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# СТРАТЕГІЧНІ ЗМІНИ У СТРУКТУРІ ДЖЕРЕЛ ЕНЕРГІЇ ВІДПОВІДНО ДО ЦІЛЕЙ СТАЛОГО РОЗВИТКУ 7 ПІД ЧАС ПОВОЄННОГО ВІДНОВЛЕННЯ В УКРАЇНІ

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**Анотація.** Мета дослідження – проаналізувати структуру виробництва електроенергії в Україні, визначити вплив війни на стан енергетичної системи та обґрунтувати стратегічні напрями її розвитку. Огляд публікацій, присвячених проблемам виробництва та розподілу електроенергії, виявив тенденцію до посилення централізованих систем виробництва та постачання енергії за участю децентралізованих елементів, особливо з використанням відновлюваних джерел енергії. Порівняння переваг та обмежень централізованих і децентралізованих систем виробництва та постачання енергії показує, що як з технічної, так і з економічної точки зору доцільно використовувати обидві системи, які доповнюють одна одну.

Проведено структурний аналіз джерел виробництва електроенергії в Україні, оцінено втрати під час виробництва та розподілу електроенергії внаслідок військових дій, а також визначено стратегічні напрями відновлення української енергетичної системи під час війни та в процесі післявоєнної відбудови.

Проаналізовано структуру виробництва електроенергії в Україні. Визначено негативний вплив війни на енергетичну систему країни. Визначено стратегічні напрями післявоєнного відновлення вітчизняної енергетичної системи з урахуванням глобальних енергетичних тенденцій, таких як розподілене децентралізоване виробництво та розподілене виробництво енергії з відновлюваних джерел. Під час планування структури енергогенерації в період післявоєнної відбудови країни особливу увагу слід приділяти фактору безпеки.

У структурі джерел енергогенерації в Україні переважають атомна (понад 50 відсотків) та теплова енергетика (близько 25 відсотків). Системи виробництва та розподілу енергії є централізованими. Під час війни агресор знищив понад половину генеруючих потужностей. Короткостроковими заходами уряду є відновлення зруйнованих об’єктів. Однак під час післявоєнної відбудови структуру енергогенерації слід змінити, а стратегічним пріоритетом має стати безпека енергетичної системи. Слід збільшити частку децентралізованих джерел енергогенерації, що використовують відновлювані джерела енергії.

**Ключові слова:** стратегія, стратегічні зміни, стратегія розвитку енергетичного сектору, структура джерел енергії, розподілена децентралізована генерація, розподілена генерація відновлюваної енергії, ціль сталого розвитку № 7.

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**STRATEGIC CHANGE IN THE STRUCTURE OF ENERGY SOURCES IN ACCORDANCE WITH THE GOALS OF SUSTAINABLE DEVELOPMENT 7 DURING POST-WAR RECOVERY IN UKRAINE**

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**Abstract.** The objective of the study is to analyse the structure of electricity production in Ukraine, determine the impact of the war on the state of the energy system and justify strategic directions for the development of the country's energy system.

Publications review devoted to the problems of power generation and distribution of electricity revealed a trend towards supplementing centralized energy generation and supply systems with decentralized ones, especially with the use of renewable energy sources. A comparison of the advantages and limitations of centralised and decentralised systems of energy generation and supply shows that, from a technical and economic point of view, it is worth using both systems, which complement each other.

A structural analysis of energy production sources in Ukraine is carried out, the losses of energy generation and distribution as a result of military operations are estimated, and the strategic directions of restoration of the Ukrainian energy system during the war and in the process of post-war reconstruction are identified.

The structure of electricity production in Ukraine is analysed. The negative impact of the war on the country's energy system has been determined. The strategic directions of the post-war recovery of the domestic energy system are outlined, taking into account the global energy trends, such as distributed decentralised generation and distributed generation of renewable energy. Special attention was paid to the safety factor when planning the power generation structure during the post-war reconstruction of the country.

The structure of energy generation sources in Ukraine is dominated by nuclear (more than 50 per cent) and thermal energy (about 25 per cent). The energy production and distribution systems are centralized. During the war, more than half of the generating capacity was destroyed by the aggressor. The government's short-term actions are the restoration of destroyed objects. But during the post-war reconstruction, the structure of energy generation should be changed; the strategic priority should be the security of the energy system. The share of decentralized electricity generation based on renewable energy sources should be increased.

**Keywords:** strategy, strategic change, energy sector development strategy, structure of energy sources, distributed decentralised generation, distributed generation of renewable energy, Sustainable Development Goal 7.

**Introduction.** Ukraine has identified key indicators for Sustainable Development Goal 7 (Affordable and Clean Energy) and has made gradual progress in reducing the energy intensity of gross domestic product (GDP), decreasing heat and electricity losses in transmission and distribution networks, and increasing the share of renewable energy sources in total electricity generation. The war has resulted in a substantial decline in energy generation capacity and extensive damage to electricity transmission and distribution infrastructure. During the post-war reconstruction of Ukraine's energy system, it will be essential to address potential risks while adopting advanced, economically viable, and environmentally sustainable energy technologies. Such an approach will not only restore energy security but also support the transition toward a more resilient, efficient, and low-carbon energy sector.

Literature review. For many decades, the approach of building a centralised integrated energy supply system has prevailed in most countries of the world [25]. The prerequisites for centralisation of power generation and supply were technological and economic: economies of scale (increasing the size of steam turbines allowed to reduce the marginal cost of electricity production); the use of alternating current instead of direct current allows to transmit electricity over long distances with a significant reduction in losses; due to the use of transmission networks generating capacities were moved outside urban centres, eliminating pollution emissions from coal-fired plants.

But along with the advantages of centralised generation and distribution, there are also weaknesses, both technological and economic. Transmission and distribution costs account for up to 30% of the total cost of electricity supplied.

Transmission and distribution losses range from 6 to 10 per cent [25]. Centralised energy supply is not cost-effective in areas with low population density due to high capital costs of building transmission infrastructure and losses in the energy transmission over long distances.

Given these limitations of centralised energy supply, distributed generation has traditionally been seen as complementary to centralised generation, primarily in areas with low population density. For energy consumers whose buildings are frequently expanded and renovated (e.g. hospitals), a distributed configuration can be cheaper due to localised and properly sized wiring, which results in lower electrical equipment costs [36].

Decentralised generation systems are small-scale power technologies, typically in the range of 3 kW to 10 MW, located very close to consumers to provide an alternative or complement to the centralised or traditional power system. Decentralised generation systems are connected directly to the distribution system or at the consumer's meter side, which significantly reduces transmission and distribution losses in the power system [18]. Different types of energy resources can be used for decentralised electricity generation, as well as their combinations: combined cycle gas turbines, internal combustion engines, combustion turbine, micro gas turbine, Stirling engines, small hydro, micro-hydro, wind turbines, photovoltaic arrays, solar thermal-central receiver, solar thermal-Lutz system, biomass gasification, fuel cells-phosphoric acid, fuel cells-molten carbonate, fuel cells-proton exchange, fuel cells-solid oxide, geothermal, ocean thermal, battery storage [1]. The main driver of decentralized generation is the need to use cleaner and more sustainable renewable resources compared to the polluting and limited fossil resources traditionally used in electricity generation [18]. Decentralised electricity generation can significantly improve energy efficiency, reduce carbon dioxide emissions, increase grid resilience and reduce investment in electricity transmission [13].

Many researchers have compared the advantages and limitations of centralised and decentralised energy generation and distribution. A study on the use of decentralised photovoltaic systems [19] has shown that grid performance is higher compared to centralised supply, because active power losses are reduced by 13.43 per cent and reactive power losses are reduced by 14.43 per cent. In addition, the bus voltage is improved compared to the centralised system. However, it was found that decentralised photovoltaic systems have a greater negative impact on power quality than the centralised system. The payback period of a decentralised PV system is 9 years, while that of a centralised system is 7 years. Certain negative environmental impacts may arise after the end of the service life of decentralised energy generation facilities, when the problem of their disposal arises [12].

**Task statement.** According to the researchers in [22], the integration of decentralized generation into radial distribution networks is gaining increasing attention because of its environmental and economic advantages. Particular attention needs to be paid to the management of distribution networks, which are often subject to electrical accidents. Based on the experience of the war in Ukraine, it should be noted that electricity distribution networks have become strategic targets of attacks aimed at disrupting the country's energy supply. The authors [32] conclude that the new environmentally friendly energy world requires forecasting the availability of renewable energy sources, assessing demand and managing energy storage systems.

In times of war, when the enemy deliberately destroys power plants, transmission and distribution facilities, decentralisation of power generation becomes an urgent task. It is much easier to destroy fifty large power plants than thousands of small and dispersed facilities [26].

Objective. The purpose of the study is to analyse the structure of electricity production in Ukraine, identify the efficiency of energy distribution, determine the impact of the war on the state of the energy system and justify strategic directions for the development of the country's energy system.

Methodology. A structural analysis of energy production sources in Ukraine is carried out, the losses of energy generation and distribution as a result of military operations are estimated, and strategic directions for restoring the Ukrainian energy system during the war and in the process of post-war reconstruction are identified.

**Results.** According to the Decree of the President of Ukraine "On the Sustainable Development Goals of Ukraine for the period up to 2030", goal 7 provides for "ensuring access to affordable, reliable, sustainable and modern energy sources for all" [7].

An analysis of the structure of electricity generation in Ukraine in the period from 2015 to 2022 shows that more than half of electricity generation is carried out at nuclear power plants (Table 1, Figure 1). Up to a quarter of the total generation was provided by thermal power plants. The share of alternative energy sources reached 10 per cent. After the enemy's full-scale invasion of Ukraine in February 2022, factors emerged that significantly affected the country's electricity production. Firstly, some power plants were partially or completely destroyed; secondly, some generating capacities were located in temporarily occupied territories or in the war zone. Thirdly, the energy distribution infrastructure has been partially destroyed. About 45 per cent of high-voltage transformers in the government-controlled territories have been damaged or destroyed [3]. Fourth, Ukraine has stopped importing primary energy resources from the aggressor country.

*Table 1*

**Structure of electricity generation in Ukraine in 2015-2025 by sources of generation, %**

| Year | Ukraine | Thermal power plants | Heat and cogeneration plants | Hydro-electric power stations | GAES | Nuclear power plants | Block sta-tions | Alterna-tive energy sources (wind, solar, biomass) |
|---|---|---|---|---|---|---|---|---|
| 2015 | 100.0 | 31.3 | 3.9 | 3.3 | 1.0 | 55.5 | 3.9 | 1.0 |
| 2016 | 100.0 | 32.2 | 4.3 | 4.8 | 1.0 | 52.3 | 4.3 | 1.0 |
| 2017 | 100.0 | 29.0 | 7.0 | 5.8 | 1.0 | 55.1 | 1.0 | 1.2 |
| 2018 | 100.0 | 30.0 | 6.9 | 6.5 | 1.0 | 52.9 | 0.9 | 1.6 |
| 2019 | 100.0 | 29.2 | 7.1 | 4.2 | 0.8 | 53.9 | 1.2 | 3.6 |
| 2020 | 100.0 | 36.2 | 11.7 | 5.5 | 1.5 | 69.7 | 1.6 | 10.0 |
| 2021 | 100.0 | 23.8 | 5.5 | 5.9 | 0.8 | 55.0 | 1.0 | 8.0 |
| 2022 | 100.0 | 21.4 | 5.1 | 8.5 | 1.1 | 54.8 | 0.6 | 8.4 |
| 2023 | 100.0 | 28.5 | no data available | 11.8 | no data | 49.2 | 0.6 | 9.8 |
| 2024 | 100.0 | 20-25 | no data available | no data | 6 | 52 | no data | 9 |
| 2025 | 100.0 | 25-32 | no data available | no data | 6-7 | 50-60 | no data | 9-11 |

*Developed by [8, 34].*

The loss of energy capacity is uneven in different parts of the country. For example, the state-owned power generating company Centrenergo lost 100 per cent of its generation capacity [33]. As of June 2024, Ukraine has lost 9 GW of energy generation [4]. According to some estimates, Russia has destroyed more than half of Ukraine's electricity production, with Ukraine's generation dropping from 55 to 20 GW, i.e. by 64 per cent [21]. Ukraine lost 80 per cent of its wind and 20 per cent of its solar power plants as a result of Russia's invasion [27]. After the first wave of attacks on Ukraine's energy sector, people and businesses began to import generators. During the winter of 2022-2023, they were imported with a total capacity of more than one million kilowatts [26].

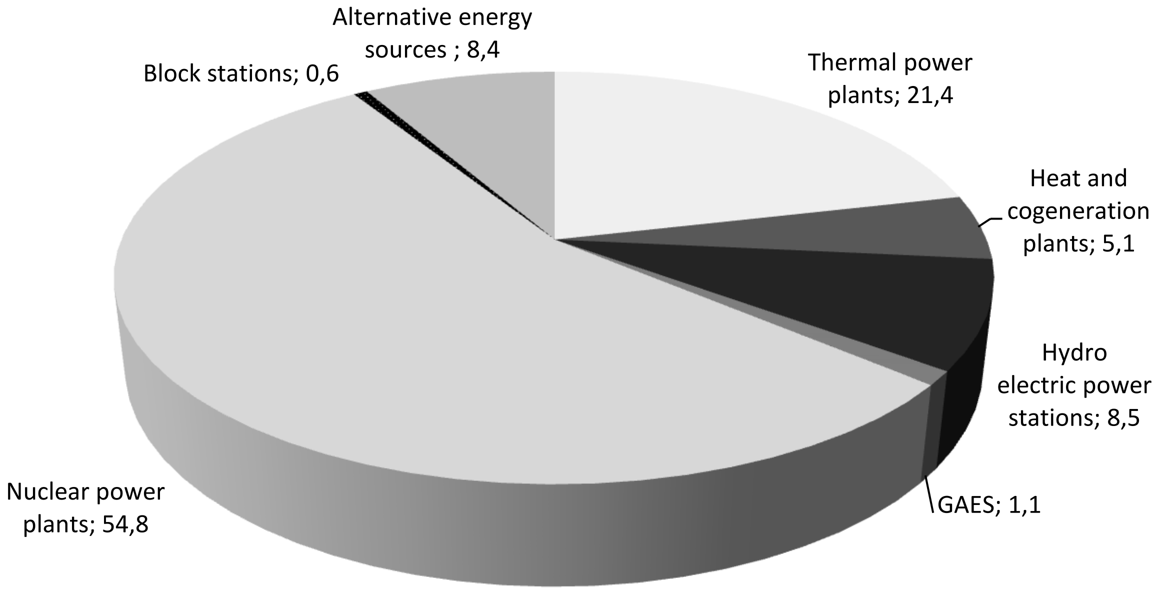


*Fig. 1.* Structure of electricity production in Ukraine in 2022 by generation sources
*Developed by [8].*

In the summer of 2024, following the ongoing attacks on Ukraine's energy sector, the country is becoming increasingly dependent on renewable energy sources. For example, when some nuclear power plant units undergo scheduled maintenance, energy generation decreases, and consumers become dependent on solar and wind power. For example, in June 2024, prolonged cloudy weather resulted in a significant reduction in solar power generation, contributing to severe electricity shortages that persisted for several days.

At the same time, in 2022-2023, more than 660 MW of new renewable energy capacity was commissioned in Ukraine [27]. According to the Energy Strategy of Ukraine, adopted in 2023, as early as 2030, the share of renewables should be at least 25 per cent in the energy balance, and by 2050, Ukraine should achieve climate neutrality [27].

According to Ukrenergo, Ukraine will require an additional 1.4 GW of highly flexible thermal power plant (TPP) capacity in the coming years to ensure the reliable operation of the power system (currently there are none at all); 1.1 GW of biofuel TPPs (currently 0.3 GW); 3.8 GW of solar power plants (SPPs, currently 6.2 GW); 4.5 GW of wind power plants (WPPs, currently 0.5 GW); 0.8 GW of electricity storage facilities (Energy Storage), which are currently not available; 2 GW of additional capacity at the Dniester and Kaniv PSPPs (currently 2 GW) [28]. Of course, the development of the energy sector requires large investments. The Ukrainian government is currently developing financial instruments to encourage households and businesses to invest in renewable energy sources.

Such devastating consequences of the impact of hostilities require decisions on how to restore Ukraine's energy sector in the post-war period. Experts point out that due to the vulnerability of the centralised power generation system and the destruction of distribution facilities, a transition to decentralised or distributed generation, which involves bringing small power generation facilities as close as possible to consumers, should be justified [28; 35; 5]. Of course, such decisions need to take into account not only technological and safety factors, but also economic justification. When generating energy in large volumes, economies of scale are achieved. On the other hand, statistics on technological losses of electricity in distribution grids show that in 2015-2022, such losses ranged from 9.8 to 11.1 per cent [9]. In other words, it is worth comparing energy losses in distribution networks and the possible higher cost of electricity with distributed decentralised generation. It is also worth using modern energy-efficient technologies when planning the post-war restoration of the country's energy system. For example, the energy intensity of gross domestic product (primary energy consumption per unit of GDP), kg of oil equivalent per international dollar according to the 2011 PPP, ranged from 0.187 to 0.166 in 2015-2020, and this indicator tended to decrease. However, there is no data for 2021-2023 [10].

Distributed generation of renewable energy should be an important part of decentralised energy generation measures. According to the “Recovery Plan for Ukraine Blueprint” in the section “Objective 3: Decarbonisation, optimisation of the energy mix and development of low-carbon generation”, it is proposed to stimulate at the state level the implementation of distributed generation of renewable energy projects [5].

After the war began, the value of renewable energy sources has been transformed from environmental to security and economic. Before the war in Ukraine, renewable energy sources were considered by the global community to be primarily a tool to combat inevitable climate change and reduce carbon emissions. Today, renewable energy sources are key to energy security and state independence, and their cost is significantly lower than fossil fuels. With the transition to renewable energy sources, energy as such will no longer be an instrument of political or military influence by one country over another. Almost all the wars that have taken place in the world to date have been related to energy and the struggle for energy resources: oil, gas, coal, etc. Ukraine, in particular, is a country that has been trying to survive for 31 years of independence under constant energy blackmail and pressure from the Russian Federation. Russia is now using the same fuel tool to influence European countries that are providing massive humanitarian and military support to Ukraine in the war. Instead, by using renewable energy sources, countries will not have to fight for them, as they are local energy resources available to all. [30]

To scientifically substantiate the strategy of increasing the share of renewable energy sources in electricity production, the National Academy of Sciences of Ukraine established the Institute of Renewable Energy, which, among other things, created the Atlas of Energy Potential of Renewable Energy Sources of Ukraine [2]. According to scientists, the development of renewable energy is one of the top priorities for improving the energy and environmental security of Ukraine.

To push the development of the alternative energy market, the Ukrainian government has introduced a green tariff, which until the end of 2029 provides all producers a guaranteed price per kWh denominated in euros. As of 2019, the tariffs were as follows: EUR 0.15 per kWh for ground-mounted solar power plants, EUR 0.16 for rooftop solar power plants, and EUR 0.10 per kWh for wind power plants with a capacity of over 2 MW peak [31]. The green tariff was reduced in 2020; for existing companies, the tariff will remain in force until 2030, whilst for new market entrants, the tariff does not apply [23]. Consequently, renewable energy companies will switch to market-based pricing mechanisms [24].

In 2019, Ukraine entered the TOP-10 countries in the world in terms of renewable energy development. In 2020, Ukraine entered the TOP-5 European countries in terms of solar energy development. In 2023, Ukraine ranked 7th on this list. In 2019, in the Climatescope ranking by Bloomberg New Energy Finance [6], Ukraine was ranked 8th (up from 63rd) among 104 countries in terms of investment attractiveness in the development of low-carbon energy sources and the construction of a green economy. In 2023, Ukraine took 47th place in this ranking, which is primarily due to military operations in the country.

According to statistics, in 2023, on average, up to 30 per cent of energy was produced from renewable sources globally, and up to 35 per cent in Europe. In Ukraine, the share of energy produced from renewable sources reached 9 per cent. At the same time, we can observe that in the leading countries, the share of energy produced from renewable sources reached more than 80 per cent in Brazil and more than 60 per cent in Sweden (Figure 2).

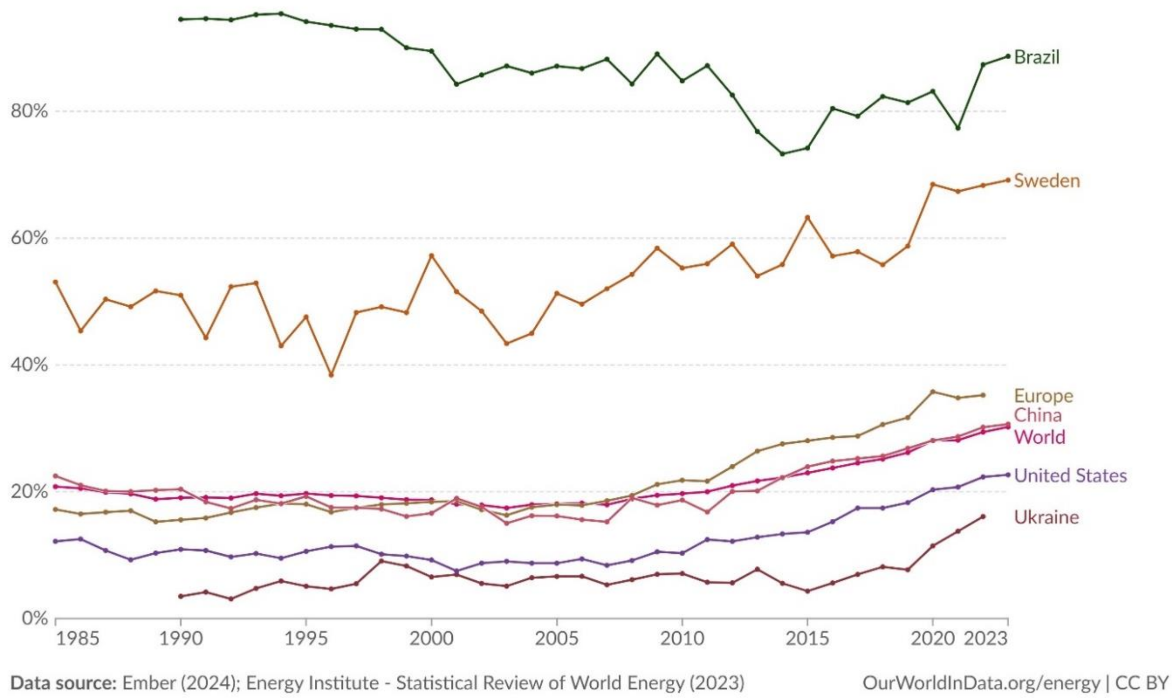


*Fig. 2. Share of Electricity Generation from Renewable Energy Sources by Country*, 1985 to 2023 [13].

There is a strong tendency for low-income countries to make much greater use of renewable energy sources: more than 60 per cent of energy produced, compared to about 30 per cent for high-income or upper-middle-income countries (Figure 3).

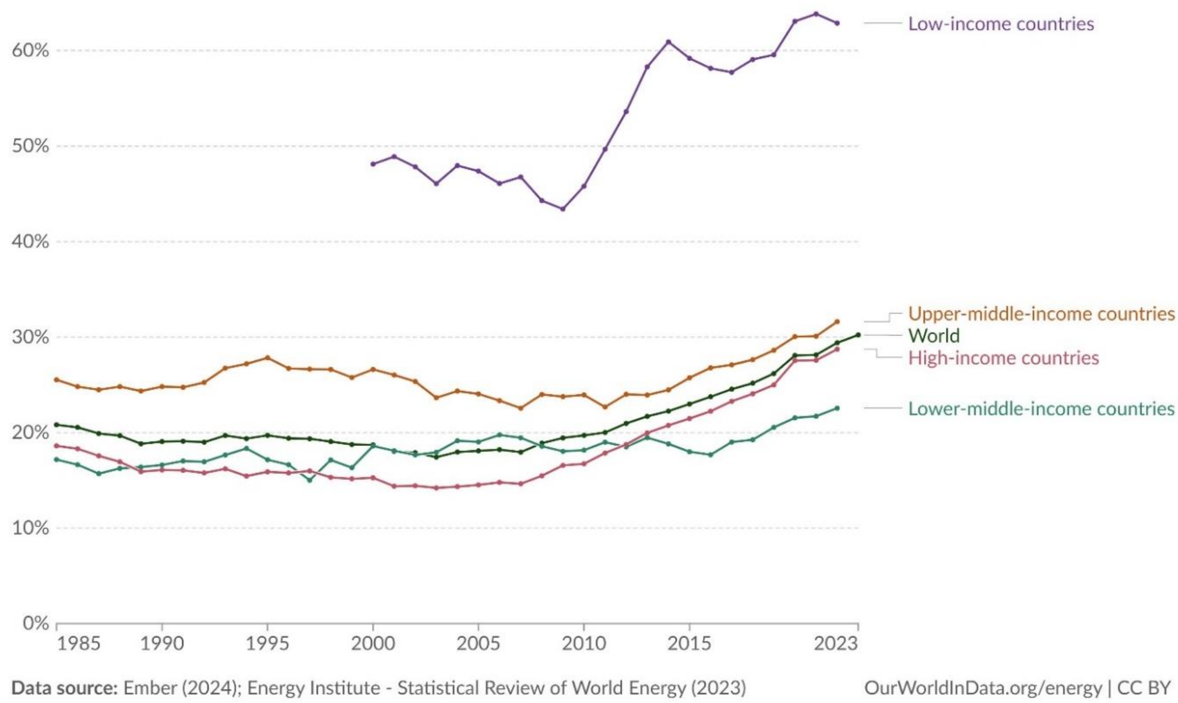


*Fig. 3*. Share of Electricity Generation from Renewable Energy Sources by Country Income Level 1985 to 2023 [13]

Ukraine, as a low-income country, should take into account this trend towards the use of renewable energy sources in the process of post-war reconstruction of the energy infrastructure.

By 2028, renewable energy sources are expected to contribute more than 40% of global electricity generation, with solar and wind energy each exceeding a 10% share and hydropower providing approximately 15% of total electricity production (Figure 4).

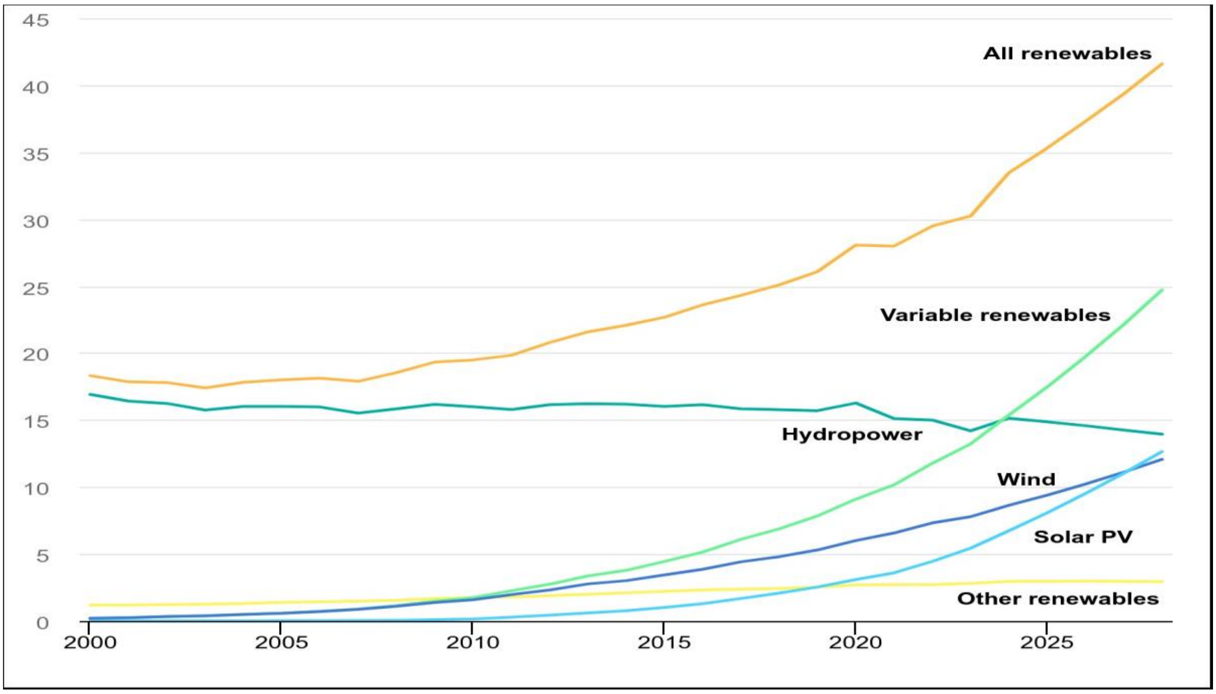


*Fig. 4.* Share of global renewable electricity generation by technology, 2000-2028 [17].

Ukraine set a goal to reduce greenhouse gas emissions by 65 per cent by 2030 compared with 1990 levels [15]. This goal can be achieved, among other things, through the widespread use of distributed generation of renewable energy. Nearly 19 000 mini-grids are installed in 134 countries, providing electricity to about 47 million people [16]. These small electric grid systems are usually comprised of generation units and distribution lines that link a number of households and other consumers.

Renewable energy sources are expected to provide between 45 and 50 per cent of global generation by 2030, and between 65 and 85 per cent by 2050, according to McKinsey's forecast [14]. In all scenarios, solar is the biggest contributor of renewable energy, followed by wind.

The structure of the solar energy market in Ukraine includes two main players: CNBM New Energy Engineering and Rengy Development, which control a third of the market, and a large number of local small producers. The “Solar Chornobyl” project has a symbolic meaning for the country, which suffered the consequences of the Chornobyl nuclear disaster. In early 2018, Solar Chornobyl, a joint venture of the Ukrainian company Batkivshchyna and Germany's Enerparc AG, put into operation in the Chornobyl exclusion zone a small solar power plant (1 MW peak), and at the end of the same year an agreement was signed to increase its capacity to 100 MW peak. The project envisages that after its completion, Solar Chornobyl will become one of the largest solar power plants in the country [31].

**Conclusions.** In a time of war, when the aggressor is deliberately destroying power generation, distribution and transmission facilities, the short-term task of the Ukrainian government is to restore the destroyed energy infrastructure as soon as possible. In the long term, however, the structure of energy generation and distribution needs to be revised. In the current situation, more than half of Ukraine's electricity is generated by nuclear power plants, and about a quarter by thermal power plants. The system of electricity generation and transmission is centralised. Despite the economic advantages of a centralised power generation and distribution system, the priority for strategic development of the country's energy system is the safety of energy facilities. Therefore, the first step is to determine the prospects for further use of nuclear power plants for electricity generation. The war has demonstrated the high risks of nuclear power plants, as their destruction can lead to an environmental catastrophe similar to the use of nuclear weapons of mass destruction.

Similarly, to improve the safety, autonomy, and resilience of the energy system, it is necessary to decentralise energy generation and distribution as much as possible. The destruction of several large power plants by the enemy leads to a significant reduction in energy generation. If there are hundreds or thousands of generation facilities, the losses from the destruction of individual stations will not be as significant.

If the strategic priority is to build a decentralised energy generation system, efforts and investments should be directed towards the use of renewable energy sources, which would be in line with Sustainable Development Goal 7 on equal access to affordable, reliable, sustainable and modern energy sources for all.

The structure of electricity production in Ukraine is dominated by nuclear and thermal power plants. The share of renewable energy sources is gradually increasing in line with Sustainable Development Goal 7. Losses of heat and electricity in the grid are decreasing. Since the beginning of the war, the energy sector has undergone significant changes: energy generation has been reduced, and some generating and distribution capacities have been destroyed. When planning the post-war reconstruction of the country's energy system, the focus should be on modern environmental and economic technologies, first of all on distributed decentralized generation, distributed generation of renewable energy that will ensure the achievement of sustainable development goals in terms of access to affordable, reliable and sustainable energy sources.

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