?	☐	☐	☐	☐	☐
... regular stomach problems?	☐	☐	☐	☐	☐
... blurred vision?	☐	☐	☐	☐	☐
.... tachycardia or heart palpitations?	☐	☐	☐	☐	☐
... problems in concentrating or remembering things?	☐	☐	☐	☐	☐
... panic attacks or similar sensations?	☐	☐	☐	☐	☐

71. In the past 12 months, have you experienced...	Yes	Not
... chronic pain?	☐	☐
... asthma?	☐	☐
... joint inflammation?	☐	☐
... cancer?	☐	☐
... depression?	☐	☐
... elevated blood pressure?	☐	☐
... bronchitis, pulmonary emphysema or chronic obstructive pulmonary disease?	☐	☐
... diabetes?	☐	☐
... heart disease?	☐	☐
... sleep problems, including sleep apnoea and insomnia?	☐	☐
... restless legs syndrome?	☐	☐

72. Your age?	☐☐☐	years	Instructions: Only write one digit in each box. Example: 4 8
73. Your weight?	☐☐☐	kg	
74. Your height?	☐☐☐	cm	

75. Gender? ☐ Female ☐ Male

Thank you for filling in the questionnaire!
Please, make sure that you have responded to all questions.

You are welcome to write any additional comments below and on the backside of this sheet: