Proceedings of Meetings on Acoustics

Volume 19, 2013 http://acousticalsociety.org/

ICA 2013 Montreal
Montreal, Canada
2 - 7 June 2013

Noise
Session 3pNSa: Wind Turbine Noise II

3pNSa4. Assessment of annoyance due to wind turbine noise

Malgorzata Pawlaczyk-Luszczynska*, Adam Dudarewicz, Kamil Zaborowski, Malgorzata Zamojska and Malgorzata Waszkowska

***Corresponding author's address: Department of Physical Hazards, Nofer Institute of Occupational Medicine, 8, Sw. Teresy Str., Lodz, 91-348, Lodz, Poland, mpawlusz@imp.lodz.pl**

The overall aim of this study was to evaluate the perception and annoyance of noise from wind turbines in populated areas of Poland. The study group comprised 156 subjects. All subjects were interviewed using a 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. In addition, 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. It has been shown that the wind turbine noise at the calculated A-weighted SPL of 30–48 dB was perceived as annoying outdoors by about one third of respondents, while indoors by one fifth of them. The proportions of the respondents annoyed by the wind turbine noise increased with increasing A-weighted sound pressure level. Subjects' attitude to wind turbines in general and sensitivity to landscape littering was found to have significant impact on the perceived annoyance. Further studies are needed, including a larger number of respondents, before firm conclusions can be drawn.

Published by the Acoustical Society of America through the American Institute of Physics

Received 22 Jan 2013; published 2 Jun 2013

INTRODUCTION

Community noise is recognized as an environmental stressor, causing nuisance, decreased wellbeing, and possibly non-auditory adverse effects on health.[1] Wind turbines are relatively new sources of community noise and their impact on people living nearby has not been yet completely determined. Most of the epidemiological evidence on wind turbine noise comes from the cross-sectional studies carried out in Sweden and the Netherlands between 2000 and 2007.[2–5]

The general aim of this study was to evaluate the perception and annoyance of noise from wind turbines in populated areas of Poland. In particular, it has been attempted to analyze factors affecting the perceived annoyance.

METHODOLOGY

A pilot field study on response to wind turbine noise was carried out people living in the vicinity of three wind farms located in the central and the north-western parts of Poland. Of the 108 wind turbines in the selected areas, 42 had a power of 2 MW, 60 turbines had a power of 1.5 MW and 6 turbines of 0.15 MW. A questionnaire was applied as the main research tool.

The study group comprised 156 subjects aged from 15−82 years. They were personally asked to complete questionnaires. No exclusion criteria were applied. Therefore, each subject who agreed to participate was included in the study.

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, noise conditions outside the dwellings were at random verified by *in situ* measurements.

Questionnaires

Subjects completed a 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[2,3] and, like the aforesaid questionnaire, was constructed to mask the main intention. The responses of 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”),
- sensitivity (paying attention) to odors and air pollution, landscape littering (visual intrusions) (“definitely yes”, “yes”, “no opinion”, “no”, “definitely no”),
- general opinion on (attitude towards) wind turbine 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. 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, felling stressed, irritable), as well as quality of sleep and normal sleep habits. However, the latter data on health aspects associated with wind turbine noise will be published elsewhere.

Statistical analysis of results of this pilot study confirmed a high consistency of questions assessing response to wind turbines by Cronbach’s α coefficient equal to 0.93.

In addition, the current mental health status of respondents was assessed using 12-item Goldberg General Health Questionnaire (GHQ-12) which was adapted for Polish conditions.[6,7] This questionnaire was derived from the main version of the Goldberg General Health Questionnaire. It consists of 12 items related to two areas, i.e., inability to carry out one’s normal “healthy” functions and the appearance of new phenomena of a distressing nature. The subjects are 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”). Two methods are used for scoring the results of GHQ-12. First of all, responses to each question were coded on the scale from 0 to 3. The total score per subject was obtained by adding the sores for 12 questions. The more mental disorders reported, the higher total score of the GHQ-12. In addition, to identify so-called „cases” (i.e. persons with mental health disorders) the GHQ method was applied for the classification. The answers: “less than usual” and “no more than usual” was coded “0”, and the answers “rather more than usual”, “much more than usual” was coded “1”. The cut-off point between “none case” and “case” for the total score of the questionnaire is 2/3. So, persons with scores 3 or more were classified as cases.[6,7]

Noise exposure evaluation

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 based on the sound propagation model described in ISO 9613-2:1996.[8] In these calculations, the A-weighted sound power levels of wind turbines specified by manufactures were used. The arrangement of turbines within each of the farms were taken from the internet maps[9], while the distances between dwellings and turbines were calculated based on the GPS data collected in front of residential premises. The SON2 (version 3.3, Z.U.O “Eko-Soft”) software package was applied for noise calculations.[10]

The calculated SPLs were at random verified by *in situ* measurements. For some respondents (n=71), noise levels were measured outside their dwellings at the height of 4 meters using a sound analyzer (SVANTEK type SVAN 958). These measurements were carried out according to Polish recommendation concerning assessment of environmental noise.[11] 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.

At each measuring point, at least 5 noise samples lasting 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 bird singing and insect hum. Measurements were carried out during the day time. The meteorological parameters (i.e., temperature, humidity, atmospheric pressure, velocity and direction of wind) were simultaneously monitored using a weather station (Technoline type WS 3650 IT).

Data 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 (four categories, i.e., noise categories of 30−35 dB, 35−40 dB, 40−45 dB and 45−50 dB). as well as according to distance of their dwellings from the nearest wind turbine (four distance categories, i.e., below 400 m, 400−800 m, 800−1200 m, and 1200 m).

To analyze the impact of different subjective variables, the subjects were also sorted into subgroups according to: (i) age (younger and older subjects), (ii) gender (male and female), (iii) sensitivity to odors and air pollutions, landscape littering and noise (sensitive and not sensitive subjects), (iv) attitude toward the wind turbines in general and to the visual impact in particular (negative and positive), (v) self-assessment of physical health (negative and positive), and (vi) the GHQ-12 score. In the latter case, subjects were classified in two ways, i.e. as subjects with and without mental health disorders (cases and others) as well as high- and low-scored in the GHQ-12 individuals (i.e., scored above and below median value of 11.0).

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 the visual impact in particular) or self-assessment of physical health were categorized as “negative” while the others (i.e., “no opinion”, “positive” or “very positive”) as “positive (not negative)”. On the other hand, when analyzing attitude to various environmental nuisances, respondents who answered “definitely yes” and “yes” were classified as sensitive to noise, landscape littering or air pollution.

Answers to the questionnaire were presented as the proportions with 95% confidence intervals in the total study group as well as the proportion of number of respondents in various subgroups. Differences between various pairs of subgroups in proportions of answers were evaluated using the exact Fisher test. Mann-Whitney U test was applied to evaluate the differences between various pairs of subgroups in answers on ordinal scale.

Relationships between subjective variables (e.g., noise sensitivity and general attitude to wind turbine expressed on 5-score verbal rating scales) 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 or distance category and subjective factors) on annoyance related to the wind turbine noise. The Nagelkerke pseudo-R^2 was applied as a measure of explained variance.[12]

The statistical analysis was carried out with an assumed level of significance α=0.05 using STATISTICA (version 9.1. StatSoft, Inc.) software package.[13]

RESULTS

Study group

Generally, the majority of respondents (71.2%) 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 railroads and/or roads were also present. Almost all respondents (96.8%) could see one or more wind turbines from their dwelling, backyard or garden. Only a few (2.6%) of them had profits from the wind turbines. About half (50.6%) of respondents were employed, while 24.4% of them were pensioners. Of those working, 36.7% were farmer workers. The majority of subjects had primary (26.3%), vocational (21.8%) or secondary (high school) education (38.5%).

The mean age in the study population was 46.2±15.8 years (median value: 48.0 years). Women were more numerous than men (60.3% vs. 39.7%). However, no statistically significant differences between females and males were found regarding sensitivity to noise (and landscape littering or odors and air pollutions) as well as well-being. Similar relationships were observed for younger (aged≤48 years) and older (aged>48 years) subjects ($p<0.05$).

Over half of the subjects were classified as sensitive to noise (57.7%), landscape littering (52.6%), odors and air pollutions (60.3%). About one fifth of respondents declared negative ("very negative" or "negative") attitude towards wind turbines in general and towards their visual impact in particular. Similar fraction (21.2%) of subjects assessed their health status as poor ("poor" or "very poor"). Only a few of respondents (4.5%) reported difficulties with hearing normal speech, while 12.2% reported difficulties with understanding speech in noisy environment.

Respondents examined using the GHQ-12 obtained a mean score at the level of 11.9±4.6 which was close to the normative result for the reference Polish population (11.17±5.11).[7] However, when the GHQ method was used for the scoring, of the total respondents, only 9.0% were recognized as cases, i.e., having mental health disorders.

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 (Spearman's rank correlation coefficient r_s varied from -0.44 to 0.81, $p<0.000001$. In particular, there was relatively high positive correlation between general attitude toward wind turbines and attitude to their visual impact in particular ($r_s=0.81$, $p<0.000001$) as well as between respondents' sensitivity to noise and sensitivity to landscape littering ($r_s=0.61$, $p<0.000001$).

Noise exposure evaluation

The study subjects lived at the distance from 235 m to 2470 m from the nearest wind turbine. They were exposed to the wind turbine noise at the measured equivalent-continuous: (a) A-weighted SPLs of 37− 48 dB, (b) C-weighted SPLs of 46−66 dB, and (c) G-weighted SPLs of 61−90 dB (**TABLE 1**). The noise prevailing at respondents' dwellings included infrasonic components but at levels lower than the relevant hearing threshold levels (**FIGURE 1**).

TABLE 1. Noise exposure conditions in areas where respondents lived and distance from the nearest wind turbine. Data are given as mean values with standard deviation (median values).

	Calculated A-weighted SPL (dB)	Measured equivalent-continuous SPL (dB)			Distance (m)
		A-weighted	C-weighted	G-weighted	
Total	41.0±3.0 (40.9)	43.0±3.1 (42.6)	58.0±5.0 (63.0)	79.5±6.5 (81.4)	739.7±284.9 (732)
Noise category:					
30-35 dB	32.9±2.1 (34.2)	39.3±2.7 (37.8)	56.4±2.4 (59.1)	79.3±2.0 (78.2)	767.8±186.3 (813)
35-40 dB	38.9±0.8 (39.1)	42.4±1.2 (42.6)	58.6±4.9 (61.4)	80.8±5.8 (84.2)	842.1±279.7 (800)
40-45 dB	42.6±1.4 (42.6)	44.1±3.6 (45.7)	58.2±4.5 (59.9)	78.9±6.7 (79.0)	694.2±283.3 (640)
45-50 dB	46.0±1.0 (45.7)	41.0±3.5 (40.8)	55.9±9.2 (50.2)	77.4±10.3 (70.4)	493.0±83.7 (512)
Distance category:					
<400 m	45.0±2.4 (44.9)	40.3±2.6 (40.8)	54.9±3.7 (53.5)	76.4±5.2 (75.3)	328.9±69.1 (353)
400-800 m	41.2±3.0 (41.3)	42.8±4.0 (42.8)	57.9±6.3 (62.4)	79.2±8.5 (84.2)	629.5±110.9 (612)
800-1200 m	39.9±2.4 (39.4)	43.3±2.3 (42.6)	58.6±4.1 (59.9)	80.9±5.0 (82.8)	913.5±92.1 (891)
>1200 m	41.8±3.3 (43.6)	44.7±2.3 (45.7)	58.7±4.7 (60.8)	75.7±3.4 (77.2)	1594.6±580 (1225)

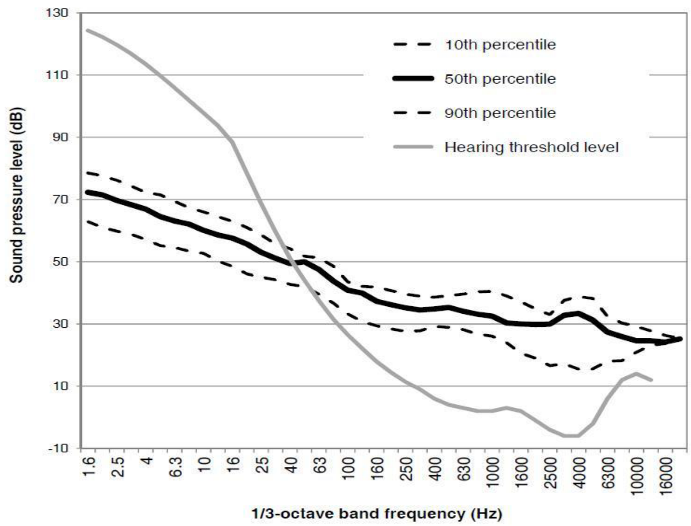


FIGURE 1. 1/3-octave band spectra of noise measured outside respondents' dwellings together with hearing threshold level in the infrasonic[14] and audible frequency range.[15]

The calculated A-weighted SPL ranged from 30 to 48 dB. Please note that mean value of difference between calculated and measured A-weighted SPLs outside respondents dwellings was 0.7 dB (95% CI ranged from -2.6 to 1.2 dB).

The most numerous noise categories were subgroups of subjects exposed to noise of the calculated A-weighted sound pressure levels of 35−40 dB (38.6%) and 40−45 dB (50.3%). On the other hand, when sorting respondents according to the distance from the nearest wind turbine, the most numerous were subgroups living at the distance of 400−800 and 800−1200 m, which comprised 61.5% and 27.6% of subjects, respectively (**TABLE 1**).

Questionnaire survey results

Over half of respondents paid attention to the environmental conditions in their place of living such as odors and air pollutions (60.3%%), landscape littering (52.6%) and noise from various sources (57.7%). The most frequent reported nuisances which were noticed outside the dwellings were the wind turbine noise (60.3%), road traffic noise (55.1%), noise from agricultural machinery (53.2%), and hand held and stationary power tools (48.7%). But there were no significant differences between the proportion of subjects noticing the wind turbine noise outdoors and the other aforesaid noises. 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 (33.3% (95% CI: 26.3−41.0%) vs. 17.3% (95% CI:12.1−24.1%), $p<0.05$).

Generally, the wind turbine noise was noticed outdoors by 60.3% of subjects, while by 39.7% of them – indoors (**TABLE 2**). Moreover, this type of noise was perceived as annoying outdoors (i.e., as “rather annoying”, “annoying” or “extremely annoying”) by 33.3% of respondents. On the other hand, 20.5% of subject said that they were annoyed indoors. But only a few of subjects were extremely annoyed by the wind turbine noise outdoors (5.2%) and indoors (3.3%).

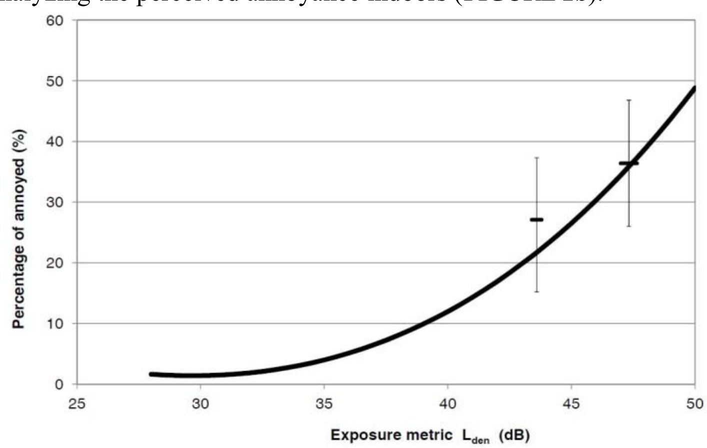
The proportions of subjects who noticed the wind turbine noise outdoors increased from 54.2% in noise category of 35−40 dB to 61.0% in noise category of 40−45 dB (**TABLE 2**). The percentage of those annoyed by wind turbine noise outdoors also increased with higher sound pressure levels (27.1% at SPL of 35−40 dB and 36.4% at 40−45 dB). Similar relationships were observed when analyzing annoyance perception indoors. On the other hand, the greater the distance from the nearest wind turbine, the smaller the percentage of subjects who were annoyed (46.9% at distance category of 400− 800 m and 23.4% at distance of 800−1200 m).

Recently, on the basis on available data from Swedish and Dutch cross-sectional studies[2–4], the exposure-response relationships between the exposure metric L_{den} (day-evening-night noise level) 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.[16] In comparison to other sources of environmental noise, annoyance due to wind turbine noise is found at relatively low noise exposure levels.

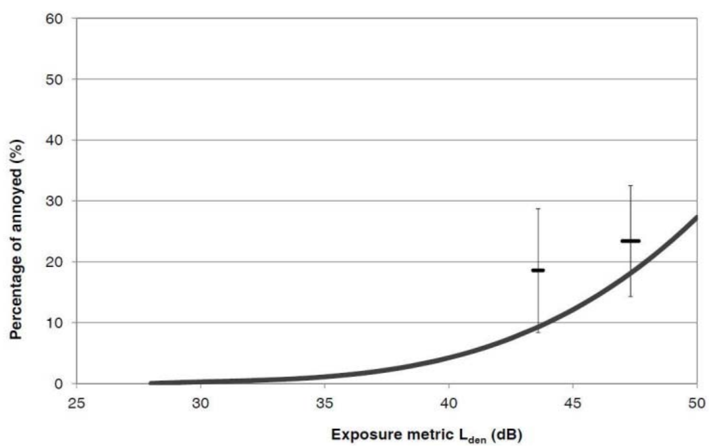
TABLE 2. Proportions with 95% confidence intervals (95% CI) of respondents who noticed or were annoyed by the wind turbine noise in various noise and distance categories and in total. Significant differences between distance categories are marked (*) ($p<0.05$).

Proportion (95% CI) (%)	Do notice noise from wind turbines outdoors	Do notice noise from wind turbines indoors	Annoyed by noise from wind turbines outdoors	Annoyed by noise from wind turbines indoors
Total	60.3 (52.6-67.9)	39.7 (32.1-47.4)	33.3 (26.3-41.0)	20.5 (14.1-26.9)
Noise category:				
30-35 dB	50.0 (16.7-83.3)	16.7 (1.1-58.2)	0.0 (0.0-44.3)	0.0 (0.0-44.3)
35-40 dB	54.2 (40.7-66.1)	40.7 (28.8-52.5)	27.1 (16.9-39.0)	18.6 (8.5-28.8)
40-45 dB	61.0 (50.6-71.4)	40.3 (29.9-51.9)	36.4 (26.0-46.8)	23.4 (14.3-32.5)
45-50 dB	90.9 (72.7-100.0)	45.5 (18.2-72.7)	63.6 (36.4-90.9)	18.2 (4.0-48.9)
Distance category:				
<400 m	100.0 (59.6-100.0)	85.7 (57.1-100.0)	71.4 (42.9-100.0)	57.1 (14.3-85.7)
400-800 m	65.6 (56.3-75.0)*	46.9 (36.5-57.3)*	35.4 (26.0-44.8)	21.9 (13.5-30.2)
800-1200 m	46.5 (32.6-60.5)*	23.3 (11.6-37.2)*	23.3 (11.6-37.2)	14.0 (4.7-25.6)
>1200 m	28.6 (7.6-64.8)	0.0 (0.0-40.4)	28.6 (7.6-64.8)	0.0 (0.0-40.4)

To compare the proportions of subjects annoyed by wind turbine noise observed in this study with the predictions of the aforesaid exposure-response relationships, a correction was added to the predicted A-weighted SPLs to obtain the exposure metrics L_{den}. A correction factor of +4.7 dB calculated by van der Berg[17] was added to those data. However, due to small number of cases, the noise categories of 30−35 dB and 45−50 dB were not taken into account when analyzing the influence of noise level on proportion of respondents who were annoyed by the wind turbine noise. As can be seen in **FIGURE 2a**, observed percentages of respondents being annoyed outdoors by noise at given L_{den} levels fitted quite well to the proposed exposure-relationship for annoyance outdoors. Similar relation was found when analyzing the perceived annoyance indoors (**FIGURE 2b**).



a)



b)

FIGURE 2. Comparison of observed proportions (with 95% confidence levels) of respondents being annoyed by wind turbine noise outdoors (a) and indoors (b) to proposed exposure-response relationships for wind turbine annoyance outdoors.[16]

The subjects were most often annoyed by the wind turbine noise during relaxing outdoors (26.3%, 95% CI: 19.2−33.3%), taking walks (23.1%%, 95% CI: 16.7−30.1%) and quiet outdoor activities (21.2%, 95% CI: 14.7−27.6%) and get-together outdoors (19.9%%, 95% CI: 14.1−26,3%). The proportions of subjects annoyed during relaxing outdoors, get-together outdoors and taking walks decreased significantly from 24−31% at distance category of 400−800 m to 5−7% in distance category of 800−1200 m.

Generally, over half of the respondents (57.1%, 95% CI: 49.4−64.7%) indicated rotor blades as the main source of the wind turbine noise, while noise from the wind turbine machinery was reported only by 16.0% (95% CI: 10,3−21.8%) of them. Similar, in all noise and distance categories, a higher proportions of respondents noticed noise from the rotor blades than from the machinery. The rotor blades as a main source of noise was less frequently reported at the distance of 800−1200 m than 400−800 m (39.5% (95% CI: 25.6−53.5%) vs. 66.7% (95% CI: 57.3−76.0%), $p<0.05$). Moreover, proportions of respondents who frequently ("almost every day" or "at least once a week/several times a week") noticed noise from the rotor blades increased significantly from 8.5% (95% CI: 1.7−16.9%) in noise category of 35−40 dB to 26.0% (95% CI: 16.9−36.4%) in noise category of 40−45 dB.

The most frequent verbal descriptors of noise characteristics were "rustling" (28.2%, 95% CI: 21.2−35.3%), "swishing" (26.9%, 95% CI: 19.9−34.0%) and quiet (23.1%, 95% CI: 16.7−30.1%). Weather conditions had impact on noise perception. Of total respondents, 39.7% (95% CI: 32.1−47.4%) 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: 2.6−9.6%) − when the wind was from the opposite direction. The noise was more clearly heard when a rather strong wind was blowing (47.4%, 95% CI: 39.7−55.1%) and during warm summer nights (30.8%, 95% CI: 23.7−37.8%). However, 10.3% (95% CI: 5.8−15.4%) of subjects noticed the noise more clearly in low wind. Similar relations were observed in all analyzed noise and distance categories.

Factors affecting perception of annoyance

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

$$p = \frac{e^{(b_o + b_1 x_1 + b_2 x_2 + \ldots + b_n x_n)}}{1 + e^{(b_o + b_1 x_1 + b_2 x_2 + \ldots + b_n x_n)}} \quad (1)$$

where:

p – is the probability of being annoyed ("rather annoyed", "annoyed" or " extremely annoyed") by noise from wind turbines outdoors,

x_1−x_n – are the explanatory variables included in the model, e.g., noise category, attitude towards the wind turbines in general, etc.,

b_o, 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.

Explanatory variables were noise and distance categories, 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 the GHQ-12 score. Fourteen various models were created, including those containing each explanatory variable separately (**TABLE 3**). In the first model only noise category was used as the independent variable. The Exp(b)=2.1, i.e., the odds ratio of being annoyed by noise from the wind turbines would increase 2.1 times from one sound category to the next. The pseudo-R^2 was 0.070, indicating that noise category explained only 7% of the variance in annoyance. Similar result (pseudo-R^2=0.04) was obtained for distance category as the explanatory variable (see model no. 2). On the other hand, general attitude to wind turbines (model no. 4) explained 43.1% of variance in annoyance. Thus, after adding to noise general attitude to wind turbines as explanatory variable (model no. 12), the pseudo-R^2 increased from 0.070 to 0.527. Including the next subjective factor, i.e., attitude to landscape littering (model no. 13) also improved the model (the pseudo-R^2 increased to 0.628). The highest value of the explained variance (63.1%) was obtained for the model containing noise category, general attitude to wind turbines, sensitivity to landscape littering and the GHQ-12 score as explanatory variables (model no. 14). It is worth to underline that all regression coefficients in the above models reached statistical significance (**TABLE 3**).

TABLE 3. Results of multiple logistic regression analyses with 95% confidence intervals.

	Explanatory Variables	Regression Coefficient b (95% CI)	P-value	Odds Ratio Exp(b) (95% CI)	Pseudo-R^2
1	Noise category	0.74 (0.20-1.29)	0.007	2.10 (1.22-3.62)	0.070
2	Distance category	-0.60 (-1.19 − -0.02)	0.044	0.55 (0.30-0.98)	0.040
3	Attitude to visual impact of WTs*	2.79 (1.79-3.79)	0.000	16.29 (6.00-44.26)	0.322
4	Attitude to WTs in general	3.67 (2.39-4.96)	0.000	39.36 (10.89-142.29)	0.431
5	Sensitivity to noise	1.23 (0.43-2.04)	0.003	3.43 (1.53-7.70)	0.093
6	Sensitivity to landscape littering	1.88 (1.05-2.71)	0.000	6.56 (2.86-15.05)	0.206
7	Self-assessment of physical health	1.27 (0.47-2.08)	0.002	3.58 (1.60-8.00)	0.088
8	GHQ-12 score	0.95 (0.20-1.69)	0.013	2.58 (1.22-5.43)	0.065
9	Noise category	0.63 (0.06-1.20)	0.030	1.88 (1.06-3.31)	0.084
	Distance category	-0.38 (-0.98-0.22)	0.215	0.68 (0.37-1.25)	
10	Noise category	0.75 (0.15-1.35)	0.014	2.12 (1.16-3.85)	0.131
	GHQ-12 score	0.79 (0.02-1.57)	0.045	2.21 (1.02-4.80)	
11	Noise category	0.72 (0.15-1.30)	0.014	2.06 (1.16-3.66)	0.269
	Sensitivity to landscape littering	1.95 (1.07-2.83)	0.000	7.04 (2.92-16.95)	
12	Noise category	1.07 (0.35-1.79)	0.004	2.91 (1.42-5.98)	0.527
	Attitude to WTs in general	4.30 (2.72-5.87)	0.000	73.50 (15.25-354.33)	
13	Noise category	0.87 (0.15-1.59)	0.018	2.39 (1.17-4.91)	0.628
	Attitude to WTs in general	4.92 (2.74-7.10)	0.000	137.24 (15.47-1 217.86)	
	Sensitivity to landscape littering	1.91 (0.73-3.10)	0.002	6.78 (2.07-22.27)	
14	Noise category	0.88 (0.08-1.68)	0.032	2.41 (1.08-5.38)	0.631
	Attitude to WTs in general	4.83 (2.55-7.12)	0.000	125.69 (12.77-1 236.89)	
	Sensitivity to landscape littering	1.74 (0.49-2.99)	0.007	5.71 (1.63-19.97)	
	GHQ-12 score	1.35 (0.21-2.50)	0.020	3.88 (1.24-12.14)	

* WTs – wind turbines

CONCLUSIONS

- It has been shown that the wind turbine noise at the calculated A-weighted sound pressure level of 30−48 dB was perceived outdoors as annoying by a one third of all respondents living in the vicinity of wind farms. Moreover, about one fifth of them were annoyed indoors.
- The wind turbine noise was more frequently reported as annoying than other environmental nuisances, in particular other environmental noises.
- The proportions of the respondents annoyed by the wind turbine noise increased with increasing A-weighted sound pressure level.
- Irrespective of noise level, subjective factors such as attitude to wind turbines in general and sensitivity to landscape littering were found to influence significantly the perceived annoyance from wind turbine noise. About 63% of variance in annoyance assessment outdoors might be explained by noise, general attitude to wind turbines and sensitivity to landscape littering.
- To sum up, results of our pilot study evaluating the perception and annoyance due to wind turbine noise in populated areas in Poland are in line with observations from earlier Swedish and Dutch cross-sectional studies. However, further studies are needed, including a larger number of respondents, before firm conclusions can be drawn.

ACKNOWLEDGMENTS

This study was supported by the Ministry of Science and Higher Education of Poland (Grant IMP 18.5/2011−2012).

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