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# PROSPECTS FOR USE OF MAN-MADE DISTURBED LANDS IN MINING REGIONS FOR THE LOCATION OF RENEWABLE ENERGY SOURCES FACILITIES

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**Abstract**. This article describes the prospects for use of man-made disturbed lands of mining regions, which for a number of reasons are not subject to recultivation, in the context of the effective use of renewable energy sources. The use of renewable energy sources is considered, first of all, to satisfy energy needs, but taking into account their environmental value and renewability. It is shown the importance of decentralization of power supply sources for consumers, which can be achieved through the use of renewable energy sources. The article provides a brief structure of Ukraine's energy consumption. The main obstacles that stand in the way of the development of renewable energy sources and improvement of energy efficiency in Ukraine are analyzed. As one of the perspective directions for the introduction of renewable energy sources, the use of wind power plants is considered. The main advantages of wind energy are listed. Formulas for calculating the power of a wind power plant are provided. The gross potential, technical potential and economic potential of the implementation of wind power plants are considered. The coefficient of wind energy utilization, which depends on the wind speed, is given. The paper gives a comparative assessment of existing types of wind turbines – with a horizontal and a vertical axis of rotation. It has been proved that vertical axis wind power plans are more effective for implementation. The vertical axis wind power plans have their advantages. It is recommended to use vertical axis wind power plans with using of a magnetic levitation. This makes vertical axis wind turbines the most efficient. Due to the use of wind generators with a vertical axis of rotation of a turbine with a magnetic-levitating bearing, in the conditions of Kryvbas, vertical wind power plants can produce electricity more than 7 times more than traditional (horizontal) ones. It has been proven that the amount of generated electricity increases with the height of the wind turbine location. The article examines the ecological advantages of placing wind power plans on man-made disturbed lands of mining regions.

**Keywords:** man-made disturbed lands, renewable energy sources, energy efficiency, wind power plants, environmental friendliness of wind turbines.

## 1. Introduction

For the smooth functioning of all sectors of the economy, an important condition is to ensure a sustainable energy supply. Today, the threat of depletion of mineral resources is the most acute, so it is important to find and use alternative energy sources to meet energy needs. It is important to take into account their environmental friendliness and renewability

Ukraine is an energy-dependent country, with imports amounting to about 72%. Therefore, taking into account the negative impact on the environment, the development and use of renewable energy sources (RES) are priority to ensure the energy independence of our country.

In today's environment, decentralization of electricity supply to consumers is becoming important for Ukraine. The use of renewable energy sources increases the share of dispersed electricity generation. Man-made disturbed lands that cannot be reclaimed for a number of reasons are best suited for placement. It is important to choose the location of RES, the equipment itself, to ensure economic and ecological efficiency. The use of RES has the potential to both improve energy security and reduce anthropogenic impact on the environment. Therefore, along with improving energy efficiency, their use should become one of the most important areas of Ukraine's energy policy.

According to the State Agency on Energy Efficiency and Energy Saving of Ukraine and Eurostat, the share of RES in the total balance of electricity production in Ukraine at the end of 2020 and beginning of 2021 was 12.4%, which indicates the prospects for the development of RES in our country.

The purpose of the paper sources is to show the prospects for the use of man-made disturbed lands of mining regions, which for a number of reasons are not subject to reclamation, in the context of effective use of RES, and to give a comparative assessment of existing types of wind turbines - with a horizontal axis of rotation and a vertical axis of rotation.

## 2. Theoretical part

The structure of Ukraine's energy consumption mainly consists of fossil fuels (oil 10%; natural gas 40%; coal 31%), followed by nuclear energy (17%) and electricity generated by hydropower plants (2%), while the use of renewable energy is still insignificant – these are signs of one of the most carbon-intensive economies in the world and a significant burden on the environment. In addition, our country is dependent on energy imports, which poses a threat to energy security.

The prospects for the use of renewable energy sources on man-made disturbed lands in mining regions are very high. There is no doubt that the level of energy consumption in Ukraine is higher than it could or should be, especially in comparison with neighboring EU countries. The main obstacles to the development of renewable energy sources and improvement of energy efficiency in Ukraine include the following: insufficient popularization and awareness of renewable energy and energy efficiency measures and their application; insufficient technical development; and excessive market regulation. To this should be added a significant shortage of land plots for renewable energy facilities, which are not available in mining regions.

One of the most promising areas of renewable energy is the use of wind power plants (WPP). Objects of the man-made landscape of mining areas are characterized by a significant height in relation to the daytime surface level. This value reaches 100–120 m and may increase over time. Given that the wind speed increases with height, the energy potential of the territory where such facilities are located also increases.

Wind energy has long been viewed as a clean, inexhaustible source of energy. The shortage of non-renewable energy sources and growing dependence on imported fuels have led to a revival of research aimed at expanding the ability to convert wind energy into a usable form of energy.

Advantages of wind energy [1] are:

– low cost of production;

– wind power can compete with nuclear, coal and gas power;

– zero cost of the fuel component, the energy source is inexhaustible and available in unlimited quantities;

– environmentally acceptable energy;

– energy production is not accompanied by carbon dioxide emissions;

– wind energy does not have risks associated with the volatility of fossil fuel prices;

– wind power allows us to avoid dependence on energy imports;

– modular design, quick installation;

– electricity supply is comparable in volume to traditional generation methods;

– dispersion over the territory;

– wind power does not interfere with agriculture and industrial activities near wind farms;

– the possibility of using technologically disturbed lands in mining regions.

A wind power plant is a complex of interconnected equipment and facilities designed to convert wind energy into other types of energy (electricity, mechanical, thermal, etc.) and includes a wind turbine. A wind turbine, in turn, consists of a wind engine, a system for transmitting wind power to the load (consumer) and the wind energy consumer itself (any device: an electric machine generator, water pump, heater, etc.).

In order to systematize the characteristics of wind energy in a particular region, in order to use it efficiently, it is necessary to develop a so-called wind energy cadastre. It should contain aerological and energy characteristics of wind, which allow determining its energy value, as well as the appropriate parameters and modes of operation of wind turbines [2].

Main characteristics of the wind energy cadastre are:

– average annual wind speed, annual and daily wind flow;

– repeatability of speeds, types and parameters of speed distribution functions;

– maximum wind speed;

– specific power and specific energy of wind;

– wind energy resources of the region.

The sources of initial information are:

1) meteorological stations that measure all climatological parameters, including wind speeds, usually 4 times a day (long-term observations);

2) continuous monitoring meteorological stations, as a rule, they are installed at the sites where wind turbines are planned to be installed;

3) aerological stations (probes and balloons), which are periodically launched to different heights.

To use wind turbines, you need to know the energy characteristics of the wind.

In the absence of turbulence, the volume of air passing per unit time through a cross-sectional area of $A$, m$^2$ perpendicular to the wind speed vector has a kinetic energy, power $P_0$,W, which is calculated by formula (1) [2]:

$$P_0 = m \cdot V^2 / 2, \tag{1}$$

where is $m$ – the mass of air, kg, defined as the mass of air in the volume of a cylinder or parallelepiped with a base area of $A$, m$^2$ and a length equal to the speed

$V$, m/s. Taking into account the air density $\rho$, kg/m³, the instantaneous power is determined by formula (2) [2]:

$$P_0 = \frac{1}{2} \cdot \rho \cdot A \cdot V^3 . \qquad (2)$$

The average specific power for a period of time t (for example, a year) $\langle P \rangle$, kW/m², taking into account the distribution of speed by gradations for this period, can be determined by expression (3) [2]:

$$\langle P \rangle = \sum_{i=1}^{n} P_{vi}^{xti} = \frac{1}{2} \cdot \rho \cdot A \cdot \sum_{i=1}^{n} V_i^3 \cdot t_i . \qquad (3)$$

And the specific energy $E_s$, kWh/m², is given by expression (4) [2]:

$$E_s = \langle P_{sp} \rangle \cdot T , \qquad (4)$$

where $\langle P_{sp} \rangle$ – the specific power for a certain operating range of wind speed, kW/m²; $T$ – is the analyzed period of time (most often a year, i.e. 8760 hours).

The energy characteristics of wind are gross, technical and economic potentials.

The gross potential (theoretical) is the wind energy potential of a region, i.e., the portion of the long-term average total wind energy available for use in the region for one year.

The region under consideration is represented as a set of areas, or zones, in which the specific wind power capacity, as well as geographical, climatic and weather conditions, are homogeneous across the entire area. As a rule, zones should correspond to the location of weather stations. The gross potential of a region $W_{gp}$, kWh/year, is the sum of the potentials of its constituent zones.

The specific gross wind energy potential $W_{gp}$, kWh/(m²year), of a zone is determined by the average specific wind power of the wind flow $\langle P \rangle$, kW/m², according to formula (5) [2]:

$$W_{gp} = \langle P \rangle \cdot T / 20. \qquad (5)$$

The gross potential of a zone (territory) is determined by formula (6) [2]:

$$W_{gp} = W_{sgp} \cdot S, \qquad (6)$$

where is $S$ – the area of the earth's surface zone, m².

The technical potential of a region's wind energy is the total electrical energy that can be obtained in the region from the use of the gross potential of wind energy at the current level of technological development and compliance with environmental standards.

The technical potential of a region is the sum of the technical potentials of all the zones that make up the region.

Thus, the technical potential $W_t$, kWh/year depends on the parameters of the wind turbine, the average annual wind speed, and the part of the area of the zone that is suitable for the installation of wind turbines. The technical potential is determined by formula (7) [2]:

$$W_t = \frac{W_{gp} \cdot C_p \cdot \eta_{gen} \cdot \eta_{gear} \cdot S_t}{S}, \quad (7)$$

where is $C_p$ – wind energy utilization factor, which depends on the wind speed, its range is 0.05–0.593 (for calculation purposes, it is taken equal to 0.2); $\eta_{gen}$ and $\eta_{gear}$ – respectively, the efficiency of the wind power plants (WPP) generator and gearbox, the value of which can be assumed to be 0.9; $S_t$ – is the area of the zone (region) where wind turbines can be located, taking into account technical and environmental constraints, %. The size of this area can vary from 10% to 30% of the total area of the zone (region). It is assumed $S_t$ to be 12%.

Substituting the above values into (7), we obtain the ratio between gross and technical potentials, which is equal:

$$W_T / W_{gp} = 0.02. \quad (8)$$

*The economic* potential of a region's wind energy is the amount of annual electricity generated in the region from the use of wind turbines, which is economically feasible for the region at the current price level for construction, equipment, production, transportation and distribution of energy, while complying with environmental standards.

The economic potential of a region is the sum of the economic potentials of the zones that make up the region.

Modern wind turbines, regardless of the power level, are either horizontal-axis propeller or orthogonal vertical-axis wind turbines (using the lift force on the blades), as these two types of wind turbines have the highest technical and economic performance.

However, in order for wind energy to bring more benefits, it is necessary to use cost-effective wind turbines that can operate reliably in automatic mode for many years and ensure uninterrupted operation with periodic maintenance.

Currently, most manufactured wind turbines have a horizontal axis of rotation and a propeller type of wind turbine. The operation of such structures begins at wind speeds in the range of 3.5 to 4.5 m/s, depending on the power and design features. With a further increase in wind speed, the speed of the wind turbine and the rotor of the electric generator increases.

It should be noted that the generator reaches its nominal operating mode only at wind speeds of 8 to 12 m/s. In the range of speeds from 2 to 6 m/s, the output power of existing wind turbines is insignificant, i.e., only a small part of the received wind energy is used. Based on the fact that when the design speed is exceeded, the rotational speed is artificially low, using only a part of the wind energy, we can explain the low wind energy utilization factor (0.41–0.47) of modern wind turbines.

**3. Results and discussion**

If we take into account the fact that in most of Ukraine, including the mining regions (e.g., Kryvbas), average annual wind speeds rarely exceed 3.5–4.5 m/s, the use of WPP with a horizontal axis of rotation becomes inefficient. Therefore, it is necessary to choose a more rational WPP so that the interaction of the transmission mechanism and the generator ensures the highest possible efficiency, starting to operate efficiently at low wind speeds.

These requirements are met by wind turbines with a vertical axis of rotation (based on Darrieus, Savonius, Musgrove, Evans rotors and their modifications) operating at lower wind speeds.

Vertical axis wind turbines have a number of advantages. Their design is relatively simple. The electric generator, gearbox and electrical control unit are located in the ground station. This makes it easy to carry out preventive maintenance on vertical-axis rotors process. Rotors with a vertical axis do not need to be pointed (turned) in the direction of the wind, so they are suitable for regions with rapidly changing wind directions.

Vertical-axis wind turbines have the following advantages over horizontal propeller wind turbines in terms of environmental impact:

– noise levels, TV and radio interference are much lower;

– smaller radius of blade fragments in case of their destruction and less probability of self-destruction;

– lower probability of blades colliding with birds.

Vertical axial wind turbines are most efficient when using a support bearing that uses the principle of magnetic levitation. This allows to achieve high reliability in the generator's operation (in the support part). It should be borne in mind that such generators always have a support bearing, and the rotor itself is essentially hanging in the air, which eliminates the bearing friction factor. Vertical wind turbines are made of chrome alloy, which includes ultra-lightweight aluminum, titanium and stainless steel with special materials, making the vertical wind turbine very stable and efficient, even in aggressive environments and at high temperature extremes. When magnetic levitation is used, the generator becomes very reliable, as there is no friction in the support bearing and even after a long period of use, it does not need to be replaced.

The start of rotation of a vertical generator is one of the quietest, and the device immediately begins to generate energy at a starting wind speed of 0.5 m/s. That is why vertical wind generators have such high performance and stability during operation [3].

Other advantages of wind turbines with a vertical axis are:

– a generator with a vertical axis of rotation does not suffer from gyroscopic instabilities, as may be the case with a wind turbine with a horizontal axis;

– vertical wind turbines operate reliably when directly connected to various devices (e.g., water pumps and other mechanical equipment);

– the generator is located at ground level, which reduces the cost of maintenance compared to a wind turbine with a horizontal axis.

Electricity generation in the conditions of Kryvbas dumps by vertical and horizontal wind turbines with a capacity of 100 kW is presented in Table 1 [4].

Table 1 – Electricity generation in the conditions of Kryvbas dumps by vertical and horizontal wind turbines with a capacity of 100 kW

| Wind speed, m/s | Number of days with wind, per year, days | Capacity of a vertical wind turbine, %. | Electricity generated, kW-days | Capacity of a horizontal wind turbine, %. | Electricity generated, kW-days |
|---|---|---|---|---|---|
| 1.8 | - | - | - | - | - |
| 2 | 9 | 1% | 9 | | |
| 2.5 | 12 | 2% | 24 | | |
| 3 | 67 | 6% | 402 | | |
| 4 | 76 | 13% | 988 | | |
| 5 | 79 | 22% | 1738 | 1% | 79 |
| 6 | 54 | 34%; | 1836 | 3% | 162 |
| 7 | 36 | 46% | 1656 | 7% | 252 |
| 8 | 18 | 57% | 1026 | 12% | 216 |
| 9 | 6 | 70% | 420 | 22% | 132 |
| 10 | 4 | 84% | 336 | 38% | 152 |
| 11 | 2 | 100% | 200 | 48% | 96 |
| 12 | 1 | 100% | 108 | 59% | 59 |
| 13 | 1 | 100% | 108 | 80% | 80 |
| 14 | - | 100% | - | 100% | - |
| Total | 365 | - | 8849 | - | 1228 |

Based on the results of Table 1, in Kryvyi Rih, vertical wind turbines can produce electricity more than 7 times more than traditional (horizontal) wind turbines.

Consider the annual production of the vertical wind turbine VTZ-500 manufactured by Solar Store for the conditions of Kryvbas (Table 2).

The amount of electricity generated increases with the height of the wind turbine. The location of horizontal wind turbines on the surface of a high dump 100 m high increases the amount of electricity generated from 1228 kW·days to 3607 kW·days, i.e. 2.9 times. A vertical wind turbine under similar conditions of location increases the amount of energy produced from 8849 to 16544 kW·days, i.e. by 1.8 times. Comparing the performance of vertical and horizontal installations when they are located on waste heaps (16544:1228 kW·days), it can be concluded that the efficiency of vertical wind turbines increases by 13.4 times [3].

Table 2 – Electricity generation by the VTZ-500 unit

| Wind speed, m/s | Number of days with wind, days | VT3-500 | Produced electricity, kWh/d |
|---|---|---|---|
| | | Capacity, %. | |
| 1.8 | | | |
| 2 | 9 | | |
| 2.5 | 12 | 2% | 120 |
| 3 | 67 | 65% | 335 |
| 4 | 76 | 10% | 380 |
| 5 | 79 | 18% | 7110 |
| 6 | 54 | 28%; | 7560 |
| 7 | 36 | 40% | 7200 |
| 8 | 18 | 52% | 4680 |
| 9 | 6 | 64% | 1920 |
| 10 | 4 | 76% | 1520 |
| 11 | 2 | 88% | 880 |
| 12 | 1 | 100% | 500 |
| 13 | 1 | 110% | 550 |
| | | | 32755 kWh/d |
| | | | 786120 kWh |

## 4. Conclusions

Objects of man-made landscape of mining areas, for example, Kryvbas, where average annual wind speeds rarely exceed 3.5–4.5 m/s and are characterized by a significant height that reaches 100–120 m in relation to the day surface mark, are the best options for effective the use of wind generators with a vertical axis of turbine rotation with a magnetic levitation bearing.

The objects of the technogenic landscape of mining areas, for example, Kryvbas, where average annual wind speeds rarely exceed 3.5–4.5 m/s and are characterized by a significant height of 100–120 m in relation to the day surface level and variability, therefore, in the conditions of mining regions, it is effective to use wind turbines with a vertical axis of rotation of the turbine with a magnetic levitating bearing.

The main advantages of such wind turbines are as follows [5]:

– there is no need to direct the axis to the wind flow, such a windmill uses the wind blowing in all directions. They are effective in the Kryvbas region, where variable winds prevail;

– if the wind gusts are strong, they increase the thrust force faster and then stabilize the rotation speed themselves. Therefore, such wind generators can operate smoothly even in strong gale force winds, while horizontal wind turbines automatically shut down in such conditions;

– there are no restrictions on sanitary protection distances, i.e. it can be installed near administrative buildings where people work, as the noise load remains within 20 dB. It has no magnetic radiation, so it can be installed in cities, on the roofs of buildings;

– does not require additional devices for launching;

– harmless to bees, birds and the environment;

– due to lower speed and lightness of the blades, it is safer;

– reaches the rated power at low speeds and low wind speeds (starting wind speed of 0.5 m/s), which is achieved by using a magnetic levitation bearing in their design [6];

– requires a minimum of land for installation, so several wind turbines can be located nearby.

The main thing is that when generating electricity, wind turbines do not pollute the air, water, or soil and do not produce hazardous waste, which is the case when mining and transporting minerals in mining regions. They do not deplete natural resources such as coal, oil, and gas and do not cause environmental pollution. Pollution-free wind energy can reduce the environmental damage caused by fuel-based energy in Ukraine. In addition, the possibility of involving man-made disturbed lands in mining regions (including through the placement of wind turbines) in the economic activities of individual regions and the country as a whole is particularly promising.

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## ПЕРСПЕКТИВИ ВИКОРИСТАННЯ ТЕХНОГЕННО ПОРУШЕНИХ ЗЕМЕЛЬ ГІРНИЧОДОБУВНИХ РЕГІОНІВ ДЛЯ РОЗМІЩЕННЯ ОБ'ЄКТІВ ВІДНОВЛЮВАЛЬНИХ ДЖЕРЕЛ ЕНЕРГІЇ

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**Анотація.** В даній статті описані перспективи використання техногенно порушених земель гірничодобувних регіонів, що з ряду причин не підлягають рекультивації, в контексті ефективного використання відновлювальних джерел енергії. Розглянуто використання відновлювальних джерел енергії, в першу чергу, для задоволення енергетичних потреб, але з урахуванням їх екологічності і відновлюваності. Показана важливість децентралізації джерел електропостачання для споживачів, чого можна добитися шляхом використання відновлювальних джерел енергії. Наведена структура енергоспоживання України. Проаналізовані основні перешкоди, які стоять на шляху до розвитку відновлювальних джерел енергії та покращення енергоефективності в Україні. Як один із перспективних напрямків впровадження відновлювальних джерел енергії, розглянуто використання вітроенергетичних установок (ВЕУ). Перераховані головні переваги вітрової енергетики. Надані формули розрахунку потужності ВЕУ. Розглянуті валовий, технічний і економічний потенціали впровадження ВЕУ. Приведено коефіцієнт використання енергії вітру, який залежить від швидкості вітру. Дано порівняльну оцінку існуючих видів вітроустановок – з горизонтальною віссю обертання і вертикальною віссю обертання. Доказано, що вертикально-осьові вітроенергетичні установки є більш перспективними для впровадження. Показані переваги використання вертикально-осьових вітроенергетичних установок. Для використання рекомендуються вертикальні осьові вітроенергетичні установки із застосуванням опорного підшипника, в якому використаний принцип магнітної левітації. Це робить вертикальні осьові вітроенергетичні установки найбільш ефективними. За рахунок використання вітрогенераторів з вертикальною віссю обертання турбіни з магнітно-лівітуючим підшипником, в умовах Кривбасу вертикальні вітроенергетичні установки можуть виробляти електроенергії більше ніж в 7 разів за традиційні (горизонтальні). Доказано, що кількість виробленої електроенергії збільшується з висотою розташування ВЕУ. Розглянуті екологічні переваги розміщення вітроенергетичних установок на техногенно порушених землях гірничодобувних регіонів.

**Ключові слова:** техногенно порушені землі, відновлювальні джерела енергії, енергоефективність, вітроенергетичні установки (ВЕУ), екологічність ВЕУ.