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REVIEW OF THE CURRENT STATE AND DEVELOPMENT PERSPECTIVES OF THE SOLAR ENERGY IN UKRAINE

Abstract. *This paper analyzes the prospects for developing solar power generation systems and the economic feasibility of further industry development. The state of global solar energy, its expansion potential, and Ukraine's position in the total statistics are examined. The rate of increase in the introduction of alternative types of energy has been determined. Statistical data on the number of commissioned power plants and the electricity they produced were analyzed. Solar energy is one of the most promising and powerful renewable energy sources. As a result of the analysis, it was concluded that Ukraine is gradually taking essential steps to expand the use of solar energy, developing a regulatory and legislative basis for the service, implementation, optimization, and stimulation of households to implement and build solar power plants. The relevance and expediency of the use of solar energy in connection with the constant growth of the cost of electricity and the future forecast of the increase of public investments in the industry at the global level are characterized. According to the analysis of statistical data and forthcoming plans for solar energy development, high rates of its growth in Ukraine have been determined. The consequences the war has on the solar energy industry are described. It is explained that, due to the war, half of the renewable energy objects are under threat of complete or partial destruction, in particular, 47% of solar power plants are located in regions where active fighting continues. The general trend of post-war development will be an increase in the share of solar energy in the overall energy balance. This will be facilitated by eliminating financial and legislative restrictions on the development of renewable energy, expanding opportunities for the export of electricity from renewable energy sources, and considering the green course, which is focused on clean energy.*
Keywords: alternative energy, renewable energy sources, solar power plants, electric energy.

1. Introduction

Energy security is economic stability's most precarious but promising aspect. Only by utilizing the potential of alternative energy, is it feasible to find a solution to the problem of raising the degree of energy security in Ukraine. Significant financial losses, a decrease in social protection, and the instability of global operations are all results of the COVID-19 pandemic. The need for alternative energy has increased, though, and the subject of information and computer technology is brought up. With natural resources depletion worldwide and their detrimental effects on the environment, developing alternative energy sources has recently become the most important. Since Ukraine has an enormous natural, geographic, and investment potential for developing renewable energy sources (RES), this is the critical area in which the national energy-saving policy is implemented. Solar energy is one of the most promising alternative energy sources [1–5].

This paper analyzes the results of alternative energy use, the prospects for developing solar power generation systems, and the economic feasibility of the future development of RES.

2. Overview of the current state of solar energy in Ukraine

One of the main tasks of ensuring the country's sustainable economic development is its energy policy and energy supply system. Energy development results and economic growth depend on the development level and implementation of RES. At this stage of development of RES, Ukraine is significantly inferior to the advanced countries of the world, which ten years ago began an active process of using alternative energy. However, due to its potential, geographical location, and climatic conditions, Ukraine is an attractive investment project in the European space to develop solar energy and construct solar power plants (SPPs).

Alternative energy [6] is a branch of energy that produces electricity, heat, and mechanical energy from alternative energy sources.

Solar energy is used worldwide and is becoming increasingly popular for electricity generation. Solar energy can be generated in two main ways [7]:

1. Photovoltaic (PV)/solar cells are semiconductors that convert sunlight directly into electricity. This technology is the fastest growing renewable energy source and plays an essential role in the future global electricity production.

2. Concentrated solar power (CSP) uses mirrors to concentrate sunlight. CSP technology generates electricity in large power plants, which usually have a field of mirrors redirecting the rays to a tall thin tower.

Solar energy is one of the most promising and powerful RES, and the growth of these capacities is increasing yearly [8–12]. Ukraine is gradually taking essential steps to expand the use of solar energy, developing a regulatory framework for the use, implementation, optimization, and encouragement of households to implement and build SPPs. According to the statistical data of the Unified National Information Agency of Ukraine "UKRINFORM" [13], there are 15 665 (875 industrial and 14 790 household SPPs) renewable energy facilities in Ukraine, which have a green tariff and have ten powerful SPPs in the territory (Table 1).

Table 1. 10 most powerful SPPs of Ukraine

Name	Capacity, MW	Area, ha	Location	Year of launch
Pokrovska SPP	240	437	near the village of Pokrovske, Nikopol district, Dnipropetrovsk region.	2019
	Pokrovska SPP is the second-largest SPP in Europe. The SPP will produce 400 million kWh of green electricity annually to provide 200 thousand private houses or apartments. Additionally, due to the station's operation, CO2 emissions into the atmosphere will be reduced by 420 thousand tons annually. Pokrovska SPP consists of 840 thousand of solar panels manufactured by Risen (China). Investments in the construction of the SPP amounted to 193 million euros.			
Nikopol SPP	200	400	near Starozavodske village, Nikopol district, Dnipropetrovsk region.	2019
	Nikopol SPP is one of the largest SPPs in Ukraine and was built in less than a year. The power plant is one of the three most powerful in Europe. The station can provide electricity to 140 thousand of households. Not a single hryvnia was spent on the construction of the Nikopol SPP from the regional or state budget – it was built exclusively at the expense of investors. The Ukrainian company DTEK and the Chinese China Machinery Engineering Corporation (CMEC) signed the agreement. The construction of the giant facility began in April 2018 on a 400-hectare site near the village of Starozavodske, Nikopol district. 750 thousand solar panels were placed here. The power plant will produce about 280 million kWh per year. According to experts, the SPP will bring about UAH 20 million in annual tax revenue to the Dnipropetrovsk region.			
SPP «Yavoriv-1»	72	115	Ternovytsia, Yavoriv district, Lviv region	2018–2019
	Yavoriv-1 SPP belongs to Eco-Optima LLC and is one of Western Ukraine's largest SPPs. The first stage of the plant was put into operation in October 2018, with a capacity of 36 MW. The second stage was put into operation on November 1, 2019. As a result, 268 thousand solar modules were installed in the Yavoriv-1 SPP and the annual electricity production of 73747 million kWh.			
Kamianets-Podilskyi SPP	63.8	110	Panivtsi village, Kamyanets-Podilskyi district, Khmelnytskyi region	2019
	Kamianets-Podilskyi SPP belong to Podolskenergo. The project's investor was the American fund «VR CAPITAL GROUP». The SPP is located on the filtration fields of the Kamyanets-Podilsky sugar plant, which are currently unsuitable for agriculture. The station has 220 thousand of solar panels. More than 50% of the station's components are manufactured by Ukrainian enterprises. The planned annual electricity production will be 68.2 GW/year, providing electricity to one-third of the 13000 households in Kamianets-Podilskyi. Note that Podolskenergo will pay 2.6 million hryvnias to the budget of Panivtsi village as rent payments, making the company the primary taxpayer for the local community.			

Continuation of table 1.

SPP Tokmak Solar Energy	50	96.4	Tokmak, Zaporizhzhya region	2018
	Tokmak Solar Energy is one of the largest SPPs in Ukraine. Tokmak Solar Energy owns the power plant. The project's investors are Astra Capital Group's investment company in partnership with the Ukrgasbank. The station's capacity is sufficient to illuminate the Zaporizhzhia region's Orikhiv, Gulyaypil, Polohiv, and partially Chernihiv districts. The SPP attracted an additional UAH 1.2 billion investment to the Tokmak region, and annual revenues to the budgets of all levels amounted to more than UAH 100 million. Additionally, Tokmak SPP significantly reduced CO2 emissions into the atmosphere. This is a significant contribution to Ukraine's energy independence and environmental safety.			
Danube SPP	43.14	80	Artsyz, Odesa region	2013
	The Danube SPP belongs to the Chinese corporation CNBM New Energy Engineering Co, which was involved in supplying solar panels. The SPP has 40 inverter stations, and more than 645 km of various cables have been laid to ensure its operation. The generated electricity is enough to provide 12 thousand households with energy. The station's operation allows reduces carbon dioxide emissions by 44.000 tons per year. Additionally, the station can produce electricity on cloudy days and even in winter. About UAH 900 million was invested in the region's economy during the plant's construction.			
Starokozacha SPP	43	80	near the village of Starokozache, Odesa region	2012
	The Starokozacha SPP belongs to the Chinese state-owned company CNBM. The solar station in Starokozache covers an area of 80 hectares and is equipped with 183.964 solar modules. The power generation capacity of this station is 42.95 MW, which not only meets the domestic electricity needs of the population of many surrounding villages but also annually reduces emissions of more than 44.000 tons of carbon dioxide.			
SPP Ternovitsa	20	12	Ternovytsia, Yavoriv district, Lviv region	2017
	The Ternovytsia SPP started operation on October 26, 2017. Its total capacity will be 20 MW, and the estimated electricity produced annually will be about 6.5 million kWh. The station consists of 22 thousand pieces of solar silicon photovoltaic modules. The component equipment of the SPP comprises foreign and Ukrainian manufacturers – the project attracted UAH 149 million in investments from Greenville Energy. This power plant will be able to provide energy to five thousand homes.			
SPP Modus Group	14	18.3	Zalukva, Galician district, Ivano-Frankivsk region	2019
	The international holding Modus Group, which includes Green Genius, has successfully implemented its first project in Ukraine – a SPP in the Carpathian region. The power plant's capacity is almost 14 MW, and the cost is 11 million euros. The village allocated 18.3 hectares of land for the SPP. It was an old decommissioned collective farm garden, which was more than 70 years old. The land lease is expected to bring about UAH 150 thousand per year to the village budget.			
Kalynivka SPP	13.5	20.22	Kalynivka village, Mykolaiv region	2019
	Kalynivska SPP was opened by TIU Canada. The station's construction began in September 2018, with a total investment of more than 11 million euros. This is the second investment made by the company under the Free Trade Agreement between Ukraine and Canada, which entered into force in August 2017. Kalynivska SPP has almost 30.5 thousand solar panels and 5 inverters that were installed to control the voltage. The total site area on which the station is located is 20.22 hectares.			

The State Agency on Energy Efficiency and Energy Saving [14] reports that in the first half of 2021, the total capacity of renewable electricity facilities increased by 8.3% or 709 MW (Fig. 1). Of these, 6 months were commissioned:

- wind power plants – 278.4 MW;
- SPPs – 257.4 MW;
- household SPPs – 156 MW;
- biomass power plants – 10.4 MW;
- biogas power plants – 6 MW;

- small hydropower – 1.6 MW.

About EUR 530 million was invested in installing 709 MW of renewable electricity. In total, as of the end of the first half of 2021, 9225 MW of renewable electricity generation capacity was commissioned in Ukraine, namely,

- wind power plants – 1593 MW;
- SPPs – 6351 MW;
- household SPPs – 933 MW;
- capacity on solid biofuels – 119 MW;
- biogas plants – 111 MW;
- small hydropower – 118 MW [15–19].

Investing in solar energy is one of the most profitable, reliable, and promising projects. Thanks to green tariffs, investors from worldwide come to the Ukrainian solar energy market. The State Agency on Energy Efficiency and Energy Saving [21] noted that green energy attracted more than 1.24 billion euros of investments in Ukraine in 2020, even in difficult times of the pandemic. In particular, last year 46 million euros were invested in energy efficiency projects under the "warm loans" program (35 million euros of loans) and energy services (122 ESCOs for 11 million euros).

According to the Government portal [22], in the second quarter of 2021, 3480 households installed SPPs with a total capacity of 98 MW, which is 1.7 points more than in the first quarter. Thus, more than 35.4 thousand families in Ukraine have switched to electricity from solar energy. The total capacity of such SPPs is 933 MW, and investments amounted to about 730 million euros. Three regions of Ukraine are the most promising and have the most significant number of solar stations compared to other regions (Fig. 2).

The National Energy Company Ukrenergo [23] reports that the total volume of electricity exports to Ukraine in 2020 exceeds imports by 2.1 times – 4754.1 million kWh and 2284.9 million kWh, respectively. In particular, in the trade zone of the IPS of Ukraine (Poland, Moldova), exports exceed imports by 8.4 times – 1734 million kWh against 205.7 million kWh, and on the Burshtyn TPP Island (Hungary, Slovakia, and Romania) by 1.45 times – 3020 million kWh and 2079.2 million kWh, respectively. The development and widespread use of SPPs are essential from the perspective of domestic and world consumers. Thus, according to [23], the volume of electricity exports in December 2020 decreased by 31.2% compared to the previous month. Simultaneously, the most significant reduction in exports occurred in Romania – by 5.6 times to 23.2 million kWh. Additionally, exports to Poland decreased by 16% to 103.4 million kWh and Hungary – by 20.2% to 169.8 million kWh (31.4% and 51.5% of total exports, respectively). Simultaneously, exports to Slovakia increased 7.8 times to 22 million kWh and to Moldova – by 3.2% to 11.1 million kWh.

According to official IRENA data [24–31] of 4 April 2021, the total capacity of SPPs in the world

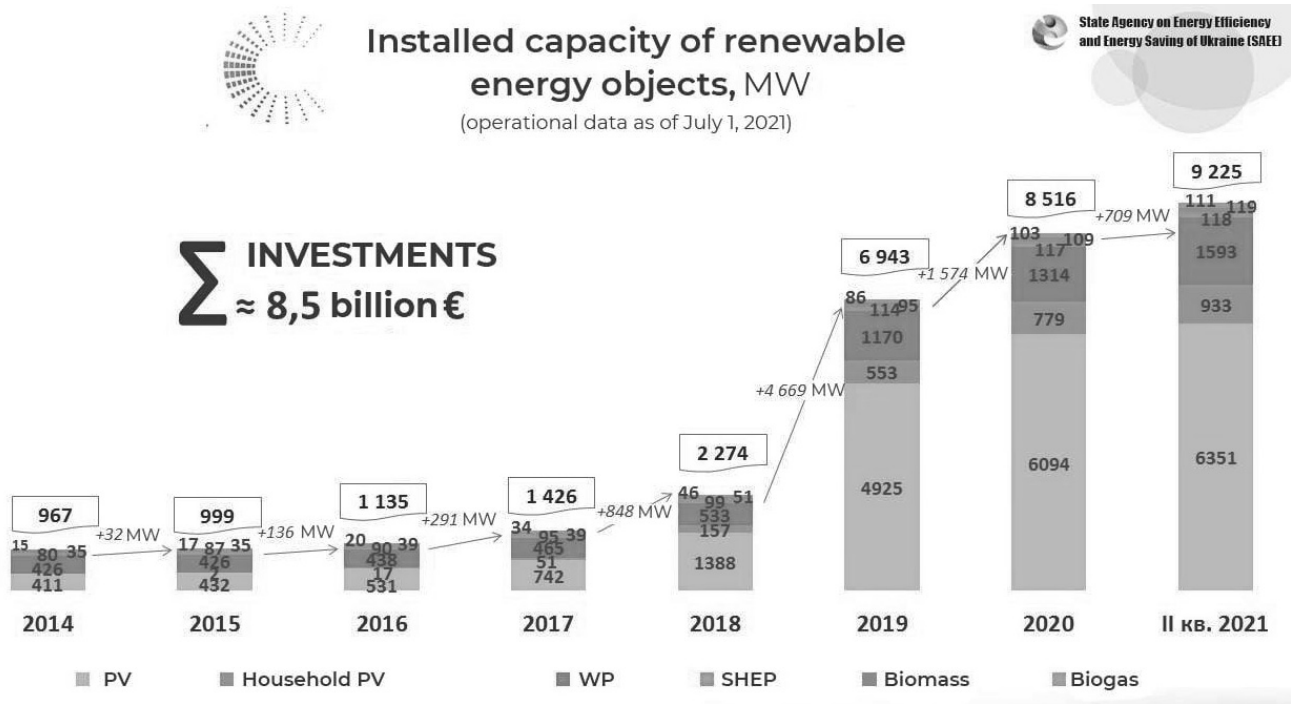

Fig. 1. Electricity market: Ukraine, total installed renewable electricity capacity (MW), 2014–2021 [20]

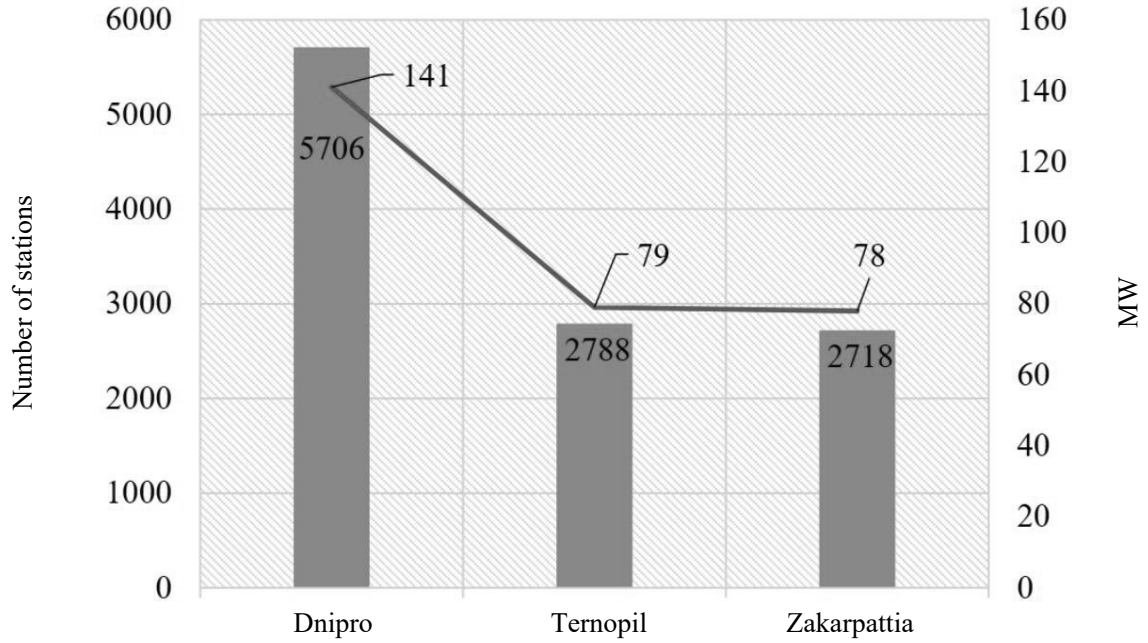

Fig. 2. Areas with the most significant number of solar stations in households

in 2020 increased by 21.6% to 714 GW. In particular, all European countries (including non-EU countries) in 2020 increase their capacity SPPs by 14.5% to 163.5 GW. In terms of total solar energy capacity in 2020 (7.33 GW), Ukraine ranks 6th in Europe, and in terms of growth – 4th with an indicator of +23.5% (Fig. 3). According to the IB Center [32], in 2021, the total investment in solar energy projects may exceed $ 80 billion worldwide.

Thus, according to statistics and long-term plans, solar energy in Ukraine has high rates of development, gaining a foothold in the energy service market every year and contributing to the following factors:

– alternative energy is a relatively new branch of energy security but has a stable, gradual development;

– the geographical location makes it possible to produce energy throughout the year continuously;

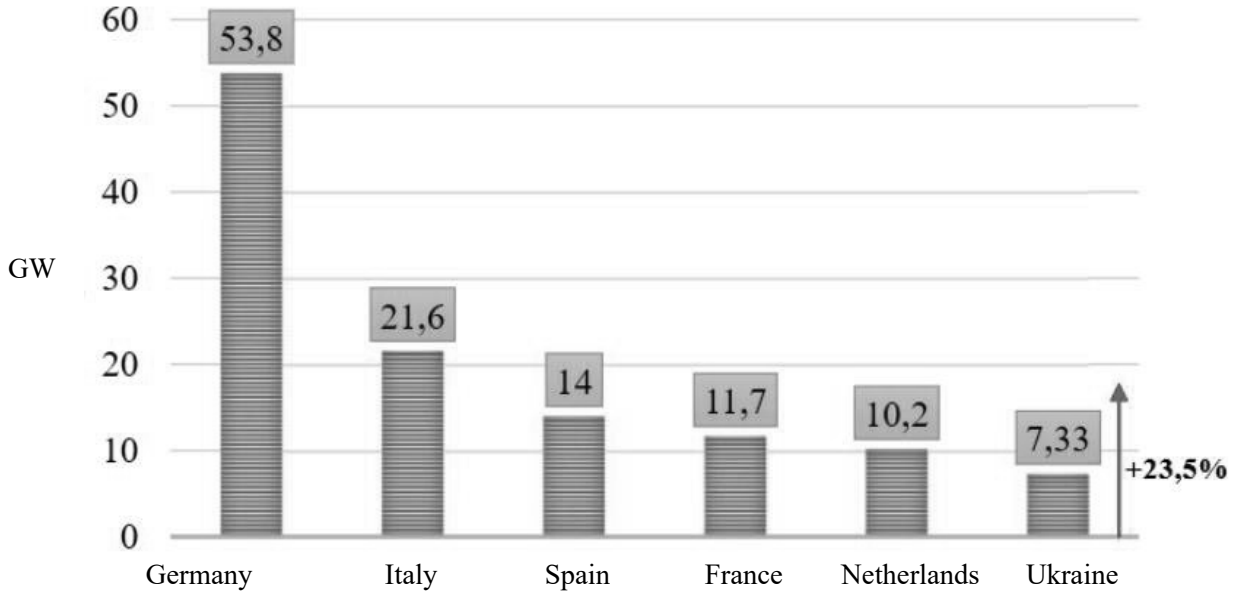

Fig. 3. TOP-6 countries in Europe by the total capacity of solar energy in 2020

– significant investment potential for international partners;

– high level of professionalism of specialists, which will contribute to the expansion of the needs of the domestic labor market and further professional development;

– social protection of the population;

– in the development of project financing policy at the state level

– long-term economically sound profit plan with further development of the investment direction;

– the creation of favorable conditions for investment will create requirements for investment in related industries [33].

SPPs have a positive economic effect not only on households but also on private businesses. These benefits include the following:

– reduction of maintenance costs, as the cost of solar energy, is lower than that of the grid;

– energy independence of production (business);

– creating a positive image of an innovative, socially responsible company that cares about the environmental situation in the world;

– payback period is short, average of 10 years;

– low operating costs;

– developing a system of providing alternative technologies will contribute to the further development of technologies in this area and other joint projects.

Foreign investments are becoming a significant factor in developing a country's economy and a prerequisite for the structural reorganization of the national economy [34]. This, in turn, ensures scientific and technological progress and, in general, the improvement of essential macro- and microeconomic indicators of the country's economic activity. Moreover, an influential investment policy helps the country overcome the crisis, stimulates production enterprises, and accelerates economic growth [35].

These achievements allowed Ukraine to improve its investment climate and rank 15th in the global renewable energy investment ranking in 2019 [36–43]. Additionally, improving Ukraine's regulatory framework for green tariffs has strengthened investor confidence in the state system of green energy support. As a result, according to the research organization BloombergNEF [44], the total direct investment in the renewable energy industry (REI) in Ukraine since the introduction of the green tariff in 2008 is estimated at $ 12 billion, of which $ 7.2 billion falls in the period 2015–2020.

Ukraine will have an ambitious REI sector at the beginning of 2022. This is how Andriy Pylypenko, Head of SE Guaranteed Buyer, assessed the state of the industry on the eve of the russian invasion during an expert discussion on the current state of the REI sector and the directions of post-war recovery.

He specified that the volume of investments in the sector exceeded USD 12 billion at that time. Additionally, the government worked on repaying accumulated debts to renewable energy producers and the direction of further movement.

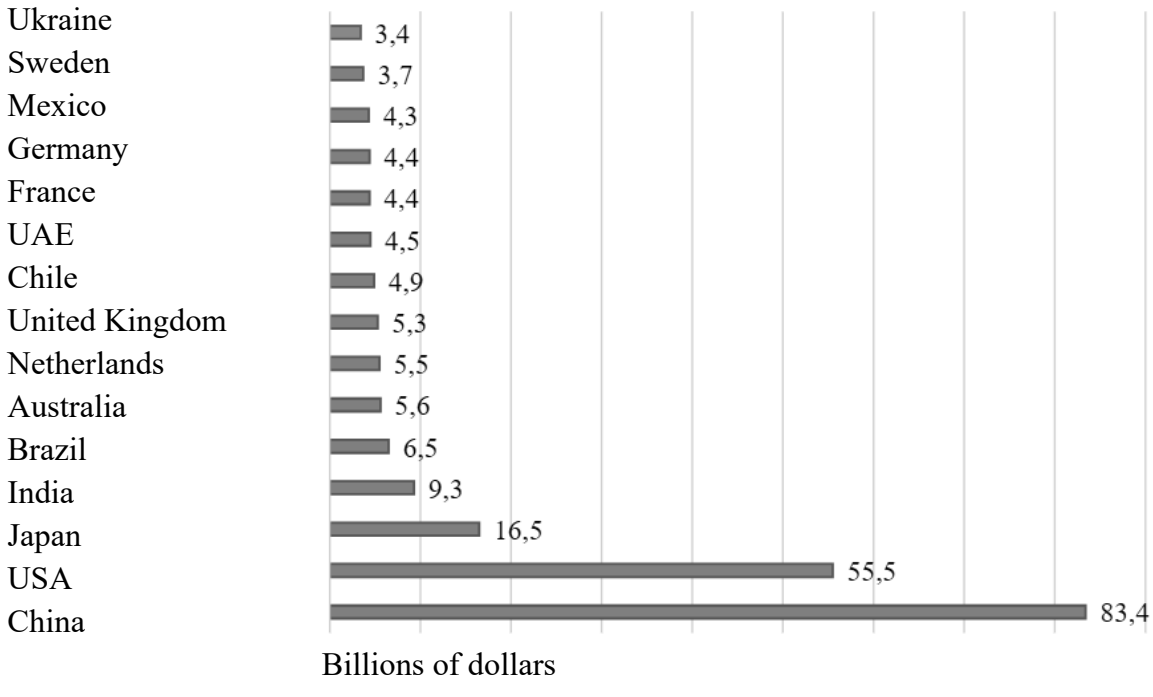

Fig. 4. Investments in RES in 2019

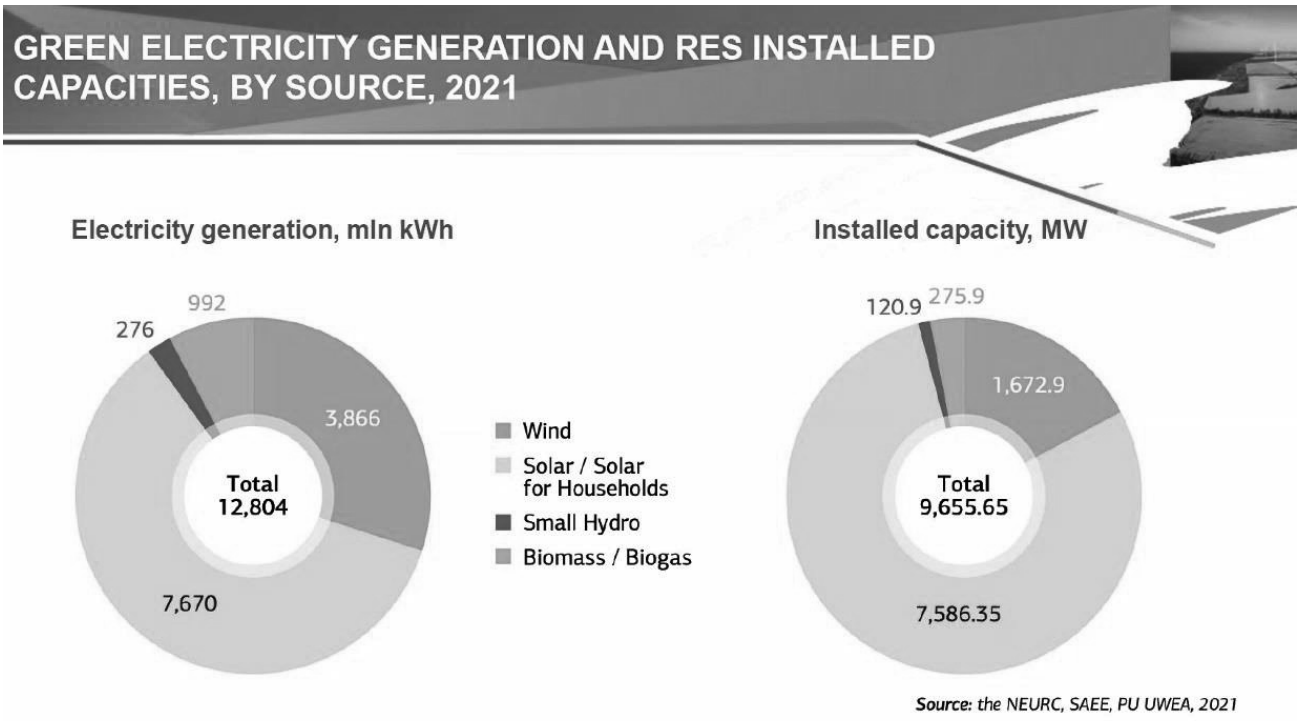

Fig. 5. Generation of green energy and installed capacities for 2021

3. The impact of the war on the solar energy sector of Ukraine

However, with the outbreak of the war, the issue of preserving the industry rather than developing it arose, as the main capacities were located in the temporarily occupied territories of the south and east of Ukraine. Every day, energy facilities, including green energy, are under the threat of shelling throughout Ukraine. Part of the infrastructure has already been damaged.

About 60% of industrial SPPs are concentrated in Ukraine's southern and southeastern regions, where active hostilities are taking place [45].

According to company executives, solar generation suffers the most significant losses from the russian occupiers.

The reason for this is a large area of industrial solar generation facilities. Thus, according to various estimates (to be specified due to the location of generation facilities in the area of active hostilities), 30–40% of power plants in the regions affected by the russian invasion suffered – 1120–1500 MW of installed capacity.

Industrial SPPs located in the Mykolaiv energy hub suffered the most.

Thus, the solar park of the Solar Generation company (22 MW) was shelled with artillery weapons, and a week later – from a helicopter – a shell on the territory detonated after repeated shelling.

Additionally, it is impossible to switch the facilities into generation due to the destruction of the 5.5 km of 150 kV power line supplying Mykolaiv city.

There is also known about the destruction of 100% of the generating capacity of SPPs in the Kharkiv region.

Simultaneously, the preserved industrial SPPs do not operate at a total capacity, as they receive dispatch commands to limit generation almost every day during daylight hours to ensure the reliability of the power system.

In such conditions, the profitability of these facilities disappears, given that, in most cases, they are credited or refinanced by Ukrainian banks and international financial institutions.

At the beginning of 2022, 1.2 GW of private household SPPs were commissioned in Ukraine.

Statistics on the location of private SPPs and overlaying it on the sites of shelling settlements in Ukraine show that an estimated 280 MW (24%) of installed capacity was destroyed.

The post-war reconstruction of Ukraine should be based on RES, insists the Chairman of the UWEA Board. According to his estimates, Ukraine will achieve 50% of its electricity generation from REI in the energy balance by 2030 [46–50].

4. Conclusions

The constant increase in the cost of electricity, dependence on suppliers, and energy intensity of the economy decrease economic development, social protection, and investment attractiveness

in general. Therefore, RES is the basis for developing an economically stable energy-independent state. The implementation of measures for the introduction of SPPs and RES, in general, will improve the energy efficiency of Ukraine. This, in turn, will positively impact the country's environmental and economic security. Energy independence, to which Ukraine aspires, is not only about rational energy consumption but also about energy development in general. Today, development is an investment in RES. The development of the alternative energy sector is Ukraine's long-term energy and environmental priority, which is stipulated by domestic legislation and participation in international agreements. In the long term, using RES is the key to energy independence and stable economic development in Ukraine.

Summarizing the experts' assessments, we can say that the general trend of post-war development will be an increase in the share of electricity from REI in the overall energy balance. This will be facilitated by eliminating financial and legislative restrictions on the development of renewable generation, expanding opportunities for exporting electricity from RES, and considering the green course, which is focused on clean energy.

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ОГЛЯД ПОТОЧНОГО СТАНУ ТА ПЕРСПЕКТИВ РОЗВИТКУ СОНЯЧНОЇ ЕНЕРГЕТИКИ В УКРАЇНІ

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Анотація. *Метою роботи є аналіз перспектив розвитку системи сонячної генерації електроенергії та економічної доцільності подальшого розвитку галузі. Проаналізовані загальний стан сонячної енергетики у світі, шляхи розвитку та місце України в загальній статистиці. Визначено темпи приросту впровадження альтернативних видів енергії. Проаналізовано статистичні дані з кількості введених в експлуатацію електростанцій та вироблених ними обсягів електроенергії. Визначено сонячну енергетику однією з найперспективніших та потужних відновлюваних джерел енергії. У результаті аналізу було зроблено висновок, що Україна поступово здійснює важливі кроки для розширення використання сонячної енергетики, розробляючи нормативно-законодавче підґрунтя з використання, впровадження, оптимізації та стимулювання домогосподарств до впровадження і будівництва сонячних електростанцій. Охарактеризовано актуальність та доцільність використання сонячної енергії у зв'язку з постійним зростанням вартості електроенергії та перспективним прогнозом збільшення загальних інвестицій у галузь на глобальному рівні. Описані наслідки війни на галузь сонячної енергетики. Згідно з проведеного аналізу статистичних даних та перспективних планів розвитку сонячної енергетики, визначено високі темпи її розвитку в Україні. Показано, що через війну половина об'єктів відновлювальної енергетики перебуває під загрозою повної або часткової руйнації, зокрема в регіонах, де тривають активні бойові дії, перебуває 47% встановленої потужності сонячних електростанцій. Загальним трендом повоєнного розвитку буде збільшення частки електроенергії від джерел сонячної енергетики у загальному енергобалансі. Цьому сприятимуть усунення фінансових і законодавчих обмежень розвитку відновлюваної генерації, розширення можливостей експорту електроенергії від джерел відновлювальної енергетики та врахування зеленого курсу, який орієнтований на чисту енергетику.*
Ключові слова: альтернативна енергетика, відновлювальні джерела енергетики, сонячні електростанції, електроенергія.

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