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O. O. VOLKOVAIA, Candidate of Geographical Sciences
V. N. Karazin Kharkiv National University
4 Svobody Sq., Kharkiv, 61022, Ukraine
e-mail: volkovaia@karazin.ua; https://orcid.org/0000-0002-4763-6423

COMPARATIVE ENVIRONMENTAL ASSESSMENT OF WIND ENERGY PROJECTS: ACOUSTIC LOAD

Purpose. Comparative environmental assessment of wind energy projects from the perspective of the potential acoustic load on the environment: compliance with permissible values, specificity of propagation and optimization of siting. **Methods.** Analysis and synthesis of information, field research, cartographic and mathematical modelling. **Results.** In the most part of the study area, the background noise level reached rather high values, higher than the «comfort» level of 45 dB. The simulation of sound propagation from the wind turbine showed an attenuation to a value of less than 20 dB at a distance of 2 kilometers. The resulting acoustic load was calculated for the points referring to the buildings of the nearest settlements (for the case of installing the Enercon E-40 and Enercon E-115 wind turbines). The calculations of the resulting sound levels make it possible to state that the acoustic effect of the wind turbines in both siting strategies is 15-20 dB lower compared to the background noise level, the main component of which is wind noise. The excess of noise level was 5 dB for Enercon E-115, and 8-9 dB for Enercon E-40. **Conclusions.** According to the type of wind turbine, the noise level may overlap with the background level and produce a relatively less acoustic impact on the local population. Even in case of the extensive wind energy development strategy, the total noise levels will not exceed the background levels within the model site.

Keywords: acoustic load, modelling, environmental assessment, wind energy

Волковая О. О.
Харківський національний університет імені В.Н. Каразіна, Харків

ПОРІВНЯЛЬНА ЕКОЛОГІЧНА ОЦІНКА ВІТРОЕНЕРГЕТИЧНИХ ПРОЕКТІВ: АКУСТИЧНЕ НАВАНТАЖЕННЯ

Мета. Порівняльна екологічна оцінка вітроенергетичних проектів з позиції потенційного акустичного навантаження на навколишнє середовище: відповідність допустимим значенням, специфіка поширення та оптимізація розташування. **Методи.** Аналіз і синтез інформації, польові дослідження, картографічне та математичне моделювання. **Результати.** На більшій частині досліджуваної території рівень фонового шуму досягав досить високих значень, більших за рівень «комфорту» у 45 дБ. Моделювання поширення звуку від вітрогенератора показало затухання до значення менше 20 дБ на відстані 2 кілометрів. Встановлене результуюче акустичне навантаження поблизу будівель найближчих населених пунктів (в разі встановлення агрегатів Enercon E-40 та Enercon E-115). Результати розрахунків результуючих рівнів звуку дають можливість стверджувати, що акустичний вплив агрегатів за обома стратегіями розташування на 15-20 дБ нижчий у порівнянні з фоновими рівнями шуму, основною складовою яких є шум вітру. Перевищення дозволених рівнів шуму у разі використання Enercon E-115 склало 5 дБ, для Enercon E-40 – 8-9 дБ. **Висновки.** Відповідно до типу вітрогенератора, рівень шуму може перекриватися фоновим рівнем і чинити порівняно менший акустичний вплив на населення. Навіть за екстенсивної стратегії розвитку вітроенергетики сумарні рівні шуму не будуть перевищувати фонових рівнів на модельній ділянці.

Ключові слова: акустичне навантаження, моделювання, екологічна оцінка, вітроенергетика

Волковая А. А.
Харьковский национальный университет имени В. Н. Каразина, Харьков

СРАВНИТЕЛЬНАЯ ЭКОЛОГИЧЕСКАЯ ОЦЕНКА ВЕТРОЭНЕРГЕТИЧЕСКИХ ПРОЕКТОВ: АКУСТИЧЕСКАЯ НАГРУЗКА

Цель. Сравнительная экологическая оценка ветроэнергетических проектов с позиции потенциальной акустической нагрузки на окружающую среду: соответствие допустимым значениям, специфика распространения и оптимизация расположения. **Методы.** Анализ и синтез информации, полевые исследования, картографическое и математическое моделирование. **Результаты.** На большей части исследуемой территории уровень фонового шума достигал достаточно высоких значений, превышающих уровень «комфорта» в 45 дБ. Моделирование распространения звука от ветрогенератора показало затухание до значения менее 20 дБ на расстоянии 2 километров. Рассчитаны значения результирующей акустической нагрузки вблизи зданий ближайших населенных пунктов (в случае установки ветрогенераторов Enercon E-40 и

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Enercon E-115). Результаты расчетов результирующих уровней звука дают возможность утверждать, что акустическое воздействие ветрогенераторов согласно обеим стратегиями расположения на 15-20 дБ ниже по сравнению с фоновыми уровнями шума, основной составляющей которых является шум ветра. Превышение разрешенных уровней шума при использовании Enercon E-115 составило 5 дБ, для Enercon E-40 – 8-9 дБ. **Выводы.** Исходя из типа ветрогенератора, уровень шума может перекрываться фоновым уровнем и совершать сравнительно меньшее акустическое воздействие на население. Даже при экстенсивной стратегии развития ветроэнергетики суммарные уровни шума не будут значительно превышать фоновых уровней на модельной области.

Ключевые слова: акустическая нагрузка, моделирование, экологическая оценка, ветроэнергетика

Introduction

In the implementation of the wind energy project, the environmental assessment is the next stage after determining the energy potential. The future acoustic load is only a component of such an assessment, but it requires detailed consideration due to the specificity of the propagation of sound, which involves not only taking into account the absolute acoustic levels of the future installation, but also the background noise and its excesses, the presence of obstacles for the propagation of sound and objects of acoustic situation [7]. Modern wind turbines produce far less noise than previous developments. But still acoustic impact remains an important factor in the choice of the site [4]. In order to ensure environmentally sound operation, the wind power installation should be remote from residential buildings, schools and hospitals so that the noise generated by the working wind turbine does not exceed 45 dB. Distancing wind farms from settlements and places of recreation solves the problem of noise effect for people. However, noise can affect the fauna [2], and therefore needs to be considered in detail. The paper considers the approach to estimating the acoustic load and the results of the comparison of noise pollution from wind farms that are made up of installations of smaller and larger power classes.

Objects and methods of research

The initial hypothesis of the study included two statements: background noise can overlap noise from turbines; in case the wind farm is composed of several less powerful wind turbines, their total noise load may exceed the one from single more powerful installation. The object of the research was the specificity of the propagation of noise from the wind turbines in the case of a construction project of a wind farm in the west of Borova district of Kharkiv region. An analysis of the wind energy potential for the territory of research has been carried out previously, and the sites of optimal placement of wind turbines were determined [3, 10]. Within the scope of the study, inter alia, the level of a potential acoustic load from the operating wind turbine on the population of closest settlements to the proposed wind farm was analyzed. For populated areas, the sound level scale is generally accepted and should not exceed 45-50 dB.

Noise is any unwanted sound, exceeding the background sound level. Wind turbines generate noise of about 100 dB, depending on the model [9]. Noise pollution is a very effective environmental risk factor, for instance, the noise of anthropogenic origin violates the vital functions of living organisms and humans. Thus, modeling of noise effects should take into account the proximity of settlements (noise from wind turbines can propagate from a distance of 300 m to several kilometers), the level of background noise (if it is low, an acoustic effect of wind turbines is more considerable), microclimatic features of the territory (especially wind regime) [2]. Wind farms are most often located in rural areas, where the background noise level is negligible. But most of the noise from the wind turbine can be masked by background sounds such as wind noise.

Modelling the background noise of the territory. To further assess the potential acoustic effects of the wind turbines, it was decided to measure and simulate the background noise of the terrain. The state standards [5, 6, 8], which relate both to acoustic measurements in general, and noise levels studies for the needs of various industries, including the needs of wind power, were taken as the basis for measurements.

The subjects to evaluation were background noise level La (dBA) and the acoustic situation in the whole study area. Iso-Tech SLM-1352A sound meter, provided by Nerzh an Avel company, was used for the measurements. Measurements of constant noise only were carried out. The magnitude of the noise level La (dBA) was read directly from the indicators of the sound meter. To increase the accuracy of measurements, reading was carried out three times at each point, the average value La_{ave} (dBA) at the point of measurement was taken as a final. The study of the site was carried out in the afternoon in the open air according to weather conditions, which allowed to measure noise; namely: the absence of precipitation, thunder and lightning, sources of sound that are temporary in the area (tractors, motor vehicles, flying planes, etc.), wind speeds were not exceeding 10 m/s. At a wind speed of more than 1 m/s, it is necessary to apply a screen to protect the microphone from the wind. The measurement points were located along the route, with a total length of 60 km. The duration of the measurements was 6 hours, including movement between the points).

Based on the data obtained after measuring sound levels and calculations, a noise distribution surface for the research area was constructed. This stage was performed in the MapInfo and Golden Software Surfer software. The obtained surface can be analyzed on the expediency of installing wind turbines in one site or another, based on the acoustic impact on the surrounding buildings (residential, recreational, etc.). Initial data were measured at 12 points, which corresponded to the most significant, in terms of research objectives, physical and geographical characteristics of the area. Based on these measurements, sites with similar characteristics were assigned with appropriate sound level values in the MapInfo software environment. Thus, the distribution of point values was obtained, which made it possible to construct a map. At this stage, the specificity of the propagation of sound was taken into account; the sound waves in the air propagate uniformly in all directions, and their amplitude decreases with increasing distance from the source. The increase in the distance in the air twice corresponds to a decrease of the amplitude of the sound wave by half, that is, reducing the sound level by 6dB. An increase in the distance of 4 and 8 times causes a decrease of 12 dB and 18 dB respectively [1]. However, this dependence is valid only in the absence of objects that reflect or absorb sound (conditions of free sound field). To construct a surface of the background noise level, consideration of these patterns is impossible due to the lack of a clearly distinguished source of the noise. The background noise level of a territory was represented in the form of a field, which in turn could be interpreted in the form of the statistical surface. Nevertheless, to calculate the noise level from the wind turbine, this specificity has been taken into account.

For further steps, Golden Software Surfer software was used. In order to construct a background noise surface, a method of kriging was used which allows creating exact digital surfaces for irregularly distributed spatial data. The kriging method is well suited for representing data in the Earth sciences. This method is aimed to catch the trends that are foreseen in the data. For instance, high-value points are better to join along the peak, rather than isolate them using closed «bull-eye» lines. On the basis of the obtained surface, a layer of the spatial distribution of the background noise values for the investigated area was constructed.

Wind energy development strategies. The choice of a specific wind energy development model in the region is a rather scrupulous process and requires a detailed analysis of available resources and conditions. In order to carry out an environmental assessment of the project, it was necessary to rely on the specific sites of the wind turbines. Within the research, we've concentrated on two variants of the wind farm project.

Variant 1. Development of wind energy without modernization of power grids (Fig. 1). Following this strategy, financing at the stage of wind farm design and installation is minimal. Thus, when choosing the location of wind turbines, it is necessary to take into account the need to minimize the costs for land use, transport networks, and connection to the local power grid, but at the same time optimally combine it with the necessity of obtaining the highest values of production. Wind turbines should be installed in a 200 meters zone from existing power lines, taking into account the limited connection due to the possibility of overloading the networks. The strategy envisages a small number of wind turbines and the purchase of wind turbines, which were previously in use.

Within the framework of this strategy, calculations were made for the Enercon E-40, which is widely used in rural large open areas. The height of the tower is 44 m, the diameter of the wind-wheel is 40 m. This installation allows the use of wind speeds in the values from the starting 2.5 m/s to the critical 33 m/s. The estimated wind speed for the installation is 13 m/s, at such values and above the rated power of the installation amounts 500 kW. Approximate price of used equipment: 100-130 thousand euros. According to the data provided by JSK «Kharkivoblenergo», local power grids could additionally accept a maximum power load of 2 MW or 10 MW, depending on the type of connection. Thus, at the research site, 20 units of the Enercon E-40 with the capacity of 500 kW per unit or 4 units in the case of connecting with a 10 kV line can be installed. The given wind farm can be connected to a 35 kV network to an open switchgear of 35 kV of the Komarivka substation or with input lines to the overhead power lines of the 35 kV overhead line Komarivka-Izyum. Thus, the wind farm should be located in the 200 m zone from the SS Komarivka or the corresponding transmission line.

The distance between the wind turbines in order to avoid the impact of the turbulent track from neighbouring units should be from a minimum of 200 meters to a maximum of 400 meters.

The Komarivka substation is located not far from the reservoir located in the hollow (around 800 meters), forested hollows are also located north and south from the substation. Because of this, the wind speed at the substation area is slightly lower (4.5-5 m/s). With the approach to the watershed, the average annual wind speed increase, reaching its maximum value of 5.4 m/s (for a 200-meter zone near the 35 kV overhead line) near the T2109 highway.

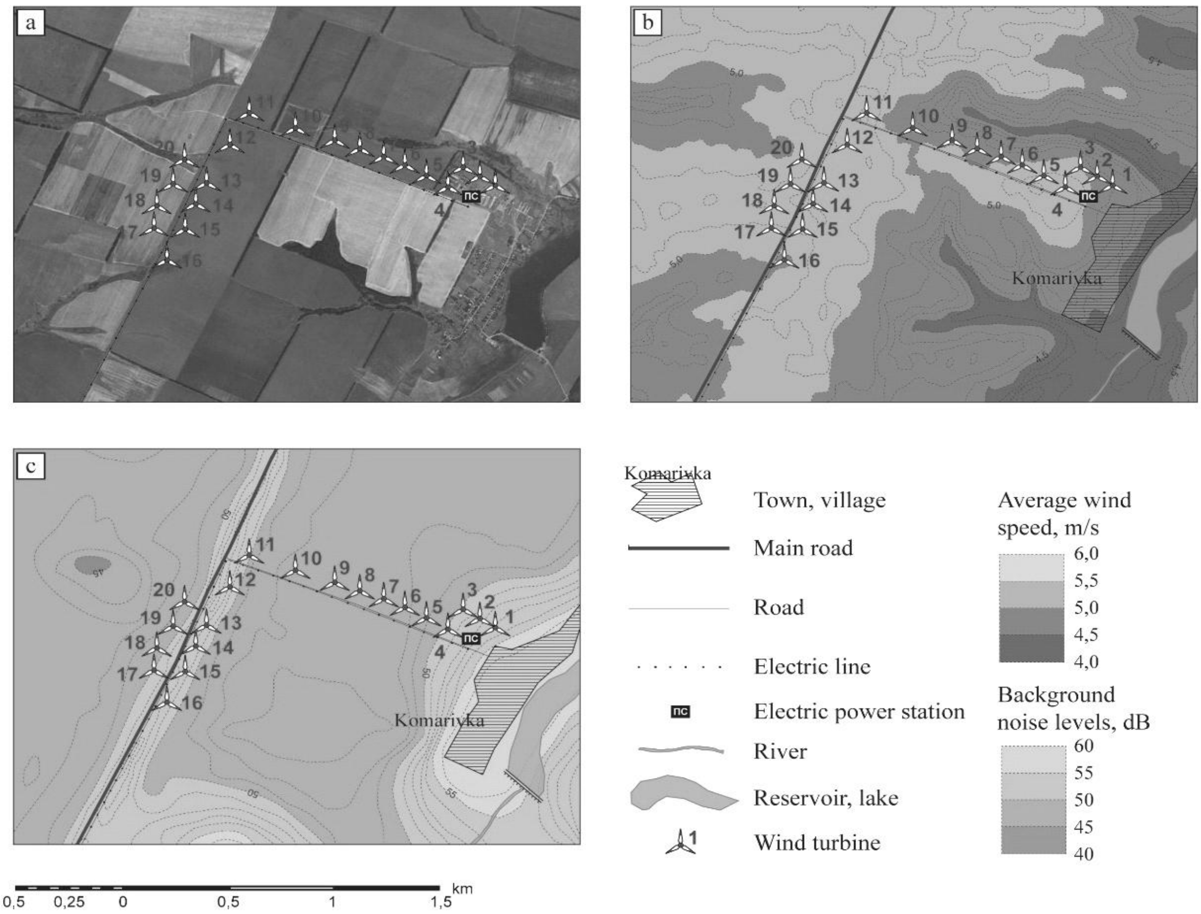

Fig. 1 – Sattelite image (a), average wind speed (b) and background noise level (c) for the site of the Enercon E-40 wind turbine according to strategy 1 (magistral principle)

Regarding the limiting parameters, the main constraint that arises in the development of this strategy is the presence of a forested hollow south of the Komarivka substation and Komarivka settlement, south-east the zone of possible installation of wind turbines. In addition, the 35 kV overhead line is located directly along the highway, and the distance of the wind turbines from the highways must be not less than 110 m. Thus, the possibility of connection to the Komarivka substation within this strategy disappears due to a combination of limiting parameters. The most favorable area is near the 35 kV overhead line in the watershed. In this case, one should choose a plot as far north as possible (wind speeds increase in this direction).

In order to reduce the cost of land withdrawal from use, this strategy focuses on wind turbines siting within the area removed from crop rotation, rocky places, pastures and slopes.

To ensure the least possible impact on the ornitho-fauna, the wind turbines should be removed from forest plantations, water bodies. Within the bounds of the limiting parameters, such a distance has already been taken into account. Since the position of the wind farm does not affect the main path of the migration of birds in the area of research, the need for the replacement of wind turbines does not occur. However, in order to reduce the probability of collisions with birds, the wind turbines should be placed at a considerable distance from each other (in this case, 400 meters is fully in line with the requirements) and topologically perpendicular to the direction of the main migration path (i.e., in a line from west to east).

It remains necessary to choose a method of grid connection. It is necessary that the transformer substation of a wind farm in accordance with the conditions of the strategy was at a distance of not more than 200 meters from the 35 kV overhead line. The method of connection (magistral or radial) depends on the total length of the cable line between the wind turbines.

Variant 2. Sufficient funding for the design of a complete wind farm, possibility to select sites with the highest potential output (Fig. 2).

For this strategy, it is necessary to use an optimal modern wind turbine. In the process of choosing a wind power unit, a wide range of models of the most well-known manufacturers was considered. Output parameters for the selection were low values of the initial wind speed (since the average wind speeds within our site belong to the lowest in accordance with European standards), the low values of the nominal wind speed (the estimated nominal wind speeds amount 10-12 m/s within the study area). Based on these parameters, the Enercon E-115 wind turbine was selected. The height of the tower is 92.5 m, the diameter of the windwheel is 115 m. This unit allows utilizing the wind speed in the range from the starting 2 m/s

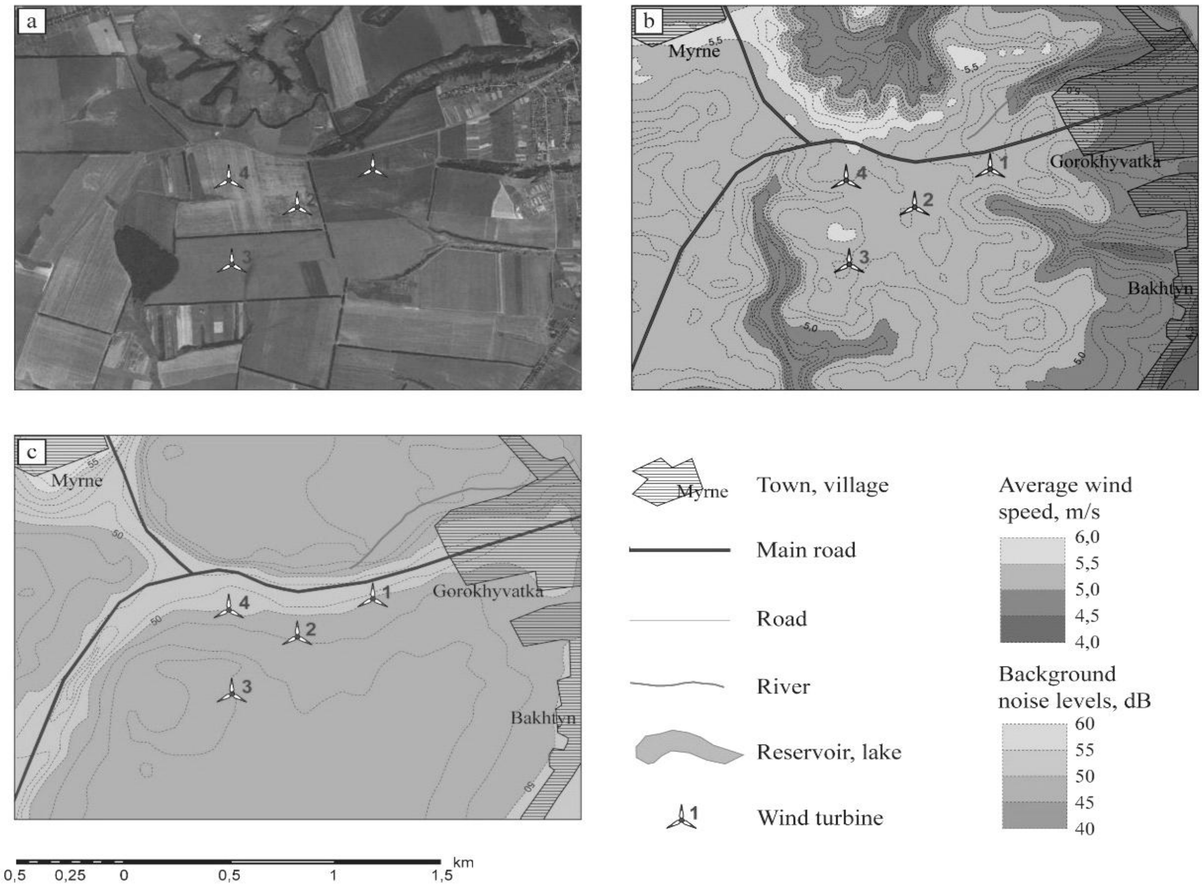

Fig. 2 − Satellite image (a), average wind speed (b) and background noise level (c) for the site of the Enercon E-115 wind turbine according to strategy 2

to the critical 28-34 m/s. The estimated wind speed for the installation is 12 m/s, at such values of wind speed and above the rated power of the installation is 2500 kW. Estimated price of the new installation: 2.5 million euros.

An important parameter that should also be considered when designing a wind power plant is to obtain a land plot for the construction of a wind turbine. As a matter of fact, wind turbine requires an area of 200-400 square meters. The road construction must also be taken into account, the length of it depends on the general scheme of roads.

If the wind farm is located in fertile lands, then the intervals between the wind turbines are used for their direct agricultural purpose. But most of them are located on lands unfit for agriculture. Within the research area, the problem of land utilization is essential for the first strategy of wind energy development. Within the framework of the second strategy, the placement of the wind turbine is planned in any location (regardless of the actual type of land use). For the first strategy, the location of the wind turbines should be selected also based on the minimum land removal (i.e., in the areas of pastures, slopes, not suitable for use). The type of use was determined using satellite imagery and elevations surface.

The basic task is the choice of the optimal number of wind turbines. It is usually more advantageous to choose one powerful wind turbine instead of a few small ones, but nonetheless, there are reasons to install several wind turbines. Small wind turbines tend to be better adapted to low average wind speeds that predominate over time. There is a limitation of the load on the local power grid; in the case of breakage of one of the wind turbines, the voltage drop is smaller if the unit has a relatively small power share in the total output and can be compensated by other wind turbines of the farm. There is a need to maintain an interval between the wind turbines. For a horizontal wind turbine, an interval of 10 times the diameter of the rotor is an acceptable distance. Industrial wind farms follow a distance of 7 to 10 rotor diameters if the installation is from the leeward side to the dominant wind direction, or from 3 to 5 diameters perpendicular to the dominant direction. These are the minimum recommended distances. But even at such a distance there can still be a significant wind disruption. Another important point is that megawatt-class power plants are usually installed on the top of the hills or in open areas with a distinct dominant wind direction. A small wind turbine can be located in an area where the wind blows from all sides throughout the year, even with the prevailing wind direction. Because of this, the minimum distance of 10 times the diameter of the rotor is the optimal option for several separate small units.

In order to get better production of wind turbines, especially of a higher capacity class, they need to be oriented topologically so that the wind turbine will not overlap and cut the winds for each other. Therefore, it is best to orient the wind turbines perpendicular to the principal wind direction in the research area. From the wind rose, one can determine that the greatest repetition belongs to several directions. However, in the case of the arrangement of units in one line, the wind turbines will be located perpendicular to two opposite directions. Therefore, it is necessary to double the direction, that is, adding repetitions of opposite directions. Thus, as a result of the summation, we obtain: (N + S) = 2896; (NE + SW) = 2344; (E + W) = 3732; (NW + SE) = 2985. Therefore, in order to obtain the highest output, the wind turbines must be located in a row from north to south.

When connecting to a maximum power capacity of 10 MW, one can install as many as 4 Enercon E-115 units with a capacity of 800 kW. The distance between the units should be from a minimum of 575 meters to a maximum of 1 150 meters.

Under this development option, it is planned to upgrade local networks. Thus, it is possible to connect to a local substation, but with an increase in its voltage level by installing more transformers and replacing the transmission lines subsequently. Limitations are related to financing.

The main factor in choosing the location of wind turbines for this strategy is the highest wind speeds observed in the northwestern part of the study area not far from Myrne village and the T2109 and T2105 roads junction, where the average annual wind speeds reach values greater than 5.5 m/s.

Obstacle parameter is the availability of planted areas and settlements (Myrne and Gorokhuvatka). The impact on the ornithofauna is insignificant in the case of a sufficient distance from the forests and installation of units as far west as possible. According to this strategy, it is possible to consider several sites near the junction of highways T2109 and T2105.

Simulation of noise levels. Sound effects from wind turbines are of a different nature and are divided into mechanical (noise from gears, bearings, generators) and aerodynamic effects. The latter can vary from low-frequency (less than 16-20 Hz) to high-frequency (from 20 Hz to several kHz). They are caused by the rotation of the impeller and are determined by the following phenomena: the dilution of the rotor or wind chute with the direction of air flow to some point of the advent of turbulent flows; pulsations of the lift on the profile of the blade; the interaction of the turbulent boundary layer with the rear edge of the blade. As a rule, aerodynamic noise increases when passing the blade past the wind turret tower.

Currently, only the calculation methods are used to determine the level of noise from wind turbines. The method of direct measurements of the noise level does not provide information on the volume of the wind turbine since the effective method of separating the wind noise from wind noise at the moment is not found.

When analyzing an acoustic situation, it is important to consider the following factors: intensity level, frequency, frequency distribution and noise source forms; the nature of the area between the source and the receiver (roughness, relief, the presence of barriers); type of receiver (residential building, territory of the Nature Preserve Fund, industrial buildings, etc.). In addition, the technical characteristics of the wind turbine are important (such data are provided by the developers) [9].

The acoustic impact of wind turbines was analyzed in several directions. Firstly, a spatial distribution of noise from wind turbines was simulated. To do this, based on the technical characteristics of the respective wind turbines,

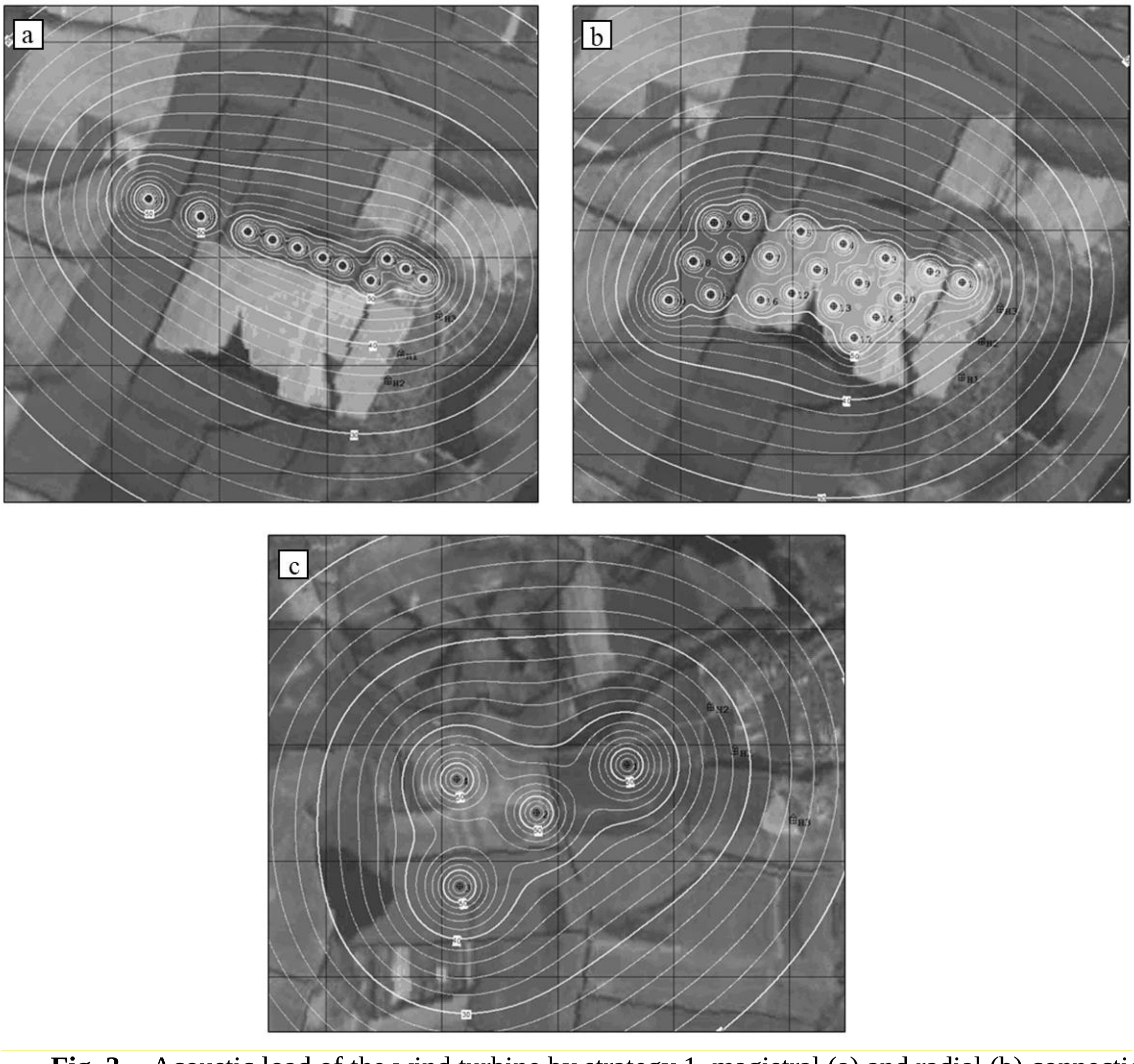

Fig. 3 − Acoustic load of the wind turbine by strategy 1, magistral (a) and radial (b) connection type; and by strategy 2 (c)

relief data, surface roughness, within the WindFarm software environment, the surface of the noise level distribution from the wind turbine was calculated for a wind speed of 8 m/s at an altitude of 10 meters above the earth's surface. For this average speed, measurements of the background noise of the study area were performed beforehand. The basis for calculating the surface was the fact, that sound has spherical propagation nature. Interference has been taken into account (effect of reflection).

For the first strategy (Fig. 3, a, b), the calculation was made for the Enercon E-40 unit, with a noise value of 101 dB at an altitude of 10 meters at the point of installation of the wind turbine. The calculation was made for both the radial and magistral type of wind farm installation.

For the second strategy (Fig. 3, c), the source data was Enercon E-115 with the output noise of 107.5 dB at an altitude of 10 cm above the earth's surface. According to the simulation results, it can be concluded that the sound from the wind turbines in the study area is insignificant (less than 20 dB) at a distance of 2 kilometers from the wind turbine. But the number of wind turbines should also be taken into account – the closer to each other they will be located, the greater will be the total acoustic impact.

This statement has the opposite sense too. This way the units will occupy a smaller territory and may be more distant from the settlements. Thus, it can be seen that although more powerful installations (strategy 2) generate higher levels of sound, however, due to their considerable dispersion and smaller number, at the distance of 1 kilometer the influence of wind farm of the second strategy equals the acoustic load of the station within the framework of the first strategy.

At last, we had to conduct the calculation of noise levels, which might be generated by the wind turbine, for specific points of location of residential buildings. For this purpose, the noise level from the unit was initially calculated. Next, this value was superimposed on the level of background noise at the point. Due to the specific nature of the sound, such summing should be made according to the formula:

$$L_{p_{res}} = 10 \cdot log(10^{\frac{L_{p_1}}{10}} + 10^{\frac{L_{p_2}}{10}} + \ldots + 10^{\frac{L_{p_n}}{10}}),$$

where

$L_{p\,res}$ – total sound level;

L_p – measured sound level.

Results

The results of the background noise study allowed to come up with a few conclusions. Firstly, the acoustic situation in the territory as a whole is quite favorable for the development of wind energy. At working wind speeds (notably for noise level measurements) in most parts of the territory, background noise reached higher values than the comfort level of 45 dB. On some sites near settlements, some increase in background noise level was noted. Thus, according to the type of wind turbine, the noise level may overlap with the background level and the location of the wind turbine will not have a significant acoustic impact on the population. The lowest level of background noise belongs to the zones of forest plantations, where vegetation acts as a natural barrier. If there is a barrier between the wind turbine and the receiver, this will significantly reduce the noise level. The only requirement is to remove the possibility of «shadowing» the wind by such a barrier (in this case, the level of wind turbine output will decrease), which can be achieved by placing the wind turbines at a sufficient distance from the barrier and in appropriate orientation according to the wind rose.

With the data on the distribution of wind speeds, one can construct the resulting surface of the background noise, which is already based on the data of the dependence of the measured background levels of sound on the wind speed (the higher the wind speed, the greater the value of the background noise). Such a resulting map may be useful for refining and for a greater approximation of values to the actual ones. There is also the possibility of creating a map by adding potential energy generation and exceed of the background noise level, which can give a more comprehensive assessment of the potential location of the wind turbines.

For the purposes of noise simulation, the points of measurement of sound levels in the residential area were chosen from the border points of the nearest settlements. For the first strategy, the value of noise for Komarivka village was calculated, for the second – Gorohuvatka village. The background noise on the territory of Komarivka was higher by 4 dB on average. The results of calculations (Table 1) make it possible to assert that the acoustic effect of wind turbines in both placement strategies is insignificant compared to the background noise levels, the main component of which is wind noise. Excessive noise levels when using Enercon E-115 were 5 dB, for Enercon E-40 – 8-9 dB.

It should be noted separately that, in some cases, the acoustic influence of wind farm positioned by the magistral principle was higher than in the case of radial positioning. This was caused by a greater distance from settlements. The fact that a significant concentration of wind turbines can lead to an increase in the overall noise level is also needed to be considered.

Table 1

Noise levels for the specific points of residential areas

Point #	Noise of the wind turbine, dB	Background noise, dB	Resulting noise levels, dB
Strategy 1 (Komarivka village)			
For magistral principle			
1	38,31	53,9	54,018
2	35,22	53,8	53,860
3	42,38	54,1	54,383
For radial principle			
1	37,30	53,9	53,994
2	39,34	53,8	53,953
3	40,77	54,1	54,297
Strategy 2 (Gorohuvatka village)			
4	31,65	50,0	50,063
5	32,48	50,1	50,174
6	25,22	50,0	50,014

Conclusions

A comparative environmental assessment of wind energy projects from the perspective of the potential acoustic load on the environment revealed the following:

1. Measurements of background noise on the study area indicated an exceeding of the level of «comfort» for a housing estate in the whole area by 7 dB on average. This situation requires additional monitoring of the background levels but provides sufficient grounds for comparative evaluation in order to detect excessive sound levels.

2. The simulation of the propagation of noise from wind turbines considering the terrain and roughness of the territory (barriers) allowed to assess the specifics of distribution and optimize the location of wind turbines in such a way that natural barriers protect the potentially vulnerable residential areas.

3. Calculation of the acoustic load on specific points within the settlements has shown that the acoustic load of twenty less powerful wind turbines is higher by 9 dB compared to the value of four more powerful wind turbines. At the same time, the resulting excess of background noise was less significant and amounted to 0.15 dB and 0.05 dB respectively.

4. The research phasing may be a methodological guide to performing similar studies for the local areas with complex orography and various landscapes.

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