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## The performance potential of wind energy in Ukraine and prospects for its recovery after the war

**ABSTRACT:** The potential of wind energy in Ukraine is examined in this article. Possibilities of its use are analyzed, an analytical assessment of the potential for its use is performed, and prospects for the use of energy resources for the development of the wind energy market is substantiated. Reasons are provided for the advantages and disadvantages of wind energy, which should be combined into the following components.

The natural resource potential of Ukraine for the development of wind energy is analyzed. It has been confirmed that the wind energy potential of different territories of Ukraine is characterized by average annual wind speeds at the level of 7.0–8.5 m/s (on the continent – at heights of about 100 m, in water areas – about 50 m), which allows using megawatt-class wind turbines with annual coefficients of capacity utilization at the level of 0.3–0.4, which is quite efficient. The specific energy potential of wind energy in Ukraine is established, according to which, the territories of the country were grouped. It has been specified that the best places for locating wind power plants are areas with strong and constant winds, which can be found on the coast of the seas and in mountainous areas.

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The situation with the production of energy resources in Ukraine is analyzed based on wind sources and means before the war. The advantages of wind energy development based on the improvement of legislative framework and promoting production of equipment for the operation of wind power plants in Ukraine are proven. The reasons for the potential of the wind energy market are stated and the main consumers of wind energy in Ukraine are outlined. The development of wind energy is considered as a method for energy independence of the national economy of Ukraine.

KEYWORDS: wind energy, potential, energy resources, market, national economy

## Introduction

There is a steady tendency towards the development of renewable energy sources and the gradual replacement of traditional types of fuel in the world. Wind is one of the renewable energy resources.

The total capacity of renewable energy sources of the world in 2019 was 2,536,853 MW. The wind-energy industry generates 25% out of it due to the rapid development of technologies and stable price (Kucheriava and Sorokina 2020). The International Renewable Energy Agency (IRENA) has compiled a document “Global Energy Transformation Report” for 2019. It suggests possible scenarios for the development of global energy until 2050. The analysis of these scenarios certifies that the weight of wind energy in the energy balance will increase in the course of the coming decades. According to IRENA experts, wind generation can provide more than one third (35%) of the total demand for electricity by 2050 (International Renewable Energy Agency 2020).

In Ukraine, the wind energy market grew rapidly in pre-war times, which made it one of the promising countries of Eastern Europe. The wind-energy sector demonstrated its readiness to develop and further contribute to the national economy of Ukraine.

According to the National Energy Company, Ukrenergo, the total installed capacity of the wind energy sector in Ukraine at the beginning of the war with Russia was 1,529 MW (National Energy Company, Ukrenergo 2021). In fact, these are not the ultimate possibilities. Therefore, it is important to carry out an economic assessment of the potential wind energy has in Ukraine.

According to the international wind-energy standards, classification of wind energy is done by the class of wind resources, which varies from “poor” to “excellent”. The potential of wind energy at a certain location is studied with the use of various probability distribution functions. This is one of the first steps in examining wind-speed data before evaluating the economic study of wind energy.

## 1. Methodology

In this study we used the following methods:

- ◆ Analysis and synthesis – using this method of research, we investigated the wind-energy potential in Ukraine by areas, capacities of wind-energy sector. This helped us to study the particularities of the wind-energy potential of different territories of Ukraine and justify domestic equipment production for the operation of wind power plants.
- ◆ Secondary Data Analysis – to explore the current state of wind-power energy and its prospects in Ukraine, we used analytical publications of Ukraine and the European Union.
- ◆ Statistical method – we used this method to obtain information about wind-energy capacity and energy production in Ukraine.
- ◆ Induction and deduction were used for drawing the conclusions of this research.

## 2. Analysis of the natural resource potential of Ukraine for the development of wind energy

Ukraine adheres to the world trends aimed at developing and implementing energy saving programs, increasing energy efficiency and reducing the use of traditional fuels, accelerating the rates of energy development with the use of renewable energy sources (RES), and increasing their share in the overall energy balance of the country. Wind energy is one of these directions.

The share of wind energy in the total installed capacity of the RES sector was 19.8% (December 2021). The share of wind energy in the total capacity of the country's energy sector was 2.97% (National Energy Company "Ukrenergo" 2021).

Wind energy is a branch of renewable energy with the focus on the use of kinetic wind energy. This type of energy source is an indirect form of solar energy, and it therefore belongs to renewable energy sources. On the planet, the occurrence of wind is random and uncontrollable in terms of both the direction and strength of the wind. Wind with speed in the range of 4–30 m/s is considered to be energetically profitable for the use of turbine generators of electricity. However, this source is unstable. The occurrence of wind depends on the geographical region, season, time of the day, topography of the area, and height above sea level (Dakovski and Vyantskovski 2007).

Wind energy is a derivative of the energy the sun gives. It is the kinetic energy of the movement of air masses. The potential advantages of wind energy are as follows:

- ◆ the ability to renew and free nature of the resource – the wind will appear until the energy of the sun reaches the earth;

◆ environmental friendliness – its use does not harm the environment (although there is an opinion that wind generators during operation create low-frequency vibrations which are harmful to living organisms; however, this has not been scientifically proven).

Disadvantages include: instability of wind flows; wind potential is distributed very unevenly; the areas most suitable for the construction of wind power plants (in places where the wind blows almost constantly) are located along the coast. The minimum wind speed should exceed 4 m/s (Wind Energy 2022).

Modern wind turbines have a nominal power from approximately 600 kW to 5 MW. The most common in commercial use are currently air turbines with a nominal power in the range of 1.5–3 MW. The power of the wind flow is proportional to its cross-sectional area and it has a cubic dependence on the wind speed; i.e. its power increases even faster than the wind speed does (Renewable Energy and Distributed Generation Systems 2022).

At the beginning of 2020, the total installed capacity of Ukrainian wind power plants was 1.17 GW. Ukraine can potentially install wind power plants with a total capacity of 688 GW in its territory. The average annual electricity production of this system can reach 2,174 billion kWh (Kudria et al. 2021). This certifies that Ukraine has huge wind energy resources.

The wind potential of different regions of Ukraine is determined by the national wind energy registry. It includes wind speed indicators (annual average and monthly average); the repeatability of the speed of wind directions during the year, month, day, etc. The average annual wind speed in the surface layer on the territory of Ukraine is 4.3 m/s, which is sufficient for the production of electricity. Wind speed increases with an increase in the height above the surface of the earth. Taking into account the fact that wind generators can use wind energy up to a height of 50 m (at a certain height from the surface, the wind speed increases), the energy potential in the territory of Ukraine makes up a huge amount (330 billion kW), which exceeds the installed capacity of Ukraine's power plants by 6,000 times (Ukraine's Power System: Peace and War 2022). Wind-speed characteristics in the studied areas vary depending on climatic conditions, geographical location, and surface profile. It is important to get the generalized wind speed characteristics to common parameters. First of all, the wind-speed data is collected in the course of five years to obtain a more accurate rate of average wind speed. Wind-speed measurements are always taken at the height of 10 and 25 m, and the latest wind turbines have a minimum hub height of 50 m to operate. Thus, the speed must be extrapolated to the specific height of the turbines under study. Therefore, the probability distribution function is used for the frequency distribution of the wind speed to estimate the wind potential of the site.

The "Economic Strategy of Ukraine for the Period until 2030" indicates that the most promising regions of the country in terms of wind-energy development are the southern and southeastern areas of the country, where the average wind speed is higher than in the remaining territory (Economic Strategy... 2030 2021).

The wind energy potential of various territories of Ukraine is characterized with average annual wind speeds at the level of 7.0–8.5 m/s (on the continent – at heights of about 100 m, on water areas – about 50 m), which allows using megawatt-class wind turbines with an annual utilization factor power at the level of 0.3–0.4, thus it is relatively effective (Fig. 1).

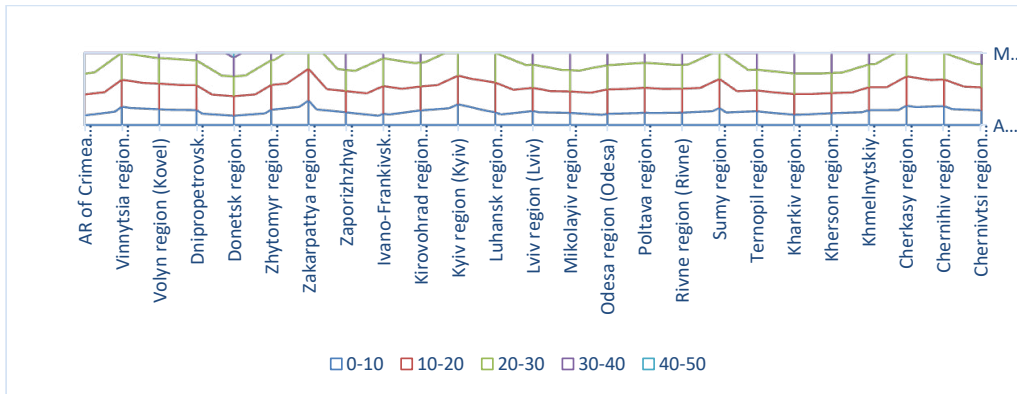


Fig. 1. Average wind speed at a height of 10 m (A...) and maximum wind speed [m/s] (M...) (Climate of Ukraine 2003)

Rys. 1. Średnia prędkość wiatru na wysokości 10 m (A...) i maksymalna prędkość wiatru [m/s] (M...)

The best location for wind-power plants are the regions with strong and constant winds, such as those located on the coast (Kherson, Mykolaiv, Odesa, Zaporizhzhya) and in mountainous areas (Zakarpattia).

Data on the specific energy potential of wind energy in Ukraine are analyzed and presented below (Table 1).

The results of the processed data indicate that the potential for the development of wind energy in Ukraine is high. The territorial capabilities of the country allow referring to the prospects for constructing profitable wind power plants (WES) both on land (in mountainous and flat areas) and in coastal areas.

### 3. Analysis of energy production based on wind sources and means

“Green” electricity in Ukraine is generated by thirty-four wind-power plants (including those located in the temporarily occupied territories of certain districts of Donetsk and Luhansk regions (hereinafter ORDLO). The largest of them are the Botievska, Primorska, Myrnska, Orlivska, Overyanivska and Novoazovska wind farms. All wind turbines of the first seven, except Boyivska and Pryazovska, were put into operation in 2019. We have considered the growth of wind-energy capacities for the period 2014–2021 (Fig. 2).

The figure clearly shows a sharp jump in the increase of capacities, starting from 2018 due to the construction of new wind power plants. This became possible due to improvement in the

TABLE 1. Specific energy potential of wind energy in Ukraine

TABELA 1. Specyfikacja potencjału energetycznego energetyki wiatrowej w Ukrainie

Region, area	Average annual wind speed (V) [m/s]	Height [m]	Natural wind potential [kW h/m <sup>2</sup> h]	Technically achievable wind potential [kW h/m <sup>2</sup> h]
Vinnytsia, Ivano-Frankivsk (N-W), Zhytomyr, Zakarpattia (W and S-W), Kyivska, Kirovohradska (partially N-W), Volyn, Lviv, Poltava (N-W), Rivne, Sumy, Ternopil, Kharkiv (partly N-W), Khmelnytska, Cherkasy, Chernivetska (without W)	< 4,25	15	1,120	200
		30	1,510	380
		60	2,030	375
		100	2,530	460
Dnipropetrovsk, Donetsk (without S), Zaporizhia (without S), Luhansk, Mykolaiv (without S), Kirovohrad*, Odesa (without S), Poltava*, Kharkiv*, Kherson (without S)	4,5	15	2,010	390
		30	2,710	520
		60	3,640	700
		100	4,540	850
Donetsk*, Mykolaiv *, Zaporizhia*, Kherson*, AR Crimea**	5,0	15	2,810	520
		30	3,790	690
		60	5,100	860
		10	6,350	975
AR Crimea***, Ivano-Frankivsk***, Zakarpattia ***, Lviv***, Chernivtsi***	4,5 < V < 5,5	15	3,200	620
		30	4,320	830
		60	5,810	1,020
		100	7,230	1,150

\* Remaining territory.

\*\* Plain part.

\*\*\* Mountain regions.

Abbreviations: N-W – north-western region, W – western region, S-W – south-western region, S – southern region.

Source: Ukrainian Renewable Energy Association 2021.

legislature on the development of renewable energy sources and the implementation of the laws of Ukraine: On amendments to the Law of Ukraine “On Heat Supply” in terms of stimulating the production of heat energy from alternative energy sources; On the Alignment of Ukraine to the Charter of the International Renewable Energy Agency (IRENA); On the electric energy market; On the approval of the Energy Strategy of Ukraine for the period until 2035 “Safety, energy

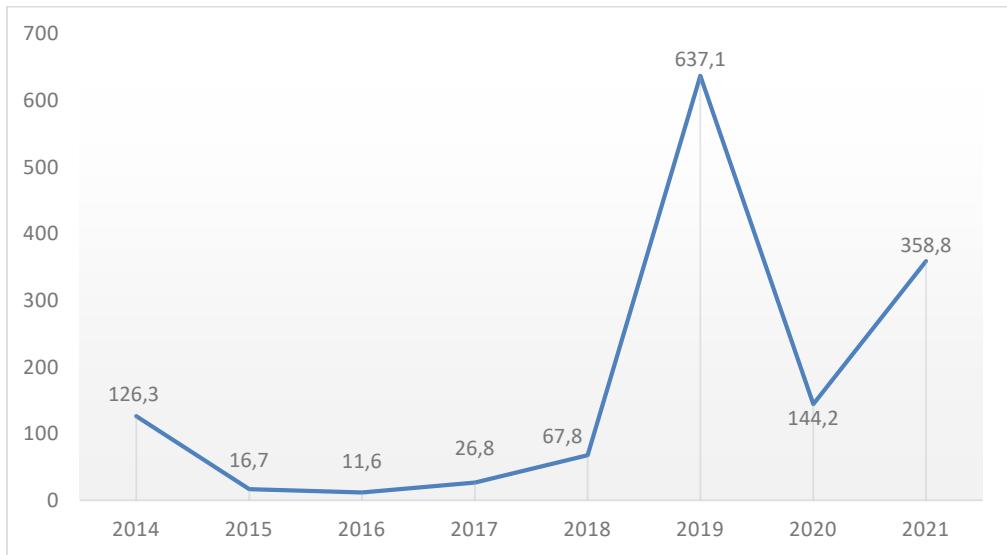


Fig. 2. Annual growth of wind-power capacities, 2014–2021 [MW]  
 (Public Union “Ukrainian Wind Power Association” 2021)

Rys. 2. Roczny przyrost mocy wiatrowych, 2014–2021 [MW]

efficiency, competitiveness”; On the approval of amendments to the preliminary agreement on the purchase and sale of electric energy between the state-owned enterprise “Energorynok” and a business entity that produces electric energy with the use of alternative energy sources, etc.

In 2019, amendments were made to the law “On Alternative Energy Sources”, according to which the capacity of small wind turbines for households was increased to 50 kW and the tariff was set at 11.63 euro cents per kWh. The “green” tariff is established until January 1, 2030: to business entities for electric energy produced from renewable energy sources; to private households for electric energy produced from the energy of the sun and wind with the capacity of power plants up to 30 kW. It is also envisaged to receive a surcharge to the “green” tariff at the amount of 5 and 10%, respectively, for the use of Ukrainian-made equipment at the level of 30 and 50% (Table 2).

Continuous increase in the cost of electricity for enterprises in the course of the year, which at the end of 2021 exceeded 5 UAH per kWh, makes entrepreneurs look for alternatives to centralized electricity supply. The seasonality of electricity consumption in enterprises coincides with seasonality of generation at wind power systems. Both electricity consumption and wind generation increase in winter. Therefore, it is wind energy that becomes an economically and ecologically feasible alternative solution to the problem of expensive electricity for enterprises.

One of the factors that confirm the prospects of this wind energy market segment is a significant growth of interest in the wind energy technologies in 2021 on the part of representatives of small and medium-sized businesses. In 2021, the scope of investments in the wind energy sector

TABLE 2. The rate of “green” tariff for wind power plants

TABELA 2. Stawka „zielonej” taryfy dla elektrowni wiatrowych

Power plant capacity and other factors affecting the “green” tariff rate	Rate for commissioned facilities [€/kWh]		
	since January 1, 2017 to December 31, 2019	since January 1, 2020 to December 31, 2024	since January 1, 2025 to December 31, 2029
Power up to 600 kW inclusive	5.82	5.17	4.52*
Power from 600 kW to 2 MW	6.79	6.03	5.28*
Power from 2 MW	10.18	9.05	7.92*

\* The rate is set for the beginning of 2025 without quarterly conversion to the Euro exchange rate.

Source: Law of Ukraine “On Alternative Energy Sources” 2022.

amounted to more than 500 million euros, which is two times less than the figure of the record year of 2019 (1 billion euros). In addition, the year of 2021 was also marked by setting ambitious goals for the development of renewable energy sources in Ukraine for the current decade. According to the “National Economic Strategy of Ukraine until 2030” adopted in March 2021, the share of renewable energy sources should have increased up to 25% in the energy balance of the country by 2030. It is also important to adopt such strategic documents as: “Energy Security Strategy”, “Second National Certain Contribution to the Paris Agreement”, and others. They are aimed at the significant development of the national sector in the area of renewable energy.

In 2015, to support domestic manufacturers of equipment and to strengthen the national economy, a surcharge was introduced to the “green” tariff for the use of Ukrainian-made equipment at renewable energy facilities. This “surcharge” replaced the so-called “local component requirement” which was previously in force, limiting access to the market of foreign equipment manufacturers and being intensively criticized by the European Energy Community.

The Black Sea Wind Park, located in the Mykolaiv region, became the first wind energy facility to receive a 10% premium for installing equipment manufactured in Ukraine. On May 17, 2017, the production of the first wind turbine with a capacity of 3.2 MW was completed at the Kramatorsk plant of Furlander Wind Technology LLC. Moreover, the production cycle of wind power plants engaged: Kramatorsk Plant of Heavy Machine Building, Energomashspetsstal, Novokramatorsk Plant of Heavy Machine Building, Mykolaiv Enterprise “ESTA Ltd”.

The distribution of the installed capacity of the wind-energy sector in the mainland of Ukraine (without the Autonomous Republic of Crimea) and in the temporarily uncontrolled territories of Eastern Ukraine (ORDLO) for the period from 2015 to 2021 is studied (Table 3).

As of the end of 2021, the total installed wind-energy capacity in Ukraine increased to 1,672.9 MW, with 1,534.9 MW of which being located in the mainland of Ukraine (138.0 MW – on the territory occupied by the Russian Federation in Luhansk and Donetsk regions). The installed capacity of wind power plants in Crimea remained unchanged and it is 87.8 MW as it was in 2013. The supply of electricity by solar and wind power plants located on the annexed territory



TABLE 3. Capacities of the wind-energy sector in the mainland of Ukraine and the territories of ORDLO, 2015–2021 [MW]

TABELA 3. Moce energetyki wiatrowej na terenie Ukrainy i na terenach ORDLO, 2015–2021 [MW]

Years	Mainland of Ukraine*	Temporarily uncontrolled territories of eastern Ukraine (ORDLO)	Total power
2015	409.5	–	409.5
2016	300.7	138.0	438.7
2017	327.1	138.0	465.1
2018	394.8	138.0	532.8
2019	1,031.9	138.0	1,169.9
2020	1,179.1	138.0	1,314.1
2021	1,534.9	138.0	1,672.9

\* Without the territory of AR Crimea.

Source: Public Union “Ukrainian Wind Energy Association” 2021.

of the Autonomous Republic of Crimea to the United Energy System of Ukraine had been suspended since April 2014, therefore, this data is not reflected in Table 2.

The total actual share (installed capacity, gross electricity production) of the wind-power industry of Ukraine to achieve the mandatory goals for the year of 2020 and indicative intermediate trajectory of achieving the share of energy from renewable sources in electricity generation was 1,314 MW and 3,270.6 kWh, respectively, according to the Directive 2009/28/EU, or 3,007.3 according to the Eurostat methodology (Fig. 3).

The data presented in Figure 3 do not take into account the facilities located in the occupied territory of the Autonomous Republic of Crimea. So, the total capacity of the wind power plants is 87,768 MW.

Since 2019, the total capacities of the wind energy sector in the mainland of Ukraine have reached the values of more than 10 GW. Data analysis certifies a significant “jump” in the capacity of the wind energy sector: from 2018 to 2019, it doubled; from 2015 to 2021 – it increased by more than 10 times. This was facilitated with the improvement of the legislative framework and the production of domestic equipment for the operation of wind power plants. It became possible to create a market for domestic equipment for the production of wind energy with support provided at the state level.

In the course of the year 2021, 91 new wind turbines with a total capacity of 358.81 MW were commissioned in three regions of Ukraine, with the most powerful presented below:

- ◆ 40 MW of the first phase of the Dniester wind farm in Odesa region;
- ◆ 76.5 MW Yuzhny Energy wind farm in the Odesa region;
- ◆ 98.01 MW of the first stage of the Zaporizhia wind farm in the Zaporizhia region;
- ◆ 144.3 MW of the second stage of the Sivash wind farm in the Kherson region.

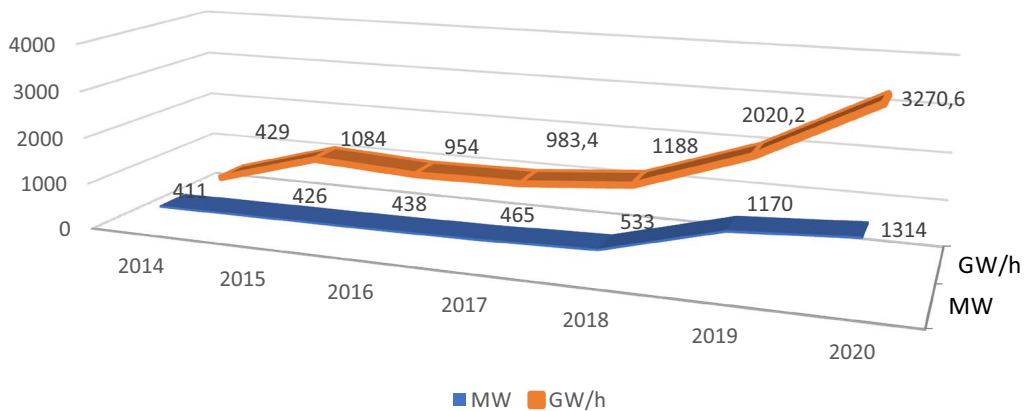


Fig. 3. Total actual share of wind energy in Ukraine  
 (State Agency for Energy Efficiency and Energy Saving of Ukraine 2020)

Rys. 3. Aktualny udział energetyki wiatrowej w Ukrainie

In terms of the number of installed wind-power capacities per year, Kherson Oblast took the first place, having installed 144.3 MW per year, being ahead of the Odesa region, which added 116.5 MW of new wind-power capacities. In addition, 98 MW of new wind power capacities appeared in the Zaporizhia region. Figure 4 shows the share of installed wind-energy capacities in the regions of mainland Ukraine in 2021.

Thus, the total installed capacity of the wind energy sector was 1,672.945 MW at the end of 2021. At the beginning of 2022, “green” electricity was generated in Ukraine by 699 wind turbines, the average unit capacity of which is 3.5 MW. In terms of the total installed capacity at the end of 2021, wind energy remains the second, after solar, in the national RES sector. However, it should be noted that it was the wind energy sector of Ukraine that added the largest amount of new capacity to the “green” energy mix of the country in 2020. In general, new wind power capacities put into operation in 2021 were 2.5 times higher compared to 144 MW in 2020. Owing to the generation of electricity from wind energy, 1.8 million tons of coal and 1171.4 thousand m<sup>3</sup> of natural gas were saved in 2021; approximately 3.1 million tons of CO<sub>2</sub> emissions were reduced (Civil Union “Ukrainian Wind Energy Association” 2021).

By the end of 2021, the wind energy market has been gradually developing. The Government of Ukraine started fulfilling its financial obligations to the producers of renewable energy sources and paying arrears from payments for “green” electricity accumulated in 2020–2021. Along with this, certain groups of buyers – entrepreneurs of small and medium-sized businesses – have formed in the market of wind energy consumers.

Therefore, the pre-war analysis of energy production based on wind sources and means indicates the intensification of activities in this direction in the energy market of Ukraine. A significant number of Ukrainian and foreign companies were functioning in the country, being engaged

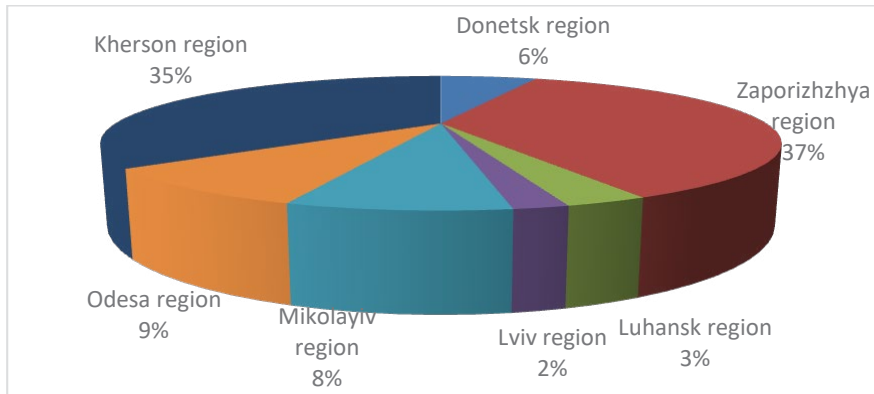


Fig. 4. The share of installed wind energy capacity in the mainland regions of Ukraine in 2021 [%]  
 (Public Union “Ukrainian Wind Energy Association” 2021)

Rys. 4. Udział mocy zainstalowanej w energetyce wiatrowej na lądzie w 2021 r. [%]

in the implementation of large and smaller investment projects in different administrative and territorial regions with good prospects in terms of wind energy.

## Conclusion

As a result of the study, the wind-energy potential of Ukraine was analyzed with an outline of the prospects for its use after the war. The rapid growth in the wind energy market of Ukraine in pre-war times was substantiated among both producers and consumers.

It was specified that the wind-energy potential of different territories of Ukraine is characterized with the average annual wind speeds at the level of 7.0–8.5 m/s (on the continent – at heights of approximately 100 m, in water areas – approximately 50 m), which allows using megawatt class wind turbines with annual coefficients of capacity utilization at the level of 0.3–0.4, thus they are quite efficient. Specific energy potential of wind energy in Ukraine was stated as a combination of the average annual wind speed, height above the surface, natural wind potential, and technically achievable wind potential. As a result of the study, the territories of Ukraine were grouped and it was identified that the best locations for wind power plants are the regions with not only powerful, but also constant winds. The dynamics of the annual growth of wind-energy capacities has been tracked. Its jump in increase due to the activation of legislative and technical innovations is substantiated in the article. The situation of pre-war energy production in Ukraine based on wind sources and means is analyzed. This provided the grounds for the advantages of wind-energy development on the basis of the improved legislative framework and the start of domestic equipment

production for the operation of wind power plants. It also traced the dynamics of the wind-energy sector power and outlined its significant growth compared to the period 5–7 years ago. The total actual share of the wind power industry of Ukraine required for achieving strategic goals of the development of industry is determined. A regional analysis of the installed wind energy capacity in Ukraine before the war was carried out. Potential performance of the wind energy market was substantiated with an outline of the key consumers of wind energy in Ukraine. The prospects of reconstruction in the “green” energy sector after the war were considered.

In further studies, it is worth conducting ecological and economic modeling of the proposed measures to calculate their effectiveness. These studies are very important to the effectiveness of the recovery of the wind-power industry after the war.

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## Potencjał wykorzystania energetyki wiatrowej w Ukrainie i perspektywy jego rozwoju po wojnie

### Streszczenie

W artykule omówiono potencjał energetyki wiatrowej w Ukrainie. Analizuje się możliwości jego wykorzystania, przeprowadza analityczną ocenę wykorzystania tego potencjału oraz uzasadnia perspektywy wykorzystania zasobów energetycznych dla rozwoju rynku energetyki wiatrowej. Ponadto omówiono także zalety i wady energetyki wiatrowej.

Analizowany jest potencjał zasobów naturalnych Ukrainy dla rozwoju energetyki wiatrowej. Stwierdzono, że potencjał energetyki wiatrowej różnych terytoriów Ukrainy charakteryzuje się średnimi rocznymi prędkościami wiatru na poziomie 7,0–8,5 m/s (na kontynencie – na wysokości ok. 100 m, a na obszarach wodnych ok. 50 m), co pozwala na zastosowanie dość efektywnych turbin wiatrowych klasy megawatowej o rocznym współczynniku wykorzystania mocy na poziomie 0,3–0,4. Ustalono konkretny potencjał energetyczny energetyki wiatrowej, według którego pogrupowano terytoria kraju. Stwierdzono, że najlepszymi miejscami do lokalizacji elektrowni wiatrowych są tereny o silnych i stałych wiatrach, które występują na wybrzeżach mórz oraz na terenach górskich.

Przeanalizowano produkcję energii elektrycznej przed wojną. Przedstawiono zalety rozwoju energetyki wiatrowej, która może się rozwijać, jeśli zostaną poprawione ramy prawne i promocja produkcji sprzętu do eksploatacji elektrowni wiatrowych. Ukazano potencjał rynku energetyki wiatrowej oraz wskazano głównych odbiorców energii wiatrowej w Ukrainie. Rozwój energetyki wiatrowej jest uważany za drogę do niezależności energetycznej gospodarki narodowej kraju.

**SŁOWA KLUCZOWE:** energia wiatru, potencjał, zasoby energii, rynek, gospodarka narodowa

