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Annoyance Related to Wind Turbine Noise

Małgorzata PAWLACZYK-ŁUSZCZYŃSKA[(1)], Adam DUDAREWICZ[(1)],
Kamil ZABOROWSKI[(1)], Małgorzata ZAMOJSKA-DANISZEWSKA[(1)],
Małgorzata WASZKOWSKA[(2)]

[(1)] *Department of Physical Hazards, Nofer Institute of Occupational Medicine*
Św. Teresy 8, 91-348 Łódź, Poland; e-mail: mpawlusz@imp.lodz.pl

[(2)] *Department of Occupational Psychology, Nofer Institute of Occupational Medicine*
Św. Teresy 8, 91-348 Łódź, Poland

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A questionnaire inquiry on response to wind turbine noise was carried out on 361 subjects living in the vicinity of 8 wind farms. Current mental health status of respondents was assessed using Goldberg General Health Questionnaire GHQ-12. For areas where respondents lived, A-weighted sound pressure levels (SPLs) were calculated as the sum of the contributions from the wind power plants in the specific area.

Generally, 33.0% of respondents were annoyed outdoors by wind turbine noise at the calculated A-weighted SPL of 31–50 dB, while indoors the noise was annoying to 21.3% of them. The proportion of subjects evaluating the noise produced by operative wind turbines as annoying decreased with increasing the distance from the nearest wind turbine (27.6% at the distance of 400–800 m vs 14.3% at the distance above 800 m, $p < 0.016$). On the other hand, the higher was the noise level, the greater was the percentage of annoyed respondents (14.0% at SPL up to 40 dB vs 28.1% at SPL of 40–45 dB, $p < 0.016$). Besides noise and distance categories, subjective factors, such as general attitude to wind turbines, sensitivity to landscape littering and current mental health status, were found to have significant impact on the perceived annoyance. About 50% of variance in annoyance rating might be explained by the aforesaid subjective factors.

Keywords: wind turbines, noise, annoyance.

1. Introduction

Wind power has been recognized as a clean renewable energy source that does not contribute to global warming and is without known emissions or harmful wastes. However, despite its rapid growth, the wind power does not only enjoy a considerable public support, but it also has its detractors. Debate on health effects of the wind turbine operation, especially of the audible and the inaudible noise continues (Knopper, Ollson, 2010).

Wind turbines are relatively new sources of community noise and their impact on people living nearby has not been completely explained yet. Nevertheless, it has been shown that people living in the vicinity of wind farms are at the risk of being annoyed by the noise, an adverse impact in itself. Noise annoyance in turn could lead to sleep disturbances and psychological distress. No direct effects of wind turbine noise on sleep disturbance or psychological stress have been demonstrated which means that people who do not hear the sound or do not feel disturbed are not adversely affected (Pedersen, Persson Waye, 2004; 2007; Pedersen *et al.*, 2009; Knopper, Ollson, 2010; Pedersen, 2011; Bakker *et al.*, 2012).

Generally, people are more likely to be annoyed when A-weighted sound pressure levels exceed 35–40 dB. Proportion of people perceiving wind turbine noise and annoyed by it increases with increasing noise levels (Pedersen, Persson Waye, 2004; 2007; Pedersen *et al.*, 2009). Subjective factors such as having turbines visible from the dwelling, negative opinion about wind turbines in general and/or their visual impact on landscape and self-reported sensitivity to noise increase the probability of being annoyed by wind turbine noise (Pedersen, Persson Waye, 2004; 2007), while economic benefits obtained from wind turbines reduce the risk of annoyance (Pedersen *et al.*, 2009). It has also been found that terrain characteristics and urbanization affect the perceived annoyance from the wind turbine noise. In particular, people living in the areas with other background noises are less affected than those from the quiet areas (Pedersen, Persson Waye, 2007; Bakker *et al.*, 2012).

Although wind power has been harnessed as a source of electricity for several decades around the world, its dynamic development in Poland is relatively recent. It is no wonder that data on reactions to wind turbine noise in populated areas in Poland are rather sparse. Recently, Mroczek *et al.* (2012) analyzed the impact of distance between place of residence and wind farms on the quality of life in nearby areas, but they did not take into consideration the noise produced by the operation of wind turbines. Their study comprising 1277 people living in rural areas up to 2 km from wind farms showed that close proximity of wind farms did not result in the deterioration of the quality of life (assessed using the SF-36 General Health Questionnaire). However, the general score of the SF-36 questionnaire obtained by the wind farm area residents was lower than the score achieved by control group (consisting of 1169 Polish citizens); the most significant differences were observed in domains evaluating general health, physical functioning and mental health (Mroczek *et al.*, 2012; Mroczek, 2013).

Therefore, the overall objective of this study was to evaluate the perception and annoyance of noise from wind turbines in populated areas in Poland. In particular, it has been attempted to:

- analyze the relationships between distance from wind turbines and/or levels of wind turbine noise at the dwelling and the percentage of people annoyed by the noise,
- analyze individual factors affecting the perceived annoyance.

2. Methodology

A field study on response to wind turbine noise was carried out on people living in the vicinity of eight wind farms located in the central and the north-western parts of Poland (Table 1). Seven areas totaling 187.7 km^2 were investigated. A questionnaire was applied as the main research tool.

The study group comprised 361 subjects aged 15–88 years. They were personally asked to complete questionnaires. No exclusion criteria were applied.

For investigated areas, *A*-weighted sound pressure levels (SPLs) were calculated as the sum of the contributions from the wind power plants in the neighborhood. In addition, for some cases, noise conditions outside the dwellings were evaluated by *in situ* measurements.

Table 1. Characteristics of investigated areas.

No.	Area [km^2]	Localisation	Number of respondents	Wind farm	Power installed	Wind turbines		
						quantity, pcs.	power	type
1	32.2	Kuyavian-Pomeranian Province, Lipno County	71	Farm no. 1	34 MW	17	2 MW	Vestas V-90
					600 kW	6	100 kW	–
2	45.2	West Pomeranian Province, Koszalin County	57	Farm no. 2	50 MW	25	2 MW	Vestas V-80
3	73.9	West Pomeranian Province, Bialogard County	23	Farm no. 3	90 MW	60	1.5 MW	Fuhrländer Fl 1500 77
4	4.7	West Pomeranian Province, Slawno County	35	Farm no. 4	20 MW	10	2 MW	Vestas V-80
					660 kW	5	132 kW	Seewind
5	4.9	West Pomeranian Province, Slawno County	35	Farm no. 5	22.5 MW	9	2.5 MW	Nordex N90
6	15.6	West Pomeranian Province, Slawno County	29	Farm no. 6	50 MW	20	2.5 MW	GE 2.5xl
7	11.2	West Pomeranian Province, Puck County	111	Farm no. 7	8 MW	4	2 MW	Vestas V80
					10 MW	4	2.5 MW	Nordex N80
					3.2 MW	4	800 kW	Enercon E40
					1.2 MW	2	600 kW	WestWind
				Farm no. 8	22 MW	11	2 MW	Gamesa G87 T78

2.1. Questionnaire inquiries

Subjects completed the questionnaire developed to enable evaluation of their living conditions, including prevalence of annoyance due to noise from wind turbines, and the self-assessment of physical health and wellbeing. The questionnaire was based on the one previously used in Swedish studies (Pedersen, Persson Waye, 2004; 2007) and, like the aforesaid questionnaire, was constructed to mask the main intention. The responses to most questions were rated on 5-score rating scales.

The questionnaire consisted of two parts. The first one comprised inquiries concerning:

- housing and satisfaction with the living environment, including questions on occurrence ("Yes/No") and the degree of annoyance experienced outdoors and indoors from various nuisances, i.e. odors (from industries, landfills and agriculture) and noises from variety of sources, e.g. agricultural machinery, hand held and stationary power tools, road traffic, railway, airplanes and wind turbines noise ("not at all annoying", "a little annoying", "rather annoying", "annoying", or "extremely annoying"),
- paying attention to noise, odors and air pollutions, landscape littering (visual intrusions) ("definitely yes", "yes", "no opinion", "no", "definitely no"),
- general opinion on (attitude towards) wind turbines and on the visual impact of wind turbines ("very positive", "positive", "no opinion", "negative", "very negative"),
- different visual and auditory aspects of wind turbines such as noise, shadows and reflections from rotor blades during various subjects' activities (e.g. relaxing. taking walks) and weather conditions.

The second part of the questionnaire was aimed at self-assessment of subjects' physical health, including hearing status ("very poor", "poor", "rather poor", "rather good" "good", "very good"). It also comprised questions on chronic illnesses (e.g. cardiovascular diseases, hearing impairment, etc.) and general well-being (headache, undue tiredness, pain and stiffness in the back, neck, and shoulders, feelling stressed, irritable), as well as quality of sleep and normal sleep habits. The results of the latter part of the questionnaire will be presented elsewhere.

In addition, the current mental health status of respondents was assessed using 12-item Goldberg General Health Questionnaire (GHQ-12) which was adapted to Polish circumstances (Makowska, Merecz, 2001; Makowska *et al.*, 2002). This questionnaire was derived from the main version of the Goldberg General Health Questionnaire. It consists of 12 items describing various symptoms of mental health problems related to two areas, and the emergence of new distressing phenomena. The subjects were asked to assess the changes in their mood, feelings and behaviors in the period of recent four weeks using 4-point response scale ("less than usual", "no more than usual", "rather more than usual" and "much more than usual"). Responses to each question were coded on the scale from 0 to 3. The total score per subject was obtained by adding the scores for 12 questions. The more mental disorders were experienced by a participant, the higher was the total score of the GHQ-12 (Makowska, Merecz, 2001; Makowska *et al.*, 2002).

2.2. Evaluation of noise exposure

For areas where respondents lived, A-weighted sound pressure levels (SPLs) were calculated as the sum of the contributions from the wind turbines in the neighborhood. The calculations followed the sound propagation model for wind power plants adopted by the Swedish Environmental Protection Agency and used as a basis for granting building permission. The aforesaid method was used in earlier Swedish studies (for details see Pedersen, Persson Waye, 2004). In these calculations, the A-weighted sound power levels of wind turbines specified by manufactures were used. The arrangements of turbines within each of the farms were obtained from the internet maps (www.geoportal.gov.pl), while the distances between dwellings and turbines were calculated from the GPS data collected in front of the residential premises. Additionally, a correction for the wind velocity distribution was added to the predicted A-weighted SPLs to obtain the day-evening-night noise levels (L_{den}) according to 2002/49/EC (van den Berg, 2008).

The calculated SPLs were at random verified by *in situ* measurements. Relatively quiet areas without too many masking noises (e.g. noises from agricultural machines, hand held and stationary power tools or road-traffic noise) were chosen. Consequently, for some of the respondents ($n = 114$), noise levels were measured outside their dwellings at the height of 1.5 and/or 4 meters, at the distance of 3 meters (or more) from the façade. Measuring points were located next to the respondents' houses in such a way that the distance from the nearest turbine was shorter than the distance between a turbine and a respondent house.

These measurements were carried out according to Polish recommendation on the assessment of environmental noise (Ordinance by the Minister of Environment of November 4, 2008). However, besides an equivalent-continuous A-weighted SPL ($L_{Aeq.T}$), other basic noise parameters such as C- and G-weighted sound pressure levels ($L_{Ceq.T}$ and $L_{Geq.T}$) were measured. In addition, frequency analysis in 1/3-octave bands from 1.6 Hz to 20 kHz was performed.

Noise measurements were carried out using a SVANTEK type SVAN 958 sound analyzer (with

SVANTEK type SV12L preamplifier and type SV22L microphone equipped with windscreen). At each measuring point, at least 5 noise samples, lasting minimum 1 minute each, were collected. Particular attention was paid to avoid including masking noises such as road-traffic noise, dogs' barking, etc. However, it was impossible to exclude birds singing and the hum of insects.

The measurements were carried out during daytime. The meteorological parameters (i.e. air temperature, air humidity, barometric pressure, wind velocity and direction) were simultaneously monitored using a weather station (Technoline type WS 3650 IT).

2.3. Statistical analysis

To analyze the relationships between distance from wind turbines and/or levels of wind turbine noise at the dwelling and the percentage of people annoyed by the noise, the study subjects were classified into subgroups (categories) according to the calculated A-weighted SPL at their dwellings (three noise categories, i.e. up to 40 dB, 40–45 dB and above 45 dB), as well as according to distance of their dwellings from the nearest wind turbine (three distance categories, i.e. below 400 m, 400–800 m, and above 800 m).

To analyze the impact of different subjective variables, the subjects were also sorted into subgroups according to: a) age (younger and older subjects), b) gender (male and female), c) sensitivity to odors and air pollutions, landscape littering and noise (sensitive and not sensitive subjects), d) attitude to the wind turbines in general and to the visual impact in particular (negative and positive), e) self-assessment of physical health (negative and positive), and f) the GHQ-12 score. In the latter case, subjects were classified as high- and low-scored in the GHQ-12 individuals (i.e. scored above and below median value of 10.0). Similarly, the median value of age (45.5 years) was used as the basis for classification of subjects as younger and older ones.

When relevant, the data from 5-score (or 6-point) verbal rating scales were dichotomized. The answers "rather annoying", "annoying" and "extremely annoying" were classified as "annoying", while the others ("not at all annoying" and "a little annoying") as "not annoying". Similarly, "very negative" and "negative" attitude towards the wind turbines (in general and to their visual impact in particular) or self-assessment of physical health were categorized as "negative", while the other answers (i.e. "no opinion", "positive" or "very positive") as "positive (not negative)". On the other hand, when analyzing paying attention to various environmental nuisances, respondents who answered "definitely yes" and "yes" were classified as "sensitive" to noise, landscape littering or air pollution, while the others as "not sensitive".

Answers to the questionnaire were presented as the proportions with 95% confidence intervals in the total study group as well as the proportion of respondents in various subgroups. Differences between various pairs of subgroups in proportions of answers were evaluated using chi-square test.

Relationships between subjective variables and objective variables (i.e. noise and distance categories and noise annoyance rating, noise sensitivity, general attitude to wind turbine expressed on verbal rating scales, etc.) were analyzed using Spearman's nonparametric rank correlation coefficient r_s. Binary logistic regression was used to study the influence of various variables (including noise and distance categories as well as subjective factors) on annoyance related to the wind turbine noise. The Nagelkerke pseudo-R^2 was applied as a measure of explained variance (Nagelkerke, 1991).

The statistical analysis was carried out with an assumed level of significance $p = 0.05$. However, when comparing pairs of various subgroups of respondents or analyzing several relationships at the same time, to avoid the risk of mass significance, p-value divided by number (N) of possible comparisons or correlations ($p = 0.05/\mathrm{N}$) was set as the limit for statistical significance. The statistical analysis employed STATISTICA (version 9.1. StatSoft, Inc.) software package.

3. Results

3.1. Study group characteristics

Generally, the majority of respondents (79.5%) lived in privately owned detached or semi-detached houses in the countryside or in small villages. The landscape was rather flat and mainly agricultural, but roads were also present. Almost all respondents (94.9%) could see one or more wind turbines from their dwelling, backyard or garden. Only a few (3.1%) of them had profits from the wind turbines. About half (51.4%) of respondents were employed, while 21.6% of them were pensioners. The majority of subjects had primary (25.2%), vocational (25.8%) or secondary (high school) (35.7%) education.

The mean age in the study population was 45.9±15.5 years (median value: 45.5 years). Women were more numerous than men (58.4% vs. 41.6%). Over half of the subjects were classified as sensitive to noise (60.1%), landscape littering (55.1%), odors and air pollutions (62.6%). Among the respondents, 18.5% and 24.7% declared negative ("very negative" or "negative") attitude towards wind turbines in general and their visual impact in particular, respectively. Similar fraction (18.0%) of subjects assessed their health status as poor ("poor" or "very poor").

Respondents examined using the GHQ-12 obtained a mean score at the level of 11.5±5.1 (median value: 10) which was close to the normative result for the reference to Polish population (11.17±5.11) (Makowska, Merecz, 2001).

3.2. Noise exposure evaluation

Generally, the study subjects lived at the distance of 204 m to 1384 m (mean value ± SD: 678 ± 196 m, median: 689 m) from the nearest wind turbine. They were exposed to the wind turbine noise at the measured equivalent-continuous: (i) *A*-weighted SPLs of 33–50 dB (mean ± SD: 42.7±3.4 dB, median: 42.6 dB), and (ii) *C*-weighted SPLs of 42–71 dB (mean ± SD: 55.6±6.0 dB, median: 56.6 dB), (iii) *G*-weighted SPLs of 56–90 dB (mean ± SD: 75.6±8.4 dB, median: 76.7 dB).

The noise prevailing at respondents' dwellings included infrasonic components but at levels lower than the relevant hearing threshold levels (Fig. 1). These results were not surprising since all wind turbines in this study were upwind devices (Leventhall, 2006). For example, O'Neal *et al.* (2011) performed noise surveys outside and within nearby residences of wind turbines from two different manufactures and they also found that the measured (at distance of 305 and 457 m) sound pressure levels (in 1/3-octave bands) in the infrasonic range were lower than hearing threshold levels.

In the areas where respondents lived, the calculated *A*-weighted SPLs ranged from 31 to 50 dB (Table 2). The most numerous noise category was subgroup of subjects exposed to noise at the calculated *A*-weighted sound pressure levels of 40–45 dB (56.2%). On the other hand, when sorting respondents according to the distance from the nearest wind turbine, the most numerous was subgroup of those living at the distance of 400–800 m, which comprised 64.3% of all study subjects (Table 2).

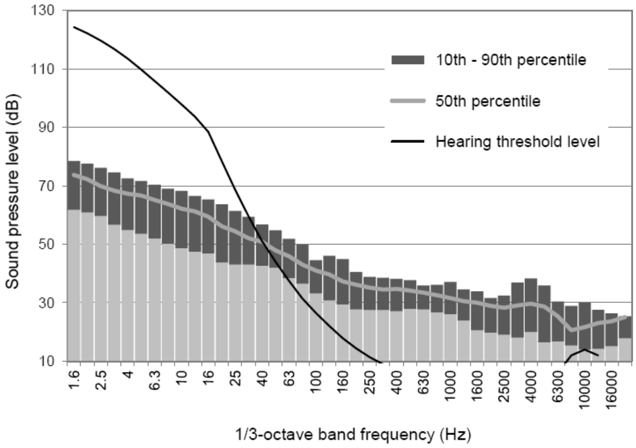


Fig. 1. 1/3-octave band spectra of noise measured outside respondents' dwellings together with hearing threshold level in the infrasonic and audible frequency range (Leventhall *et al.*, 2003; ISO 226:2003).

It is worth underlining that over longer periods of time, the direction and speed of wind will vary and affect the actual SPL at respondent's dwelling. Moreover, unreliability related to the calculations might have led to an over- or underestimation of noise levels experienced in daily life. Thus, the mean value of the difference between measured and calculated *A*-weighted SPLs was 2.0 dB (95%CI: 1.0–3.0 dB).

Table 2. Summary results of noise calculations for areas where respondents lived together including distance of their dwellings from the nearest wind turbine.

Study group	Number of subjects	Calculated *A*-weighted sound pressure level [dB]	Calculated day-evening-night noise level, L_{den} [dB]	Distance [m]
		Mean ± SD (median) Range		
Total subjects	361	41.4±3.4 (41.5) 30.6–50.3	46.1±3.4 (46.2) 35.3–55.0	678±196 (689) 204–1384
Noise category:				
1 (≤40 dB)	107	37.4±2.0 (37.7) 30.6–40.0	42.1±2.0 (42.4) 35.3–44.7	830±152 (800) 567–1384
2 (40–45 dB)	203	42.1±1.3 (41.9) 40.1–45.0	46.8±1.3 (46.5) 44.8–49.7	665±150 (650) 317–968
3 (>45 dB)	51	46.8±1.3(46.6) 45.1–50.3	51.8±1.3 (51.3) 49.8–55.0	408±105 (392) 204–573
Distance category:				
1 (<400 m)	31	47.0±1.7 (46.6) 42.0–50.3	51.7±1.7 (51.3) 46.7–55.0	334±62 (361) 204–392
2 (400–800 m)	232	41.7±2.7 (41.7) 35.4–47.6	46.4±2.7 (46.4) 40.1–52.3	625±109 (611) 403–800
3 (>800 m)	98	38.8±2.8 (39.3) 30.6–42.4	43.5±2.8 (44.0) 35.3–47.1	913±109 (885) 801–1384

3.3. Questionnaire survey results

3.3.1. General assessment of environmental conditions

According to general questions at the beginning of the questionnaire concerning evaluation of living conditions, over half of respondents paid attention to the environmental nuisances in their place of living such as odors and air pollution (62.6%), landscape littering (55.1%) and noise from various sources (60.1%). The most frequent reported nuisances which were noticed outside the dwellings were the wind turbine noise (56.5%), road traffic noise (53.5%), noise from agricultural machinery (46.8%), and noise from hand held and stationary power tools (46.5%) (Table 3). There were no significant differences between the proportions of subjects noticing the wind turbine noise outdoors and the other aforesaid noises ($p > 0.007$). Similar relationships were observed when analyzing the perception of various nuisances indoors. However, the wind turbine noise was significantly more frequently assessed as annoying than other environmental nuisances, in particular than road-traffic noise (33.0% vs. 23.8%, $p = 0.0065$).

Generally, the wind turbine noise was noticed outdoors by 56.5% of subjects, while by 34.6% of them it was perceived indoors (Table 4). Moreover, this type of noise was perceived as annoying outdoors (i.e. as "rather annoying", "annoying" or "extremely annoying") by 33.0% of respondents. On the other hand, 21.3% of subjects said that they were annoyed indoors. But only a few of respondents were "extremely annoyed" by the wind turbine noise outdoors (3.3%) and indoors (2.5%).

The proportion of subjects who noticed the wind turbine noise outdoors decreased significantly from 77.4% in distance category below 400 m to 45.9% in distance category above 800 m (Table 4). The percentage of those perceiving the wind turbine noise indoors also decreased significantly with greater distance (58.1% at distance <400 m and 21.4% at distance >800 m). Similar relationships were observed for the proportions of respondents being annoyed by noise (both outdoors and indoors) (Fig. 2).

On the other hand, the proportion of subjects who noticed the wind turbine noise outdoors increased (but not significantly) from 56.2% in noise category of 40–45 dB to 62.7% in noise category above 45 dB (Table 4). The percentage of those annoyed by wind turbine noise outdoors also increased with higher sound pressure levels (32.5% at SPL of 40–45 dB and 41.2% at SPL >45 dB). A similar tendency was observed for

Table 3. Comparison of proportions (with 95% confidence intervals) of respondents who noticed or were annoyed by wind turbine noise with proportions of respondents who noticed or were annoyed by other environmental nuisances. Cases without significant difference were denoted ([a]) or ([b]), ($p > 0.007$). For other cases, significant differences were found.

	Proportion of respondents (95% CI) (%)	
Do notice	Outdoors	Indoors
Noise from wind turbines	56.5 (51.4–61.5)	34.6 (29.9–39.7)
Road-traffic noise	53.5 (48.3–58.5)[a]	34.1 (29.4–39.1)[b]
Noise from agricultural machinery	46.8 (41.7–52.0)[a]	24.9 (20.8–29.7)
Noise from hand held and stationary power tools	46.5 (41.5–51.7)[a]	27.1 (22.8–32.0)[b]
Odors from agriculture	41.8 (36.9–47.0)	12.5 (9.4–16.3)
Noise from flights	38.2 (33.4–43.3)	23.5 (19.5–28.2)
Odors from industries	17.5 (13.9–21.7)	6.6 (4.5–9.8)
Railway noise	5.8 (3.8–8.8)	3.0 (1.7–5.5)
Annoyed by	Outdoors	Indoors
Noise from wind turbines	33.0 (28.3–38.0)	21.3 (17.4–25.9)
Road-traffic noise	23.8 (19.7–28.5)	15.5 (12.1–19.6)
Noise from agricultural machinery	11.6 (8.7–15.4)	8.6 (6.1–12.0)
Noise from hand held and stationary power tools	17.2 (13.6–21.4)	10.8 (8.0–14.5)
Odors from agriculture	16.9 (13.4–21.1)	6.4 (4.3–9.4)
Noise from flights	18.3 (14.6–22.6)	10.8 (8.0–14.5)
Odors from industries	14.4 (11.2–18.4)	5.3 (3.4–8.1)
Railway noise	0.8 (0.2–2.6)	1.1 (0.3–2.9)

[a] No significant difference between proportions of respondents who noticed wind turbine noise and other environmental nuisance outdoors ($p > 0.007$).

[b] No significant difference between proportions of respondents who noticed wind turbine noise and other environmental nuisance indoors ($p > 0.007$).

Table 4. Proportions with 95% confidence intervals (95% CI) of respondents who noticed or were annoyed by the wind turbine noise in total and in each of the noise and distance categories. (Individual noise and distance categories were compared in pairs. To avoid the risk of mass significance, $p < 0.016$ was required for statistical significance).

	Proportion of respondents (95% CI) (%)						
	Total	Noise category			Distance category		
		1 (≤ 40 dB)	2 (40–45 dB)	3 (> 45 dB)	1 (< 400 m)	2 (400–800 m)	3 (> 800 m)
Do notice noise from wind turbines							
outdoors	56.5 (51.4–61.5)	54.2 (44.8–63.3)	56.2 (49.3–62.8)	62.7 (49.0–74.7)	77.4[a] (59.8–88.8)	58.2[b] (51.8–64.3)	45.9[a, b] (36.4–55.8)
indoors	34.6 (29.9–39.7)	36.4 (28.0–45.9)	32.0 (26.0–38.7)	41.2 (28.8–54.9)	58.1[a] (40.7–73.5)	37.1 (31.1–43.5)	21.4[a] (14.4–30.7)
Annoyed by noise from wind turbines							
outdoors	33.0 (28.3–38.0)	29.9 (22.1–39.2)	32.5 (26.5–39.2)	41.2 (28.8–54.9)	51.6[a] (34.9–68.0)	34.9 (29.1–41.3)	22.4[a] (15.3–31.8)
indoors	21.3 (17.4–25.9)	17.8 (11.6–26.2)	20.7 (15.7–26.8)	31.4 (20.3–45.1)	41.9[a, b] (26.5–59.3)	22.0[b] (17.1–27.8)	13.3[a] (7.8–21.6)

[a, b] Significant differences between pairs of distance categories ($p < 0.016$).

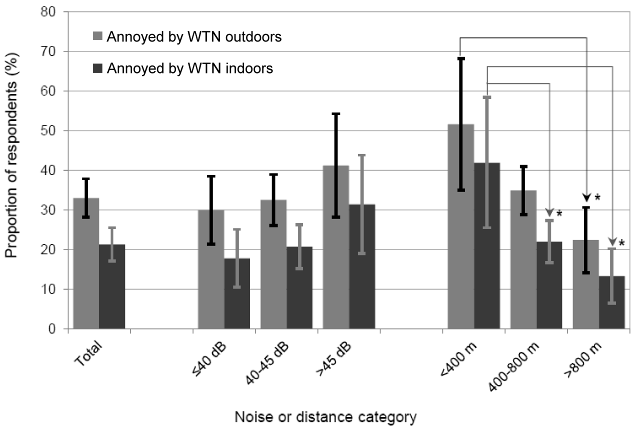


Fig. 2. Comparison of proportions (with 95% confidence intervals) of respondents being annoyed by the wind turbine noise (WTN) in various noise and distance categories and in total. Significant differences between distance categories are marked (*), ($p < 0.016$).

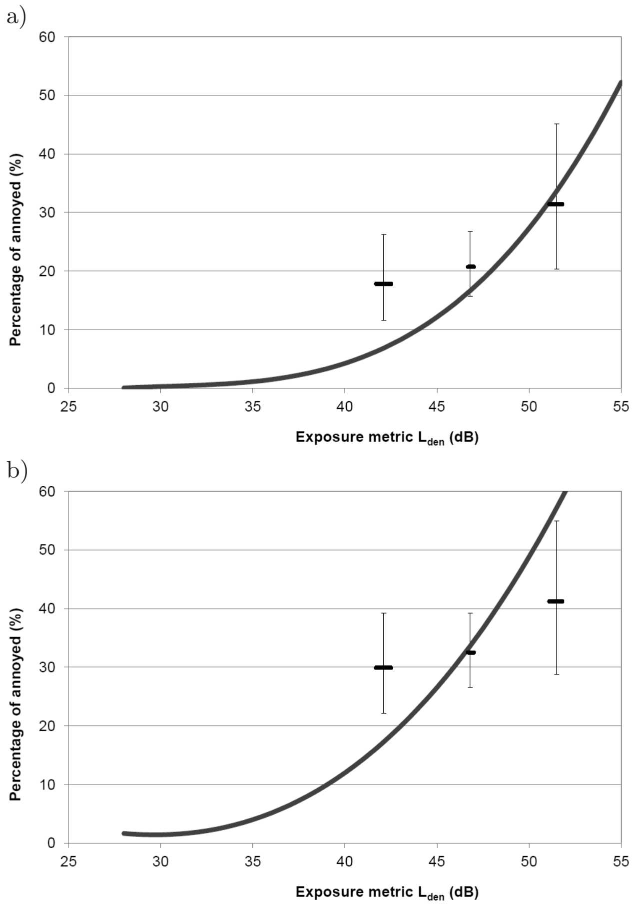


Fig. 3. Comparison of observed proportions (with 95% confidence levels) of respondents being annoyed by wind turbine noise indoors (a) and outdoors (b) to proposed exposure-response relationships for wind turbine annoyance indoors and outdoors (Janssen *et al.*, 2011). Solid lines – the percentages of annoyed residents according to Janssen *et al.* (2011), marks with whiskers – results of this study.

annoyance perception indoors. However, when analyzing the annoyance, significant differences were not observed between noise categories neither outdoors nor indoors (Table 4, Fig. 2).

Recently, based on the accessible data from Swedish and Dutch cross-sectional studies (Pedersen, Persson Waye, 2004; 2007; Pedersen *et al.*, 2009), the exposure-response relationships between the exposure metric L_{den} (annual day-evening-night noise level according to 2002/49/EC) and self-reported annoyance indoors as well as outdoors of the dwellings due to wind turbine noise were determined using the method previously applied to derive the exposure-response relationships for transportation and industrial noise (Fig. 3) (Janssen *et al.*, 2011). However, to obtain the exposure metrics L_{den}, a correction of +4.7 dB, calculated by van den Berg (2008), was added by Janssen *et al.* (2011) to the predicted A-weighted SPLs. In this way the influence of the wind speed velocity distribution at hub height on wind turbine noise was taken into consideration. Finally, four exposure-response relationships showing the percentages of annoyed and highly-annoyed residents by wind turbine noise at given L_{den}, were determined. Generally, in comparison to other sources of environmental noise, annoyance due to wind turbine noise was found at relatively low noise exposure levels.

To compare the proportions of subjects annoyed by wind turbine noise in this study with the predictions of the aforesaid exposure-response relationships, the calculated A-weighted SPLs were also corrected to obtain the exposure metrics L_{den} (see Tables 2 and 4). However, the statistical wind velocity data were not available for all investigated areas. Hence, assuming that the wind velocity distributions in Poland are similar to those observed in the Netherlands, likewise Janssen *et al.* (2011) a correction of +4.7 dB was added to the calculated A-weighted SPLs.

As can be seen in Fig. 3a, the percentages of respondents being annoyed indoors by wind turbines noise at given L_{den} levels observed in this study, fitted quite well the proposed exposure-relationship in case of noise categories of 40–45 dB and above 45 dB. However, when analyzing the perceived annoyance outdoors, a good agreement with the aforesaid predictions was observed only for most numerous noise category of 40–45 dB (Fig. 3b).

3.3.2. Nuisances related to wind turbines

According to later more specific questions concerning wind turbines, over half of the respondents (55.7%, 95% CI: 50.5–60.7%) indicated rotor blades as the main source of the wind turbine noise, while noise from the wind turbine machinery was reported only by 16.6% (95% CI: 13.1–20.8%) of them. Similarly, in all noise and distance categories, higher proportions of respondents noticed noise from the rotor blades than from the machinery.

The proportion of respondents evaluating as annoying noise accompanying operation of wind turbines increased significantly from 14.0% in noise category ≤40 dB to 28.1% in noise category of 40–45 dB (Table 5, Fig. 4). On the other hand, the greater was the distance from the nearest wind turbine, the smaller was the percentage of subjects who assessed the aforesaid noise as annoying (51.6% at distance below 400 m and 14.3% at distance above 800 m, $p < 0.016$). Thus, the relationships between noise level (or distance) and percentage of respondents being annoyed by wind turbine noise were more pronounced when analyzing annoyance in relation to subjective identification of main source (or sources) of wind turbine noise.

Table 5. Proportions with 95% confidence intervals (95% CI) of respondents who noticed and were annoyed by various nuisances including noise accompanying operation of the wind turbines in total and in each of the noise and distance categories. (Individual noise and distance categories were compared in pairs. To avoid the risk of mass significance, $p < 0.016$ was required for statistical significance. Annoyance of wind turbine noise was rated in relation to respondents' opinion on the main source (or sources) of wind turbine noise.

	Proportion of respondents (95% CI) (%)						
	Total	Noise category			Distance category		
		1 (≤40 dB)	2 (40–45 dB)	3 (> 45 dB)	1 (<400 m)	2 (400–800 m)	3 (>800 m)
Annoyed by							
Noise from wind turbine	26.0 (21.8–30.8)	14.0^{a,b} (8.6–22.0)	28.1^{a} (22.4–34.7)	43.1^{b} (30.5–56.7)	51.6^{a,b} (34.9–68.0)	27.6^{b,c} (22.2–33.7)	14.3^{a,c} (8.6–22.7)
Shadow flicker	27.1 (22.8–32.0)	17.8^{a} (11.6–26.2)	29.6 (23.7–36.2)	37.3^{a} (25.3–51.0)	32.3 (18.6–50.0)	30.6^{a} (25.0–36.8)	17.3^{a} (11.1–26.2)
Reflection from rotor blades	15.0 (11.6–19.0)	9.3 (5.0–16.6)	16.3 (11.8–22.0)	21.6 (12.4–34.9)	19.4 (8.9–36.8)	17.7^{a} (13.3–23.1)	7.1^{a} (3.3–14.3)
Often disturbed by							
Noise from wind turbine	24.1 (20.0–28.8)	22.4 (15.5–31.3)	23.2 (17.9–29.5)	31.4 (20.3–45.1)	35.5^{a} (21.1–53.2)	26.3 (21.1–32.3)	15.3^{a} (9.4–23.9)
Shadow flicker	21.3 (17.4–25.9)	15.0^{a} (9.4–23.1)	22.2 (17.0–28.4)	31.4^{a} (20.3–45.1)	32.3 (18.6–50.0)	22.8 (17.9–28.7)	14.3 (8.6–22.7)
Reflection from rotor blades	13.0 (9.9–16.9)	8.4 (4.4–15.5)	13.8 (9.7–19.3)	19.6 (10.9–32.7)	16.1 (6.7–33.3)	15.1 (11.0–20.3)	7.1 (3.3–14.3)

^{a,b,c} Significant differences between pairs of noise or distance categories ($p < 0.016$).

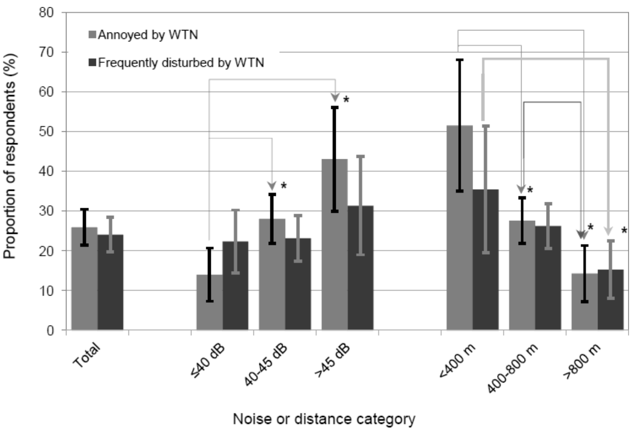


Fig. 4. Comparison of proportions (with 95% confidence intervals) of respondents who assessed wind turbine noise (WTN) as annoying (in relation to their opinion on main sources of WNT) and were frequently disturbed by WTN in total and in each of the noise and distance categories. Significant differences between noise and distance categories are marked (*), ($p < 0.016$).

About one-quarter (24.1%) of the respondents were frequently ("almost every day" or "at least once a week") disturbed by the wind turbine noise. Proportions of those frequently disturbed by the noise decreased significantly from 35.5% at distance below 400 m to 15.3% at distance above 800 m (Table 5, Fig. 4). Furthermore, both outdoors and indoors, subjects were most often annoyed by the wind turbine noise in the evening (25.2%, 95% CI: 19.8–31.6% and 16.2%, 95% CI: 11.8–21.8%).

The respondents most often perceived the wind turbine noise as annoying during relaxing outdoors (28.8%), taking walks (26.3%), quiet outdoor activities (22.2%), get-together outdoors (21.9%) (Table 6). The proportions of subjects annoyed outdoors during the aforesaid activities decreased significantly from approx. 29–48% at distance below 400 m to 9–15% at distance above 800 m (Fig. 5).

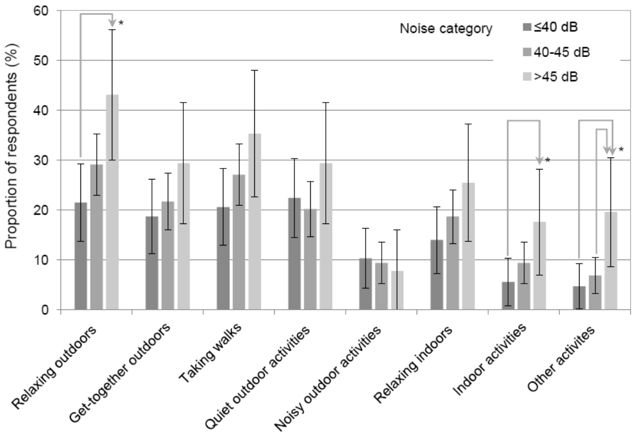
The most frequent verbal descriptors of noise characteristics were "rustling" (41.3%, 95% CI: 36.3–46.4%), "very quiet" (23.8%, 95% CI: 19.7–28.5%) and "swishing" (17.2%, 95% CI: 13.6–21.4%). Weather conditions had an impact on noise perception. 37.4% (95% CI: 32.6–42.5%) of total respondents reported that they could hear the noise more clearly than usual when wind was blowing from turbine towards their dwelling, while only 5.8% (95% CI: 3.8–8.8%) when the wind was from the opposite direction. The noise was more clearly heard when a rather strong wind was blowing (37.7%. 95% CI: 32.8–42.8%) and during warm summer nights (27.7%, 95% CI: 23.3–32.5%).

Table 6. Proportions with 95% confidence intervals (95% CI) of respondents who were annoyed by the wind turbine noise during various activities in total and in each of the noise and distance categories. (Individual noise and distance categories were compared in pairs. To avoid the risk of mass significance, $p < 0.016$ was required for statistical significance).

Activity	Proportion of subjects (95% CI) (%)						
	Total	Noise category			Distance category		
		1 (≤40 dB)	2 (40–45 dB)	3 (>45 dB)	1 (<400 m)	2 (400–800 m)	3 (>800 m)
Relaxing outdoors	28.8 (24.4–33.7)	21.5[a] (14.8–30.3)	29.1 (23.3–35.7)	43.1[a] (30.5–56.7)	48.4[a] (32.0–65.1)	31.9[b] (26.2–38.2)	15.3[a, b] (9.4–23.9)
Get-together outdoors	21.9 (17.9–26.5)	18.7 (12.4–27.2)	21.7 (16.6–27.9)	29.4 (18.7–43.1)	29.0[a] (16.0–46.8)	26.3[b] (21.1–32.3)	9.2[a, b] (4.8–16.8)
Taking walks	26.3 (22.0–31.1)	20.6 (14.0–29.3)	27.1 (21.5–33.6)	35.3 (23.7–49.1)	41.9[a] (26.5–59.3)	28.9[b] (23.4–35.0)	15.3[a, b] (9.4–23.9)
Quiet outdoor activities	22.2 (18.2–26.7)	22.4 (15.5–31.3)	20.2 (15.2–26.3)	29.4 (18.7–43.1)	32.3 (18.6–50.0)	23.7 (18.7–29.6)	15.3 (9.4–23.9)
Noisy outdoor activities	9.4 (6.8–12.9)	10.3 (5.7–17.7)	9.4 (6.0–14.3)	7.8 (2.7–19.1)	0.0 (0.0–13.4)	13.4[a] (9.6–18.4)	3.1[a] (0.7–9.1)
Relaxing indoors	18.3 (14.6–22.6)	14.0 (8.6–22.0)	18.7 (13.9–24.7)	25.5 (15.5–39.0)	35.5[a] (21.1–53.2)	19.8 (15.2–25.5)	9.2[a] (4.8–16.8)
Indoor activities	9.4 (6.8–12.9)	5.6[a] (2.4–12.0)	9.4 (6.0–14.3)	17.6[a] (9.4–30.6)	25.8[a] (13.6–43.5)	11.2[b] (7.7–16.0)	0.0[a, b] (0.0–4.7)
Other activities	8.0 (5.6–11.4)	4.7[a] (1.8–10.8)	6.9[b] (4.1–11.4)	19.6[a, b] (10.9–32.7)	25.8[a, b] (13.6–43.5)	8.2[b] (5.3–12.5)	2.0[a] (0.2–7.7)

[a, b, c] Significant differences between pairs of noise or distance categories ($p < 0.016$).

a)



b)

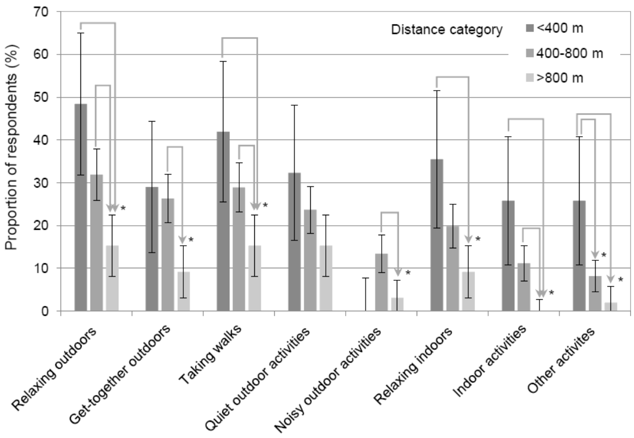


Fig. 5. Proportions (with 95% confidence intervals) of respondents who were annoyed by wind turbine noise during various activities in all noise (a) and distance (b) categories. Significant differences between noise or distance categories are marked (*), ($p < 0.016$).

Besides the noise, the shadow flickers and reflections from rotor blades were also perceived as annoying by 27.1% and 15.0% of subjects, respectively (Table 5). Almost half (54.0%, 95% CI: 48.3–59.1%) of respondents noticed shadow flickers accompanying operation of wind turbines, while reflection from rotor blades were noticed by relatively few respondents (24.9%, 95% CI: 20.8–29.7%). In particular, the proportions of those annoyed by shadow flickers were significantly higher in noise category above 45 dB than in noise category up to 40 dB (Table 5). Similar relationships (i.e. significant differences) were observed when analyzing perception and annoyance due to shadow flickering in distance categories of 400–800 m and above 800 m (30.6% vs. 17.3%, $p < 0.016$).

When asked for general assessment of wind turbines, the respondents most frequently characterized them as "necessary" (44.3%, 95% CI: 39.3–49.5%) and "annoying" (21.3%, 95% CI: 17.4–25.9%). Furthermore, subjects living at distance <400 m from the nearest wind turbine more often than those living at distance > 800 m described them as "annoying" (41.9%, 95% CI: 26.5-59.3%, vs. 13.3%, 95% CI: 7.8–21.6%, $p < 0.016$). On the other hand, subjects exposed to lower SPLs (noise category of 40-45 dB) less frequently than those exposed to higher SPLs (above 45 dB) characterized wind turbines as "annoying" (20.7%, 95% CI: 15.7–26.8%, vs. 37.3%, 95% CI: 25.3–51.0%, $p < 0.016$).

Similarities to earlier Swedish surveys (Pedersen, Persson Waye, 2004), are worth mentioning. This study showed a high correspondence between the responses to the general questions on noise from wind turbine at the beginning of the questionnaire and to the later, more specific, questions. Statistical analysis confirmed a high internal consistency of the aforesaid different questions evaluating response to wind turbine noise by Cronbach's α coefficient equal to 0.96.

3.3.3. *Factors affecting perception of annoyance related to wind turbine noise*

Generally, significant correlations were observed between subjective variables (such as sensitivity to noise or landscape littering, general attitude to wind turbines and to their visual impact, etc.) and annoyance assessment on 5-score verbal rating scale (Table 7). In particular, relatively strong correlations were observed between attitude to wind turbines in general and their visual impact on landscape in particular (Spearman's rank correlation coefficient r_s varied from −0.63 to −0.49, $p < 0.0013$). On the other hand, noise category was only weakly correlated with the annoyance rating in relation to respondents' opinion on the main source (or sources) of wind turbine noise ($r_s = 0.19$, $p < 0.0013$), while distance category was in addition correlated with the general assessment of noise annoyance indoor ($r_s = -0.22$ and $r_s = -0.17$, $p < 0.0013$).

It is worth underlining that the majority of subjective factors (i.e. sensitivity to various environmental nuisances, attitude to wind turbines, physical and mental health status) were correlated to each other. In particular, there was relatively high positive correlation between the general attitude towards wind turbines and the attitude to their visual impact in particular ($r_s = 0.73$, $p < 0.0013$) as well as between respondents' sensitivity to noise and sensitivity to landscape littering ($r_s = 0.72$, $p < 0.0013$). However, subjective factors such as sensitivity to noise or landscape littering, general attitude to wind turbines and to their visual impact, self-assessment of physical health and mental health status, expressed in the GHQ-12 score, were not correlated neither with noise category nor with distance category (Table 7).

Table 7. Relationships between noise annoyance ratings, noise category, distance category and the subjective factors in study group. Except for the score in the GHQ-12, analyzed variables were given in 5-point or 6-point scale. (Statistically significant correlations are typed in boldface. To avoid the risk of mass significance, $p < 0.0013$ was required for statistical significance).

Spearman's rank correlation coefficient r_s	Distance category	Noise category	Sensitivity to noise	Sensitivity to landscape littering	Attitude to visual impact of wind turbines	General attitude to wind turbines	Self-assessment of physical health	GHQ-12 score
WTN annoyance rating outdoors	−0.15	0.05	**0.36**	**0.47**	**−0.61**	**−0.63**	**−0.27**	**0.26**
WTN annoyance rating indoors	**−0.17**	0.09	**0.23**	**0.33**	**−0.49**	**−0.52**	**−0.28**	**0.23**
WTN annoyance rating in relation to opinion on the main source of WTN	**−0.22**	**0.19**	**0.37**	**0.46**	**−0.58**	**−0.54**	**−0.24**	**0.24**
Distance category		**−0.51**	0.00	−0.05	0.16	0.03	0.00	−0.02
Noise category			0.05	0.07	−0.10	−0.02	0.06	−0.06
Sensitivity to noise				**0.72**	**−0.28**	**−0.31**	−0.17	0.05
Sensitivity to landscape littering					**−0.43**	**−0.42**	−0.14	0.16
Attitude to visual impact of wind turbines						**0.73**	**0.26**	**−0.25**
General attitude to wind turbines							**0.32**	**−0.28**
Self-assessment of physical health								**−0.39**

WTN – wind turbine noise.

In order to analyze the impact of both objective and subjective factors on noise annoyance rating, the binary multiple logistic regression was applied with the logistic model expressed as follows:

$$p = \frac{e^{(b_0+b_1x_1+b_2x_2+\ldots+b_nx_n)}}{1+e^{(b_0+b_1x_1+b_2x_2+\ldots+b_nx_n)}},$$

where p is the probability of being annoyed ("rather annoyed", "annoyed" or "extremely annoyed") by wind turbine noise, $x_1 - x_n$ are the explanatory variables included in the model, e.g. noise category, attitude towards the wind turbines in general (negative or positive), etc., b_0, b_1, …, b_n are the regression coefficients, i.e. the logarithmic values of the odds ratio for the unit change in the respective variables.

It is worth underlining that general assessment of annoyance caused by wind turbine noise, both outdoors and indoors (i.e. answers to general questions on wind turbine noise at the beginning of the questionnaire) and noise annoyance rating in relation to respondents' subjective opinion on main noise sources (answers to more specific, later questions in the questionnaire) were correlated (r_s ranged from 0.53 to 0.72, $p < 0.0013$). Thus, only the latter noise annoyance rating was analyzed in this study. Explanatory variables were: noise and distance categories, age, gender, attitude to wind turbines in general and to their visual impact, sensitivity to noise and landscape littering, self-assessment of physical health and mental health status expressed in terms of GHQ-12 score.

Various models were created, including those containing each explanatory variable separately. However, only those in which all regression coefficients reached statistical significance are presented in Table 8.

In the first model, only the noise category was used as the independent variable. The Exp(b) = 2.16,

Table 8. Results of multiple logistic regression analyses with 95% confidence intervals. (Various models were created with objective and subjective factors as explanatory variables of variance in being annoyed by wind turbine noise category).

No.	Explanatory variable	Regression coefficient b	p-value	Odds ratio Exp(b) (95% CI)	Pseudo-R^2
1	Noise category	0.77	0.000	2.16 (1.47–3.18)	0.065
2	Distance category	−0.91	0.000	0.40 (0.26–0.63)	0.068
3	Self-assessment of physical health	1.25	0.000	3.48 (1.98–6.14)	0.073
4	GHQ-12 score	1.14	0.000	3.12 (1.75–5.55)	0.083
5	Sensitivity to noise	1.67	0.000	5.34 (2.82–10.11)	0.136
6	Sensitivity to landscape littering	1.87	0.000	6.47 (3.47–12.05)	0.176
7	Attitude to visual impact of WTs	2.37	0.000	10.70 (6.02-19.01)	0.301
8	General attitude to WTs	3.22	0.000	25.07 (12.51–50.24)	0.390
10	Noise category	0.75	0.000	2.11 (1.40–3.18)	0.186
	Sensitivity to noise	1.66	0.000	5.28 (2.76–10.09)	
11	Noise category	0.76	0.000	2.15 (1.41–3.26)	0.225
	Sensitivity to landscape littering	1.86	0.000	6.45 (3.43–12.14)	
12	Noise category	0.83	0.000	2.29 (1.46–3.58)	0.350
	Attitude to visual impact of WTs	2.44	0.000	11.50 (6.30–20.99)	
13	Noise category	1.02	0.000	2.78 (1.70–4.53)	0.445
	General attitude to WTs	3.44	0.000	31.13 (14.63–66.26)	
14	Noise category	0.80	0.001	2.23 (1.39–3.57)	0.400
	Attitude to visual impact of WTs	2.31	0.000	10.04 (5.37–18.77)	
	Sensitivity to noise	1.38	0.000	3.97 (1.90–8.29)	
15	Noise category	1.00	0.000	2.73 (1.62–4.58)	0.492
	General attitude to WTs	3.22	0.000	24.96 (11.16–55.86)	
	Sensitivity to landscape littering	1.52	0.000	4.56 (2.22–9.37)	
16	Noise category	1.24	0.000	3.44 (1.81–6.53)	0.547
	General attitude to WTs	3.71	0.000	40.74 (13.59–122.11)	
	Sensitivity to landscape littering	1.80	0.000	6.04 (2.36–15.44)	
	GHQ-12 score	1.12	0.004	3.08 (1.42–6.68)	
17	Distance category	−0.93	0.000	0.39 (0.25–0.63)	0.199
	Sensitivity to noise	1.70	0.000	5.50 (2.88–10.52)	
18	Distance category	−0.92	0.000	0.40 (0.25–0.65)	0.231
	Sensitivity to landscape littering	1.88	0.000	6.53 (3.47–12.29)	
19	Distance category	−0.69	0.009	0.50 (0.30–0.84)	0.326
	Attitude to visual impact of WTs	2.31	0.000	10.09 (5.64–18.07)	
20	Distance category	−0.98	0.000	0.37 (0.22–0.65)	0.429
	General attitude to WTs	3.27	0.000	26.43 (12.82-54.50)	
21	Distance category	−0.72	0.007	0.49 (0.29–0.83)	0.385
	Attitude to visual impact of WTs	2.18	0.000	8.81 (4.79–16.22)	
	Sensitivity to noise	1.42	0.000	4.13 (1.99–8.57)	
22	Distance category	−0.97	0.001	0.38 (0.22–0.67)	0.482
	General attitude to WTs	3.07	0.000	21.48 (9.86–46.82)	
	Sensitivity to landscape littering	1.51	0.000	4.52 (2.22–9.22)	
23	Distance category	−1.14	0.001	0.32 (0.16-0.63)	0.544
	General attitude to WTs	3.51	0.000	33.39 (11.73–95.05)	
	Sensitivity to landscape littering	1.74	0.000	5.68 (2.24–14.44)	
	GHQ-12 score	1.16	0.003	3.18 (1.48–6.83)	
24	General attitude to WTs	3.27	0.000	26.29 (10.10–68.43)	0.502
	Sensitivity to landscape littering	1.76	0.000	5.82 (2.35–14.38)	
	GHQ-12 score	1.09	0.004	2.96 (1.41–6.23)	
25	General attitude to WTs	3.00	0.000	20.13 (9.57–42.35)	0.447
	Sensitivity to landscape littering	1.54	0.000	4.65 (2.30–9.42)	

WTs – wind turbines, 95% CI – 95% confidence interval; GHQ-12 – 12-item Goldberg's General Health Questionnaire.

i.e. the odds ratio of being annoyed by noise from the wind turbines would increase 2.16 times from one sound category to the next. The pseudo-R^2 was 0.065, indicating that noise category explained only 6.5% of the variance in annoyance. Similar result (pseudo-$R^2 = 0.068$) was obtained for distance category as the explanatory variable (model no. 2). On the other hand, sensitivity to landscape littering (model no. 6) and general attitude to wind turbines (model no. 8) explained 17.6 and 39.0% of variance in annoyance, respectively. Thus, when the general attitude to wind turbines as explanatory variable was added to noise category (model no. 13), the pseudo-R^2 increased from 0.065 to 0.445. Including the next subjective factor, i.e. attitude to landscape littering (model no. 15) also improved the model (the pseudo-R^2 increased to 0.492). Similar results were found when analyzing distance category instead of noise category (models no. 20 and 22).

The highest value of the explained variance (54.7%) was obtained for the model containing distance category, general attitude to wind turbines, sensitivity to landscape littering and the GHQ-12 score as explanatory variables (model no. 16). Similar result (pseudo-$R^2 = 0.544$) was obtained when distance category was included into model instead of noise category (model no. 23). However, almost the same percentage (50.2%) of variance in annoyance assessment was explained when only general attitude to wind turbines, sensitivity to landscape littering and the GHQ-12 score were included in the model as explanatory variables (model no. 24). On the other hand, about 44.7% of variance in annoyance assessment might be explained by general attitude to wind turbines and individual sensitivity to landscape littering (model 25).

4. Conclusions

Nearly one third of all respondents living in the quiet countryside or in small villages in the vicinity of wind farms (at a distance of 204 m to 1384 m from the nearest turbine) were annoyed outdoors by noise accompanying operation of the wind turbines at the calculated A-weighted sound pressure level of 31–50 dB. Moreover, the aforesaid noise was also perceived as annoying indoors by approx. 21% of individuals.

There were no significant differences between the percentages of subjects noticing, both outdoors and indoors, the wind turbine noise and other environmental noises such as road traffic noise, noise from agricultural machinery as well as noise from hand held and stationary power tools used in open space. However, noise accompanying operation of the wind turbines was more frequently reported as annoying than aforesaid environmental noises, in particular road traffic noise.

The proportions of the respondents evaluating the wind turbine noise as annoying increased with increasing A-weighted sound pressure level. On the other hand, the greater was the distance from the nearest wind turbine, the smaller was the percentage of subjects who were annoyed.

Besides noise level and distance from the nearest wind turbine, subjective factors such as general attitude to wind turbines and sensitivity to landscape littering as well as current mental health status (expressed in terms of GHQ-12 score) were found to have the significant impact on noise annoyance rating. About 50% of variance in annoyance assessment might be explained by the aforesaid subjective factors.

In conclusion, the results of our study evaluating the perception of annoyance due to wind turbine noise in populated areas in Poland are in agreement with observations from earlier Swedish and Dutch cross-sectional studies. Nevertheless, further studies are needed, including a larger number of respondents with different living environments (i.e. dissimilar terrain, different urbanization and road traffic intensity) before firm conclusions can be drawn.

Acknowledgments

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