Original Research

Factors Influencing Social Perception of Investments in the Wind Power Industry with an Analysis of Influence of the Most Significant Environmental Factor – Exposure to Noise

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Abstract

This paper presents the most significant factors – economic, social, health, and environmental – that influence public perception of investments in the wind power industry. It particularly discusses the most significant factors conditioning potential investment venue: noise emissions generated by wind turbine units. The author, on the basis of the results of his own research, an academic literature analysis, and an assessment of legal and methodological conditions, has reviewed factors influencing the assessment accuracy of such investments' impact on audible and infrasound noise, and local communities and the environment. The publication also presents hypotheses that are not scientifically validated but which prevail within society concerning the negative influence of such investments on residents' health. These hypotheses may significantly affect social behaviour and the directions of further studies concerning the scope of research.

Keywords: noise, infrasound, social costs, wind power industry

Introduction

The wind power industry is the most dynamically developing branch of the renewable power generation industry in the world. It is estimated that the power of all the functioning wind farms in the world currently amounts to slightly more than 120 gigawatts (2% of all the electrical power generated in the world). In recent years, a dynamic increase in the use of this source of energy has been witnessed – almost a 20-fold rise in power during the last dozen years [1].

A number of factors affect the social acceptance of such investments [2]. Noise and infrasound emissions, fire risk connected with wiring malfunction, windmill elements' breaking off, "shadow flicker" effects, injury to passing birds, injuries arising from pieces of ice formed on installations breaking off, and landscape changes are the most commonly described and discussed negative environmental effects. The first four of them can be curbed by technological progress and the use of modern designs of these installations.

One particular factor conditioning completion of these investments at a proper distance from people's residences is currently noise emission by wind turbine units.

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The aim of this paper is to select factors influencing social perception of investments concerning wind turbine generator systems, taking into particular consideration the influence of the factor that is most crucial for local communities: exposure to the noise emitted by such installations.

Experimental Procedures

The analysis was conducted on the basis of the author's own environmental measurements, which were intended to illustrate applied methods to assess exposure to noise generated by wind turbine units. Moreover, a critical assessment of the academic literature and economic, legal, and social determinants was made, as they influence the local community's perception of investments in the wind power industry.

A DSA-50 integral noise meter of (first-class accuracy) manufactured by SONOPAN, as well as a set of octave and third filters and a G filter (the device possesses a calibration certificate) were used for environmental measurements of noise exposure. The measurements were carried out in accordance with the procedure included in the IEC 61400-11:2002 (EN 6140-11:2003) [3] European standard, which had been modified so that the microphone's subsequent positions of the noise level meter were axially situated, between the wind turbine tower and referential point No. 1 on the leeward side. Such measures were taken to assess noise exposure within a longer range from the wind turbine unit. Measurements of noise and infrasounds emitted by 7 exemplary, different, modern, detached, randomly chosen single wind turbine units (single constructions) were taken in the Wielkopolska Region, Poland. It is worth pointing out that Wielkopolska is one of the leading areas where such investments are going to be completed within the next few years (nowadays, companies from the wind power industry are applying for permission to begin such investments in almost 80 places in Wielkopolska.

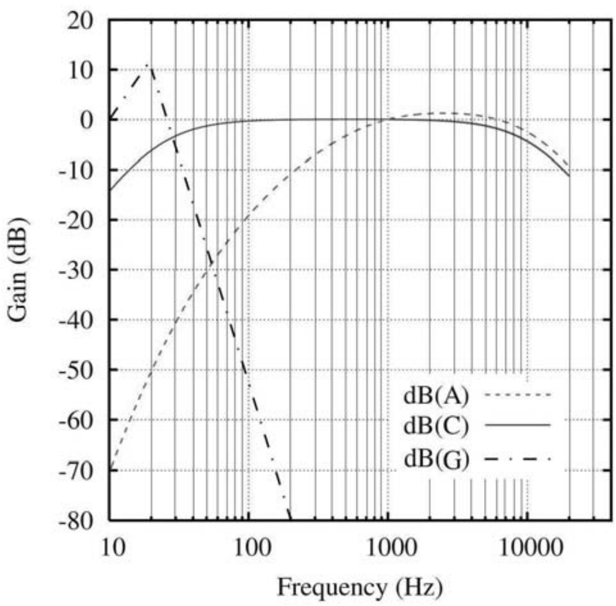

Fig. 1. Frequency characteristics of the filters used while conducting audible noise (A and C) and infrasound noise (G) measurements [10, 11]. The A curve is a curve of reference used during measurements of exposure to environmental noise. A significant drop in the sensitivity of the sound level meter to sounds below 1000 Hz during measurements with the A filter can be reported. The C curve is a curve of reference in assessments of exposure to high-intensity noise in workplaces.

On account of this publication's character, only exemplar and representational results are presented, so as to illustrate the problems concerning the determinants of such investments.

The scientific literature analysis for the purpose of this publication was carried out using the PubMed base and the Google search engine. Field measurements and scientific literature analysis were carried out between 5 April and 30 November 2010.

Results and Discussion

The Characteristics of Exposure to Noise Emitted by Wind Turbine Units

The Characteristics of Emitted Noise

A characteristic feature of noise generated by a wind turbine is its pulsating nature, for both the frequency range heard by the human ear and infrasounds, acoustic oscillations whose frequency is below the low frequency limit of audible sound (16 Hz-, or more commonly considered as 20 Hz) (IEC 1994). But this definition is incorrect, as sound remains audible at frequencies well below 16 Hz) [4, 5]. Such fluctuations in acoustic pressure within the range of low frequencies may, for example, cause vibrations near the source of infrasounds and light buildings. On account of the noise source, the noise made by wind turbines can be divided into mechanical (made by an engine pod caused by a generator, a gearbox, yaw drives, cooling fans, and auxiliary equipment), and aerodynamic – caused by moving blades. The mechanical noise is audible – its band is above 100 Hz. This frequency range does not pose a serious threat to the natural environment, which is far from the source, e.g. when an area is acoustically protected since sounds are muffled by the air or absorbed by the ground. Moreover, most wind turbines are properly insulated against the noise made by elements of the engine pod – which additionally reduces the noise. On the other hand, aerodynamic noise is generated as a result of the malfunction of a resilient centre on the tip of moving blades, turbulence, the air cavitation phenomenon, and changes in the pressure of a resilient centre when a blade passes the tower [6]. Noise generated in this way is audible, and in the form of infrasounds. Apart from noise of a determined level, sounds arising from the turbulent flow of air may appear near turbine units. In such a situation, listeners may not regard this acoustic phenomenon as a noise, but as a certain negative factor of the acoustic environment, which fades away when a turbine stops or changes its rotational speed [7]. Moreover, it is worth pointing out that the noise generated by wind turbines is characterized by the so-called "fluctuating swish" of the 500-1000 Hz frequency range [7].

Noise Propagation

Noise propagation is a significant factor that influences sound levels (and their fluctuations), and it contributes to discomfort for people living in the neighbourhood of wind turbines. The most significant factors affecting noise propagation are [4]:

- the distance factor – in the case of a spot noise source which is a single wind turbine, circular wave fronts propagate in all directions from the point's source, and the sound pressure levels decay at the rate of -6 dB per doubling of distance in the absence of atmospheric effects. However, the further from the source (a wind turbine unit), the more possible it is to discern the phenomenon of atmospheric absorption. The level of atmospheric absorption depends on the frequency of spreading sound waves and, but to a significantly lesser extent, the air temperature and its relative humidity; Fig. 2 presents an example of a noise spectrum coming from wind turbine units and within a different range from them. It is worth drawing attention to the characteristic drop in acoustic pressure within the range of higher frequencies as a function of the distance from the noise emitter (sound level A), and to the effect of wind-induced refraction. Fig. 2 shows the results of measurements confirming previous studies [4, 6, 8]. Simple mathematical models of propagation of sound waves can produce inadequate results;
- the impact of atmospheric conditions – an impact on the noise level at spots situated at different distances from the source can be made by the direction and strength of wind, refraction caused by wind and temperature gradients, distributed source effects, and in the case of low frequency noise so-called "channelling effects" may occur;

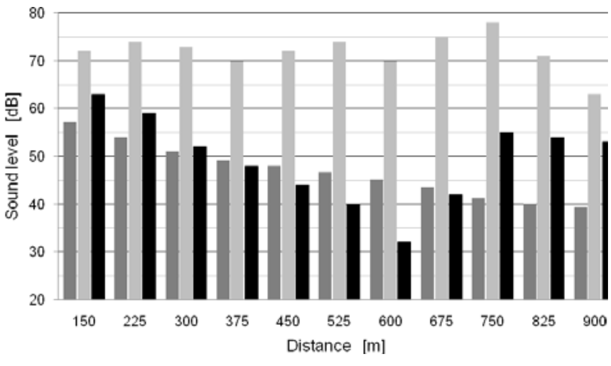

Fig. 2. The levels of sound intensity: A, G at the 50 Hz frequency on the leeward side (wind speed between 10-14 m/s) as a function of the distance from the chosen wind turbine unit of average power (about 2 MW), tower height around 100 m, bladespan of 100 m (author's own measurements). Error of an individual measurement arising from measurement instruments' activities: ±1.0 dB.

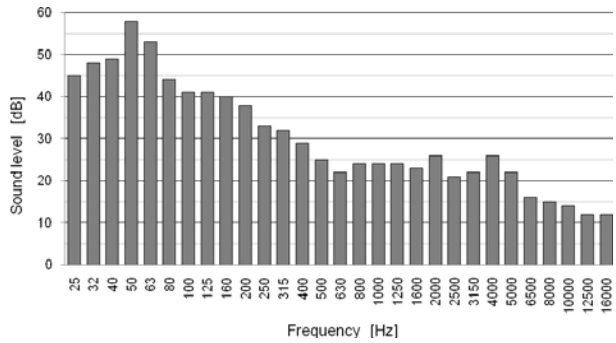

Fig. 3. An example of an audible noise frequency spectrum emitted by a wind turbine unit of average power and accompanying wind of 10-14 m/s speed as a function of the distance from the chosen wind turbine unit of average power (about 2 MW), tower height around 100 m, bladespan 100 m (author's own measurements). Error of an individual measurement arising from measurement instruments' activities: ±1.0 dB.

- landform features – an effect connected with so-called "land roughness," which impacts ground absorption, reflection, and diffraction.

Changes in noise propagation may cause fluctuations in the discomfort level of generated noise. A greater air flow at the altitude of a turbine (especially at night) and a lesser flow close to the ground can be a typical effect that is unfavourable to local residents; this may cause the noise generated by a turbine to be a greater nuisance. It is worth remembering that night-time atmospheric sound transmission is not adequately modelled in the sound transmission models [8].

Wind Impact as a Modifying Factor on Wind Farm Neighborhood's Exposure to Noise

Wind is both a natural source of noise (including infrasound noise) and the means of propelling wind turbine units, and its impact should always be taken into account when making acoustic analyses of wind turbines. During measurement at low frequencies, within a certain range from the noise source, it is not possible to distinguish between the level of noise generated by a wind turbine and wind itself. Fig. 4 presents the spectrum of the author's own measurements of the noise coming from a wind turbine unit and the background noise. It is easy to discern the overlapping of both graphs at low frequencies (at high frequencies the background noise level overlaps the lower limit of the noise meter's sensitivity). In such a situation, in the case of infrasound noise measurements, it is not possible to distinguish between the level of noise generated by a wind turbine and the wind itself. Other researchers also confirm the existence of such a phenomenon [4, 6]. This effect is especially remarkable at high wind speeds for audible frequencies, too [6]. In this case, rules on exposure (in Polish conditions) to environmental noise should be modified and possibly also take into account also the so-called "baseline sound level" – for a large spectrum of sound frequencies.

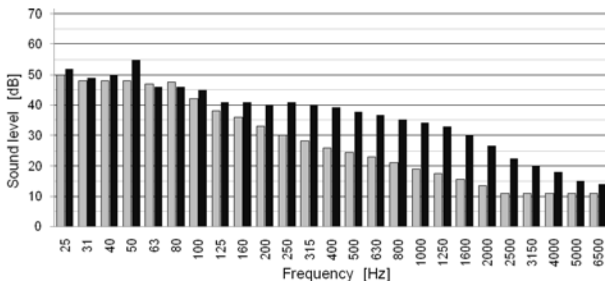

Fig. 4. An example of a background frequency spectrum (in grey) and frequencies generated by a wind turbine plus background (in black) as a function of the distance from the chosen wind turbine unit of average power (about 2 MW), tower height around 100 m, bladespan 100 m (author's own measurements). Error of an individual measurement arising from measurement instruments' activities: ±1.0 dB.

It is worth pointing out that wind, and such atmospheric phenomena as rain or lightning, generate noise possessing substantial infrasound volume, which may cause anxiety among people.

Factors Influencing Noise Perception by Local Communities Living Close to Wind Turbine Generator Systems

Subjectivity of Noise Perception

Assessing noise nuisance is subjective. It has been confirmed that noise nuisance assessments may depend on individual perceptions of these installations. Economic factors such as financial satisfaction coming from the financial benefits of such investments, may mean that polled residents can regard this investment as less bothersome.

Methodology of Environmental Noise Measurements and Exposure to Environmental Noise Modelling

The EN 61400-11:2003 standard, which is binding within the European Union, being also the International Standard IEC 61400-11, determines procedures for measuring audible and infrasound noises generated by these installations. Measuring noise within a short range from its source is a certain limitation of this method, and therefore exposure to noise within a longer range is usually estimated by specialist computer programs (modelling). Field measurements are rarely taken further from a windmill. Obtained values are related to currently applicable regulations in Poland, concerning exposure to environmental noise [9]. It is worth drawing attention to the limitations of noise measurement methodology with the aim of assessing environmental exposure to this factor. Noise level measurements using the A filter (its frequency characteristics and the characteristics of another C filter used during measurements are presented in Fig. 1) are taken in accordance with regulations applicable in Europe and Poland [10]. Whereas in the case of assessing exposure to infrasounds, it is a measurement taken with the G filter (Fig. 1) [11]. This methodology has certain limitations. The A filter curve is the curve of the human ear's sensitivity at low levels, which is, in the case of environmental noise, a correct methodology. However, on account of the noise spectrum generated by wind turbine units, it makes low frequency noise undervalued (Figs. 1 and 3). It seems that because of the muffling of sounds of higher frequency by the natural environment and the walls of buildings, using filters of different characteristics ought to be taken into account [12]. The presented characteristics of the G filter prefer frequencies close to 20 Hz, and this sensitivity fluctuates significantly toward both higher and lower frequencies. However, research concerning infrasound emissions by wind turbine units indicates that the largest emission concerns infrasounds of frequencies lower than 20 Hz [4]. Therefore, applying the methodology of noise measurement with the recommended A and G filters may lead to the possibility of understating values of the noise level near wind turbine units in the project's documentation and environmental impact assessments.

It is also worth remembering that wind may cause refraction on acoustic rays radiating from elevated point sources, e.g. a wind turbine unit [4]. This phenomenon may be particularly important in relation to low-frequency and infrasound noises, on account of their lesser extent of muffling in the atmosphere in comparison with sounds of high frequency "preferred" by the A filter. Fig. 2 presents the A and G sound levels at the 50 Hz frequency (which dominates within the noise spectrum of the wind turbine unit assessed as an example). It is worth pointing out that the A sound level decreases on account of atmospheric absorption (when the wind-induced refraction phenomenon can be discerned). Whereas, the G sound levels at the 50 Hz frequency fluctuate significantly on account of wind-induced refraction and wind generated noise overlapping with the noise coming from a turbine (measurements were taken when wind ceased to blow at the spot where the sound level meter was situated). In such a case, basic mathematical models do not allow the proper assessment of exposure to low frequency noise, and are not often adequate to assess exposure to higher frequencies. What is more, it is worth noting that the highest values of the G sound level were obtained at a distance of 750 m, and buildings in Poland are often situated at the same distance. Moreover, it is worth pointing out that in the case of environmental exposure to noise inside buildings, low frequency and infrasound noise are subject to the least extent of muffling; they can even cause special problems owing to the resonance effect. In such a case, applying research methodology targeted at a correct assessment of the level of such exposure has special importance. The characteristics of the filter to be used in the noise meter have already been suggested so as to assess the noise generated by a wind turbine in the best possible way, but this filter is not commonly used [4].

Norms of Exposure to Environmental Noise

In Poland, the values of the A sound permissible level, for areas of single family dwellings, semi-detached or terraced housing, homestead buildings, and leisure and recreation areas amount to 50-55 dB-A during the daytime and 40-45 dB-A at night. The World Health Organization has determined this level at 40 dB-A during night-time [13]. According to the World Health Organization, in cases of prolonged exposure to environmental noise at night, there are no observed biological effects of such exposure up to 30 dB outside (no observed effect level – NOEL). In the case of exposure to higher noise levels (30-40 dB), an impact on sleep in the form of more frequent occurrence of body movements, awakening, self-reported steep disturbance and arousals, has been reported. Vulnerable groups (for example children, the chronically ill, and the elderly) are more susceptible. However, even in the worst cases the effects seem modest. The noise level of 40 dB is the lowest level when adverse effects are observed (low observed adverse effect level – LOAEL). According to experimental research, which has not yet been proved, and conducted on guinea pigs (the biology of their ears is similar to that of humans), infrasounds may stimulate outer hair cells (OHC) below the auditory threshold (noise levels of 40 dB). This is contrary to prevailing opinions that state that only audible noise may have an impact on the human body. Studies in Sweden and the Netherlands have found direct relationships between modelled sound pressure level and self-reported perception of sound and annoyance, and the connection between the first two factors was stronger [14-18].

According to that research, audible noise within the range of 35 to 45 dB-A was bothersome to 4-10% of those polled.

In the case of infrasound noise, there is a lack of norms, as in the case of audible noise in the natural environment, and as a result there are no measurements of noise of this range of frequency in the documentation concerning installations' impact on the natural environment. More and more academic publications stress that the nature of low frequency noise impact on humans (audible and infrasound noise below 250 Hz) differs from noise of a different spectrum but possesses a similar level of sound intensity. Discomfort is the most significant and most often described effect of exposure to low-frequency noise. Low-frequency noise is usually described as more bothersome than noise without a majority of low-frequency components. What is most important is the fact that low-frequency noise discomfort is usually reported at relatively low levels of sound intensity. People sensitive to this kind of noise do not have to be generally sensitive to noise [19]. Among the ailments associated with discomfort from low-frequency sounds are: tiredness, irritation, anxiety, headaches or the feeling of a "heavy head", dizziness, a feeling of pulsating or pressing against eardrums, sleep disorders, and nausea [14, 20]. Some of them, particularly tiredness, headache and irritation, may affect work efficiency [14, 21, 22]. The importance of the problem of exposure to low-frequency noise in a public environment is stressed in the recently published guidelines of the World Health Organization, although there is still a lack of proper norms and legal regulations [2]. A majority of older experimental research conducted under laboratory conditions, whose aim was to assess the impact of infrasounds and low frequency sounds on human mental functions, did not provide any unambiguous results and did not allow a determination of threshold values for such measures [19, 23, 24]. Meanwhile, the results of recently conducted analyses of different research methodologies suggest that in conditions of exposure to low frequency noise of relatively low levels of acoustic pressure (40-45dB(A), disturbances of complex mental processes may occur, and people sensitive to this factor are particularly exposed to it [14, 25-27]. The problem of low-frequency noise discomfort and its impact on the fitness of human mental functions seems to be particularly important while doing activities requiring focused attention and mental effort (this applies to schools and children in their home environment).

Factors Affecting Local Communities' Perception of Future Installations in Relation to Noise Exposure

Lack of Analyses Conducted by Independent Entities before Investment Completion

The financial dependence of a company conducting analyses on an investor is an important factor that may be negatively assessed by a local community.

Lack of Quality Requirements for Companies Assessing Exposure to Environmental Noise

In Poland, companies providing such services are not required to have any certificates issued by independent accrediting institutions, which could prove their competence in the domain (there are such requirements for institutions measuring and analyzing noise levels in relation to workplaces, and they have to comply with the European EN ISO/IEC 17025:2005 standard).

The Influence of Unconfirmed Data and Publications

Both social agreements and an environmental impact assessment are some of the most important problems concerning the installation of wind power industry units. Perception of such installations is often connected with knowledge about them. Unfortunately, this is limited in Poland. There are entities in each country whose interests concerning the wind power industry are divergent. The level of subsidies described above makes investors eager to carry out such investments. There are also methodologically valid analyses of such investments' influence on the natural environment and the human body. The opinions and stances of organizations and people who resort to "ecoterrorism", exploiting the lack of a local communities' proper knowledge about this domain, are factors that disrupt a rational assessment of wind turbines' impact.

Publications devoid of any scientific values concerning the subject of wind turbines' impact on the human body are another problem. The book *Wind turbine syndrome. A report on a natural experiment* by N. Pierpont, published in the USA in 2008, is the most often used publication in public debates as it presents the negative impact of wind turbines on their neighbourhood [28]. Its author presents a subjective description of the ailments of 10 families (38 people altogether) who suffered after wind turbine units were installed in their neighbourhood. The author defined "wind turbine syndrome," whose symptoms include such subjective ailments as: sleep disorders, headaches, swooshing sounds in the ears (sometimes described as ringing in the ears), "pressure" in the ears, dizziness, nausea, irritation, deteriorated eye sharpness, problems with attention focus, and memory and panic attacks arising from a feeling of movement and quivering inside the body. According to the author, tachycardia may be a symptom that can be assessed during medical physical examination. The author suggests two reasons for the symptoms mentioned above: vestibular organ dysfunction (a part of the middle ear), as when this organ undergoes low frequency noise and vibrations, it brings disorder to the vegetative functions of the human body (frequencies of 1-2 Hz) and causes resonance inside the chest and the abdominal cavity (frequencies of 4-8 Hz). It is worth pointing out that "wind turbine syndrome" has not been described by other scientists – there is no such article in a peer-reviewed journal (the PubMed base as at 27th November 2010).

The similarity of "wind turbine syndrome" and noise annoyance may suggest previously-known symptoms connected with the influence of noise as an unspecific stressor. Although, according to the author, the described population is sufficient, as far as the statistic significance of the obtained results is concerned, it must be stated clearly that such an analysis is not methodologically or statistically sufficient to draw such conclusions.

"Vibroacoustic syndrome," described by Portuguese doctor and scientist N.A. Castello-Branco, is another term used during public debates. He uses this term to describe pathological changes that appear as a result of damage made by noise and vibrations (particularly low-frequency noise) to different tissues [6, 29]. However, changes in the organism were noticed by him only when there was a high exposure to these factors (it mostly concerned occupational exposure, e.g. an airplane pilot.

It is worth pointing out that all the publications dealing with "vibroacoustic disease" have been written by N.A. Castello-Branco and his collaborators [29-31]. The publications found in PubMed are only case series. There are no publications confirming this description of pathological changes published by other authors (the PubMed base as at 27th November 2010). During one of the latest conferences devoted to such issues (2nd International Meeting on Wind Turbine Noise 20-21 September 2007 in Lyon), Castello-Branco also presented the hypothesis that such pathological changes occur in people living near wind turbine units [30]. As with the "wind turbine syndrome" case, there are no publications in peer-review journals that describe such symptoms suffered by people who live near wind farms (the PubMed base as at 27th November 2010).

Salt et al. described the possibility of infrasound influence (low sound levels) to outer hair cells. According to these authors, this may cause the possibility that exposure to the infrasound component of wind turbine noise could influence the physiology of the ear [32].

Other Significant Factors Influencing Local Communities' Perception of Future Investments Concerning Wind Power

- economic benefits for local communities
- lack of administrative proceedings' transparency
- the actual impact of an investment in renewable sources of energy on the natural environment
- manipulating the costs of investments in the wind power industry and forecast profits from such investments
- utilizing obsolete technologies
- impact on employment and stimulating the economy

Conclusions

1. The measurements of this author and other authors indicate that the frequency spectrum of the noise generated by wind turbines is not fully reproduced by the currently applied methodology of measurements used in assessing the impact on the environment (measurements with the A and G filters), and simple mathematical models cannot properly assess noise and its impact on investments in the wind power industry. Lack of a reliable assessment of exposure to noise may cause a negative social response and induce aversion to such investments.
2. Wind turbine units are also a source of infrasounds, exposure to them is reduced by wind at a longer distance from the source. Levels of infrasound noise generated by wind turbine units are below audible thresholds. The potential health effects of infrasounds' impact below these levels need assessing.
3. On account of the huge investments in the wind power industry, there is a need to create an educational programme that would pass on basic and truthful knowledge about this domain to local communities.
4. In the case of infrasound noise measurements, it is not possible to distinguish between the level of noise generated by a wind turbine and the wind itself. The rules on exposure (in Polish conditions) to environmental noise should be modified and possibly also take into account the so-called "baseline sound level" – for large spectrum of sound frequencies.

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