Sustainable development – state and prospects
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Analysis of the acoustic impact of windparks in the Ukrainian Carpathians on adjacent residential areas

Introduction

Windpower engineering in the modern sense is a set of means for converting kinetic wind energy into electric power. The birth of wind power dates back to late nineteenth century, when the first wind turbines (WT) were installed in the United States and Denmark. But for a long time, wind power was just a field for experiments by scientists and engineers. Industrial wind energetics began its development during the global energy crisis in the mid-1970s. At that time, a number of countries (in particular, the USA and Denmark) adopted state programs to support wind energetics. As a result, significant funds were invested in the development of fundamentally new wind turbine models, their serial production was launched, and the first industrial wind power plants – wind farms (WF) – were built to transfer the generated electricity to electric power grids. Since then, wind energetics in the world has been developing at a phenomenal pace – every three years, the installed wind power capacity of the world's wind farms doubles.

In many countries of the world, state-level documents were adopted to stimulate (in various ways) the development of renewable energy [1], in particular, wind energy (according to [1], the number of such countries in 2011 reached 118). In the *Directive 2009/28 / EU of the European Parliament and Council of April 23, 2009 on the promotion of the use of renewable energy*, the European Union (EU) countries are tasked by 2020 to achieve a 20% renewable energy share in the total electric power usage in the EU [2]. According to current estimates [3], this share will reach 24.4%.

Wind power is the most significant sector of renewable energy – in the structure of the latter, the share of wind power according to the forecast for 2020, will be ≈40%. The share of wind power in the total electricity consumption in the EU countries will be at least 8%.

Relevance of the topic

Wind power is an innovative technology for generating electricity. Determination of the acoustic load of wind farms with a view to establishing their impact on the environment in order to ensure environmental safety in wind energetics has its own specificity, which makes it impossible to use in full the known methods [4, 5], in particular those used in traditional energetics [6]. This specificity is due to the characteristics of wind as an energy resource, as well as the specifics of the process of converting mechanical wind energy into electricity. To ensure the environmental safety of a certain territory in this industry, new, maximally justified approaches are needed to assess the feasibility and effectiveness of these projects. Therefore, the topic of this article is relevant, its results make it possible to substantiate the environmental safety of wind farms in Ukraine and thereby create conditions for the development of Ukrainian wind power industry.

The object of the study was the wind turbines (WT) of the wind farm (WF) of the *Atlas Volovets Energy* LLC which is part of the wind park. The site of the Volovets Wind Farm is located in the north-west of the Transcarpathian region within the Borzhava Polonyny of the Eastern Flysch Carpathians. The Transcarpathian region is located in the far west of Ukraine within the Carpathians and the Middle Danube lowlands. The territory of the region covers an area of 12.8 thousand square kilometers. The extension from north to south is 80 km, from west to east – 184 km.

According to the Environmental Impact Assessment Report *"Construction of a 120 MW wind farm on the territory of the Volovets settlement council of Volovets district and on the territory of the Bereznyky, Dusyno, Nelipeno and Tybava village councils (outside the settlements) of the Svalyva district of the Transcarpathian region" No. 2018821379 of 2 May 2018 (hereinafter referred to as the Report) the ATLAS VOLOVETS ENERGY* Limited Liability Company plans to implement a new investment project *Construction of a 120 MW Wind Farm* on the territory of the Volovets settlement council in Volovets district and the Bereznyky, Dusyno, Nelipeno and Tybava village councils (outside the settlements) of Svalyava district in the Transcarpathian region under the current law and regulatory documents.

The construction of a wind farm (WF) with a total power capacity of 120 MW with the necessary infrastructure (including access roads, underground 110 kV cable lines and internal 35 kV cable networks, distributing points and substation) is to be carried out in separate land plots with a total area of 30.6041 ha, the area under the wind turbines (WT) being 28.259 ha. The land was granted to the *ATLAS VOLOVETS ENERGY* LLC for a long-term lease (for 25 years). Land under the roads and for laying cable underground lines will be provided for use at the easement.

In total, about 50 hectares will be used for the wind farm operation, which is about 0.01% of the total area of the Borzhava Polonyny (4.1 thousand hectares). They stretch along the Polonynsky range in the territory of four districts of the Transcarpathian region (the total stretch of about 50 km). The wind farm is to be located in two districts of the Transcarpathian region, namely: in the southern part of Volovets district, to the south of the district center Volovets settlement; in the north-eastern part of the Svalyava district.

The wind field of the future wind farm is formed on some elevations of the Borzhava Polonyny of the Ukrainian Carpathians, including the town of Temnatyk (1,342 m a.s.l.), the town of Meichelyna (1,300 m a.s.l.), the town of Play (1,330 m a.s.l.), the town of Velykyi Verkh (1.598 m a.s.l.), and others.

The territory of the planned activity (PA) is located outside the settlements. The closest to the territory of the planned activity are the following settlements: Volovets – from the north – 2.2 km from the nearest wind turbine; Bereznyky – from the south – 8.26 from the nearest wind turbine; Vovchyi – from the west – 4 km from the nearest wind turbine; Pylypets – from the east – 4.5 km from the nearest wind turbine; Podobovets – from the east – 4.2 km from the nearest wind turbine.

Research & Methods

The assessment of the impact of wind turbines of the project wind farm on the acoustic and vibration conditions of the adjacent territory was carried out on the basis of acoustic calculations and comparing the results with the permissible levels of acoustic load in accordance with current regulatory documents. The acoustic load on the protected objects when performing any kind of activity should not exceed the levels established by the current standards for the corresponding time of day.

The simulation of the acoustic pollution prevalence over the study area near the settlements adjacent to the territory of the wind farm (on the territory of the urban-type settlement of Volovets) was carried out by using the program ARM *Acoustics* 2.4 INGOs *Ekoblik*. A calculation module was applied that takes into account the requirements of ISO 9613-1:1993. The ARM *Acoustics* 2.4 program is designed to automate activities when assessing the external acoustic effect of noise sources on standardized objects. The calculation module is integrated in the program according to the requirements of ISO 9613-1:1993. The program can be used to carry out project work on the placement of new facilities, taking into account the existing urban development situation, assessing the noise impact of the existing facilities on the environment, as well as assessing the effectiveness of the projected measures to reduce the levels of external noise.

The calculations are carried out in accordance with the existing methods, handbooks and regulatory documents. The ARM *Acoustics* 2.4 program allows creating a spatial plan of the study area, taking into account the housing development and existing sources of acoustic load (point and linear), calculate the levels of acoustic impact at any point in the plan in space (x, y, z), build colored fields and isolines of sound levels in the horizontal and vertical planes with the given parameters, receive detailed and final reports on the calculation of acoustic impact at a selected point in the plan for each computing step of the calculation.

The algorithm of the program is based on accounting for sound propagation from two types of noise sources: point and linear. Point sources refer to sources of constant noise with small, in terms of calculation distance, geometric dimensions.

The main step in assessing the level of sound effect of a noise source on a standardized object is to calculate the noise propagation in the area between the source and the calculation (target) point.

Sources and mechanism of acoustic influence of wind turbines (WT). The main source of acoustic load and infrasound during wind turbine operation is the rotation of the blades which create audible sound in the frequency range 63÷8,000Hz and inaudible infrasound in the frequency range 2÷31.5Hz. Resonance vibrations, speed-increase unit noise, and the effectiveness of the applied sound-absorbing (sound-insulating) elements can be of significant importance.

During the operation period of a wind farm, two categories of acoustic load created by wind turbines can be distinguished: mechanical; aerodynamic (Table 1).

Table 1.Types of acoustic load, propagation conditions and receivers from wind turbines

Acoustic load sources	Noise propagation paths	Receiver
- aerodynamic - mechanical	- Distance - Wind gradient - Absorption - Soil	- Acoustic environmental background - Internal / external influence - Vibration of buildings

Aerodynamic acoustic load is divided into tonal, continuous broadband, low-frequency and low-frequency impulsive. The aerodynamic acoustic load can be described as whistling or rustling. In addition, the acoustic load may increase with increasing speed of rotation of the turbine blades. Therefore, the turbines the design of which provides a decrease in rotational speed during strong winds are more “quiet”.

The acoustic load of the turbine depends on the background noise, which depends on the wind speed. The acoustic load increases with increasing wind speed, but this dependence is different. The acoustic load caused by the wind will increase by about 2.5 dB (A) with each increase in wind speed by 1 m/s, while the noise level of the wind turbine will increase by only about 1 dB (A) with an increase of wind speed by 1 m/s.

Wind turbines, at a variable speed, rotate more slowly at low wind speeds. In this case, the level of acoustic load of the turbine remains below the background noise at almost any wind speed. Wind turbines can only be heard under certain conditions. When the wind subsides, the wind turbine stops, then it is not heard at all. When the wind exceeds 8 m/s, the sound from the wind installation is overlapped by the noise of the swinging trees or other noises that the wind causes. Wind turbines can be heard only when the wind speed is in the range from 3 to 8 m/s. The sound propagates more from the leeward of the wind turbine, in other directions the sound level is lower. The project provides for the use of wind turbines, the design of which stipulates measures to reduce the noise of mechanical units and also the profiles of wind turbine blades with high aerodynamic properties. For the day mode of operation of the wind farm, the noise level will not exceed the normative limit of 55 dB (A) and will not cause a negative impact on the residential area.

Recent improvements in the mechanical components of large wind turbines have led to a significant reduction in the mechanical acoustic load on the surrounding area. For example, it was possible to reduce the noise of gear-speed reducers (speed-increase unit) by a factor of four due to the use of variable hardness gears, in which the gear rim is made of hard high-alloy material, and the bulk part is much softer and such that dampens the noise and vibration of the metal. As a result, the aerodynamic noise of modern wind turbines is predominant.

The aerodynamic acoustic load from the blades comes mainly from changes in the air stream in front of and behind the blades, it has a zone of influence only at height – at the point of rotation of the blades, but does not propagate to the locations of people in the ground layer.

The level of this acoustic load depends on the shape of the blades, the interaction of the air stream with the blades and the tower, the shape of the back edge of the blades, the shape of the blade tips, the type of regulation of wind turbines (swinging blades or without blades swinging), the conditions of air turbulence.

The characteristics of the aerodynamic acoustic load are in many respects similar to the characteristics of natural noise that arise, for example, when a wind stream passes through a tree crown. Thus, the background acoustic load created by the wind at a speed of 8 m/s and higher is stronger than the aerodynamic one from a wind turbine. However, such acoustic load can be reduced by the optimal design of the blades, especially their tips and back edges, and the way they are mounted on the wind wheels.

In modern wind turbines, the acoustic load is significantly reduced due to the use of "quiet" gear-speed reducers, lifting of the main equipment to a considerable height and the use of acoustic insulating materials in the nacelle.

According to the certificate data of manufacturers of various wind turbines with a capacity of 2-3.5 MW, the level of acoustic load directly in the source of its formation (nacelle of wind turbines) ranges from 96 to 110 dB (A) for various wind turbines. The sound pressure level decreases quadratically, depending on the distance between the wind turbine and the subject. At a distance of 200 m, the acoustic load will be 4 times less (6 dB (A)) than at a distance of 100 m. At a greater distance, the operation of the wind turbine is slightly audible against the background of the acoustic load on the environment. It is on this basis that laws have been adopted in Germany, the Netherlands, Denmark and other countries that limit the minimum distance from wind turbines to residential buildings to 300 m.

Correspondence of the acoustic load when moving away from the wind turbines is given in Table 2.

Table 2. Correspondence of acoustic load at distance from wind turbine

Distance (in rotor diameters)	Correspondence
1d	50-55 dBa – clothes dryer
2d	44 dBa – quiet living room
6d	40 dBA – slightly differentiated or merges with the background

When determining the levels of acoustic load at an appropriate distance, it is necessary to take into account the features of "noise" as a physical unit: doubling of sound pressure (power) is an increase in the index by 3 (sound of 100 dB (A) is 2 times more powerful than 97 dB); the sound pressure level decreases with the square of the distance (at a distance of 200 m, the acoustic load will be 4 times less than at a distance of 100 m).

Table 3.Regulatory maximum permissible equivalent and maximum acoustic load levels

Territory assignment	L.A. equiv, dBA		L.A. max, dBA		Regulations
	day	night	day	night	
Dwellings apartments	40	30	55	45	SN 3077-84; DBN B 1.1-31:2013; appendix No. 16 DSTI 173-96
Territories adjacent to residential buildings	55.0	45.0	70.0	60.0	
Area of existing residential development (+5 dB (A))	60.0	50.0	75.0	65.0	
	60.0	50.0	70.0	60.0	
1 level of development in the zone of influence of vehicles (+10 dB (A))	65.0	55.0	80.0	70.0	

Table 4. Permissible levels of acoustic load and sound pressure levels for areas directly adjacent to residential buildings

Indicators	Sound pressure levels dB, in octave with geometric mean frequencies, Hz									Equivalent sound level, dBA	Maximum sound level, dBA
	31.5	63	125	250	500	1,000	2,000	4,000	8,000		
Permissible levels of acoustic load (in the daytime)	89	75	66	59	54	50	47	45	43	55	70
Permissible levels of acoustic load (at night)	83	67	57	49	44	40	37	35	33	45	60

*According to item 25 of table. 1 DBN B.1.1-31:2013 Protection of territories, buildings and structures from noise

Accordingly, in the settlement which is located at a distance of 600 m from the wind farm, the sound pressure level will be from 36 to 40 dB (A) when the wind is blowing from the side of the wind turbine. This complies with the requirements of *the State Sanitary Rules for the Planning and Development of Settlements* of 19 June 1996, No. 173 and the *Sanitary Standards of Permissible Noise in Residential and Public Buildings and on the Territory of Housing Development*, SN No. 3077-84.

The regulatory maximum permissible equivalent and maximum noise levels which are in force in Ukraine (SN 3077-84, DBN B.1.1-31:2013, appendix No. 16 DSTI 173-96) are given in Tables 3 and 4.

Results and discussion

The input data for performing acoustic calculations according to the requirements of DBN B.1.1-31:2013 are noise characteristics of noise sources (sound power levels, *Lp*, dB), determined by certificate data, catalogs or, in the absence thereof, by experimental data of analogues (measured noise levels, *Lm*, dBA) or by calculation.

Below are the results of calculating the propagation of the acoustic load from the operation of 34 units of wind turbines (construction stage I, II) taking into account the maximum values of sound levels at the corresponding wind speeds (according to the certificate data of wind turbine manufacturers).

DSTU 31295.1-2005 (ISO 9613-1:1993). IDT; ISO 9613-1:1993. MOD *Noise. Sound attenuation when propagating over terrain. Part 1. Calculation of sound absorption by the atmosphere* establishes a method for calculating sound attenuation as a result of sound absorption during propagation in the atmosphere under various meteorological conditions. The attenuation of the sound of pure tone is characterized by the attenuation coefficient dependent on the frequency of the tone, the air temperature and relative humidity, atmospheric pressure.

The results of calculating the attenuation coefficient are presented in tabular form for the following conditions: sound frequency from 50 to 10,000 Hz; temperature from -20°C to +50°C; relative humidity from 10% to 100%; atmospheric pressure 101.325 kPa (1 standard atmosphere).

The standard DSTU 31295.1-2005 (ISO 9613-1:1993). IDT; ISO 9613-1: 1993 describes the basic mechanisms of sound absorption by the atmosphere in the absence of thick fog or mechanical pollution.

The following designations are used for the physical quantities: f is sound frequency, *Hz*; fm is the geometric mean frequency, *Hz*; h is the concentration of water vapor, %; pr is the reference atmospheric pressure, kPa; p_i is the initial sound pressure, Pa; p_t is sound pressure, Pa; p_0 is reference sound pressure, MPa (20 MPa); p_a is atmospheric pressure, kPa; s is the length of the sound propagation path, m; T is air temperature, ^{0}C; T_0 is reference air temperature, ^{0}C; α is the attenuation coefficient of the pure tone sound due to sound absorption by the atmosphere (hereinafter referred to as the attenuation coefficient), dB/m or dB/km; ∂L_t is decrease in sound pressure level due to sound absorption by the atmosphere, dB.

When calculating, it was taken into account that according to the standard DSTU 31295.1-2005 (ISO 9613-1:1993). IDT; ISO 9613-1:1993, the reference atmospheric pressure is equal to the pressure of the standard atmosphere, namely 101.325 kPa. The reference air temperature is 293.15 K (20°C).

When the sound of a clear tone travels a distance, the initial sound pressure due to sound absorption by the atmosphere decreases exponentially, as when a plane sound wave propagates in a free sound field.

Sound pressure is calculated by the formula:

$$p_t = p_i \exp(-0.1151\alpha s) \tag{1}$$

Note – the expression exp $(-0.1151\alpha s)$ means that the transcendental number is raised to a degree equal to the natural logarithm of the number $0.1151\alpha s$. In this case, the constant $0.1151 = 1 / [10 \lg (e^2)]$.

Table 1 of DSTU 31295.1-2005 (ISO 9613-1:1993). IDT; ISO 9613-1:1993 indicates the calculated attenuation coefficient in decibels per kilometer (dB/km) depending on the sound frequency f, T temperature and relative humidity at a pressure equal to one standard atmosphere (101.325 kPa). The attenuation coefficient values are valid for the length of the sound propagation trajectory of about several kilometers.

When using Table 1 of DSTU 31295.1-2005 (ISO 9613-1:1993). IDT; ISO 9613-1:1993, it is not recommended to interpolate for intermediate values or extrapolate beyond the Table values.

Taking into account the fact that the project is considering 1 type of wind turbine – *Siemens Gamesa RENEWABLE ENERGY*, with a single installed capacity of 4.1 MW (mode 1); 3.9 MW (mode 2); 3.7 MW (mode 3), an average annual capacity being 3.53 MW, then to account for the noise impact of the wind turbines (when installed throughout the wind field), noise propagation maps were constructed for this particular type of wind turbine.

The results of the calculation of the acoustic load propagation are presented taking into account the maximum values of sound levels at the corresponding wind speeds (according to the certificate data of wind turbine manufacturers).

The characteristics of the equivalent sound level for the designed type of wind turbines, adopted in computer calculation, are shown in Table 5.

Table 5. Characteristics of the equivalent sound level of wind turbines which are considered for installation

Item No.	Type of wind turbine (WT)	Power capacity (MW)	Maximum tower height (m)	Equivalent sound level (dBA)
1	Siemens Gamesa RENEWABLE ENERGY, SWT-DD-142	4.1MW (mode 1); 3.9 MW (mode 2); 3.7 MW (mode 3); average annual capacity of 3.53 MW	107	108

Additional parameters of acoustic source impact – *Siemens Gamesa RENEWABLE ENERGY SWT-DD-142*, including sound pressure levels in octave frequency bands, adopted in this calculation option are shown in Table 6.

Table 6. Additional parameters for noise sources – *Siemens Gamesa RENEWABLE ENERGY SWT-DD-142*

Noise source	Sound pressure levels dB, in octaves with geometric mean frequencies, Hz									Equivalent sound level, dBA
	31.5	63	125	250	500	1000	2000	4000	8000	
WT No.1	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 2	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No.3	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 4	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 5	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 6	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 7	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 8	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 9	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 10	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 11	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No.12	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 13	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 14	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 15	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 16	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 17	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 18	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 19	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 20	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 21	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 22	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 23	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 24	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 25	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 26	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 27	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 28	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 29	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 30	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 31	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 32	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 33	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024
WT No. 34	112.2	112.2	112.3	110.2	106	102.3	96.9	91.2	85.2	108.024

The simulation was carried out of acoustic pollution propagation depending on the main climatic indicators affecting the sound propagation across the territory: ambient air temperature, °C; relative humidity, %. The construction area refers to the climatic region III B-5 (*Architectural and construction climatic zoning of the territory of the Transcarpathian region for construction, DSTU-N BV.1.1-27: 2010 Construction climatology*). In summer, the average temperature is +21 °C, in winter – -4 °C. The growing season in the lowlands lasts up to 230 days, in the foothills – 210 to 230 days, in the mountains – 90 to 210 days.

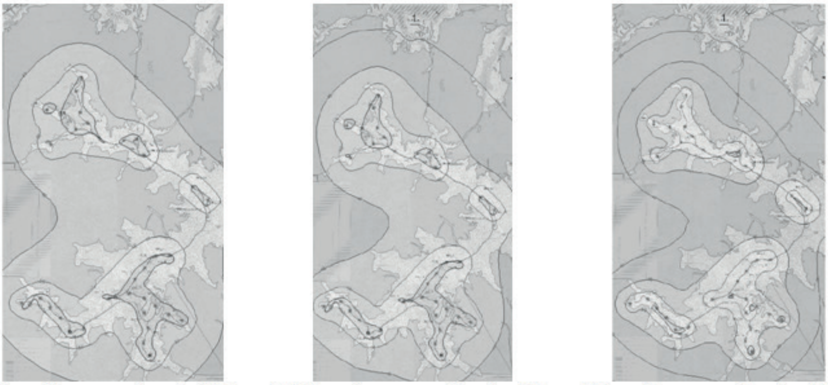
The Borzhava Polonyny range is located practically in the central mountainous areas of the region. It extends from the northwest to the southeast. The main peaks of the range are: mont Stiy (1,681 m a.s.l.), M Velikiy Top (1,595 m a.s.l.), Gimba (1,494 m a.s.l.), mont Magura-Zhyde (1,516 m a.s.l.), mont Hrab (1,378 m a.s.l.)

The climate of the Borzhava Polonyny, starting from an altitude of 1,000 m a.s.l., is harsher and sharper continental, both in the subalpine meadows and in the lowland part of the area. For this part of the region, as well as for the whole region, the high-altitude western and southwestern transport of atmospheric air masses prevails during the year. There is less frequent movement of high-altitude atmospheric masses from eastern Europe as well as from the Arctic. Humid high-altitude air masses from the Atlantic bring, especially in summer, a large amount of precipitation, they causes high relative air humidity, and in winter intense snowfall, fog and low cloud cover which from time to time settle on the subalpine meadows.

The average long-term amount of precipitation within the Borzhava Polonyny range is from 1,046 to 1,646 mm. The greatest amount of precipitation falls in the warm period of the year: 693-1,028 mm, and in the cold period: 351-618 mm. In some years, more than 3,000 mm can fall on the highlands of the Borzhava. The highest monthly rainfall was recorded at 507 mm (Play, October, 1977), and in winter, 359 mm (Play, January, 1989). Most precipitation falls in the summer (June, July). On average, there are 192 days of rainfall per year.

Based on the calculation results, noise maps were constructed. For detailing graphical materials, noise load sketch maps are constructed both for the equivalent sound level and for individual sound pressure levels in the octave frequency bands (Figs. 1 and 2).

When carrying out the acoustic calculation of the required noise reduction at control points, the principle of superposition of noise sources was taken into account. A typical scheme of accounting for the principle of superposition of noise sources for calculation point No.1 is shown in Fig. 3.



a) Sound pressure levels dB, in the octave band with geometric mean frequencies – 31.5 Hz

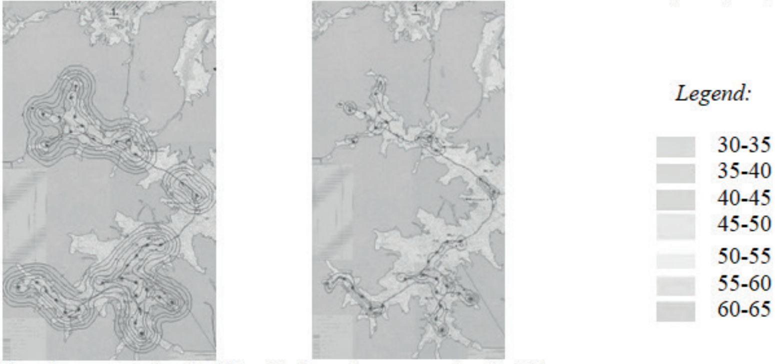
b) Sound pressure levels dB, in octave band with geometric mean frequency – 125 Hz

c) Sound pressure levels dB, in octave band with geometric mean frequency – 250 Hz

d) Sound pressure levels dB, in octave band with geometric mean frequency – 500 Hz

e) Sound pressure levels dB, in octave band with geometric mean frequency – 1,000 Hz

f) Sound pressure levels dB, in octave band with geometric mean frequency – 2,000 Hz



g) Sound pressure levels dB, in octave band with geometric mean frequency – 4,000 Hz

h) Sound pressure levels dB, in octave band with geometric mean frequency – 8,000 Hz

Fig. 1. Sketch maps of the noise load of the study site

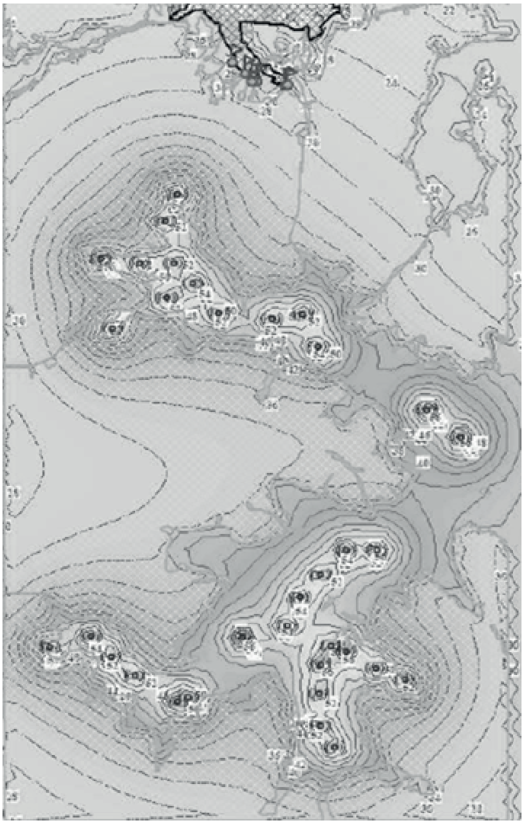


Fig.2. 3D model of noise propagation in the territory of the wind farm and in the adjacent residential area

Fig. 3. Typical scheme for taking into account the principle of superposition of noise sources for calculation point No. 1

Calculation points (CP) were selected at the nearest settlements, where the influence from wind turbines is most characteristic: CP No.s 1-6 – uts. Volovets – the closest residential development – over 2.2 km.

According to this principle, schemes for taking into account the principle of superposition of noise sources for other calculation points were constructed. During the calculations, the expected equivalent sound levels were determined with frequency correction (A) at the control point.

The noise map of the facility clearly shows that the level of noise pollution at the boundaries of the settlements near the wind farm reaches a level below the normative value for residential and public buildings.

The major factor in reducing acoustic pollution is the large buffer zone between the settlements and the boundaries of the wind field.

The shortest distance from a single wind turbine to the boundaries of the nearest settlement – uts. Volovets – is over 1.7 km. At this distance, the level of noise generated by all wind turbines reaches normative values for all climatic scenarios.

Noise levels near the settlements located in the vicinity of the wind farm for the most unfavorable scenario are shown in Table 7.

Table 7. Noise levels and sound pressure levels from wind turbines at the calculation points near the settlements located in the vicinity of the wind farm

Height of CP, m	Sound pressure levels dB, in octaves with geometric mean frequencies, Hz									Equivalent sound level, dBA
	31.5	63	125	250	500	1000	2000	4000	8000	
1.5	48.1	48	47.5	43.8	36.4	28.9	16.4	0	0	38.9
1.5	48.2	48.1	47.6	43.9	36.5	29	16.4	0	0	39
1.5	48.2	48	47.6	43.8	36.4	28.7	15.8	0	0	38.9
1.5	46.6	46.4	45.9	41.8	33.5	24.8	9.6	0	0	36.6
1.5	46.4	46.2	45.7	41.5	33.1	24.2	7.2	0	0	36.2
1.5	47.6	47.4	47	43.1	35.5	27.6	15	0	0	38.1

Noise levels and sound pressure levels near the settlements in the vicinity of the wind farm for the most unfavorable climatic scenario and comparison of calculated values with normative values are given in Tables 8 and 9.

Table 8. Noise levels from wind turbines at the calculation points near the settlements located in the vicinity of the wind farm

Settlement	CP No.	The distance from the boundaries of the settlement to the calculation point, km	Noise level at the border of residential buildings, dBA		Normative equivalent noise level, dBA		Fixed exceedance	
			Day	Night	Day	Night	Day	Night
uts. Volovets	1	More than 2.2 km	29.6	29.6	55.0	45.0	-	-
	2		29.8	29.8	55.0	45.0	-	-
	3		30.3	30.3	55.0	45.0	-	-
	4		30.4	30.4	55.0	45.0	-	-
	5		30.1	30.1	55.0	45.0	-	-
	6		29.7	29.7	55.0	45.0	-	-

Table 9. Pressure levels of the sound from wind turbines at the calculation points near the settlements located in the vicinity of the wind farm

The name of the settlement	CP No.	Sound pressure levels dB, in octaves with geometric mean frequencies, Hz									Fixed exceedance
		31.5	63	125	250	500	1,000	2,000	4.000	8.000	
uts. Volovets	1	41.8	41.5	40.4	35.1	24.9	13.4	0	0	0	-
	2	41.9	41.6	40.5	35.2	25.2	13.8	0	0	0	-
	3	42.1	41.8	40.8	35.7	25.9	15.4	0	0	0	-
	4	42.1	41.8	40.9	35.8	26.1	15.8	0	0	0	-
	5	42	41.6	40.7	35.5	25.7	15.2	0	0	0	-
	6	41.7	41.4	40.3	35.1	25.1	14.4	0	0	0	-

Conclusions

Noise exposure and vibration created by the rotation of the blades and during the operation of generators can negatively affect living organisms, as well as cause undesirable geophysical processes, for example, the occurrence of snow avalanches in case of their high intensity, however, for the selected modern types of wind turbines, the manifestation of these factors is insignificant.

Regarding wind farms, in order to minimize the effects of noise and vibration on mammals, it is recommended that construction work be started gradually so that they can adapt to noise (that is, a smooth start). This may be combined with the use of passive acoustic mammal monitoring to minimize the risk of animals appearing in the construction area when welding work begins. Repeller devices and an acoustic signal repeater can provide additional containment to mammals entering the construction zone.

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