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Health impact of wind farms

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Abstract

Introduction and objective: Wind power is employed worldwide as an alternative source of energy. At the same time, however, the health effects of wind turbines have become a matter of discussion. The purpose of this study is a critical review of available reports providing arguments both for and against the construction of wind farms. The authors also attempt to propose recommendations in accordance with the Evidence-Based Medicine (EBM) guidelines. In the case of exposure to wind farms, a randomized controlled trial (RCT) is impossible. To obtain the highest-level recommendations, analysis of case-control studies or cohort studies with control groups should be performed. Preferably, it should include geostatistical analysis conducted with the use of variograms and the kriging technique. Combinations of key words were entered into the Thomson Reuters Web of Knowledge[SM] and the Internet search engine Google.

Short description of state of the art: The nuisance caused by wind turbines is stereotypically linked with the noise that they produce. Nevertheless, the visual aspect of wind farms, opinions about them, and sensitivity to sound seem to be of the greater importance. To date, the direct correlations between the vicinity of modern wind farms, the noise that wind turbines make, and possible consequences to health have not been described in peer reviewed articles. Health effects are more probably associated with some environmental factors leading to annoyance or frustration. All types of studies share the same conclusion: wind turbines can provoke annoyance. As with any project involving changes in the local environment, a certain level of irritation among the population can be expected. There are elected officials and government representatives who should decide what level of social annoyance is acceptable, and whether wind power advantages outweigh its potential drawbacks. The influence of wind turbines on human emotional and physical health is a relatively new field of research. Further analyses of these issues are justified, especially because none of the studies published in peer-reviewed journals so far meet the criteria for cohort or case-control studies.

Summary: Due to methodology, currently available research results do not allow for higher than C-level recommendations. In the case of wind farms, the ideal types of research would be: a retrospective observation of a particular group of residents before and after the wind farm construction, case-control studies or cohort studies with control groups matched in respect of socioeconomic factors, predisposition for chronic diseases, exposure to environmental risk factors, and only one variable which would differentiate cases from controls – the distance between place of residence and a wind farm.

Key words

wind farms, health effects, wind energy

INTRODUCTION AND OBJECTIVE

One of the most important problems of modern civilisation is the depletion of traditional sources of energy [1] which compels decision-makers to look for new methods to ensure energetic safety [2]. Renewable wind energy is an ecological alternative for fossil fuels, and which increases the energy independence of particular countries [3]. The development of wind energy in Poland is an excellent example of both benefits and difficulties associated with the implementation of sustainable development [4]. The need for the development of renewable energy sources (RES) results from the provisions of Directive 2009/28/CE of 23 April 2009 on the promotion of the use of energy from renewable sources [5]. This issue is also widely discussed in the strategy *Europa 2020* [6, 7].

Wind turbines as a new and strange element of the landscape are potential sources of stress associated with the environment [8, 9]. There are opinions that wind power technology may have an impact on human health, related to two primary issues: wind turbine design and infrastructure (electromagnetic frequencies from transmission lines, shadow flicker from rotor blades, etc.) and wind turbine noise (infrasound, low frequency sounds etc.). If nothing is done to control these factors and to solve existing problems, they could potentially have some effects on health. In terms of noise, both infra- and audible sound contribute to learning, sleep and cognitive problems, as well as stress and anxiety [10, 11, 12, 13, 14]. As with other achievements of civilisation, wind turbines are perceived by local communities as a potential source of adverse effects (e.g. industrial catastrophes, devastation of the natural environment, climatic changes, and diseases). They increase the probability of distrust towards some key elements of the State system, and thus the emergence of the 'risk society' [15]. That being so, the construction of wind farms evokes strong emotions and, as a consequence, results in conflicts between residents, local governments and investors [16, 17]. On the one hand, studies on social attitudes carried out in Europe and Canada provide evidence for strong support for wind power technology [18], but on the other hand, it is difficult to determine the attitudes

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of residents towards wind energy because, as long as an investment is not planned in their close neighbourhood, the so called NIMBY (*Not In My Back Yard*) effect can be observed. This refers to the situation in which social surveys show that there is social support for particular investments (e.g. wind farm construction), but at the same time, these plans arouse resistance among local communities living in the region of investment [19, 20]. When the arrangements for investment are already underway, people begin to protests, writing letters to the authorities and making demands. The world literature proves that the acceptance of wind power on a nationwide level does not correspond with acceptance at the local level. Therefore, research should be conducted in two directions, and the results ought to be taken into consideration while planning open debate [21, 22, 23].

The first wind power station in Poland was built in 2001. At the end of June 2012 in Poland, there were 619 wind power stations with a total power output of 2,189 MW. In 2011, the power output increased by 437 MW (18 MW less than in 2010). According to the Polish Wind Energy Association (PWEA), this was considerably less than the operators predicted (i.e. up to 2,000 MW) and significantly below the business possibilities. The main reason for this enfeeblement was and still is uncertainty about the system of financing and regulation [24]. Considering the geographical distribution, it may be noticed that the most favourable conditions for wind farms are in northwest Poland, and this is the region with the greatest number of wind power stations. The West Pomeranian Region is the leader (716.8 MW), followed by the Pomeranian Region (246.9 MW) and Great Poland (245.3 MW) (data from 30 June 2012) [25].

The study on the representative group of Poles demonstrated strong social support for wind energy accompanied, however, by very little knowledge of these issues [16]. The start of a wind energy investment in their surroundings may initiate protests triggered by such factors as contradictory information about the impact of wind farms on health [16, 17].

The purpose of this study is a critical review of available reports providing arguments both for and against the construction of wind farms. The authors also propose recommendations in accordance with the Evidence-Based Medicine (EBM) guidelines.

METHODS

In the case of exposure to wind farms, a randomized controlled trial (RCT) is impossible – both the examined individuals and researchers know the exposure factor. In accordance with the EBM guidelines, in order to obtain the highest-level recommendations, analysis of high quality cohort studies or case-control studies (both types with control groups) should be performed. Preferably, this should include geostatistical analysis conducted with the use of variograms and the kriging technique (Tab. 1). A high quality cohort study is referred to as the one with clearly defined comparison groups and analyses the exposure and outcomes in the same (preferably blinded), objective way in both exposed and non-exposed individuals [26].

Combinations of key words were entered into the Thomson Reuters Web of Knowledge^{SM} as well as the Internet search engine Google. In search of full texts of published articles, the authors referred also to the ResearchGate. If the terms

Table 1. Levels of evidence according to Oxford Centre for Evidence-based Medicine [26].

Level	Prevention/Aetiology/Harm
1a	SR (with homogeneity*) of RCTs.
1b	Individual RCT (with narrow Confidence Interval).
1c	All or none (when all patients died before the Rx became available, but some have now survived it; or when some patients died before the Rx became available, but none now die of it).
2a	SR (with homogeneity*) of cohort studies.
2b	Individual cohort study (including low quality RCT; e.g., <80% follow-up).
2c	'Outcomes' Research; Ecological studies.
3a	SR (with homogeneity*) of case-control studies.
3b	Individual Case-Control Study.
4	Case-series (and poor quality cohort and case-control studies**).
5	Expert opinion without explicit critical appraisal, or based on physiology, bench research or 'first principles'.

* By homogeneity is meant a systematic review that is free of worrisome variations (heterogeneity) in the directions and degrees of results between individual studies. Not all systematic reviews with statistically significant heterogeneity need be worrisome, and not all worrisome heterogeneity need be statistically significant. As noted above, studies displaying worrisome heterogeneity should be tagged with a '-' at the end of their designated level.
** By poor quality cohort study is meant one that failed to clearly define comparison groups and/or failed to measure exposures and outcomes in the same (preferably blinded), objective way in both exposed and non-exposed individuals, and/or failed to identify or appropriately control known confounders, and/or failed to carry out a sufficiently long and complete follow-up of patients. By poor quality case-control study is meant one that failed to clearly define comparison groups, and/or failed to measure exposures and outcomes in the same (preferably blinded), objective way in both cases and controls, and/or failed to identify or appropriately control known confounders.
Grades of Recommendation
A – consistent level 1 studies.
B – consistent level 2 or 3 studies or extrapolations* from level 1 studies.
C – level 4 studies or extrapolations* from level 2 or 3 studies.
D – level 5 evidence or troublingly inconsistent or inconclusive studies at any level.
*Extrapolations are where data is used in a situation that has potentially clinically important differences from the original study situation.

'wind farm' and 'health effects' are simultaneously entered into an Internet search engine, it displays 141,000 websites in Polish and 107,000 in English (data from 23 November 2012). It often happens, however, that these websites report the same outcomes. This article presents available studies published in peer-reviewed journals, which had to comply with the principles of scientific research, and can be used as a basis for recommendations formulated in accordance with the EBM guidelines [26].

The authors did not analyse coherent publications or website documents (study by M. Alves-Pereira and N.C. Branco and the study by N. Pierpont), which are often referred to by those objecting to wind farms, even though they do not meet the criteria for methodological correctness and have not been published in peer-reviewed journals. Studies such as *Assessment of wind farm impact on the environment* were not taken into consideration either, because these studies are not based on original research, and were conducted in accordance with strictly defined procedures. Studies devoted exclusively to the measurement and assessment of the noise emitted by wind turbines, and the effects of infrasound and low-frequency noise on health, both after occupational and environmental exposure, were also not analysed if the noise was not caused by wind farms.

DESCRIPTION OF STATE OF THE ART

Wind turbine impact on environmental pollution. Wind power has been recognised as a source of clean renewable energy which neither adds to global warming nor produces harmful wastes [27]. Wind power generates 50 times lower CO_2 emissions per MWh than coal combustion, even when the turbine manufacture process is considered [28]. It is estimated that in 2007 in the USA, wind power prevented the emission of almost 28 million tons of CO_2. In 2009, the emission of 106 million tons of CO_2 (per year) was avoided thanks to the use of wind power in Europe, which can be compared to the withdrawal of 25% of cars from EU traffic [29]. Thanks to wind power, Europe avoids fuel costs and thus saves €6 billion per year [29]. It is worth emphasising that CO_2, as a greenhouse gas, is the reason for climate warming.

Literature from available databases lacks articles which meet the criteria for cohort studies with control groups, or case-control studies, measuring the health impact of wind turbines in the context of environmental pollution.

Noise. Sound is a pressure wave that may differ in frequency. The human ear records sounds from 20–20,000 Hz (infrasound frequency is below 20 Hz) [30]. Noise issues depend on intensity, frequency, propagation and source type, ambient noise level, land topography between the source and receiver, type of receiver, and the receiver's position relative to the source. The effects of noise on humans may be classified into three categories:
1) subjective effects (irritation, discomfort, and dissatisfaction);
2) interference with certain activities (conversation, sleep, and learning);
3) physiological effects (anxiety, tinnitus) [30].

Sound levels related to modern wind turbines cause only the first category effects. The third category cases occur in situations such as work in industrial plants or in the vicinity of aircraft. Whether or not the sound is undesired depends on the type of sound (tonal, broadband, low frequency or pulse) and sensitivity of the person (receiver) hearing it [30]. All machines with movable parts generate sound and wind turbines are no exception (Tab. 2) [31, 32]. Turbine elements that may cause noise include: cooling fans, generator, power converter, hydraulic pumps, yaw motors, bearings and rotors. Information regarding noise generated by turbines is provided by the manufacturers and measured to international standards. This information is used to determine the level of sound at a particular site. The audibility of wind turbine operation depends on many factors (such as ambient noise) [33]. Correctly designed turbines are silent in operation, compared to, for instance, road traffic, railway, aircraft and construction work. The noise generated by operating wind turbines is very low. Outside homes located at least 500 m away (often further), the noise of a turbine producing electricity is comparable to the noise of a running stream located 50–100 m away, or to the sound of leaves rustling in a gentle wind. This may also be compared to the noise level in a room with an operating gas heater, the reading room in a library where book pages are being flipped, or an empty air-conditioned office [32]. Turbine operation noise is also lower than the noise generated by other daily activities.

Table 2. Noise sources and noise levels in dB (based on data from Pawlas, 2009 [32]).

Noise sources	Noise levels in dB
100 km/h wind; jet aircraft engines (in an engine room)	120–140
Helicopters	115
Rocket launch (distance 40 km)	77–95
Truck or bus driver's cab	97–115
1 m from a wind turbine	95–110
Jet aircraft at a distance of 250 m	105
Pneumatic hammer at a distance of 7 m	95
Truck moving at 30 m/h at a distance of 100 m	65
Noisy large office	60
Vehicle moving at 40 m/h at a distance of 100 m	55
Wind farm located 350 m away	35–45
Silent bedroom	35
Rural environment during the night	20–40

A wind turbine generates two types of noise: aerodynamic (from rotor) and mechanical (from rotating mechanisms). Aerodynamic noise has been compared to the rustle of tree branches during a breeze. Mechanical noise may be minimized by the application of proven engineering practices and planning tools to estimate wind farm noise [31]. Both the speed of wind and its direction frequently change, which cause the airstream to be seldom stable. Additionally, wind velocity increases with height, especially at night, which may lead to turbulence from nearby machinery (e.g. turbines) producing a strange noise, sometimes referred to as 'swishing' or 'thumping'. These sounds are described as very irritating and hardly disguised by ambient noise [34, 35, 36]. The spread of noise produced by wind farms depends not only on constructional solutions, the sizes and number of turbines, but also wind direction and its character (calm or turbulent). While on a summer day, even while strong wind blows, this noise is audible at a distance of no more than several hundred meters, and at night it can be heard even at a distance of several kilometres [37].

Moorhouse presented findings of scientists from the University of Salford (UK), who found that residents of 27 out of 133 sites situated near working wind farms complained about the noise at various times of the day. Since 1991, 239 formal complaints were reported, but as many as 152 referred to the same location. The investigation also revealed that in only one case the noise generated by wind turbines exceeded the law standards and caused a nuisance. In four other places, residents protested against aerodynamic noise. Analysis of meteorological data, however, suggested that the conditions necessary for this type of noise were recorded in these places for 7–15% of the time. Thus, the noise was not present for most of the time, but occurred only occasionally for several days. Concerning this, in one case a turbine control system was employed [38]. Most complaints against wind turbines, or rather discomfort caused by their work, stem from the characteristic swish of the rotor blades, not exceeding the average ambient noise level. In some cases, annoyance was related to the turbine noise, but such a noise could also be produced by passing cars, farming machinery, or household appliances [39]. It should be remembered that irritation is not a disease, and is closely related to subjective reception rather than sound intensity [35, 40, 41, 42, 43, 44].

Pedersen (2003) [45], in his in-depth literature review for the *Swedish Environmental* Protection *Agency, came to* the conclusion that wind turbines can be bothersome, and since they are strange and unnatural elements of a landscape, even their sight may be tiring for tourists in recreation areas. Nevertheless, they do not bring about any pathological changes. In 2007, Pedersen et al. [42] examined the influence of the visual aspect of the environment with wind turbines on noise perception. The results suggested that the correlation between the exposure to the noise and the health assessment is complex, and probably all variables have not yet been identified. Therefore, the influence of wind turbines on human health and well-being should be evaluated with regard to values which are important for people, also those associated with their environment and living conditions.

In their research from 2008, Pedersen and Larsman [41] assessed the visibility of wind turbines, visual attitudes and vertical visual angle (VVA) in different landscapes. Their study was related to previous outcomes demonstrating the correlation between noise annoyance experienced by residents of wind farm areas, and the contribution of visual aspects to the noise perception as well as individual attitudes towards noise [35, 42, 43, 46]. Pedersen and Larsman [41] found that wind turbines in a flat landscape are identified by residents as strange elements contrasting with the scenery, and the noise they generate was usually assessed as more tiring than in mountainous areas. The noise perception did not depend on the level of acoustic pressure, or turbine aesthetics. Hence, the conclusion that watching wind turbines every day from a house in flat and countryside areas enhances the sensation of noise. Pedersen and Larsman imply that these results indicate the importance of visual effects for the attitudes of both residents and tourists towards the sources of noise.

Findings reported by Pedersen and Persson Waye [35, 42, 43] prove that people have a tendency to perceive wind turbine sounds almost linearly with increasing sound pressure levels. Their *cross-sectional survey research* (2004: n=351; 2007: n=754) included questions about chronic diseases (diabetes, tinitus noise in ears, circulatory diseases, etc.), mental health, headaches, the feeling of fatigue, excessive tension, irritation, sleep problems (the quality of sleep, sleep disturbed by the noise, etc.). The people surveyed were also asked about their employment and working hours. Out of 754 respondents taking part in the Pedersen and Persson Waye's study [42], 39% noticed wind turbine noise outside their houses, and almost a linear increase in the proportion of the respondents who noted the noise was accompanied by noise intensification. In total, 31 of 754 respondents [42] recognised wind turbine noise as tiring and irritating, while about 5% reported sleep disorders. Additionally, the authors found that the noise was perceived as more bothersome by people with negative attitudes towards such investments. The level of annoyance was significantly lower in those individuals who derived economic benefits from wind farms than in those who did not, even though they were exposed to comparable sound levels [44]. Similar results were obtained in a study performed on a representative group of 1,277 Poles. The Polish research demonstrated that the close proximity to wind farms did not affect the subjective health assessment, and was not perceived as a contributor to a worse health state (average health assessment – X=55.3±24.6 in 2009) [47]. People who draw economic benefits from wind farm investments assess their health better than those who do not take advantage of the existence of a wind farm. The incidence of the above-mentioned health problems is similar to that observed in populations living far from such farms [48].

Similar results have also been published by other research teams on the basis of analysis of the scientific literature, such as the expert team of Colby et al. (2009) [49], the CMOH Report (2010) [50], and Van den Berg et al. (2008) [51] from the University of Groningen in the Netherlands. These authors conducted a survey-based study – Project WINDFARMperception – on people living at a distance of about 2.5 km from wind farms,. A group of 1,948 randomly-chosen residents were sent a questionnaire similar to that applied by Pedersen in Sweden (2003, 2004, 2007 and 2008). Questions about health, based on the validated General Heath Questionnaire (GHQ), were added. The completed questionnaire forms were returned by 725 (37%) respondents; others were asked to complete a shortened questionnaire. Responses to the latter did not differ from those in the full-length questionnaire. Calculations of the noise levels in the respondents' houses were based on the turbine type and the distance of a house from a wind farm, in accordance with the international standard ISO for predicting sound propagation. Exposure to the noise in the study group ranged from 24–54 dB LAeq. The surveyed complained about waking up at night, problems with falling asleep, and other ailments associated with the noise level.

Conclusions drawn from the research show that noise is the most irritating aspect of wind turbines, and that it is more troublesome at night. The higher noise levels, both outside and inside houses, cause sleep disorders and annoyance. Even with the lowest noise levels, 20% of the respondents had sleeping problems at least one night in a month [51].

In 2010, Pedersen et al. [36] suggested that if high levels of background sound can reduce annoyance by masking wind farm noise, it would be justified to erect turbines near motorways instead of quiet rural areas. This hypothesis, however, is not supported by the available data [43], which proves rather that the visual aspects of wind farms may be a more essential source of annoyance.

In 2011, Pedersen [9] described the outcomes of three cross-sectional studies:
1) performed in a flat rural region of Sweden (n = 351);
2) in suburban sites with hilly terrain in Sweden (n = 754);
3) in the Netherlands (flat landscape but with different degrees of road traffic intensity (n = 725)).

The purpose of these studies was to determine the relationship between wind turbine noise and potential adverse effects to health. To obtain information about irritation and health effects caused by wind turbine noise, people from the three areas were sent questionnaires via e-mail, and asked about several potential environmental stressors. To reduce self-reporting survey bias, the respondents were not told that the study focused on the noise emitted by wind turbines. For each respondent, sound pressure levels (dB(A)) were calculated for nearby wind turbines. The questionnaires were designed to obtain information about people's reactions to noise, and these included annoyance, pathological symptoms (chronic diseases, cardiovascular disease, diabetes, high blood pressure, impaired hearing, tinnitus), signs of stress (headaches, excessive fatigue, the feeling of stress or tension), and sleep disorders (sleep interrupted by any source of noise).

The results demonstrated that the number of respondents annoyed by wind turbines was associated with an increase in the sound pressure level, as odds ratios (OR) show with 95% confidence intervals (CI) greater than 1.0. In two of the three studies (flat areas), sleep disturbances were related to the noise levels. However, in contrast to people's tendency to notice wind turbine noise linearly with increasing sound pressure levels, sleep disturbances spiked at 40 dBA and 45 dBA instead of increasing regularly with noise levels. The results of Pedersen [9] showed that the number of those annoyed was related to an increase in sound pressure level. Such health problems as the feeling of tension, stress, or irritation were caused by noise annoyance rather than the noise itself (OR and 95%CI > 1.0). The interruption of sleep, on the other hand, was related to the sound level and annoyance (OR and 95%CI > 1.0). Pedersen holds the opinion that the self-reported health effects may be associated with the change in the environment, and not necessarily the presence of wind turbines themselves.

Nissenbaum et al. (2011) [52] reported that people living within 375–1,400 m from two US wind farms, slept worse and were more sleepy during the day than those residing 3–6.6 km from wind turbines. Moreover, they had lower summary scores on the mental component of the short form 36 health survey. Modelled dose-response curves of both sleep and health scores against a distance from the nearest turbine were significantly related to a sharp increase in effects between 1–2 km [52].

A survey carried out by Shepherd et al. in New Zealand (2011) [53] demonstrated that people who lived at a distance less than 2 km from wind turbines had a worse health-related quality of life, and suffered from sleep disturbances. Shepherd et al. (2011) [53] analysed the effects of wind turbines within a 2 km radius from wind farms, and similar to Pedersen et al., found that the primary effect of wind farms on human health is the worsening of sleep quality. An additional factor increasing the feeling of fatigue caused by wind turbines is individual sensitivity to noise. Secondary issues are lower well-being and stress-related problems. According to the authors, under specific weather conditions, the effects of wind turbine noise may be experienced even at a distance of more than 2 km from such farms. In the study conducted by Krogh et al. (2011) [54], the influence was noted of wind turbine exposure on the feeling of fatigue, sleep disturbances and headaches. The number of people affected by these problems decreased with the distance from wind farms.

Another available study is the publication by Hanning [34] which, however, is a review of the above-mentioned studies. The author pays particular attention to the role of sleep in human health. Based on the analysis of original papers, he draws the conclusion that noise from wind turbines may cause sleep disorders, and that further research in this field is necessary because of the low quality of studies conducted so far. Hanning holds the view that especially articles based on questionnaires and sleep self-evaluation are not valuable sources.

Keith et al. [31] claim that the predicted sound level from wind turbines in such places as residences, hospitals, schools, etc., in a quiet rural setting, should not be higher than 45 dB(A), which does not exceed the value recommended by the World Health Organization (WHO) for sleep and speech disturbance, moderate annoyance and hearing impairment. According to the authors [31], such a level of noise may lead to a 6.5% increase in the proportion of very annoyed people. Since publication of the study by Keith et al., new Night Noise Guidelines for Europe have been issued by the WHO European Region [14], stating that: 'The new limit is an annual average night exposure not exceeding 40 decibels (dB), corresponding to the sound from a quiet street in a residential area'. The value of 40 dB is regarded as the lowest observed adverse effect level (LOAEL) for night noise. This is based on the finding that an average night noise level of 30–40 dB for a year can affect sleep, leading to such disorders as body movements, awakening, self-reported sleep disturbance and awakenings [40]. The WHO states that even in the worst cases these effects seem modest [40].

The difference between rural and suburban areas was described in terms of the background sound level. What is interesting, is that annoyance and noise perception were related to personal expectations associated with particular types of landscape [42]. It was also implied that negative connotations caused by audible exposure to wind turbine noise are strengthened by visual exposure, which proves the role of aesthetics: 'respondents who think of wind turbines as ugly are more likely to appraise them as not belonging to the landscape and therefore feel annoyed' [42].

None of the above-mentioned studies meets the criteria for case-control studies or cohort studies with control groups. They all are level 4 studies according to the EBM.

Infrasound and low-frequency noise. Infrasound is a sound wave inaudible to humans because its frequency is too low to be detected by the human ear (1–20 Hz). Infrasound, however, is common in our environment, and is caused by natural phenomena (storms, tsunami, bolides, waterfalls, sea waves, avalanches, strong winds, thunders, tornadoes, aurora borealis, earthquakes, volcanoes, animals: elephants, giraffes, okapi, whales, alligators) and human activity (blenders, refrigerators, vacuum cleaners, air conditioners, heavy vehicles, bridge vibrations, explosions, speakers, jets and helicopters, industry: piston compressors, vacuum and gas pumps, drilling towers, turbo blowers, wind turbines, forging hammers, compressors; pipelines, fans, and film music) [11, 32, 55, 56, 57].

Wind farms produce aerodynamic noise of a large low frequency and with an infrasound component. This type of noise does not soothe at a distance as easily as higher frequency sounds. Current techniques of noise measurement seem to mask the contribution of infrasound and impulsive low frequency noise [58]. The self-reported health effects (sleep disorders, headaches, tinnitus, ear pressure, vertigo, nausea, visual blurring, tachycardia, irritability, problems with concentration and memory, and panic episodes) have been assumed to be associated with wind turbine infrasound. Studies where biological effects were observed due to infrasound exposure were conducted at sound pressure levels (145 dB and 165 dB [11, 59]; 130 dB [13]) much greater than those produced by wind turbines [60]. Wind farms are not the only source of infrasound, it is an ever-present element of the environment generated both by natural and man-made sources, which means that residents of wind farm areas had been exposed to infrasound before the wind turbines were erected.

Low frequency noise has been demonstrated to be considerably more irritating than higher frequency sounds. Additionally, it may have negative health effects, such as nausea, headaches, worse sleep, and cognitive and psychological impairment [61]. It has been proposed that infrasound, previously ignored because it is below the auditory threshold, due to the cochlear mechanism, may affect humans and contribute to adverse effects [62].

Sounds produced by many wind turbines working in one place interfere with each other, creating the noise which resembles rustling or whistling, and in certain conditions has also a tonal component. As a result, people exposed to this type of noise perceive it as much more troublesome than the noise generated by other sources. The infrasound noise level caused by wind farms is below the auditory threshold, and research results published to date prove that pathological changes in humans, resulting from exposure to sound, including infrasound, occur only when the noise is audible. Thus, the low-frequency components of wind turbine noise ranging from 100–500 Hz are the problem. The level of noise generated by turbines within this frequency range exceeds the auditory threshold. Therefore, it is not only noticeable, but also produces extra-auditory effects due to its duration, changeability, and the phenomenon of pulse noise described as 'slapping'. Leventhall claims that this pulse noise is mistaken for infrasound [55, 59]. Jakobsen (2005) [55] reports that infrasonic levels of wind turbine sound are significantly below the auditory threshold, and that depending on turbine types ('downwind' or 'upwind') there may be a difference of 30 dB in the noise level. Leventhall (2006) [59] describes natural and man-made sources of infrasound and low-frequency noise, receptors of these signals, and the reasons for misunderstanding and social anxiety. As he writes, specificity of the noise generated by wind turbines as a result of wind turbulence requires suitable evaluation criteria. The noise produced by wind farms has the tonal components and characteristics of a modulated sound signal. If these two features are audible, they make a noise that is considerably more tiring [63]. This is probably why the noise generated by wind turbines is so wearing, even if the sound levels are lower than the low-frequency noise emitted by other sources (aviation, traffic, industrial) [32].

Salt et al. (2010, 2011) [62, 64] suggest that cochlear inner hair cells may not be sensitive to low frequency sounds, but that the outer hair cells (OHC) are sensitive enough to transmit low frequency signals and cause health effects without evoking auditory sensations. This is how the authors explain the nuisance occurring during exposure to wind turbine noise, even if its levels are significantly lower than the case of other noise sources. At a conference in Rome in 2011, these authors presented their results [65] which showed that Corti's organ reacts to this range of frequency. They suggested that there is a need for further research on this issue.

Publications on infrasound (none of which has been published in a prestigious medical journal) showing the negative view of wind turbines, present analyses performed on cell colonies or animals. The studies were not conducted on pure infrasound, but always combined with audible sounds. Moreover, the noise exposure in these experiments may be compared to a direct impact of wind turbines on people at a distance of less than 1 metre for many years without a break, 24 hours a day, 7 days a week, 30–31 days a month [11, 13, 59].

The molecular changes in cells presented in the above-mentioned studies are not typical of infrasound only. They can be caused by various types of physical and chemical stimuli, such as touch, pressure changes, environmental pH changes, permeation of chemical substances through skin and mucous membrane, medicines, stimulants, or food.

None of the above-mentioned studies meets the criteria for case-control studies or cohort studies with control groups. They all are level 4 studies according to the EBM.

Electromagnetic radiation and impact on operation of telecommunication systems. Electromagnetic radiation is emitted by natural sources, such as the sun, the earth or the ionosphere. Each electric device generates an electromagnetic field. Radio frequency electromagnetic radiation is emitted by devices such as mobile phones, base stations, radar installations, remote control equipment and electric and electronic equipment. In the case of wind turbines, four potential sources of this phenomenon are listed:
1) power line connecting the turbine to the power grid;
2) turbine's generator;
3) electric transformer;
4) underground cabling.

An electromagnetic field from the connection line is at a level comparable to that generated by household appliances, therefore there are no reasons for fear. In the case of generators and underground cabling, the electromagnetic field around these elements is equal to zero. The transformer is located in such a way that no one could come close enough to experience any health effects from its electromagnetic field [66].

No publications meet the criteria for case-control studies or cohort studies with control groups, which would assess health effects of wind turbine electromagnetic radiation.

Light and shadow flicker caused by turbine rotors. The shadow flicker effects through periodic changes in light intensity and occur as a result of crossing a certain point by the turbine rotor. This effect usually takes place at dawn and dusk, when the sun is on the horizon [67]. Many factors decide whether the shadow flickering is troublesome or not (among them, the year of the wind turbine construction, distance between an observer and a turbine, orientation of a residence, flickering frequency, and duration time of this effect). Modern wind turbines constructed by leading producers work with the speed of 20/12 rpm [67].

Harding et al. [46] and Smedley et al. [68] examined the connection between photo-induced seizures (photosensitive epilepsy) and the flicker of wind turbines (or shadow flicker). The phenomenon of shadow flicker is relatively rare, since wind turbines are designed not to cause it for more than 30 hours a year. Wind turbine flicker which scatters or mirrors sunlight at frequencies greater than 3 Hz is suggested to create a potential risk of stimulating photosensitive seizures in 1.7 people per 100,000 with photosensitive epilepsy. This means that three-blade turbines should not rotate faster than 60 rpm. Large wind farms normally use considerably lower frequencies.

Wind turbines have a semi-gloss surface, therefore they do not reflect light. Turbine surfaces are convex, so light is dispersed; differences in wind direction cause the rotors of particular turbines to have different orientations; hence, it is unlikely that an observer will notice reflections of a number of turbines at the same time. Additionally, shadow flicker requires certain atmospheric conditions and position of the sun to occur. Thus, light reflections do not affect the residents' health, and only cause some irritation. This happens especially in the case of the old-type wind turbines with constant rotation amplitude (e.g. Zagórze, West Pomerania) [69].

No publications meet the criteria for case-control studies or cohort studies with control groups, which would confirm health effects of wind turbine light and shadow flickers.

'Wind Turbine Syndrome'. Van den Berg and Lutman claim that the symptoms of Wind Turbine Syndrome (WTS) derive

Table 3. List of reviewed scientific publications (from peer-reviewed journals).

Reference	Type of publication	Study design	Results	Conclusions
Burningham, 2000[19]; Jones & Eiser, 2009 [20]	Review	Literature review	Description of the NIMBY ('Not In My Back Yard') phenomenon	Despite strong support of the general public, local communities react with increasing aversion to plans for wind farm investments in their surroundings
Mroczek et al., 2010	Original	Study on a representative group of Poles (study group, n=1277 and control group, n=1169) performed with the SF-36 questionnaire	People who benefit economically from wind farms tolerate them better than those who do not take advantage of their existence	Residence in wind farm areas did not result in lower quality of life assessment and health-related problems, such as sleep disorders, fatigue, depression, or headaches, and occurred with similar frequency in places situated far from wind turbines
Mroczek et al, 2011 [48]	Original	Continuation of research analysis from 2010	Strong social support for wind energy accompanied by a superficial knowledge of RES	Education of local communities should take place before starting an investment
Leventhall, 2006 [59]	Review	Literature review	Description of low-frequency noise and infrasound sources and receptors of these signals	Pulse noise is mistaken for infrasound; specificity of the noise generated by wind turbines requires suitable evaluation criteria
Jakobsen, 2005 [55]	Review	Literature review	Infrasonic levels of wind turbine sound are considerably below the auditory threshold	The probability that wind turbine noise affects human health is very low
Salt et al., 2010 [64], 2011[62]	Review	Literature review	Cochlear inner hair cells are not sensitive to low-frequency sounds, but outer hair cells are sensitive enough to transmit low-frequency signals	Low-frequency sounds cause health effects, even though they do not create auditory sensations
Van den Berg, 2003 [37]	Original	Measurement of noise level (400 night hours for 4 months, performed at 400 and 1,500m)	Spreading of wind turbine noise depends not only on structural solutions, the size and number of turbines, but also on the wind type (calm or turbulent) and direction	Due to specificity of atmospheric phenomena, both the noise level and pulsation are more perceptible at night, which makes this noise even more tiring
Berglund, 1996 [56]	Review	Literature review	Description of infrasound sources	Infrasound is omnipresent in the natural environment
Pawlas, 2009 [32]				Infrasound is also generated by household appliances, such as air conditioners or refrigerators
Kryter, 1970 [63]	Review	Literature review	The noise generated by wind farms has the tonal components and characteristics of a modulated sound signal	These two features make the noise significantly more tiring if they are audible
Pedersen & Persson Waye, 2004 [35]	Original	A cross-sectional study was performed in Sweden in 2000 using questionnaires (n=351; response rate: 68.4%). Doses were calculated as A-weighted sound pressure levels for each respondent.	A statistically significant dose-response relationship was found, showing a higher proportion of people reporting perception and annoyance than expected from the present dose-response relationships for transportation noise	The surprisingly high proportion of annoyance may be attributed to visual and auditory impact, as well as the presence of certain sound features
Pedersen et al., 2007 [42]	original	A study performed in the Netherlands, n=754	The odds of perceiving wind turbine noise increased with higher SPL (OR 1.3; 95% CI 1.25 to 1.40). The risk of annoyance also increased with higher SPLs (OR 1.1; 95% CI 1.01 to 1.25). Annoyance and perception of wind turbines were associated with topography and urbanisation: 1) the risk of perception and annoyance was higher in rural areas; 2) in a rural setting, the risk was higher in hilly or rocky scenery than flat areas. Annoyance was associated with both objective and subjective factors and led to lower sleep quality and negative emotions	The unique features of a particular environment should be taken into consideration while planning wind farm investments in order to prevent adverse health effects.
Pedersen et al., 2009 [44]	Original	Further analysis of research results from 2007; n=725	A dose-response relationship between calculated A-weighted sound pressure levels and annoyance was noted. Wind turbine noise was perceived as more irritating than transportation or industrial noise at similar levels, probably because of specific sound features, such as a 'swishing', temporal variability, and the lack of night-time abatement. The sight of wind turbines increases negative reactions, especially when seen from a dwelling house. Annoyance was strongly related to negative attitudes towards the sight of wind turbines as an element of the landscape.	The level of annoyance is significantly lower in those individuals who derive economic benefits from wind farms than in those who do not, even if they are exposed to comparable sound levels
Pedersen et al., 2010 [36]	Original	Noise was measured using the WINDFARMperception survey in the Netherlands in 2007 (n=725). The aim of this study was to check whether wind turbine sound was masked by road traffic noise or just the opposite, increased annoyance.	Generally, annoyance with wind turbine noise was not reduced by the presence of road traffic sound, except in the situation when the levels of wind turbine noise were moderate (35–40Â dB(A) Lden), and road traffic sound level exceeded that level by at least 20Â dB(A). There was a correlation between both types of noise, but this was probably due to individual factors	The visual aspect of wind turbines and attitudes towards them are strongly related to the noise they make. The outcomes can be used to select the most suitable (possibly already noisy) sites for wind farms.

Table 3 (Continuation). List of reviewed scientific publications (from peer-reviewed journals).

Reference	Type of publication	Study design	Results	Conclusions
Pedersen et al., 2011 [9]	Original	The results of 3 cross-sectional studies: 1) performed in a flat rural region of Sweden (n = 351); 2) at suburban sites with hilly terrain in Sweden (n = 754); 3) in the Netherlands (flat landscape but with different degrees of road traffic intensity (n = 725)). The study was designed to assess the relationship between wind turbine noise and potential adverse health effects. Questionnaires were e-mailed to people in the 3 areas to obtain information about annoyance and health effects in response to wind turbines noise.	The number of people annoyed with wind turbines was related to the sound pressure level, as shown by odds ratios (OR) with 95% confidence intervals (CI) greater than 1.0. Sleep disorders were linked to the sound level in 2 of the 3 studies (areas with flat terrain). However, in contrast to the tendency to notice wind turbine noise linearly with increasing sound pressure levels, sleep disturbances spiked at 40 dBA and 45 dBA, instead of increasing regularly with noise levels	Consistent findings. All 3 studies demonstrated the same results; some associations were found with the noise produced by wind turbines
Van den Berg et al., 2008 [51]	Original	Postal survey among Dutch residents (n = 725; response rate: 37%). Assessment of their auditory and visual exposure due to wind farms in their place of residence	The nuisance of wind turbine noise increases with noise level. The research proved again that noise is more tiring if wind turbines are in view of exposed people.	The noise is particularly irritating at night; turbines are more troublesome in rural areas, and less in industrial and military areas, or near fast motorways
Colby et al., 2009 [49]	Review	Analyses of scientific literature	Subjective quality of life assessment in people exposed to wind farm noise depends on the personality, and is not perceived as having negative effects on health.	Health-related problems, such as sleep disorders, fatigue, depression, or headaches, occur with similar frequency in places situated far from wind turbines
Hanning, 2012 [34]	Review	Analyses of scientific literature	The author emphasises the importance of sleep for human health, and refers to the results reported by other authors.	Wind turbine noise may cause sleep disorders; the research quality is often too low; survey-based studies are especially assessed as being of low-quality; undoubtedly, results based on polysomnographic studies would be more accurate, but carrying out field research is neither cheap nor easy
Pedersen & Larsman, 2008 [41]	Meta-analysis	Model based on 2 original studies (n=1095)	Specific swishing and sight of wind turbines, shadow flicker and constantly rotting blades attract the attention of residents and do not let them forget about their existence. Even with sound pressure levels of about 30 dBA, nearly 3% of the population was considerably tired, which was caused by wind turbine noise. This proportion increased with the levels to 30% at sound pressure level of ca. 40 dB A.	In dwelling houses wind turbine noise may disturb the necessary mental and physiological regeneration
Shepherd et al., 2011 [53]	original	Effects of wind turbines within a 2 km radius from a wind farm	Primary effects of wind farms on human health are tiredness and worsening of sleep quality; an additional factor increasing the feeling of weariness is individual sensitivity to noise; secondary effects include lower well-being and stress-related health problems.	Under specific weather conditions, the effects of wind turbine noise may be experienced even at a distance greater than 2 km from such farms
Krogh et al., 2011 [54]	review	Literature review	The contribution of wind turbine exposure to the feeling of fatigue, sleep disorders, and headaches was observed. The number of people with such problems decreased with distance from the wind farm.	The vicinity of wind farms could be a reason for fatigue, sleep disorders and headaches
Harding, 2008 [46]	review	Literature review	In 5% of people with epilepsy, light and shadow flicker may affect well-being, which refers also to the frequency of 2.5–3 Hz; in most people, reaction of the organism occurs when the frequency is significantly higher (16 – 25 Hz)	the possible relationship between shadow flicker and seizures
Smedley 2010 [68]	original	Evaluation of shadow flicker theoretical model	The frequency of light and shadow flicker is low (below 3 Hz)	As recommended by the Epilepsy Foundation, light and shadow flicker does not exceed the frequency capable of inducing epileptic seizures (above 10 Hz)

from stress [70], and is currently deemed as misinterpreted symptoms of a response to irritation caused by sounds generated by wind turbines. Furthermore, evidence for the existence of the so-called Vibro-Acoustic Disease is not reliable, considering the sound level generated by wind turbines [39].

No publications meet the criteria for case-control studies or cohort studies with control groups, which would confirm the existence of the 'Wind Turbine Syndrome'

Visual impact, attitudes to wind turbines and other subjective factors. The above-described articles show clearly that the connection between wind turbines and human perception of them is extremely complex and related to many factors, mainly nonphysical. There is a common belief that wind farms can be a source of annoyance for some people. Peer reviewed studies show that annoyance is related to subjective factors, such as visual impact, attitudes towards wind turbines, and sensitivity to noise rather than noise itself. Although the sound pressure level in most of the peer reviewed studies was scaled to dB(A), infrasound is an element of sound measurements and was inherently accounted for in the studies. Both peer-reviewed articles and governmental health agencies admit that although wind turbine noise is not so loud that it results in hearing impairment or other undesirable health effects, it can be annoying for some people [27, 50, 71].

A large number of self-reported health effects are related to anxiety and annoyance (e.g. Pedersen (2011) [9]). According to Shargorodsky et al. [72], about 50 million adult citizens of the United States complain about tinnitus, which is statistically associated with age, racial/ethnic group, history of smoking, loud leisure-time, hypertension, firearms, occupational noise, hearing impairment and generalized anxiety disorder. In fact, anxiety disorder was the most important of all analysed factors contributing to the odds of tinnitus. Based on a study on 174 patients treated for tinnitus at the Oregon Health Sciences University Tinnitus Clinic from 1994–1997, Folmer and Griest [73] proposed that there is a relationship between insomnia and higher severity of tinnitus, as well as anxiety and irritation. Bowling et al. [74] proved that perception of the surroundings may affect human health. Problems in the place of residence (noise, crime, air pollution, rubbish, traffic) may contribute to a lower health score. In their publication from 2003, Henningsen and Priebe [75] describe the phenomenon of the 'New Environmental Illness', referring to diseases which in patients' opinions are caused by environmental factors, in spite of the fact that their symptoms do not correspond with empirical data and remain medically unexplained. Furthermore, it has been proved that annoyance-related health effects can be alleviated by behavioural and cognitive behavioural interventions [71, 76], which supports Pedersen's [9] conclusion that health effects can be explained by the cognitive stress theory. In other words, health effects seem to be associated with the change in the environment rather than infrasound or other turbine-specific variables.

There are opinions that certain wind farms are visually more aesthetic than others. These opinions are based on individual values and judgments, and are affected by the importance attributed by a particular person to the proposed site, and the importance attributed by a particular person to clean electricity production and decreasing pollution. The level of knowledge of the technology and alternative energy sources, as well as the interest in energy production, is crucial [9, 16]. Some turbine manufacturers try to improve the appearance of their machines. This led to a shift from lattice to cylindrical towers, and the introduction of sleeker and more subtle turbine machinery. Attention is also paid to the colour of turbines, which decreases its conspicuousness [77].

Visual impact, attitudes to wind turbines and other subjective factors may change in time. Regardless of its sources, environmental stress can affect the subjective assessment of the well-being of residents living close to wind farms. Research projects which meet the criteria for case-control studies or cohort studies with control groups, and confirm the importance of the visual impact, attitudes to wind turbines, and other subjective factors, are at risk of mistakes due to considerable individual differences in these variables.

SUMMARY

Wind power is employed throughout the world as an alternative source of energy. In 2007 in the United Kingdom, there were already 172 wind farms; globally there are 100,000 turbines in operation (10,000 in North America). Moreover, the so-called household wind farms, used to produce energy for the purposes of a particular household, are becoming increasingly popular. Irritation and certain health effects (sleep disorders) caused by wind turbines are stereotypically linked with the noise that they produce, especially when sound pressure levels exceed 40 db(A). Nevertheless, the visual aspect of wind farms, opinions about them and sensitivity to sound, seem to be of greater importance.

To date, direct correlations between the vicinity of modern wind farms, the noise (audible, low frequency noise, or infrasound) that they produce, and possible consequences to health have not been described in peer reviewed articles. Infrasounds are not generated exclusively by wind turbines, nor are health effects reported by people from wind farm areas exclusive to residents of these areas. Provided that visual aspects of wind turbines and attitudes towards them are stronger contributors to the state of annoyance than the noise itself, it can be assumed that the health effects reported by residents of wind farm areas are more likely to be a physical manifestation of annoyance than the effects of infrasound. This hypothesis seems to be supported by the peer-reviewed articles focused on the relationship between environmental strains and health.

The authors are involved in community public consultations with the advocates of new projects who discuss their environmental impact [16, 17]. Fears of wind turbine projects among the population are usually associated with the potential impact of such investments on their property, and above all, their health. It is obvious that new projects may arouse certain anxiety and irritation in some members of society, even before their implementation. The limited number of peer-reviewed articles about the influence of wind turbines on human emotional and physical health proves that this is a relatively new field of research. It appears justified to conduct further analyses of these issues, also in the context of public consultations with community groups in order to reduce social anxiety. Public announcement of a project should be preceded by the above-mentioned consultations, which could involve an opinion poll and community health survey, as well as the monitoring of noise and infrasound [16, 17, 78].

Due to methodology, currently available research results do not allow for higher than C-level recommendations according to the EBM guidelines. The ideal types of research on wind farms would be a retrospective observation of a particular group of residents before and after wind farm construction, as well as cohort studies or case-control studies with control groups matched with respect to socioeconomic factors, predisposition for chronic diseases, and exposure to environmental risk factors, and only differentiated by the distance between the place of residence and a wind farm. Analysis of the psychological functioning of residents and their attitudes towards changes in their surroundings is an indispensable element of such research.

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