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STRATEGIC PRIORITIES FOR THE DEVELOPMENT OF THE ENERGY SECTOR OF UKRAINE'S ECONOMY IN THE CONTEXT OF POST-WAR RECOVERY

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Strategic Priorities for the Development of the Energy Sector of Ukraine's Economy in the Context of Post-War Recovery

The article examines the problems and prospects of the energy sector in Ukraine in the context of war and post-war recovery. The aim of the article is to identify strategic priorities for the development of the energy sector of the national economy to ensure post-war recovery, taking into account the potential of the energy sector of Ukraine and global trends in energy development of the economy. Some indicators of the energy sector of Ukraine are analysed. The geographical structure of electricity imports is presented. The dynamics of Ukraine electricity exports and imports is analysed. The prerequisites for the development of renewable energy, in particular, the need for decarbonisation of the economy, are identified. The dynamics of primary energy consumption and consumption of primary energy from renewable sources and biofuels in Ukraine from 2013 to 2023 are analysed. The prospects for increasing the share of renewable energy sources (RES) in the overall structure of final energy consumption in accordance with the strategic guidelines of national energy development are identified. The losses from damage caused by Russian attacks on the electric power industry capacities, in particular: electricity distribution and transmission systems, nuclear power plants, thermal power plants, thermal power plants, large hydroelectric power plants and pumped storage power plants, are identified. The article presents global programmes and strategies for the development of the energy sector in the long term and identifies their key characteristics and directions. Based on the analysis of the potential of the energy sector development to meet the needs of the economy, global trends and initiatives, the strategic priorities for the development of the energy sector of Ukraine's economy to meet the needs of post-war recovery are identified, in particular: decarbonization of the economy, expansion of the use of renewable energy sources, development of carbon capture and storage, development of energy storage and smart grids, modernization and reconstruction of energy facilities, introduction of intelligent technologies.

Keywords: *energy sector of the economy, decarbonisation, renewable energy sources, sustainable development, sustainable energy, global initiatives.*

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Трофименко О. О., Бояринова К. О., Рощина Н. В. Стратегічні пріоритети розвитку енергетичного сектора економіки України в умовах повоєнного відновлення

У статті досліджено проблеми та перспективи енергетичного сектора в Україні в умовах війни та повоєнного відновлення. Метою статті є визначення стратегічних пріоритетів розвитку енергетичного сектора національної економіки для забезпечення повоєнного відновлення з урахуванням потенціалу енергетичного сектора України та глобальних трендів енергетичного розвитку економіки. Проаналізовано окремі показники енергетичного сектора України. Приведено географічну структуру імпорту електроенергії. Проаналізовано динаміку експорту й імпорту електроенергії в Україні. Визначено передумови для розвитку відновлюваної енергетики, зокрема, потреби у декарбонізації економіки. Проаналізовано динаміку споживання первинної енергії та споживання первинної енергії з відновлюваних джерел і біопалива в Україні з 2013 по 2023 рр. Визначено

динаміку та структуру відновлюваної енергетики в Україні. Ідентифіковано перспективи підвищення частки відновлюваних джерел енергії (ВДЕ) у загальній структурі кінцевого енергоспоживання відповідно до стратегічних орієнтирів національного енергетичного розвитку. Ідентифіковано збитки від пошкоджень у результаті російських атак потужностей електроенергетики, зокрема: систем розподілу та передачі електроенергії, атомних електростанції, теплових електростанцій, теплових електроцентралей, великих гідроелектростанцій та гідроакумулюючих електростанцій. Наведено світові програми та стратегії розвитку енергетичного сектора на довгострокову перспективу та визначено їх ключову характеристику та напрями. На основі проведеного аналізу потенціалу розвитку енергетичного сектору щодо забезпечення потреб економіки, глобальних трендів та ініціатив ідентифіковано стратегічні пріоритети розвитку енергетичного сектору економіки України для забезпечення потреб повоєнного відновлення, зокрема: декарбонізація економіки, розширення використання відновлюваних джерел енергії, розвиток уловлювання та зберігання вуглецю, розвиток накопичувачів енергії та «розумних» мереж, модернізація та реконструкція енергетичних об'єктів, впровадження технологій інтелектуальної декарбонізації.

Ключові слова: *енергетичний сектор економіки, декарбонізація, відновлювані джерела енергії, сталий розвиток, стала енергетика, глобальні ініціативи.*

Рис.: *7.* ***Табл.:*** *1.* ***Бібл.:*** *26.*

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Introduction. The energy sector is a key component of the national economy of Ukraine, which plays a crucial role in ensuring the stable functioning of all spheres of public life. Therefore, the state and efficiency of the energy sector directly affect economic growth, Ukraine's competitiveness in the global environment and the welfare of its citizens. In the conditions of Russia's full-scale military invasion of Ukraine, control over energy resources and ensuring the efficiency of energy supply is becoming a strategic element for maintaining economic stability.

The current global transformations pose unprecedented challenges for the energy sector, which are caused by a set of interrelated factors. Geopolitical changes, including military conflicts, trade disputes and the reshaping of global alliances, have a significant impact on the availability and cost of energy resources, creating new threats to the energy security of countries. Increased awareness of environmental issues related to climate change, environmental pollution and depletion of natural resources is driving the transition to environmentally sustainable development of the energy sector. In turn, technological advances, including the development of renewable energy sources, the introduction of smart grids and the use of artificial intelligence, are opening up new opportunities to increase efficiency, reduce costs and minimise negative environmental impact. These directions of the energy sector development are reflected in global initiatives, in particular: REPowerEU - a plan of the European Union introduced in 2022 and developed in response to Russia's full-scale invasion of Ukraine, to reduce dependence on Russian energy resources and accelerate the transition to renewable energy sources [1]; European Green Deal – a comprehensive plan of the European Union aimed at achieving climate neutrality by 2050 [2]; National Blueprint for Transportation Decarbonisation - a strategic document developed by the US government that defines a plan to achieve zero emissions in the transport sector by 2050 [3]; Net Zero Strategy: Build Back Greener - a strategic plan of the UK [4], etc. These trends and current conditions make it necessary for Ukraine to adapt and transform its national energy sector by strengthening its resilience, diversifying energy sources and introducing innovations.

The onset of the war in 2022 has become a catalyst for profound transformations in Ukraine's energy sector, creating unprecedented challenges and new opportunities for its development. Massive missile strikes on critical infrastructure caused serious damage to energy facilities, including power plants, substations and power lines. This resulted in a decline in electricity production, interruptions in energy supply and an increased need to import energy to cover the shortfall. The hostilities have exacerbated the problem of energy security, highlighting the urgent need to diversify energy sources and reduce dependence on supplies from aggressor countries.

At the same time, the ongoing war has become an incentive to actively search for alternative energy sources, accelerate the introduction of energy-saving technologies and develop distributed generation, which ensures greater reliability and

stability of energy supply to consumers. In addition, it has highlighted the need to expand international cooperation in the energy sector, as well as to attract foreign investment to restore and modernise energy infrastructure, which is important in the context of war and post-war recovery. The above determines the relevance of this study in determining strategic priorities for the development of the energy sector of Ukraine's economy to ensure its recovery.

Many Ukrainian scientists have studied the energy sector of the economy and identified the directions for energy development in Ukraine, including: V. Geiets [5], O. Ilyash [6], V. Khaustova [7], O. Kyrylenko [8], O. Trofymenko [9], V. Kubatko [10], V. Oleksiuk [11] and others. Foreign authors examine the global dimension of energy development, in particular, A. Grübler [12], Kumar R. [13], Wang H. [14], Gallagher K. [15] and others. However, despite a significant number of scientific publications, there are still a number of open questions about assessing the potential of the energy sector for the needs of the national economy, defining strategic priorities for the development of the energy sector at the State level, taking into account the conditions of war and the needs of post-war recovery, as well as best international practices. In addition, during the war, statistical data for assessing the development of the energy sector as a strategic industry is partially closed, and we used the OSINT methodology to assess the state and formulate directions for the development of the energy sector of the national economy, which allowed us to conduct a comprehensive study.

The aim of the article is to identify strategic priorities for the development of the energy sector of the national economy to ensure post-war recovery, taking into account the potential of the energy sector of Ukraine and global trends in energy development.

Results. Ukraine's dependence on traditional energy sources, such as coal, natural oil and natural gas, is one of the key challenges for the national economy and energy security. This dependence was formed historically, in particular due to the structure of the industry and the significant role of fossil fuels in the country's energy consumption. However, current geopolitical risks, economic constraints, and environmental concerns highlight the critical need to reduce this impact.

Coal has traditionally been the main resource for electricity generation in Ukraine due to its large reserves, especially anthracite mined in the Donbas region. However, the coal industry faces a number of challenges, especially low production efficiency, high production costs and a serious environmental burden.

Coal combustion is one of the main sources of greenhouse gas emissions, which exacerbates climate change and leads to air pollution, which negatively affects public health. The situation has been exacerbated by the Russian invasion of Donbas, which began in 2014, resulting in the loss of control over some coal mines and forcing Ukraine to increase coal imports. This has further increased the energy sector's vulnerability to external risks and has become a significant obstacle to energy independence.

Natural gas is playing a key role in Ukraine's energy mix, providing both electricity generation and heating for the residential and industrial sectors. Reducing dependence on gas imports is strategically important for both Ukraine and the EU, some of which have enforced an embargo on natural gas imports from Russia as a result of its full-scale war on Ukraine. The dependence on external suppliers significantly poses risks to energy security, including vulnerability to political pressure and price volatility in global energy markets [16].

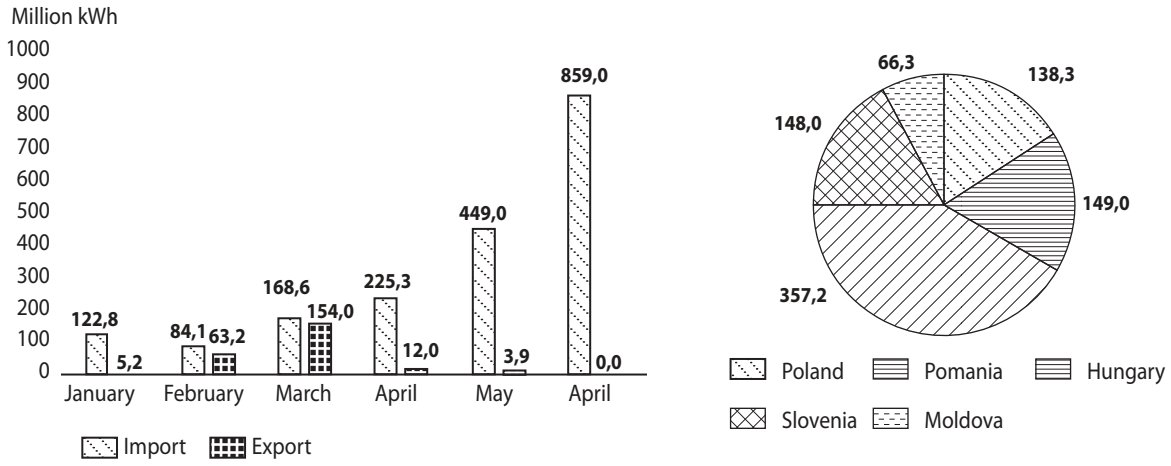


Fig. 1. Ukraine electricity exports and imports in January-June 2024, million kWh

Source: compiled by the authors on the basis of [17]

Fig. 1 shows the dynamics of electricity exports and imports in January-June 2024. Exports started to decline in April and were 0 in June. In terms of electricity exports, June 2024 was the worst month of this period in the last 10 years. Compared to February, electricity imports increased more than 10 times in June 2024. In addition, June 2024 was a record month in terms of imports over the past two years. Renewable energy sources, in particular bioenergy, geothermal energy and hydrogen technologies, are the main factors in improving the efficiency of energy systems, reducing dependence on energy imports and minimising the negative impact on the environment. However, in order to realise the potential of these technologies, comprehensive government support is required, including not only funding for research, but also the creation of a favourable

regulatory environment. Attracting investments, developing infrastructure and creating new jobs in the renewable energy sectors are also an integral part of this process.

Ukraine successfully completed the 2023/2024 heating season using only domestically produced natural gas, setting a historical precedent. This was largely due to increased production by State-owned companies, with JSC Ukrgazvydobuvannya raising output by over 5% and PJSC Ukrnafta by 6%. The Naftogaz Group's effective mechanism for purchasing natural gas from independent producers also played a key role in ensuring winter stability [18].

Changing the dependence on export natural gas is a strategically important task that requires active diversification of supply sources, expanding reverse supply opportunities with the European Union, and stimulating the development of domestic production. Successful implementation of these measures will help to increase Ukraine's energy sustainability and strengthen its economic security in the face of growing geopolitical instability. At the same time, sustainable energy security is based on achieving carbon neutrality, which is confirmed by the national energy strategies of leading countries and necessitates the development of renewable and alternative energy sources. The latest data show a negative trend in global greenhouse gas emissions related to energy – In 2023, they amounted to more than 40 gigatons of CO_2-equivalent. Fig. 2 shows a visualisation of greenhouse gas emissions by geography in 2023. China accounts for the largest emissions – 13.7 billion tonnes of CO_2-equivalent, followed by the United States – 5.89 billion tonnes of CO_2-equivalent, and India - 4.2 billion tonnes of CO_2-equivalent. In Ukraine, this figure in 2023 was 214.93 million tonnes of CO_2-equivalent, which indicates the need to introduce measures to decarbonise the energy sector - development of renewable energy and intelligent decarbonization.

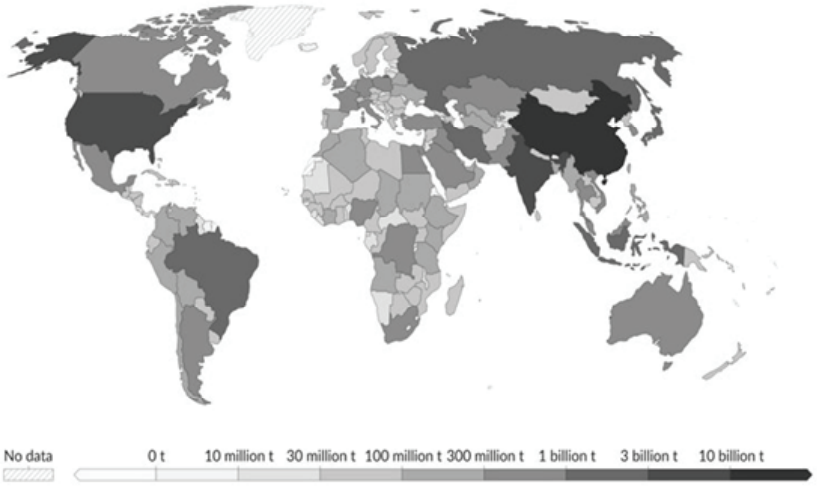


Fig. 2. Global greenhouse gas emissions, 2023

Source: [19]

It should be noted that despite the gradual development of renewable energy sources and the implementation of energy efficiency measures, their share remained insufficient to significantly reduce dependence on traditional energy resources, which significantly increased the vulnerability of the energy sector to external risks, such as price fluctuations in global markets, political pressure from suppliers and limited investment in the modernisation of the industry. Fig. 3 shows the dynamics of primary energy consumption and combined renewable electricity and biofuels primary energy input consumption in Ukraine for the period 2013–2023. As a result of Russia's full-scale invasion, energy consumption in Ukraine in 2023 decreased by 1.14 exajoules compared to 2021, while energy consumption from renewable sources and biofuels decreased from 0.21 to 0.18 in 2022, and increased to 0.2 in 2023, indicating an intensification of efforts in this direction. In general, such dynamics are explained by damage to energy infrastructure as a result of Russian attacks, a decline in industrial production and consumer activity, intensified efforts to improve energy efficiency and diversify energy sources, optimisation changes in the behaviour of energy consumers, and modernisation of capacities.

Figure 4 shows the development of renewable energy in Ukraine by the types of sources. An analysis of the data on the development of renewable energy sources (RES) in Ukraine from 2010 to 2021 shows a marked increase in the capacity of various types of power plants. Since 2010, we have been able to study the development of renewable energy sources in Ukraine, which allows us to assess the effectiveness of the State's energy policy and strategy. Solar power plants (SPPs) showed the largest increase in capacity, from 1 MW in 2010 to over 6.3 GW in 2021. A particular surge in development was observed after 2014, and the peak was reached in 2019, when the capacity of SPPs reached almost 5.9 GW. At the same time, a slight decrease was recorded in 2021, indicating a certain stabilisation of the solar energy market. As for household solar power plants (HSPPs), their capacity has been increasing since 2014, reaching 1.2 GW in 2021. This demonstrates the high demand for small-scale solar generation among private consumers [16; 21].

Wind power plants (WPPs) also show a gradual increase. Between 2014 and 2019, the capacity of wind farms increased from 1.2 GW to 1.7 GW, which indicates the active development of wind energy in Ukraine, particularly in regions with

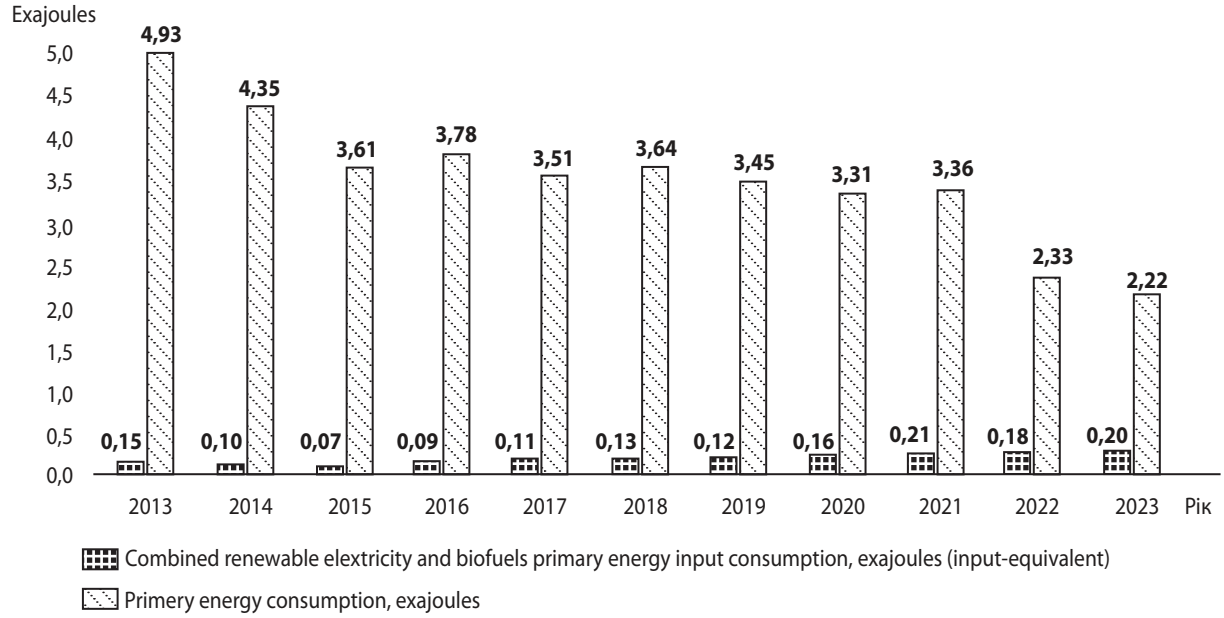


Fig. 3. Primary energy consumption and combined renewable electricity and biofuels primary energy input consumption, 2013–2023, exajoules

*Source: c*ompiled by the authors on the basis of [20]

high wind potential. However, in recent years, the growth rate of this industry has slowed somewhat. The capacity of bioenergy power plants (BPPs) has also been gradually increasing, but the pace of their development has been much slower compared to solar and wind power plants. Between 2010 and 2021, the capacity of bioelectric power plants increased from zero to more than 120 MW, indicating the gradual introduction of biomass-based bioenergy technologies.

The development of biogas power plants (BPPs) has intensified since 2014. While at the beginning of this period their capacity was only 39 MW, by 2021 this figure had increased to 124 MW. This indicates a growing demand for technologies that use organic waste to produce energy. As for mini-hydroelectric power plants (mHPPs), their capacity has been fluctuating, particularly since 2013, when the largest number of capacities was commissioned. In 2021, the capacity of mini-HPPs reached 152 MW, which confirms the importance of this type of energy in Ukraine, although the potential for further development remains limited due to natural and technological factors [21].

Overall, the development of renewable energy sources in Ukraine is showing positive dynamics in terms of capacity growth, especially in the solar and wind energy sectors. However, to further develop sectors such as bioenergy, biogas and mini-hydro, additional steps are needed to create a favourable regulatory environment and attract investment.

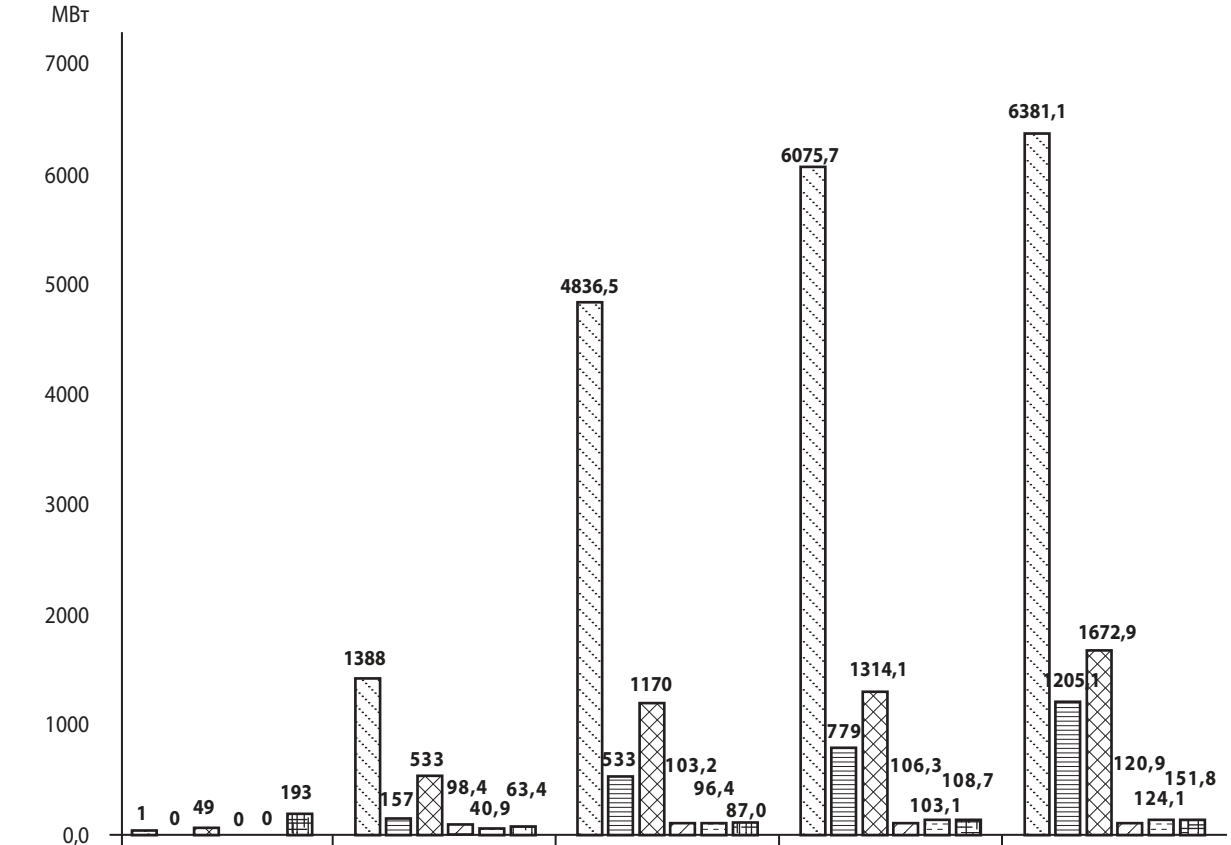
The ongoing war has significantly changed the long-term prospects for the development of Ukraine's energy sector, affecting both its current state and strategic guidelines. The focus on energy security, supply diversification, and promotion of renewable energy sources (RES) has become a key response to the wartime challenges. At the same time, large-scale destruction of infrastructure and a decline in investment activity significantly complicate the implementation of these tasks.

The massive missile attacks on Ukraine that began in autumn 2022 caused the destruction of the electric power industry (Fig. 5). According to estimates [22], the damage to renewable energy capacities as of May 2024 amounted to USD 282 million. By comparison, thermal power plants suffered the largest amount of damage, reaching USD 3.588 million.

This resulted in large-scale power outages that affected millions of citizens in the winter of 2022-2023, creating significant difficulties for the functioning of the economy and the basic needs of the population. Of particular concern was the occupation of the Zaporizhzhia nuclear power plant by Russian troops, which created additional risks not only for Ukraine's energy security but also for the environmental stability of the entire region.

At the same time, it is worth mentioning Ukraine's energy infrastructure, which needs significant investment and modernisation to meet modern requirements. According to research [22], the needs for the restoration of energy infrastructure for the demands of the economy are as follows: electric power industry – USD 33.839, natural oil and gas sector – USD 14.812 million, coal industry – USD 521, district heating – USD 1.350 million.

As for the development of sustainable energy, outdated power grids built in the Soviet era are not able to effectively integrate renewable energy sources (RES). Limited transmission line capacity and low capacity of transformer substations create significant difficulties in transmitting electricity from remote sources, such as wind and solar power plants, to consumers. In addition, the current energy storage system limits the use of renewable energy sources, which are characterised by intermittent generation due to dependence on weather conditions. The war has significantly deteriorated the state of the energy infrastructure, leading to its significant damage. The current situation in Ukraine significantly hinders the development of



	2010	2018	2019	2020	2021
СЕС	1	1388	4836,5	6075,7	6381,1
СЕСд	0	157	533	779	1205,1
ВЕС	49	533	1170	1314,1	1672,9
БіоЕС	0	98,4	103,2	106,3	120,9
БіогазЕС	0	40,9	96,4	103,1	124,1
мГЕС	193	63,ы4	87,0	108,7	151,8

Fig. 4. Dynamics and structure of renewable energy capacities in Ukraine in 2010–2021, MW

Source: [16; 21]

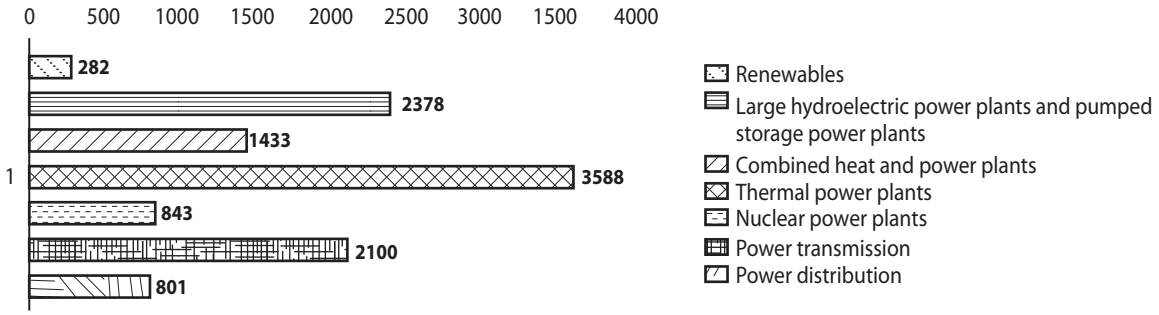


Fig. 5. Estimated damage to the electric power industry for May 2024 (USD million)

Source: compiled by the authors based on [22]

renewable energy sources and, accordingly, energy infrastructure, as they are significantly damaged, which results in significant financial resources being directed to restore the destroyed facilities.

Despite these difficulties, Ukraine continues to consider the development of RES a strategic priority and plans to increase their share in the energy balance as part of post-war recovery [23].

Thus, overcoming the consequences of the war will require significant financial resources, technical and technological solutions, and international investment support. However, it can already be noted that the investment climate in Ukraine remains challenging, particularly in the energy sector, where there are a number of factors that support investment attraction. Instability in legislation, changes in regulations, and the absence of a clear and long-term energy strategy create a high level of uncertainty for large investors. Additional obstacles include corruption, bureaucracy and complex permitting procedures, which impede business operations and reduce the country's investment attractiveness. The war has further deteriorated the investment climate, increased the level of risks and reduced the interest of foreign investors in the Ukrainian energy sector. To improve the situation, it is necessary to ensure the stability and transparency of regulations, simplify licensing procedures, fight corruption more actively, and create favourable and predictable conditions for investment activity.

Despite the challenges posed by the war, Ukraine continues to advance the development of renewable energy sources (RES), recognizing their critical role in ensuring energy independence and sustainable development. Before the onset of the full-scale invasion, there was a positive trend in the growth of solar and wind power capacities, driven by the introduction of "green" tariffs and the growing interest of investors in renewable energy.

The National Renewable Energy Action Plan by 2030 envisages an increase in the share of RES to 27% of gross final energy consumption (Figure 6). To achieve this goal, it is necessary to create favourable conditions for investing in RES, simplify licensing procedures, develop smart grids and energy storage systems, and stimulate the use of RES in all sectors of the economy. Particular attention should be paid to the development of solar and wind energy, which have the greatest potential in Ukraine. Another important area is the development of bioenergy, which will help reduce dependence on energy imports and promote rural development. Geothermal energy can also play a role in certain regions of Ukraine, providing a stable and environmentally friendly source of heat and electricity.

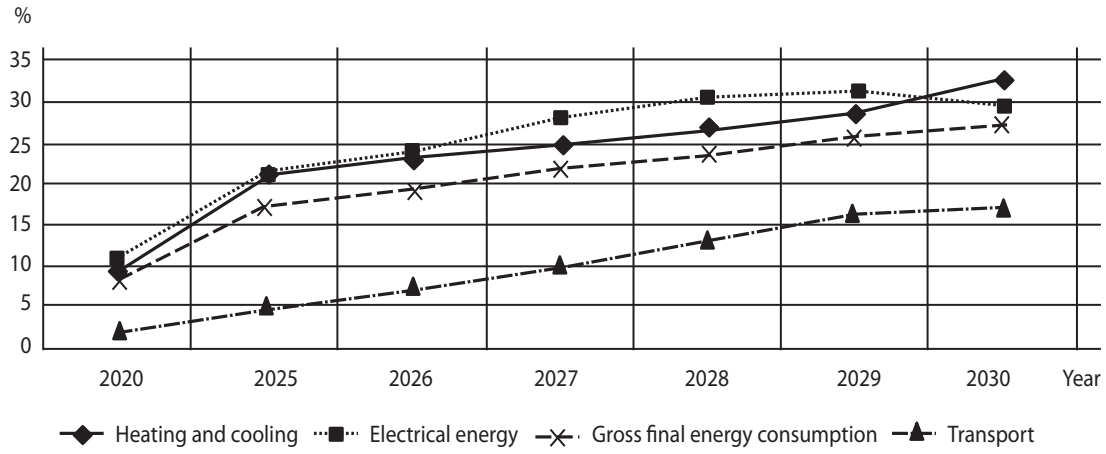


Fig. 6. RES in gross final energy consumption by 2030 (in %)

Source: [24]

In order to determine strategic priorities for the development of the energy sector in Ukraine, it is advisable to refer to the experience of leading countries in the field of sustainable energy development (Table 1), as well as to take into account the urgent security needs of the economy. The priority directions for development in Ukraine to meet the needs of post-war recovery include the following: Decarbonisation of the economy, Expansion of renewable energy, Development of carbon capture and storage (CCS), Development of energy storage and smart grids, Modernisation and refurbishment of energy facilities.

The introduction of the latest technologies is a crucial factor for improving the efficiency and sustainability of the energy sector. The development of digital technologies and artificial intelligence creates new opportunities for improving the management of power systems.

This includes accurate forecasting of energy demand, optimisation of resource use, energy efficiency and reduction of energy losses. The integration of these technologies allows for real-time monitoring of energy consumption, adaptation of energy production and distribution to changing conditions, and helps to reduce operating costs. To boost innovation in the energy sector, comprehensive government support is needed, including funding for research and technological development, a favourable regulatory environment, and attracting investment in the latest technologies. In addition, creating conditions for effective interaction between the public sector, scientific institutions and private companies is the basis for achieving success in implementing innovative solutions in the energy sector.

Conclusions. Based on the analysis of statistical data using the OSINT methodology, the main indicators, challenges

Table 1

Key strategic priorities for energy development in various countries

Country	Energy Program/Strategy	Key Priorities for Energy Sector Development
Germany	Energiewende (Energy Transition)	▪ Transition to renewable energy sources (wind, solar) ▪ Phasing out coal and nuclear power ▪ Energy efficiency improvements ▪ Expansion of grid infrastructure for renewables
France	Multiannual Energy Plan	▪ Reduction of greenhouse gas emissions ▪ Expansion of nuclear power and renewables ▪ Development of hydrogen energy ▪ Energy efficiency in buildings and industry
Spain	National Integrated Energy and Climate Plan (PNIEC)	▪ Decarbonization of the economy ▪ Expansion of renewable energy (wind, solar) ▪ Electrification of transport ▪ Energy efficiency improvements ▪ Energy storage development
Sweden	Sweden's Climate Policy Framework	▪ Achieving net-zero emissions by 2045 ▪ Expansion of renewable energy (bioenergy, wind, hydro) ▪ Electrification of transport ▪ Investment in green technologies
United Kingdom	Net Zero Strategy	▪ Achieving net-zero emissions by 2050 ▪ Expansion of offshore wind power ▪ Phasing out coal by 2024 ▪ Development of carbon capture and storage (CCS) and hydrogen energy
Finland	Energy and Climate Strategy 2035	▪ Achieving carbon neutrality by 2035 ▪ Expansion of renewable energy (biomass, wind, solar) ▪ Development of energy storage and smart grids ▪ Electrification of transport

Source: compiled by the authors on the basis of [3; 25; 26]

and prospects for the development of the energy sector to ensure the post-war economic recovery of Ukraine are analysed. The scale of damage to the energy infrastructure as a result of Russian attacks and the need for its restoration are studied. Prospects for the development of Ukraine's energy sector in the context of sustainable development, in particular, taking into account the needs for decarbonisation of the economy and strategic initiatives of individual EU countries, are identified.

According to the analysis, the priority directions for development in Ukraine to meet the needs of post-war recovery include the following: decarbonisation of the economy, expansion of renewable energy, development of carbon capture and storage (CCS), development of energy storage and smart grids, modernisation and refurbishment of energy facilities.

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