UDC 528.8(477.87)+502.17:620.9 http://dx.doi.org/10.31548/zemleustriy2025.03.06

APPLICATION OF GIS TECHNOLOGIES TO ASSESS THE IMPACT ON THE SURROUNDING ENVIRONMENT OF THE LOCATION OF WIND POWER PLANTS USING THE EXAMPLE OF "POLONYNA RUNA" OF THE TURYE-REMETIVSKAYA AH COMMUNITY

V. PERESOLIAK,
Candidate of Sciences in Public Administration,
Associate Professor Uzhhorod National University
E-mail: v.peresolyak@gmail.com;
ORCID:0000-0002-6255-1559
I. RADISH,
Candidate of Technical Sciences, Associate Professor
E-mail: ihor.radysh@uzhnu.edu.ua;
ORCID: 0000-0003-0187-4183
I. KRYLYO,
Master, Lecturer
Natural Sciences and Humanities Professional College
Uzhgorod National University
E-mail: ihor.krylo@uzhnu.edu.ua

Abstract. *In the current conditions of the development of renewable energy, which includes wind energy, the most important task is to minimize the environmental impact of wind power plants (WPPs) on the environment in the context of decarbonization of economic sectors. The use of geographic information systems (GIS) allows for effective analysis and modeling of the impact of wind farm placement, taking into account: environmental, landscape, economic, climatic and social factors that affect the sustainable development of territories. The article considers the use of geographic information systems (GIS) to assess the environmental impact of the location of a wind farm (WPP), which is planned to be built on the territory of the "Polonyna Runa" tract of the Turye-Remetivska rural territorial community of the Uzhhorod district of the Transcarpathian region.*

The study involves the collection and processing of spatial data, including relief, wind speed and direction, the presence of protected areas, and habitats of sensitive species of flora and fauna. GIS will be used to analyze visual and noise impacts, assess risks to biodiversity and public health, and model alternative locations for the station's wind turbines.

The assessment results contribute to making informed design decisions regarding the location of wind farms, reducing negative environmental impacts and ensuring a *balance between the sustainable development of wind energy in the region and the preservation of the natural environment.*

Keywords: *wind energy, environmental impact assessment, geographic information systems, spatial planning, sustainable development of territories, renewable energy sources, decarbonization, CO_2 emissions.*

Introduction

In today's climate of global warming and the growing need for renewable energy sources, wind energy occupies an important place among environmentally friendly technologies. Wind farms (WPPs) contribute to the reduction of greenhouse gas emissions and the reduction of dependence on traditional energy resources. However, their placement can have a significant impact on the environment, including biodiversity, landscape, noise pollution and the quality of life of local populations.

To assess the impact of wind farms on the environment, it is important to use the latest analysis methods, among which geographic information systems (GIS) occupy a special place. GIS technologies allow for spatial analysis, modeling the potential impact of wind turbines, evaluating alternative options for their location, and minimizing environmental risks.

Ukraine has favorable conditions for the development of wind energy:

- land free from industrial, residential and intensively used agricultural land for the construction of wind power plants (WPP);
- high capacity of factories capable of producing modern wind turbines, especially in regions with potential for the use of WPP;
- many years of observation data and the availability of highly qualified personnel for the construction of high-tech structures, such as wind farms.

According to various estimates, the industrial potential of wind power in Ukraine is about 500 billion kWh per year [1]. Based on the experience of most European countries in implementing wind power plants in Ukraine, electricity production can be increased by using more powerful wind turbines and commissioning new onshore wind power plants up to 17,455 GWh in 2030 (with a total capacity of 6.214 GW) [16]. According to the Regulation on Approval of the National Renewable Energy Action Plan for the Period Until 2030 and the Action Plan for its Implementation [17], it provides for the construction of wind power plants with a total capacity of 16,000 MW, therefore the importance of site selection and development of wind power plant construction has not changed. In December 2024, Elementum Energy successfully closed a deal to acquire a 200MW wind power project in western Ukraine. The new wind farm is expected to generate approximately 700GWh of electricity annually, equivalent to the annual electricity consumption of approximately 600,000 people.

Wind energy plays a leading role in the decarbonization of the Ukrainian economy. In addition, wind power plants replace traditional energy sources that burn fossil fuels to produce electricity. Thanks to wind energy technologies, CO_2 emissions into the atmosphere have been reduced by 835 million tons.

The popularization of small wind turbines has a rapid and tangible impact on the national economy. The installation of small wind turbines can be widely used not only for electricity generation, but also to facilitate mechanical processes (mills, deep well pumps, pumping water from wells, pumps, etc.).

Analysis of recent research and publications

In the field of assessing the impact of wind farm (WFP) siting on the environment using geographic information systems (GIS), a number of studies have been conducted that emphasize the importance of an integrated approach to planning and implementing renewable energy projects.

Certain ecological, economic and technical aspects of wind energy use were considered in their works by such scientists as Y. Bashynska, V. Didyk, S. Kudrya, O. Sukhodolya and others. In legal science, the issues of legal regulation of relations in wind energy were studied in their works by O. Sushik, H. Grigoriev, K. Karakhanyan, M. Kuzmina, E. Rybnikova, Y. Rud, T. Kharitonova, I. Chumachenko, V. Peresoliak, M. Lopushanska and others proposed a methodology for assessing the environmental impact of renewable energy facilities, tested on the example of the Polonyna Runa wind farm in the Turye-Remetivska rural territorial community of the Uzhhorod district of the Transcarpathian region. This methodology covers all stages of the project life cycle and takes into account environmental, economic and social aspects of the impact. The use of GIS allows for detailed analysis of spatial data and modeling of potential environmental risks.

The purpose of the study is to use GIS technologies to assess the impact of wind farm (WPP) location on the environment, taking into account the following factors: environmental, landscape, economic, climatic, social and special studies of regulatory and legal requirements for the construction and operation of wind power plants with an emphasis on their impact on the environment in the natural resource management system.

Materials and research methods

The research methods used to study the topic were: cartographic analysis, spatial analysis, modeling, visualization, logical generalization, and information presentation. Namely: for the creation and analysis of planning and cartographic materials that represent spatial data in a graphical form - the method of cartographic analysis; for the relationships between project objects and existing ones, such as distance, direction, adjacency, interpenetration - a spatial analysis method; for predicting the impact on the environment and ecological features of the territory - a modeling method; for creating and presenting the results of the analysis for a wide range of users - a method of presenting information.

Results and their discussion

For the environmentally efficient use of wind energy, comprehensive information about its characteristics is necessary. When analyzing the wind energy potential of a region, a wind energy cadastre is compiled.

A wind energy inventory is an objective, reliable and necessary set of quantitative data characterizing wind as an energy source. Based on long-term observations, a wind energy inventory presents all wind characteristics in tabular or graphical form.

The main source of initial data for wind energy cadastres is the organization of wind speed observations using a reference network of hydrometeorological stations [13]. Such observations are made a certain number of times per day, cover a period of several decades, and provide the raw data for analysis. The advantage of such observations is that they are collected in a unified manner.

The average annual wind speed is the first characteristic of the overall level of wind energy. This value can be used to determine the efficiency of a wind turbine in a specific sector or in a region as a whole. It should be noted that wind speed depends on the terrain, especially the roughness of the surface, the presence or absence of shading elements and the height above ground level at the selected site. These conditions vary greatly from station to station. Therefore, for comparison, they need to be converted to average wind speed. These conditions are usually referred to as open, flat terrain and a height of 0 meters above the ground.

Energy resources are usually assessed on the basis of potential, technical and economic resources. Technical resources of wind energy are considered as part of the potential resources that can be exploited using existing technical means. Technical resources of wind energy are part of the potential resources that can be used using existing technical means and are determined taking into account inevitable losses when using wind energy. According to the theory of an ideal wind turbine, only a portion of the energy that is used and converted, i.e. passes through the cross-section of the wind turbine, is useful work. The maximum amount of useful energy is estimated as the wind energy utilization factor (WEF) limited by a constant of 0.593. The best wind turbine models today maintain this parameter in the range of WEF- 0.45-0.48.

It should be noted that modern wind turbine designs do not fully utilize the entire range of wind speeds. At minimum wind speeds, the amount of electricity produced is below the minimum operating power of the wind generator, which is insufficient to overcome the friction forces of the wind generator components. Only in the range from the minimum operating speed to the design speed can the wind turbine use its installed capacity and wind energy can be used with the greatest benefit. If the wind speed continues to increase to the maximum operating speed, the wind turbine output power is maintained at the level set by the controller. If the wind speed exceeds the maximum operating speed, the wind turbine is shut down and stopped to prevent technical breakdowns.

Modern wind turbines are large technological structures (megawatt wind turbines have a diameter of 60-120 m and a tower height of 60-100 m or more), built using the latest developments in aerodynamics, electrical engineering, electronics, and computer technology. Currently, the installed capacity of a wind turbine is 1 kW, and its cost is 800-1000 USD. In the future, this figure is expected to decrease to 600 USD.

Estimates of wind energy potential for a narrow area are based on general climate maps covering a country or region and measurements from meteorological stations located tens, and in some cases hundreds, of kilometers from the study area, therefore, very approximate results can be obtained, which, of course, describe only the current circulation process and the background wind field. To obtain more accurate estimates, it is necessary to consider the surrounding landscape conditions and topography at a distance of several kilometers from the study area. Only such desk-based methods can assess the potential for local air current activity at low altitudes.

When selecting sites for energy facilities, it is necessary to take into account a number of different parameters, such as meteorological observations, topographic data, and local economic development plans [7,11].

Areas with the following characteristics may be suitable for the construction of wind farms:

- optimal average annual wind speed;
- absence of high-altitude obstacles on the leeward side;
- there are no uneven terrain, buildings and structures, vegetation in a certain proximity to the wind turbine;
- the site on the top of the hill should be flat with gentle slopes or the site should be located on a plain, shallow water or island;
- the presence of local landforms that affect the phenomena of "push" and acceleration of the wind flow is not found (among them are high valleys and flat peaks of heights;
- a mountain tunnel-like gorge, which has an orientation in space parallel to the prevailing wind directions (Fig. 1).

Fig. 1. Location of a wind turbine in a tunnel-like valley

GIS can be used to more accurately determine the environmental impacts of wind farms and make informed decisions about siting, ensuring a balance between the needs of the energy sector and the protection of natural ecosystems.

In summary, we can say that modeling the construction of future wind farms requires the analysis of large amounts of information, the collection of which can be effectively organized using geoinformatics methods. There are numerous examples of using geographic information systems (GIS) to solve the problem of selecting sites for the construction of wind farms. In particular, it is assumed that digital topographic maps can be used to identify areas that are flat or have a slight slope in the direction of the wind flow, taking into account the absence of surrounding obstacles (hills, trees, buildings, etc.) [12].

A comprehensive approach to site selection for wind turbines requires a qualitative assessment of local characteristics that can contribute to high wind speed and stability, and therefore potential energy production (Fig. 2). When lower-height towers are used for wind turbines, especially those below 20 m, it is more accurate to calculate wind protection zones relative to objects in specific areas and buffer zones that limit potential turbulence zones. This data can also be used to identify areas where wind speeds may slow down.

One of the most important conditions for successful investment in wind energy is a good understanding of the typical wind conditions for a given microregion. As noted above, the power

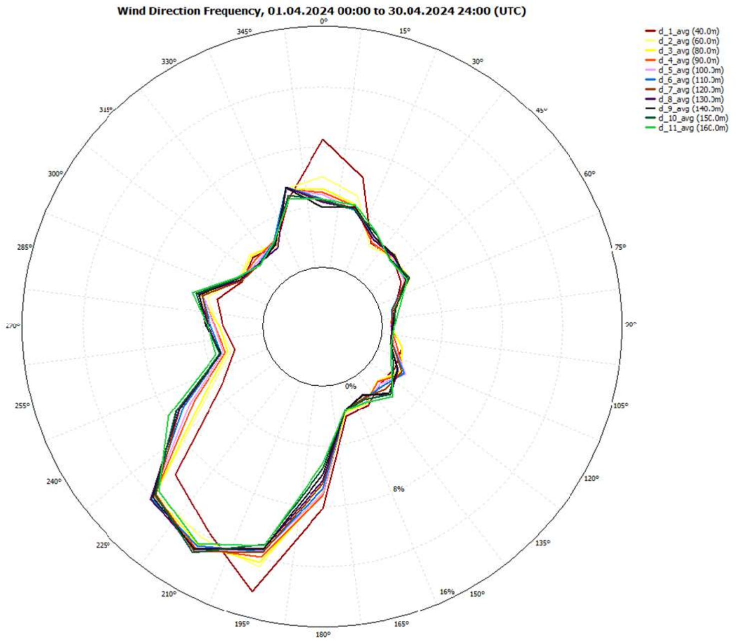


Fig. 2. Wind frequency and direction "Polonyna Runa" from 01.04.2024 to 30.04.2024

of the air flow passing through the rotor of a wind farm is proportional to the cube of the wind speed. Even in regions with good wind conditions, the location of future power plant sites must be carefully selected taking into account the geometry of the site, including the potential presence of obstacles. These factors are often underestimated, but their impact on the performance of each individual power plant is crucial. As a result, choosing a project location between favorable and unfavorable zones can easily compensate for the two- to three-fold difference in energy efficiency and, consequently, in electricity costs between similar power plants [8].

The potential wind energy depends on the roughness of the ground surface at a given location, including sports facilities, buildings, trees, damage to wind turbine cages, and other tall obstacles. Wind tunnel experiments have been conducted in Sweden to determine the minimum distance between wind turbines to avoid interference. The experiments have shown that the distance should be at least six wind turbines in diameter. There is also evidence that this distance should be 8-12 cm in diameter.

The results of wind shadow simulation calculations for different types of obstacles are shown in Fig. 7 [4]. The main methods of geoinformation modeling and analysis necessary for the implementation of the above schemes are:

- proximity analysis, construction of buffer zones;
- terrain surface analysis, determination of visibility between objects, calculation of slope gradients and exposures;
- 3D modeling and web mapping of terrain and wind farm objects.

Wind farms produce energy with little or no chemical impact on the environment, but they have many consequences, such as changing the landscape due to land allocation for construction, noise impact, and radio interference. In this document, the main environmental impacts of wind turbines are analyzed from a land management perspective: determining the degree of noise impact from the operation of wind turbines - noise zone Wind turbines generate noise, which is usually divided into infrasound and noise that affects humans and other living organisms.

Infrasound is acoustic vibrations in the air with a frequency below 20 Hz, i.e. below the threshold of human hearing. Sources of infrasound in nature include wind noise, ocean waves, waterfalls, storms and earthquakes. At the same time, infrasound is widespread in everyday life, for example through the use of heaters, compressors, and automobiles. Urban infrastructure, such as tunnels, bridges, and high-rise buildings, is also a source of infrasound propagation. The infrasound range is considered safe for human health if its level is within 130 dB.

In other words, researchers from the USA and France stated that low-frequency noise from wind turbines negatively affects the human body, causing persistent depression, severe irrational anxiety, and disruption of vital functions, that is, the area around wind farms is not suitable for a comfortable life for people, animals, and birds. At the same time, according to a study commissioned by the German Federal Office of Health, low-frequency vibrations from wind turbines do not have a negative impact on the environment or human health, as the noise level is below the detection threshold of 30 dB.

The problem of reducing the noise impact of wind turbines is solved by locating wind turbines at a certain distance from residential buildings, where the noise level does not exceed 40-50 dB. For different wind turbine capacities, there are general recommendations for impact ranges ranging from 150 to 350. However, the Danish Wind Energy Manufacturers Association [3] recommends a minimum of seven rotor diameters or a distance of 300 meters.

The Association's website (www. Windpower.org) has a freely available calculator that calculates noise levels from a wind turbine at various distances, which is visualized as a raster map.

As is known, protective and sanitary protection zones are established around all industrial enterprises. In order to assess the impact of wind turbines on the environment, it is necessary to calculate protective zones.

In the study of wind energy systems, protection zones are used to assess the impact of wind turbine noise on the environment, for example, to determine the impact of restrictions on the sanitary protection zone around hazardous facilities. The impact of tall objects on the landscape on wind flows is also assessed. Examples of protection zones around objects are shown in Figures 3-6. For example, Fig. 3 shows a polygonal object whose boundaries are equidistant from the object boundary by a certain value, in this case the radius R.

The buffer radius can be a numeric constant or the value of an attribute of a specific spatial object. In the first case, all protected areas have the same radius; in the second case, a buffer area with a unique radius is defined around each object. Additionally, you can use multiple buffers, i.e. an array of radii that can form an array of buffer zones. If the radius is negative (the radius is smaller than the selected area), the buffer zone is created inside the polygonal object.

When solving many applied geoinformatics problems, it is necessary to determine the so-called proximity zones. These zones are also called Voronoi diagrams or proximity zones. Al-

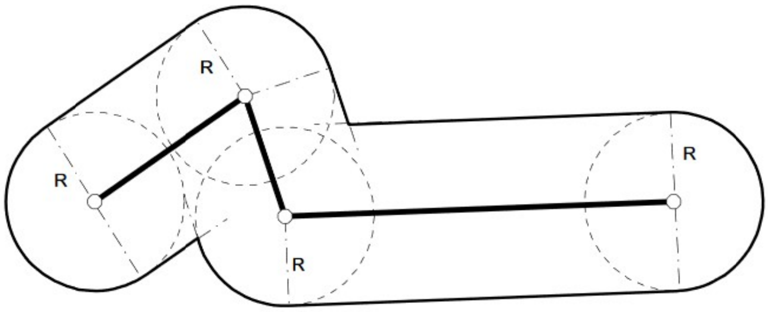
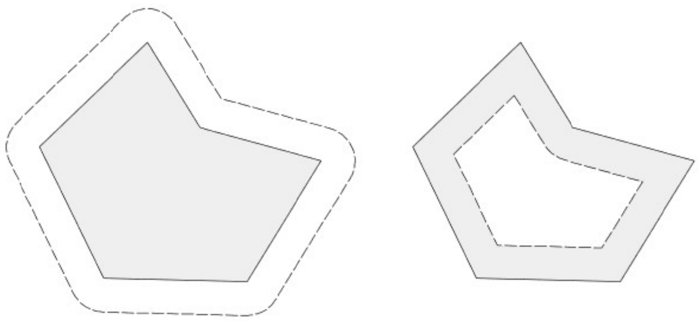


Fig. 3. Scheme of construction of the security zone



a b

Fig. 4. Protection zones with positive (a) and negative (b) radius

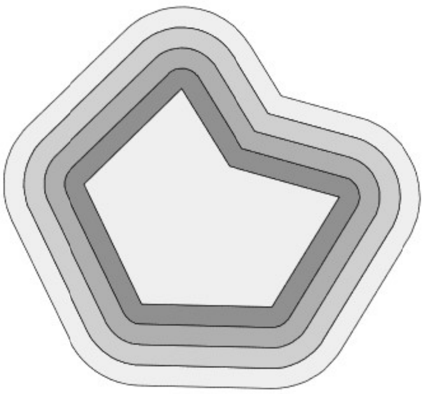


Fig. 5. Ring security zones

gorithms that calculate the slope and exposure of the terrain allow the creation of new regularized grids based on raster DEMs, where each node corresponds to the angle of slope and exposure.

In accordance with the above requirements, the noise impact of the operation of a large-capacity wind turbine was assessed by creating a buffer zone in the GIS. A minimum distance of 450 m from the installation site is considered sufficient to ensure that the noise impact is negligible. The recommended distance from a powerful wind turbine to a permanent human presence area (noise zone) is 350 m.

The next step uses a line-of-sight algorithm to calculate the points that can be observed along a given line on the terrain surface. This calculation also requires the height of the observer above the ground (HA) and the height of the object above the ground (HB) [5]. The algorithm for calculating line of sight consists of several stages. In the first stage, a profile is created along a given line. In the next stage, a segment AB is created for each point of the profile, where point A corresponds to the observer's position and point B corre-

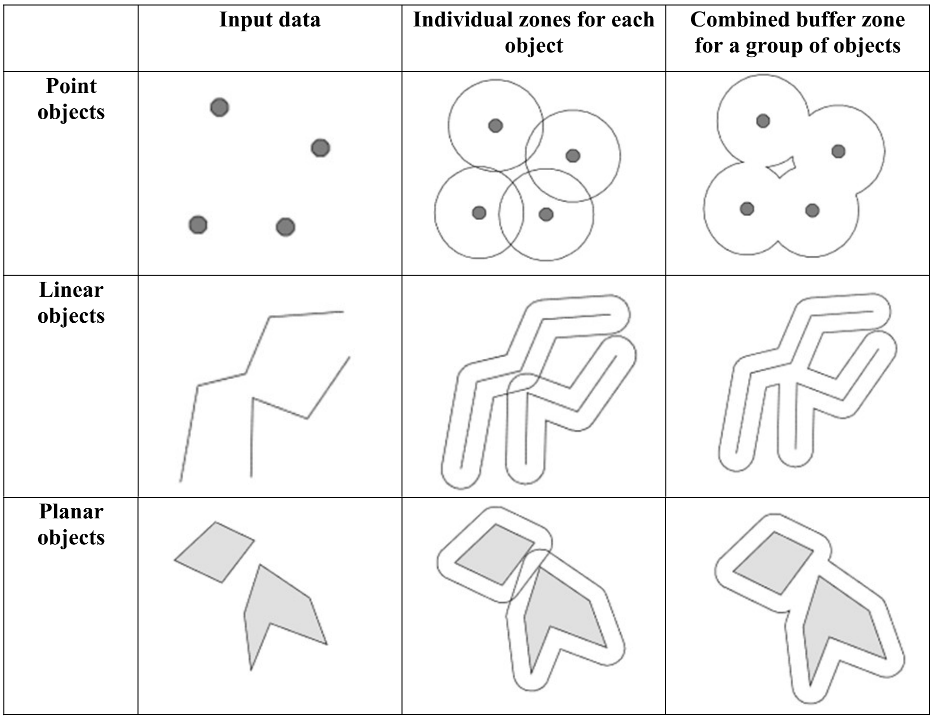


Fig. 6. Scheme of security zones for objects of different localization

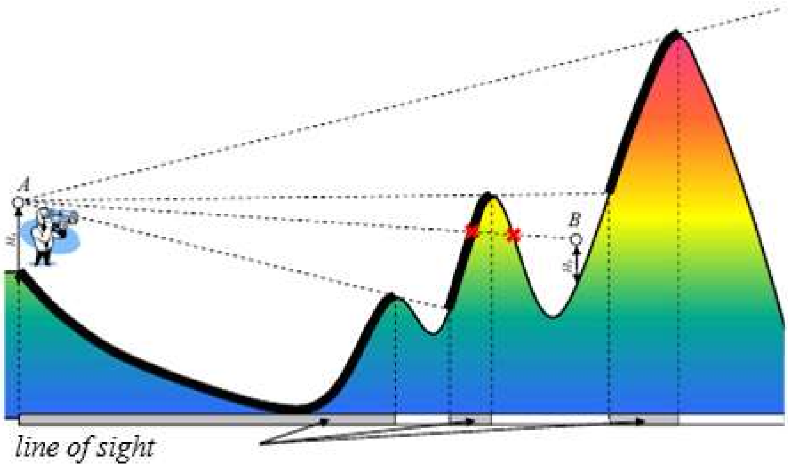


Fig. 7. Scheme for determining lines of sight

sponds to the observation point (the next point of the profile). Note that point A is at a height HA above the ground surface and point B is at a height HB. The third step is to check whether this segment intersects with the previously created elevation profile. If there is no intersection, point B is visible from point A. In Fig. 7, point B is not visible because segment AB intersects the profile line at the point marked in the figure. The thick line shows the part of the profile where the point is visible from point A at HB = 0.

The results of the algorithm can be visualized as line-of-sight segments on electronic GIS maps or as polygons representing visible areas projected onto a 3D terrain model. If the calculations involve significant distances, it is necessary to take into account the curvature of the earth's surface.

A continuation of the previous calculations is the calculation of visible or invisible zones. In this task, the area in which all points are visible from a given observation point is determined. In geoinformatics, there are two approaches to solving this problem: the authors chose the most effective one, which consists in creating radial, linear lines of visibility centered at the observation point. Sight lines are plotted on the map at an angle through a certain angular value, for example, 5 degrees (Fig. 8). The advantage of this method is the high speed of calculations, but the disadvantage is the difficulty of detailing visible and invisible areas.

This study of the spatial characteristics of wind farms assesses the spatial location of wind turbines in relation to landscape elements such as topography, settlement contours, and forests. The topographic conditions of the study area were obtained from the OpenStreetMap service in the form of FerGIS shape files. This data was corrected and supplemented with a master plan and high-resolution satellite imagery. Additions were made regarding the city's administrative boundaries, the current state of the road network, power lines, and development.

The topographic data for this area was the global SRTM model (NASA, USA). These versions were obtained from the SRTM 90m Digital Elevation Databases ev4.1 website (Fig. 8).

We take into account the mutual location of the wind turbine towers using the GenerateNearTable tool in ArcToolBox. Create a position table (Fig. 9) (calculated distances and orientations between all objects in all combinations).

Assuming that the diameter of the wind turbine is 50 m, the shortest distance is 201 m, i.e. the diameter of the wind turbine is 4 m. The directions to the nearest wind turbine show that the towers do not block each other with respect to the wind flow.

This is explained by the fact that the direction to the nearest tower is 53°, which is close to the winter wind direction of 45°. However, the distance between these towers is 424 m, which eliminates the “parking effect”. Accord-

Fig. 8. Lines of sight

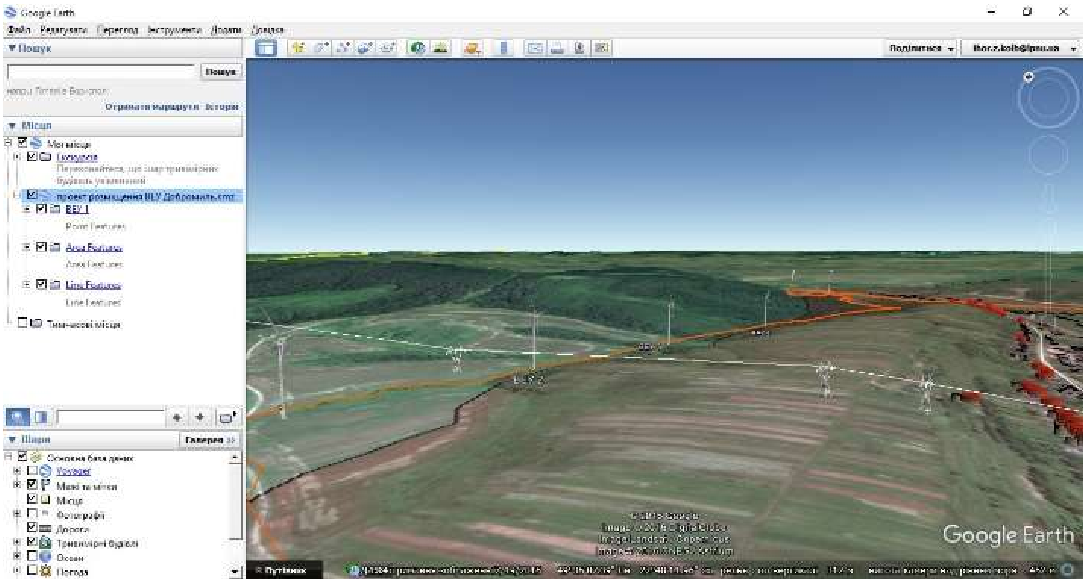


Fig. 9. Topographic data from the SRTM 90m Digital Elevation Databases ev4.1 website

Fig. 10. Result of three-dimensional modeling of the wind farm in Polonyna Runa in the Google Earth service

ing to the modeling results, the site is generally suitable for the construction of a wind farm with 6 towers with a height of 80–100 m.

In this work, the popular and, perhaps, well-known web mapping service Google Earth was used as a means of three-dimensional modeling of the designed wind farm.

To achieve a natural image of the terrain model, 3D models of wind turbines and high-voltage power line towers were used.

The cartographic layers that form the digital map of the area in ArcMap were exported to a KMZ format file, which is readable in the Google Earth service (Fig. 10).

The result of the modeling is a high-quality, textured three-dimensional terrain model. The model is fully controllable, you can change the scale, viewing angle, measure areas, directions, distances. The controls are easy to learn for a wide range of Internet users.

Polonyna Runa

The feasibility of developing a detailed plan of the territory is due to investment proposals for the construction and operation of a wind power plant within the Polonyna Runa area outside settlements. A detailed plan of the territory is being developed for land plots of communal property of the Turye-Remetiv village council of the Uzhhorod district of the Transcarpathian region, which are located outside the boundaries of settlements, for the placement of a separate construction object on Polonyna Runa street - wind energy facilities - in accordance with current legislation using materials from the urban planning and land cadastre. The development of a detailed plan of the territory included the entire mountain range, except for the top part, where the ruins of the Bars military complex are located.

The figure below shows a copy of the Planning Scheme of the Transcarpathian region, which indicates the boundaries of the territory of the mining and recreational complex centered in the village of Lumshory.

According to this cartographic material and data from the land cadastre of Ukraine, the development of a detailed plan of the territory within the project boundaries does not contradict the Planning Scheme of the Transcarpathian region.

The project proposes to place 30 wind turbines, type WTU 5.2, with a nominal capacity of up to 5.2 MW, with a mast height of 100 meters and a blade span of 151 meters on Polonyna Runa. That is, the maximum height of the structure can reach 175 meters.

According to the calculation of the wind rose of the territory, a decision was made to place 30 wind farms at the highest points of the Polonyna territory - on its

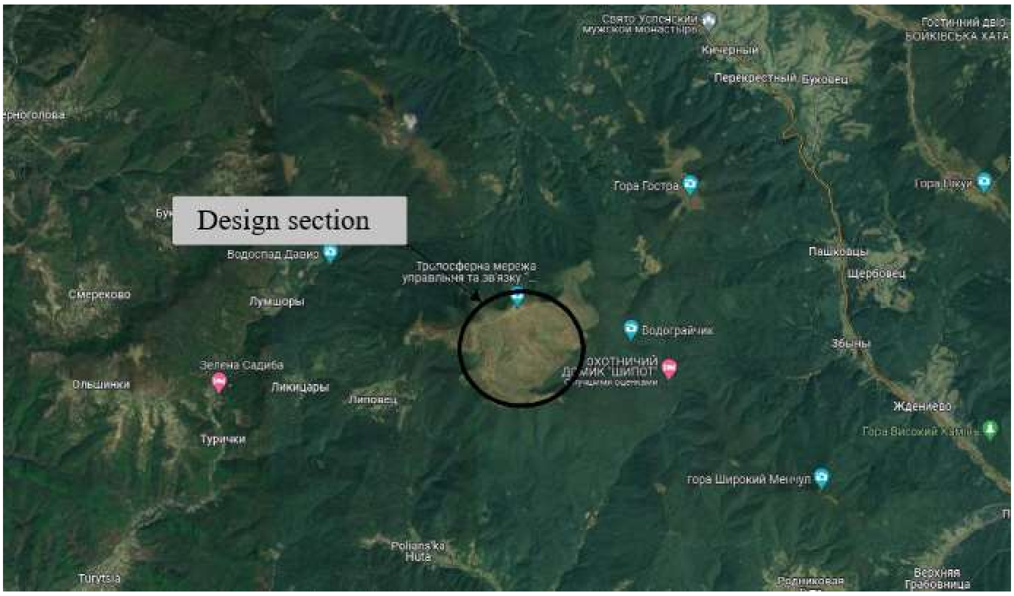


Fig. 11. Location of the design area on Google Maps

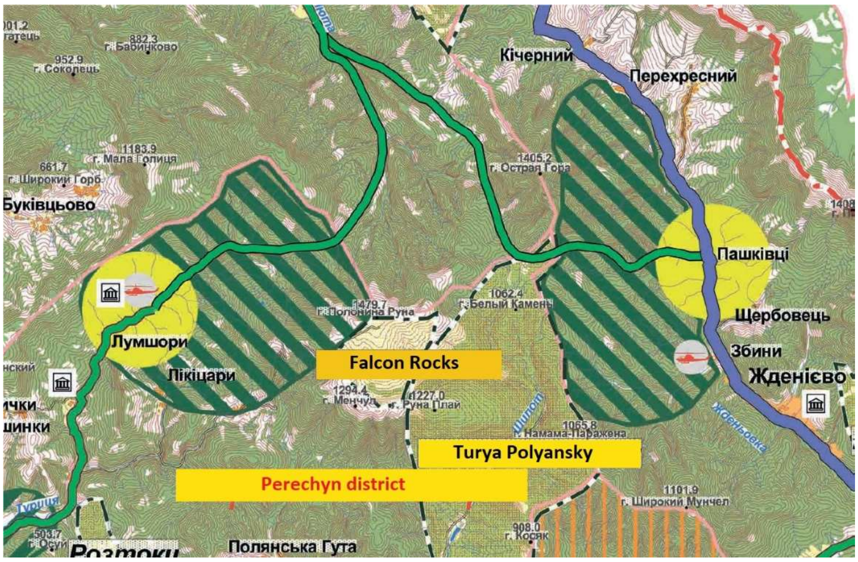


Fig. 12. Copy from the Territorial Planning Scheme of the Transcarpathian region

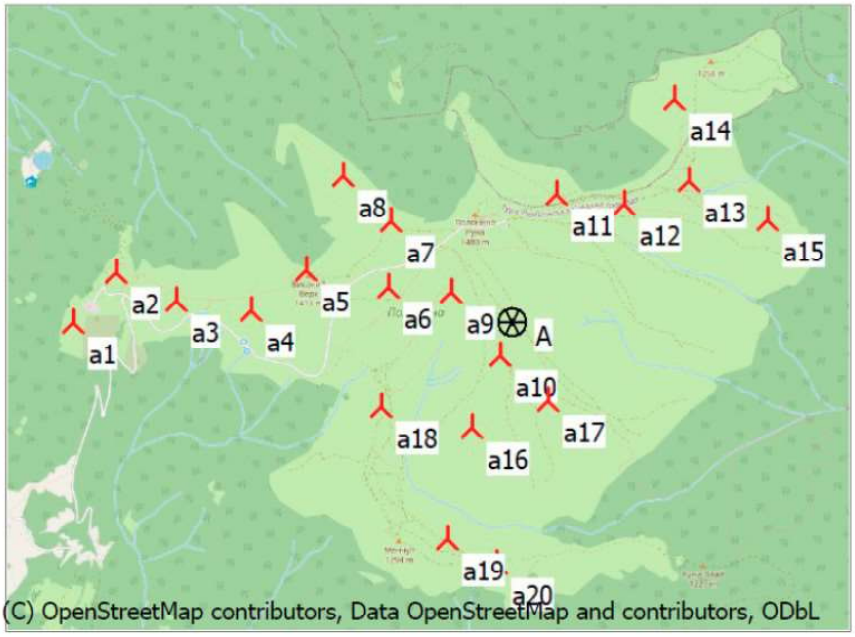


Fig. 13. The best places for placing wind turbines in the Polonyna Runa area

conditional watersheds (Polonyna ridges), since according to the calculations, the wind in these places is quite good.

Wind turbines (WTGs) are variable speed power plants powered by inverters with a three-blade rotor in a headwind configuration. Variable speed is achieved by frequency control of the phase winding of the stator of a synchronous generator.

A significant feature of modern wind turbine models is the low rotor rotation speed. Due to innovations in the design of power transmissions, the rotor rotation speed has been reduced. This significantly reduces the noise level from the wind turbine and, in addition, significantly reduces the risk of birds colliding with the moving blades of the wind turbine.

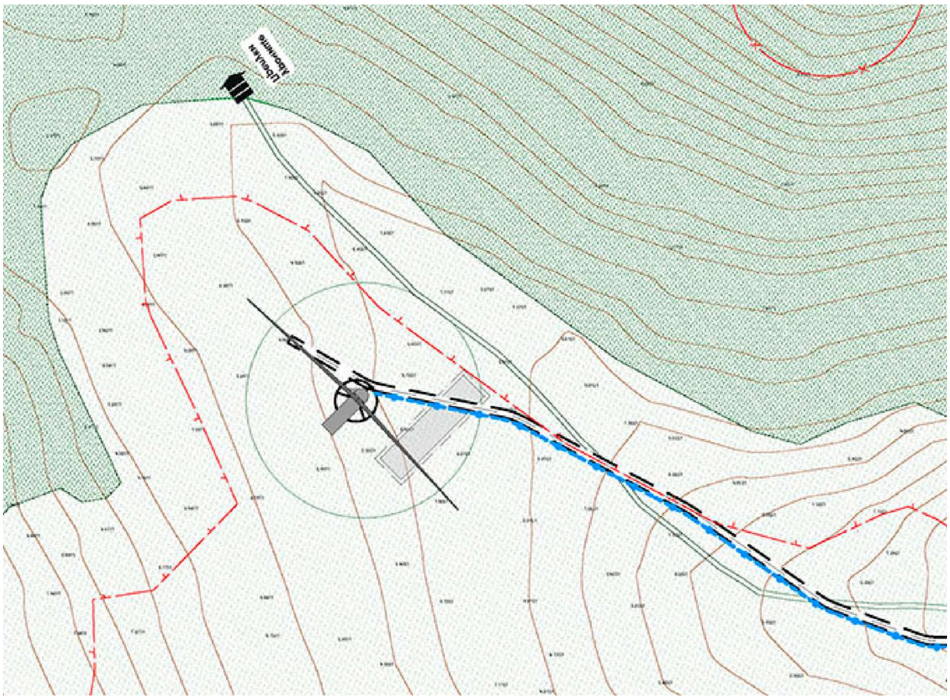


Fig. 14. Typical wind turbine site

In general, each wind turbine has a typical site after construction is completed, and in this case, the area will be completely landscaped, even the maintenance area is proposed to be kept landscaped, to ensure the preservation of the area and prevent fragmentation and reduce negative environmental impacts.

The main structure is the wind turbine mast, the transformer located inside the mast (to provide open access to the territory), and the maintenance platform. A typical platform for a wind turbine is shown in Fig. 14.

Structurally, a wind turbine is a cone-shaped tower, on top of which is a nacelle with a rotor and blades.

The wind turbine is equipped with an automated safety system that ensures safe operation of the wind turbine in the event of a control system failure, component or system failure. To identify errors in the operation of the drives of the main components of the wind turbine, a condition monitoring system is provided. The installation is equipped with a highly efficient lightning protection system.

Conclusions

Assessing the impact of a wind farm's location on the environment using geographic information systems is an important tool in the planning and implementation of renewable energy projects. The use of GIS allows for comprehensive analysis of spatial data, modeling of environmental risks, and taking into account factors such as terrain, biodiversity, noise exposure, and possible socio-economic impacts.

The results of the study show that integrating GIS into the process of selecting a wind farm location helps minimize negative environmental impacts and ensures a balance between wind energy development and environmental conservation. Spatial analysis can identify optimal areas for installing wind farms that will ensure maximum efficiency of energy production and at the same time not harm ecosystems and local populations. The possibility of effective analysis of identifying problems and advantages in the spatial location of wind power plants is shown.

So, the construction of wind farms is an alternative and environmentally sound form of using inexhaustible and renewable energy resources, practically requiring no active and deep exploitation of the territory.

In addition, the construction of wind power plants will increase the stability of electricity supply to industrial and municipal enterprises in the context of energy shortages in Ukraine.

References

1. Kudria, S. O. (Ed.). (2020). Vidnovliuvani dzherela enerhii [Renewable energy sources]. Kyiv: Institute of Renewable Energy of NASU. 392 p.
2. Vikhariev, Yu. O., & Radysh, I. P. (2003). Rol' vykorystannia ponovliuvanykh dzherel enerhii v Zakarpatti – rehioni operatyvnoho monitorynhu transkordonnykh perenosiv shkidlyvykh rechovyn. In Proceedings of the International Energy-Ecological Congress “Enerhetyka. Ekolohiia. Liudyna” (). Kyiv: Ukrainski entsyklopedychni znannia. 147–149 pp.
3. Denysiuk, S. P., Radysh, I. P., Nehoduyko, V. O., & Pertko, P. P. (2011). Harmonijnyi rozvytok enerhetyky – zaporuka staloho rozvytku Ukrainy. In Proceedings of the International Scientific-Practical Conference “Carpathian Conference on Environmental Protection Issues” Mukachevo–Uzhhorod. 187–188 pp.
4. Global Wind Atlas. (n.d.). Global Wind Atlas. Available at: https://globalwindatlas.info/en/.
5. Denysiuk, S. P., Vikhariev, Yu. O., Radysh, I. P., Hololobov, O. I., Kovaliov, O. V., & Mashkara, O. H. (2000). Enerhoefektyvnist' ta napriamy samoenerhozabezpechennia rehioniv na prykladi Zakarpattia (M. P. Kovalko, Ed.). Kyiv: Ukrainski entsyklopedychni znannia. 118 p.
6. Serikov, Ya. O. (Ed.). (2014). Vitroelektrychni stantsii [Wind power stations]. In Information technologies in solving safety, ergonomics, labor protection and environmental tasks (Vol. 2). Kharkiv: KhNUMG. 183 p.
7. Kudria, O. S. (n.d.). Perspektyvy rozvytku vidnovliuvanoi enerhetyky v Ukraini. Rozvytok vitroenerhetyky ta soniachnoi enerhetyky [Presentation]. Available at: https://ua-energy.org/upload/files/16_EIF_Kudria.ppt.
8. Kudria, S. O., Yatsenko, L. V., & Dushyna, H. P. (2001). Atlas enerhetychnoho potentsialu vidnovliuvanykh ta netradytsiinykh dzherel enerhii. Kyiv: Institute of Electrodynamics of NASU. Available at: https://saee.gov.ua/sites/default/files/Kudria.pdf.
9. Lopushanska, M. R., Ivanov, Ye. A., Vyzhva, A. M., & Tsyhanok, L. V. (2024). Metodyka otsinky vplyvu na dovkillia dlia obiektiv vidnovliuvanoi enerhetyky (na prykladi vitrovoi enerhetyky u Lvivskii oblasti). Ekologichni nauky, 1(52), 126–133 pp. DOI: https://doi.org/10.32846/2306-9716/2024.eco.1-52.1.19.
10. Ukrainian Hydrometeorological Center. (n.d.). Meteorolohichne zabezpechennia ta obsluhovuvannia [Meteorological support and service]. Available at: https://meteo.gov.ua/files/content/docs/meteo_kerdoc/Nastanova%20z%20gydrometzabezpechennja.pdf.
11. Syrotiuk, M., & Hrynda, O. (2011). Metodychni aspekty otsiniuvannia vitroenerhetychnoho potentsialu. Visnyk Lvivskoho Universytetu. Seriia Heohrafiia, 39, 313–319 pp.
12. Pivniak, H., Shkrabets, F., Neuberger, & Tsyplenkov, D. (2015). Osnovy vitroenerhetyky [Fundamentals of wind ener-

gy]. Dnipro: National Mining University. Available at: https://vde.nmu.org.ua/ua/lib/%D0%9E%D0%92-2015-02-11.pdf.
13. Ukrainian Wind Energy Association. (n.d.). Official website. Available at: http://www.uwea.com.ua/press.php.
14. Pavlyha, A. V., & Dubinin, Yu. S. (2021). Ekolohopravovi vymohy do rozmishchennia ta funktsionuvannia obiektiv vitrovoi enerhetyky v Ukraini. Yurydychnyi naukovyi elektronnyi zhurnal, 11, 341–345 pp.
15. Planuvannia ta rozmishchennia VEU. (n.d.). Available at: http://xn--drmstrre-64ad.dk.
16. Pop, S. S., Peresoliak, V. Yu., Potish, L. A., & Prykhodko, V. P. (n.d.). Zvit z otsinky vplyvu na dovkillia "Atlas Volovets Energy". Available at: https://ecozakarpat.gov.ua/?page_id=4743.
17. Cabinet of Ministers of Ukraine. (2024). Pro zatverdzhennia Natsionalnoho planu dii z vidnovliuvanoi enerhetyky na period do 2030 roku [Order No. 761-p]. Available at: https://zakon.rada.gov.ua/laws/show/761-2024-%D1%80#Text.
18. Verkhovna Rada of Ukraine. (2011). Pro rehuliuvannia mistobudivnoi diialnosti [Law No. 3038-VI]. Vidomosti Verkhovnoi Rady Ukrainy, 34, Article 343p.
19. Verkhovna Rada of Ukraine. (2018). Pro stratehichnu ekolohichnu otsinku [Law No. 2354-VIII]. Vidomosti Verkhovnoi Rady Ukrainy, 16, Article 138p.
20. Cabinet of Ministers of Ukraine. (2024). Pro Natsional'nyi plan dii z vidnovliuvanoi enerhetyky na period do 2030 roku [On the National Action Plan for Renewable Energy until 2030] (Order No. 761-p). Available at: https://zakon.rada.gov.ua/laws/show/761-2024-%D1%80#Text.
21. Cabinet of Ministers of Ukraine. (2023). Pro skhvalennia Enerhetychnoi stratehii Ukrainy na period do 2050 roku [Order No. 373-p]. Available at: https://zakon.rada.gov.ua/laws/show/373-2023-%D1%80#n6On.

Пересоляк В. Ю., Радиш І. П., Крильо І. В.

ЗАСТОСУВАННЯ ГІС ТЕХНОЛОГІЙ ОЦІНКИ ВПЛИВУ НА НАВКОЛИШНЄ СЕРЕДОВИЩЕ МІСЦЯ РОЗТАШУВАННЯ ВЕС НА ПРИКЛАДІ «ПОЛОНИНА РУНА» ТУР'Є-РЕМЕТІВСЬКОЇ ОТГ

ЗЕМЛЕУСТРІЙ, КАДАСТР І МОНІТОРИНГ ЗЕМЕЛЬ 3'25: 51-67.
http://dx.doi.org/10.31548/zemleustriy2025.03.06

Анотація. *У сучасних умовах розвитку відновлюваної енергетики, до якої відноситься і вітроенергетика найважливішим завданням є мінімізація екологічного впливу вітроелектростанцій (ВЕС) на навколишнє середовище в контексті декарбонізації галузей економіки. Використання геоінформаційних систем (ГІС) дозволяє ефективно аналізувати та моделювати вплив щодо розміщення ВЕС враховуючи: екологічні, ландшафтні, економічні, кліматичні та соціальні фактор, які впливають на сталий розвиток територій. У статті розглядається застосування геоінформаційних систем (ГІС) для оцінки впливу на навколишнє середовище місця розташування вітроелектростанції (ВЕС), яка планується будувати на території урочища «Полонина Руна» Тур'є-Реметівської сільської територіальної громади Ужгородського району Закарпатської області.*

Дослідження передбачає збір та обробку просторових даних, включаючи рельєф, швидкість та напрямок вітру, наявність природоохоронних територій та місць проживання чутливих видів флори та фауни. За допомогою ГІС проводитиметься аналіз візуального та шумового впливу, оцінка ризиків для біорізноманіття та

здоров'я населення, а також моделювання альтернативних варіантів розміщення вітрогенеруючих турбін станції.

Результати оцінки сприяють прийняттю обґрунтованих проектних рішень щодо вибору місця розташування ВЕС, знижуючи негативний екологічний вплив та забезпечуючи баланс між сталим розвитком вітрової енергетики в регіоні зі збереженням навколишнього природного середовища.

Ключові слова: вітроенергетика, оцінка впливу на довкілля, геоінформаційні системи, просторове планування, сталий розвиток територій, відновлювані джерела енергії, декарбонізація, викиди CO_2.