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Prospects for the Development of Photovoltaics in Ukraine

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Abstract:

Purpose: *The study of the photovoltaic market in Ukraine and the determination of its development prospects during post-war reconstruction is the main goal of our research.*
Design/Methodology/Approach: *The article uses a review of the information available in the scientific literature and regulations, as well as on the Internet. The collected information was processed using statistical methods and SWOT analysis, which made it possible to identify the strengths and weaknesses of the Ukrainian photovoltaics market, while identifying opportunities and threats to its development.*
Findings: *In the post-war period we should expect a significant development of the photovoltaic market in Ukraine, since: geographical location of Ukraine is favorable, significant deposits of silicon are located on the territory of Ukraine; Ukraine has a strong scientific potential for the development of photovoltaic technologies. In addition, the restoration of cities and villages will need to be carried out according to the principle of a "smart" city (village), taking into account the principles of sustainable development, including the generation of energy from renewable energy sources.*
Practical Implications: *The factors that influence the functioning of the Ukrainian photovoltaic market, which are external opportunities, and factors that negatively affect it, the impact of which should be eliminated or at least minimized, are identified. The advantages and disadvantages of investing in photovoltaics in Ukraine are substantiated.*
Originality/Value: *The research found that the entire territory of Ukraine is suitable for the development of heat and power supply systems using solar energy. The development of the photovoltaic market in Ukraine will contribute to the development of the silicon mining and processing industry, because Ukraine has silicon reserves both to meet its own needs and for export. The markets for related products will also develop. The development of photovoltaic technologies can also be a driving force for the development of electromobility, which in*

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recent years has become a priority for the development of the automotive industry, especially in the EU. Ukraine also has the opportunity to use the infrastructure (one of the largest in Europe) of the gas transportation system and underground gas storage facilities to develop the photovoltaic market.

Keywords: *Renewable energy sources, solar energy, photovoltaics market, photovoltaic panels, SWOT analysis.*

JEL Classification: *Q42, Q43.*

Paper type: *Research article.*

1. Introduction

The energy crisis caused by Russia's war against Ukraine has shown that Europe's modern energy system is heavily dependent on natural gas, oil and coal, most of which comes from Russia. If before the war the main reason for switching to environmentally friendly renewable energy sources was climate protection on the planet (including the decarbonization of industry), now the main driving force has become the desire to ensure the energy security of European countries.

This situation has led to an increase in demand for new technologies aimed at the development of renewable energy sources around the world (Grima and Thalassinos, 2020; Pociovalisteanu *et al.,* 2010). According to experts, „not only European countries and the USA, but also China and India will switch to so-lar and wind energy in the near future...” (Hurkov, 2022).

The production of electricity using solar panels has long been considered as an environmentally friendly, well-established (Pearce, 2002) energy technology based on the use of the most accessible and abundant source of renewable energy on the planet – solar energy (Thalassinos *et al.,* 2022). The production of solar energy will not only affect energy security, but will also make a significant contribution to the implementation of sustainable development goals. In particular, this will result in:

- transition to optimal models of energy production and consumption;
- access to affordable, reliable, sustainable and modern energy sources;
- economic growth and full employment;
- fight against climate change.

In addition, according to Maka and Alabid (2022), it is new solar energy production technologies that are an integral part of the energy sector development programs that determine the future direction of changes in this industry in the world.

In order to ensure the national interests of Ukraine regarding the sustainable development of the economy, civil society and the state, as well as to achieve an

increase in the level and quality of life of the population (Decree 722, 2019), the observance of the Sustainable Development Goals of Ukraine (Goals of sustainable…, 2017) for the period up to 2030 has been declared, including the development of renewable energy sources (Czainska *et al.,* 2021).

They are the results of the adaptation of the General Assembly of the United Nations resolution adopted on September 25, 2015 No. 70/1 (Resolution…, 2015) taking into account the specifics of the development of Ukraine. Today, renewable energy is the key to the development of the economy and energy independence of Ukraine.

The solar energy of Ukraine is a relatively new branch of the domestic electric power industry. As of the end of 2020, solar power plants (SPPs) with a total nominal capacity of 6,320 MW were installed, excluding about 407.9 MW of capacities located in the territory occupied by Russia and generating 1.265 billion kWh of electricity per year. In the first quarter of 2021, the share of solar power plants was 6% of the total electricity generation in the country (The largest solar…, 2021). The annual receipt of solar radiation on the territory of Ukraine is comparable to countries that actively use solar collectors (e.g., Sweden, Germany, USA).

However, the most promising regions of the country for the development of solar energy are the Crimean peninsula and the steppe part of Ukraine. For power generation, photovoltaics and solar thermal conversion are used. Since 2008, the "Green Tariff" has been operating in Ukraine.

Studying the photovoltaic market in Ukraine and determining the prospects for its development during the post-war reconstruction is the main goal of our study.

2. Literature Review

Research on renewable energy has been devoted to many scientific articles. For example, according to Sysoiev (2012), Ukraine may quickly become a large renewable energy market if certain political uncertainties are overcome. Kurbatowa *et al.* (2014) analyzed state mechanisms to encourage the implementation and development of green energy in Ukraine.

They described changes in applicable legal acts and the effects of the impact of regulatory policy on the development of renewable energy. They also discussed the main challenges in the field of legal regulations regarding RES projects and formulated proposals to improve the state policy applied at that time.

On the other hand, in the articles by Kurbatova and Khlyap (2015), Shahbaz (2020), and Bobrov (2021), the state of the energy sector in Ukraine and the state policy for its development in the long-term perspective are presented. Strielkowski (2021) and Lisin (2018) identified the majorfactors of the sustainable development of the electrical power sector.

Onyshchenko (2022) considered the following issues investment potential of Ukraine for the development of the solar energy generation system, taking into account the existing powerful solar power plants, where their investment component in the country's economy is characterized.

The authors examined the advantages and purposefulness of the development of renewable energy sources, based on the analysis of the most economically profitable directions of their use. Key barriers that reduce the effectiveness of RES implementation were also analysed (Lowe, 2022). Liutak *et al*. (2017) examined the theoretical foundations and specifics of the use of alternative energy sources in Ukraine in comparison with other regions of the world.

They devoted special attention to the analysis of energy efficiency of Ukraine's regions and the factors determining it. As a result, they determined that an important element of the implementation of the policy in the field of energy saving and the use of alternative sources is the introduction of financial, organizational and economic projects that will allow the implementation of the principles of sustainable development.

The articles by Kalinina *et al.* (2020) and Trypolska, (2021) focus on how the development of renewable energy will affect the level of employment in Ukraine. The authors believe that the creation of territorial-industrial clusters (for the production of devices for solar and wind energy, with a closed production cycle) is a long-term premise for the socio-economic stability of the country and stimulates employment.

At the same time, they note that there is a significant shortage of qualified technicians and specialists in the field of innovative technologies (in the field of renewable energy and energy efficiency). In the authors' opinion, the problem of labor supply in industry is solved mainly at the level of enterprises that invest in the development of their own employees.

The aim of the article by Kuzior *et al.* (2021) was to analyze the challenges facing Ukraine in the context of implementing green energy. It presents the results of sociological research on environmental issues related to the energy industry. The research results showed that there is a demand for green energy and the society is ready to use renewable energy sources. The authors also drew attention to the issue of strengthening the country's energy security.

Trypolska *et al.* (2022) showed that the use of renewable energy sources is an opportunity to replace energy imports, and prosumption is one of the important solutions that ensure energy security of the country (Honcharuk, 2020).

According to the authors, as part of the recovery energy packages (after the end of the war), special attention should be paid to increasing energy prosumption. Such a

solution will increase energy generation, reduce greenhouse gas emissions and increase employment, which Ukrainians will be looking for. The energy policy implemented in Austria was proposed as a model.

The article by Ivanov *et al.* (2022) analyzes the geographical location and current condition of renewable energy facilities in the Lviv region and forecasts their further development. Solar energy in 2020 accounted for more than 70% of renewable energy in this circuit. As a result of the conducted research, the authors concluded that wind energy and bioenergy will also be promising areas for renewable energy in the Lviv region.

Trypolska *et al.* (2022) focus on dealing with waste equipment from solar and wind power plants. They assessed the quantity and market value of materials that could potentially be recovered from these devices (in the perspective of 2044-2059). They also estimated how this will affect employment in Ukraine. In the article by Nunes, (2023) analyzed public policies for renewable energy from the perspective of the circular economy.

They claim that changes in national legislation are necessary in order to introduce the principle of extended producer responsibility, which in the future should ensure effective recycling of worn-out RES power plant equipment. In turn, Steffen and Patt (2022) examined how the Russian-Ukrainian war changes public support for clean energy policy.

Sala *et al.* (2023) examined the effectiveness of investments in renewable energy sources. The authors identified the relationships between key technical and economic parameters and these investments, on the example of wind power plants located in the south-eastern part of Ukraine. There are slightly fewer articles in which the authors examine solar energy in Ukraine.

The economic aspects of the implementation of solar energy in households are discussed in the article by by Mandych *et al.* (2018). It discusses the current economic barriers that prevent its rapid development in Ukraine, including, high prices of photovoltaic systems; long payback period; not enough working capital in manufacturing enterprises; lack of mechanisms stimulating production in the form of subsidies, tax exemptions, preferential tariff policies, etc.

The article focuses on the energy policy in the field of using renewable energy sources in rural areas, namely the dynamics of launching photovoltaic power plants by households was analyzed. The article by Sotnyk *et al.* (2020) discusses the conditions for the rapid development of solar energy in households in Ukraine. It indicated that financial support for this type of investment projects is of decisive importance. The authors estimated the financial sustainability of the construction of photovoltaic power plants under the "Eco-Energy" credit program.

On this basis, they developed recommendations for improving financing and other economic mechanisms supporting the development of renewable energy in Ukrainian households.

The article by Malogulko *et al.* (2020) is devoted to the analysis of the increase in the amount of energy obtained from renewable energy sources for the operation of electric networks in Ukraine. The authors examined, among others, the impact of solar energy generation on the network of the energy company Vinnytsyaoblenergo.

They also analyzed the applicable regulations in the field of photovoltaic stations. They showed the connection between reliability indicators of electric network operation and an increase in the number and installed capacity of renewable energy sources, in particular photovoltaic stations. In turn, the aim of the authors of the article by Yankiv-Vitkovska *et al.* (2020) was to develop a method for finding large sites (near cities) that could be suitable for installing photovoltaic power plants. Although the method was approved in Zaporizhia city, it can be used in any region.

The articles by Sotnyk *et al.* (2023), and Meleh (2020), are devoted to the study of legal and organizational conditions necessary for the development of solar energy in Ukraine. They assessed the net present value, the profitability ratio and the discounted payback period for the construction of industrial photovoltaic power plants of various capacities.

The authors chose three variants of the indicator "green electricity used for own needs/sold in the feed-in tariff": 1) 20/80; 2) 50/50; 3) 100/0. They found that clean self-consumption was the most profitable in creating a business class of solar prosumers. The authors also identified potential post-war drivers of prosumerism, including electricity prices, taxation of green energy sales, investment incentives, etc. As a result, they recommended, the abolition of feed-in tariffs for enterprises, investment support for the implementation of energy storage systems and prosumer microgrids.

Despite so many publications, in our opinion, there is a lack of a comprehensive study of solar energy in Ukraine, especially taking into account the ongoing war in the country.

Therefore, it is relevant today not only to switch to renewable energy sources, but also to ensure energy security, which is possible due to the development and active introduction of renewable energy sources, both for Ukraine and for the world as a whole.

3. Research Methodology

In this article, we have attempted to prepare forecasts regarding the directions of development of photovoltaics in the post-war period. To carry out this task, we used

the following research methods: analysis of the literature of the research subject; analysis of legal acts; secondary data analysis; SWOT analysis; inference based on the conducted analyses.

3.1 Research Results and Discussion

Structure of the energy industry and primary energy consumption in Ukraine:
The Ukrainian energy market is facing energy challenges related to accelerated economic development of the countries of the world, uneven distribution of energy resources, excessive energy load on nature and globalization. At the same time, it is developing dynamically despite the shortage of its own production of hydrocarbons and the imbalance in energy consumption and production.

Consumption of primary energy resources in Ukraine is carried out through supply from various sources: domestic production, imports, exports and changes in reserves of primary energy sources. Between 2007 and 2020, these reserves decreased by 53,546 ktoe (by 38.22%).

The reduction in consumption took place in all types of traditional energy resources, namely: coal and oil about 50%; natural gas by 57.10%; oil and oil products by 7.06%; atomic energy by 17.63% (Energy balance…, 2007, 2010, 2015, 2020). In 2020, total primary energy consumption in Ukraine was only 86.6 Mtoe. The largest shares in its structure were: natural gas (27.54%), coal (26.39%) and nuclear energy (23.10%). Ukraine itself produces about two-thirds of the required energy resources (JSC Naftogaz…, 2022).

However, in order to meet domestic demand, it is forced to import natural gas, crude oil, oil products and coal. Therefore, in all groups of primary energy resources there is an import dependence. Analysis of the data shows that the following trends can be traced in the structure of the energy balance:

- natural gas and oil continue to play a key role in primary energy consumption, but their shares are declining;
- the share of oil and oil products has increased over the past 5 years due to the growth in consumption of this energy resource in the country;
- the share of renewable energy sources increased from 1.7% in 2007 to 6.63% in 2020.

During 2007-2020, there was a significant reduction in energy consumption in Ukraine. Its cause could be the constant rise in the cost of energy and a decrease in the industrial production of goods. The following also contributed to the reduction in energy consumption:

- crisis caused by Russia's aggression against Ukraine in 2014;

- introduction of energy efficient technologies at industrial enterprises;
- a large-scale increase in the use of modern energy efficient technology;
- use of energy efficient lighting devices in households.

Against the backdrop of war, it is energy saving that comes to the fore. No less important are the diversification of power generation and power supply, as well as building the adaptive potential of the energy infrastructure, which will be able to withstand not only changes in market conditions, but also ensure the survival of the energy system during hostilities.

The energy balance of Ukraine for 2021 is characterized by an increase in the volume of used energy resources due to an increase in energy consumption by 5.5 Mtoe (+7%) – from 86.6 Mtoe in 2020 to 92.1 Mtoe in 2021. Among them, the generation of nuclear energy, imports of coal and oil products have increased. In particular, the production of nuclear energy in 2021 provided an additional 2.6 Mtoe (+13%) compared to 2020 (Energy balance…, 2020).

The growth in energy consumption in Ukraine in 2021 was caused by increased demand for electricity from the population and industry. This growth is partly due to the recovery in demand after the relaxation of lockdown restrictions imposed in 2020 in connection with the Covid-19 pandemic. The reason for this is also a colder winter in 2021 compared to the warm winter of the previous year. It should be noted that in 2021, fossil fuels accounted for 65.26% of primary energy consumption (JSC Naftogaz…, 2022).

In general, the structure of primary consumption of energy resources in Ukraine is distinguished by a relatively low share of oil, and at the same time by higher levels of use of nuclear energy and thermal coal compared to European countries. The trend to reduce the consumption of most traditional types of energy resources is evidence that Ukraine is gradually moving away from the use of carbon and hydro-carbon energy, reducing its dependence on the import of these resources, as well as the negative impact on the environment. At the same time, the country is increasing the use of renewable energy sources, in particular, biomass, wind and solar energy.

Recall that in the early 90s of the XX century, the energy system of Ukraine was a vertically integrated energy complex. As a result of the country's transition to market relations, the energy system had to be reformed. In the mid-1990s, a coordinator was appointed to develop a wholesale electricity market model. The World Bank became it, which attracted foreign consultants to create the model. The following principles were used as the basis for reforming the industry and creating the electricity market:

- preservation of the unified energy system of the country and its centralized management,
- demonopolization of regional energy associations;

- creation of conditions for competition among energy producers and suppliers of electric energy (The history…, 2022).

As a result of the restructuring of Ukraine's electricity industry in 1995, eight production energy associations were liquidated and 27 electricity supply companies, four TPS generating companies, two hydro-generating companies, the State Electric Company „Ukrelektroperedacha" and the National Dispatch Center (NDC) of Ukraine were created. The NDC included eight regional dispatch centers and the newly created „Energorynok" division.

The National Energy Company „Ukrenergo" was created by the order of the Ministry of Energy of Ukraine of April 15, 1998 to coordinate the development and operation of main and interstate power grids and to improve the operational and technological management of the unified energy system (UES). The newly created company united the National Dispatch Center of Ukraine and the State Electric Company „Ukrelektroperedacha" (Khomenko *et al.*, 2020).

Since 1994, the centralized management of energy by the Ministry of Energy has significantly decreased. In particular, in 1995 the National Electricity Regulatory Commission (NERC) (Decree…738, 1994) was formed. Its tasks included: regulation of the wholesale market; licensing activities in the energy sector; maintenance of the tariff policy; protection of the rights of electricity consumers.

Four years later (in 1999), the Ministry of Fuel and Energy of Ukraine was established. It included (Decree…598, 2000): Ministry of Energy of Ukraine; Ministry of Coal Industry; State Department of Electric Power; State Department of Oil, Gas and Oil Refining Industry; State Department of Nuclear Energy.

Today, UES of Ukraine is one of the largest energy associations in Europe, which covers seven regional electricity systems: Dniprovska; Western; Crimea (uncontrolled); Southern; Southwest; North and Central. They are interconnected by backbone and main power lines. The structure of the national energy system includes power plants of various types, main and distribution networks, which are located over a large area.

The United Energy System (UES) of Ukraine consists of such elements: Combined Heat and Power Plant (CHPP), Renewable Energy Sources (RES), Nuclear Power Plant (NPP), Thermal Power Station (TPS), Hydroelectric Power Plant (HEPP) and Hydraulic Power Plant (HAPP) (Decree…722, 2019).

Ukrainian UES is a set of power plants, electricity and heat networks operating in the modes of generation, transmission and distribution of heat and electricity. Today, the production of electricity in Ukraine is carried out at nuclear, thermal and hydroelectric power plants. Additionally, electricity is generated at stations operating on alternative sources (SPP, WPP, etc.).

On March 16, 2022, a historic event took place – the Ukrainian energy system was finally disconnected from its Soviet past (power grids of Russia and Belarus). The energy system of Ukraine was fully synchronized with the energy network of continental Europe ENTSO-E. The corresponding decision was taken by the ENTSO-E system operator association on March 11, 2022. After synchronization, the UES of Ukraine works stably, the frequency is maintained at the level of 50 Hz. As of 01.04.2023, in the UES there are:

- 4 nuclear power plants (2 of them remained in the uncontrolled territory);
- 15 TPS and 43 CHP plants (10 of which are located in the uncontrolled territory);
- 8 large hydroelectric power plants and 3 pumped storage power plants;
- a significant number of industrial solar and wind power plants, most of which are located in the southern regions of Ukraine (the largest Ukrainian SPP is installed in the Nikopol district of the Dnipro region and is the second largest SPP in Europe, and the largest Ukrainian SPP is located in the Zaporizhzhia region) (The structure…, 2021).

It should be noted that more than 10 GW of the main installed capacity are not yet available to the Ukrainian energy system and are under the control of the Russians. In particular, in the occupied territory there are:

Zaporizhzhia NPP (the largest nuclear power plant in Ukraine and Europe); Zaporizhzhia TPS; Luhans'ka Power Station; Vuhlehirs'ka TPS; Kakhovska HEPP. In addition, during October-December 2022, almost all energy infrastructure facilities received significant damage. Let us consider the actual balance of electricity of the UES of Ukraine before the full scale war breaks out (Table 1).

***Table 1**. The structure of electricity generation in Ukraine during 2016-2021.*

Category	**Unit of Measure**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
TPS; CHPP	million kWh	61494.4	55841.3	58807.8	55785	52360.8	45834
	Percentage of total production, %	39.72	35.93	36.90	36.23	35.18	29.27
HEPP; HAPP	million kWh	9297.5	10567.7	12008.4	7868.6	7583.9	10445.8
	Percentage of total production, %	6.01	6.80	7.54	5.11	5.09	6.67
NPP	million kWh	80950.1	85576.1	84398.2	83002.7	76202.6	86205.4
	Percentage of total production,	52.29	55.06	52.96	53.91	51.19	55.06

	%						
RES	million kWh	1560.3	1898.1	2632.7	5542.2	10862	12519.7
	Percentage of total production, %	1.01	1.22	1.65	3.60	7.30	8.00
Block stations and other sources	million kWh	1515.1	1530.9	1503.5	1768.6	1846.9	1570.8
	Percentage of total production, %	0.98	0.99	0.94	1.15	1.24	1.00
Total	million kWh	154817.4	155414.1	159350.6	153967.1	148856.2	156575.7

Source: *Formed by the authors to (Energy Universe, 2022).*

Thus, the production of energy resources in Ukraine resumed after a fall of 3% in 2020. In 2021, the volume of electricity production by Ukrainian power plants as a whole amounted to 156,575.7 million kWh, which is 7,719.5 million kWh (by 5.2%) more than last year.

Today in Ukraine nuclear and hydro power are the cheapest ones, and “green” is the most expensive. A feature of "green" energy is the complete dependence on weather conditions and the seasonality of its generation. The structure of alternative energy generation is presented in Table 2.

Table 2*. The structure of alternative energy production in Ukraine during 2016-2021*

Category, %	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Solar Power Plants	31.46	38.91	42.07	52.92	54.96	61.26
Wind Power Plants	61.14	51.81	45.12	36.45	30.11	30.88
Biomass energy	6.79	8.53	11.41	7.34	6.95	5.53
Others	0.61	0.75	1.39	3.29	7.98	2.33
Total	100.00	100.00	100.00	100.00	100.00	100.00

Source: *Estimated by the authors to (State Agency…, 2023; Konechenkov, 2022).*

Among alternative energy sources, an increase in the share of solar energy was noted. At the end of 2008, a „green tariff” was adopted to stimulate the development of renewable energy in Ukraine. According to it, electricity obtained from alternative sources is purchased by the state at tariffs that are much higher than the market value. Such a program is designed until 2030 with a gradual reduction in the cost of 1 kW.

At the end of the program, the cost of „green” electricity will become standard. It is

expected that in 2030 the share of electricity generation from renewable sources (including large hydroelectric power plants) will be about 25-30% (today this figure is only 9%) (National economic strategy…, 2021). The ratio of generation sources and the balance of the energy system are very important for the energy security of the state. They must guarantee a stable power supply to the country under various natural, man-made, managerial, socio-economic conditions and foreign policy factors.

It should be noted that for many years thermal power plants have been the basis of Ukraine's energy sector. They worked on two types of primary resources – fuel and water (with fuel priority: coal, gas, fuel oil). To-day, however, they are supplemented by nuclear power plants, which produce more than 50% of electricity. Moreover, in recent decades, nuclear energy has become a stabilizing factor in the unified energy system of Ukraine (Energy Universe, 2022).

The nuclear energy potential of Ukraine is represented by four nuclear power plants: Zaporizhya (ZNPP); South Ukraine; Rivne; Khmelnytskyi. ZNPP is the largest nuclear power plant in Europe. It has six VVER-1000 nuclear units. However, today it is under occupation.

Therefore, in such a difficult period, it is advisable to concentrate on other sources of energy, in particular on solar energy. The strategic purpose of renewable energy is to provide a flexible component of electricity generation.

Summarizing the analysis of the energy market of Ukraine, it is necessary to note the following features:

- limited own resources of natural gas, oil and nuclear fuel;
- weak diversification of energy resources supply sources;
- use of the vast majority of the capacities of its own hydro resources;
- high technogenic load on the environment;
- unsatisfactory technical condition of some energy facilities, including energy resource transportation systems.

It is the rational structure of the balance of energy consumption (nuclear fuel, water resources, non-traditional types of energy), as well as the reduction and optimal ratio of natural gas and coal used, that is one of the conditions for ensuring the energy security of Ukraine.

Origin and development of the solar energy market in Ukraine before 2022:
The efficiency of solar power plants based on photovoltaics directly depends on the intensity of solar radiation. Therefore, it is advisable to develop it primarily in regions with a high level of solar radiation, low cloudiness and low rainfall. From this point of view, the climatic conditions in Ukraine are favorable for the use of

solar energy for both the production of electricity and heat.

According to rough estimates, the potential of solar energy in Ukraine is equivalent to 6 Mtoe and its use would replace 5 bln m^3 of natural gas (Strategy of energy…, 2006). This circumstance determines the interest of scientists, entrepreneurs and state autho-rities in the development of solar energy.

Annual studies and measurements of the level of solar radiation make it possible to create up-to-date maps of global horizontal radiation, which become an information base for making decisions on the construction of solar power plants (SPPs). The highest potential for the development of solar energy is concentrated in the south of the country, in particular in the territory of the Autonomous Republic of Crimea, Odesa, Mykolaiv, Kherson, Zaporizhzhia and Donetsk regions. At the same time, other regions of Ukraine have quite favorable conditions for the development of solar energy.

Taking into account the fact that today it is electrical energy that is the most convenient and relatively affordable source of energy, we will try to investigate the history of the origin and development of solar energy in Ukraine. Special attention will be paid to the use of solar radiation for the production of electrical energy, that is, on the basis of photovoltaics.

We will also assess the level of development of solar energy in Ukraine as of January 2022. In the later period we will forecast the development of Ukraine's energy sector in the post-war period, taking into account the losses incurred by the country's energy infrastructure during the war. At the same time, we will take into account modern trends in innovative energy development, including decarbonization trends, large-scale development of non-traditional renewable energy and, above all, solar energy.

The first industrial solar power plant (SPP) on the territory of Ukraine (SPP-5) was built in the Crimea in 1985 near the village of Shcholkino. Its capacity was 5 MW. The specified power plant produced 2 million kWh of electricity for 10 years of its operation, but in the mid-90s of the XX century it was closed. In independent Ukraine (starting from 1991), not a single powerful solar power plant was built until 2010, and only in 2011 solar batteries with a capacity of 67.55 MW were put into operation. In particular, a powerful solar park was built in the Crimea, which is one of the largest in Europe.

In terms of the pace of development of photovoltaics during this period, Ukraine came to the fore. In particular, the Austrian company Activ Solar in the Saky region (Crimea) put into operation the “Omao Solar” solar power plant with a capacity of 20 MW, consisting of 90 thousand crystalline solar modules located on an area of 40 hectares.

The power plant supplies electricity to 5,000 households. In addition, in 2011 Activ Solar built a solar power plant with a capacity of 80 MW in the village of Okhotnikovo (Saky district of the Autonomous Republic of Crimea). At the end of 2011, construction of another solar power plant with a capacity of 100 MW was completed near Perovo (Crimea) (Dzyadykevich *et al.*, 2018).

In general, 2011 can be considered the year of the birth of photovoltaics in independent Ukraine, and it was in this year that the total capacity of solar power plants reached 196 MW. In subsequent years, there was a further development of solar energy, and in almost all of regions in Ukraine.

As a result (at the end of 2021), the installed capacity of solar power plants (excluding the occupied territories) reached 9656 MW. The chronology of the construction of solar power plants in Ukraine is presented in Table 3. However, the data from 2014 are given without taking into account the 407.9 MW of power located in the occupied territory of Crimea.

Table 3. *Chronology of deployment of solar power plants in Ukraine*

Year	Installed capacity, MW	Generation, million kWh
2010	3	No data available
2011	196	No data available
2012	326	No data available
2013	616	563
2014	411	485
2015	432	475
2016	568	491
2017	742	739
2018	1388	1108
2019	4925	2933
2020	6320	6605
2021	9656	7670

Source: *Estimated by the authors to (State Agency…, 2023; Konechenkov, 2022).*

One of the main and fundamental laws regulating relations in the field of alternative energy (including solar energy) is the Law of Ukraine „On Alternative Energy Sources" (The Law of Ukraine…, 2003). It defines the legal, economic, environmental and organizational foundations for the use of alternative energy sources and the expansion of their use in the fuel and energy complex. The adoption of this Law made it possible to stimulate those producers of electricity from alternative energy sources, which, according to the results of the auction, acquired the right to obtain support.

Currently, one of the key aspects of this law is the presence of a surcharge to the „green tariff", the auction price for use at electric power facilities, in particular at power plants (start-up complexes) that produce electricity from solar radiation.

The improvement of the situation in the field of practical application of alternative energy occurred with the adoption of the Law of Ukraine „On Amendments to Certain Laws of Ukraine on Ensuring Competitive Conditions for the Production of Electricity from Alternative Energy Sources" dated 04.06.2015. It has improved the mechanism for stimulating the development of renewable energy by taking into account the „green" the tariff for the period of establishment of SPPs.

It should be noted that today the „green tariff" in Ukraine is one of the highest in the world, and the legally defined conditions for investing in alternative energy and the production of "green" energy are quite competitive compared to other European countries.

The Law of Ukraine „On Electricity Market" (The Law of Ukraine…, 2017) introduced the possibility of concluding long-term contracts for the purchase of electricity produced at the „green tariff" until 2030. In addition, it introduced and regulated the basis for concluding contracts for the purchase and sale of electricity between guaranteed buyer and an enterprise that produces electricity from alternative, in particular renewable, energy sources and, as a result of the auction, acquired the right to obtain support. This means that the most efficient producers of green electricity receive priority access to the market.

Describing the realities of the use of „green tariffs" in Ukraine, it should be noted that public authorities use the practice of stimulating investments in alternative (including solar) energy. It is known that the „green tariff" is the basis of the economic mechanism of remuneration for the generation of electricity from renewable energy sources. With the help of payments (the size of which varies over time), the following goals are achieved:

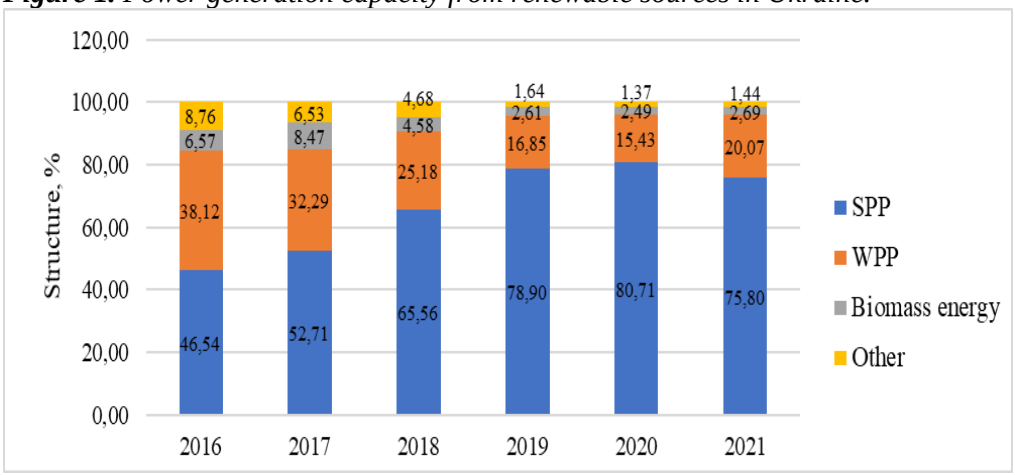
- compensation for the cost of installed equipment;
- further encouragement of generation after the pay-back of previously installed equipment is achieved;
- transition to renewable energy sources.

As for stimulating investments in solar energy through the use of „green tariffs", we note that the growth of electricity generation at solar power plants cannot replace traditional (basic and shunting) electricity generation, but should be considered as a whole.

The use of „green tariffs" in Ukraine has led to an increase in the generation of electricity not only by business entities, but also by private households, which have expanded the range of electricity market producers (became prosumers). Power generation capacity from renewable sources in Ukraine after the introduction of the green tariff as of 04.01.2021 shown on Figure 1. As you can see, the installed capacity of commercial solar power plants in Ukraine increased especially rapidly in the period from 2017 to 2020 – from 742 to 6094 MW. In the same period, the

installed capacity of SPP of households increased from 51 to 779 MW (State Agency…, 2023).

Figure 1. *Power generation capacity from renewable sources in Ukraine.*



Source: *Estimated by the authors to (State Agency…, 2023).*

The National Electricity Regulatory Commission of Ukraine (NERC) periodically changes the green tariff rate, setting it at the rate of twice the weighted average tariff for electricity purchased from power generating companies in the year preceding the year of tariff setting. In the event of significant fluctuations in the hryvnia exchange rate against the euro, NERC is obliged to make appropriate adjustments to the green tariff rates. As of March 2020, the following green tariff rates apply (1 cop. = 0.01 hryvnia) (Table 4).

Table 4. *Comparison of „green tariffs" for different types of generating capacities*

Type of generating capacity	**Tariff, cop./kWh**
Solar Energy	460.43
Biomass	134.46
Wind Power Plants	295.77
Small HEPP	84.18

Source: *Estimated by the authors to (Renewable Energy Law…, 2020).*

A significant difference in the level of "green" tariffs (for different types of alternative energy) reflects the different level of the cost of electricity at this stage of development of alternative electricity production technologies. In accordance with the Law of Ukraine „On Amendments to Article 9 of the Law of Ukraine „On Alternative Energy Sources" on the Settlement of the Issue of Electricity Generation by Private Households" (The Law of Ukraine…, 2018), "green tariff" for electricity produced by private households is set at the level of the retail tariff for consumers of the second voltage class as of January 2009, multiplied by the "green" tariff coefficient for private households.

Taking into account the indicated coefficients for private households in Ukraine, the following tariffs were in effect (Table 5). The change in „green tariffs" indirectly reflects not only the development of photovoltaic technologies, but also the reduction in investment and operating costs.

Table 5. *Tariff for electricity produced from solar radiation energy by private household generating plants with installed capacity not exceeding 30 kW.*

The period of putting generating capacities into operation	**Price, cop./kWh**
from April 1, 2013 to December 31, 2014	1385.52
from January 1, 2015 to June 30, 2015	1246.14
from July 1, 2015 to December 31, 2015	773.90
from January 1, 2016 to December 31, 2016	734.37
from January 1, 2017 to December 31, 2019	699.00
from January 1, 2020 to December 31, 2024	628.27

Source: *(The Law of Ukraine…, 2018)*.

Consequently, the introduction and practical use of „green tariffs" in Ukraine contributed to the rapid development and increase in the capacity of generating electricity from solar energy both at industrial solar stations and at private households. These processes actively continued until February 2022.

SWOT analysis of the photovoltaic market in Ukraine:

A common method of assessing the environment to identify the strengths and weaknesses of the object under study, while simultaneously identifying the opportunities and threats inherent in the external environment, is the SWOT analysis technique.

This method is based on the allocation of factors and phenomena that affect the functioning and development of the market or business entities into four categories: strengths (S), weaknesses (W), opportunities (O), threats (T). The procedure of a SWOT analysis is based on a preliminary analysis of the internal and external environment. At the same time, the analysis of the internal environment consists in identifying the strengths and weaknesses of the market/entity in order to select the optimal directions and strategies for its development.

Analysis of the external environment provides the identification of threats and opportunities that objectively exist in the environment. It allows you to identify those factors influencing the functioning of the market / entity, which are external opportunities, and factors that negatively affect it, the influence of which must be eliminated or at least minimized.

Strengths: Fossil fuel sources have been replaced by solar, wind, water and geothermal energy sources, which are being studied by scientists from different parts of the world. At the same time, it is solar technology that is the fastest growing and

widespread renewable energy in the world (TOP-18 advantages…, 2022). Solar energy, using an inexhaustible source of "green" energy, has its strengths. First of all, it contributes to reducing emissions of carbon dioxide (CO_2) and other greenhouse gases; air pollution abatement; environmental protection; improving social standards.

Solar panels are cost effective in the long run. This is due to the fact that a solar station requires significant capital investments, while benefiting from its use (even with the use of „green tariffs") is moderate and gradual, which leads to a longer payback period. In addition, the energy obtained from solar panels can be stored in batteries and used when there is no sunlight. The absence of a monthly fee for the supply of electricity should be considered an advantage.

The use of solar panels reduces the consumption of traditional electricity in countries where its price is quite high and constantly growing. Since the solar panels remain stationary after installation, they do not require significant maintenance efforts (periodic cleaning of dust particles from the surface of the panels is enough). In addition, individual parts of solar panels – solar cells that convert solar energy into electrical energy – can be detached and replaced. Solar panels can also be combined with wind turbines to form hybrid energy systems.

Ukraine is located at latitudes where the intensity of UV radiation is low, there are practically no hurricanes, sandstorms and tornadoes, therefore, there is practically no loss in solar panel performance due to natural conditions and UV radiation. Solar panels only lose about 1% efficiency per year, which is considered a good indicator of quality (Solar System, 2023).

Weaknesses: Among the shortcomings, one should point out the high cost of purchasing and installing solar panels, which leads to the inaccessibility of obtaining this type of energy among the general public.

A negative factor is also the significant loss of solar energy when generated by polycrystalline solar panels, because about 20% of the energy received is converted into electricity. The most efficient (at the level of 23%) are monocrystalline solar panels. However, the complex technology of silicon purification leads to their high cost. The efficiency of polycrystalline and thin-film models is 18% and 13%, respectively (How to choose…, 2023). It is worth noting that monocrystalline solar panels show the highest efficiency only when the sun's rays fall perpendicularly, therefore, they must be installed at a height or in open areas, which requires the use of significant areas (Type of solar…, 2023).

In addition, the efficiency of solar energy generation depends on the intensity of solar radiation, and a change in cell temperature causes a change in current and voltage. Also, the amount of energy produced is influenced by some natural elements, such as weather conditions, time of day and latitude.

During the winter and rainy season, solar radiation is very weak, limiting the availability and amount of energy generation. Also among the shortcomings, we highlight the lack of solar radiation at night. The disadvantages in Ukraine include the lack of a developed system for insuring solar panels against natural and other factors.

Opportunities: During the history of the development of photovoltaics, a number of different types of solar panels have been developed, covering 3 generations of technologies: 1) silicon (first generation); 2) thin film (second generation); 3) organic (third generation). The types of solar cells of the second and third generations differ in efficiency, cost, duration, technologies and the possibility of their modification.

The main attention is paid to materials that absorb light: from inorganic mono- and polycrystalline semiconductors to organic, polymeric and hybrid compounds. Only due to the combination of all the necessary components of the solar panel is it possible to achieve efficient conversion of light energy into electrical energy.

According to IRENA (Deployment, investment, technology…, 2019), first-generation technologies remain the main driver for the development of the solar PV industry and still hold a large market share (95%). Tandem and perovskite technologies also offer interesting solutions, but on the way to mass production, issues of pricing and cell strength must be addressed. The change in the cell architecture has made it possible to achieve a higher level of efficiency, in particular:

- due to bifacial cells and modules;
- due to the PERC technology – a passivated (dielectric) layer on the back side of the cell (Passivated Emitter Rear Cell – PERC);
- due to the combination of photovoltaic cells with other innovative elements, such as half-cut cells and other.

Since solar equipment manufacturers are focusing on improving the performance of photovoltaic devices, they have chosen single-crystal silicon as the basis of the technology. This material has a lower number of defects compared to polycrystalline silicon, which allows for higher energy efficiency of the cells.

Panels based on monocrystalline silicon dominate the solar energy market in the world, and their market share is estimated at about 80% (Solar Power Europe, 2023). Panels based on polycrystalline silicon occupy about 20% of the market and are expected to completely disappear in the coming years.

We should emphasize the positive trend towards increasing the efficiency of solar panels over the past few decades and the constant search for new materials and technologies for their development (Chekunova, 2021).

It has already been mentioned that, the conversion of solar energy into electricity is carried out using silicon. Its production and reserves have a positive impact on the production of solar panels. However, silicon is not found in its pure form.

For industrial needs, it is extracted from raw materials, including various natural silicates and aluminosilicates, which are among the most common earth minerals (28% of the earth's crust). More often, silicon is mined in combination with oxygen – silica (SiO_2) and further purified. The purity of the material determines how efficient the solar panel will be (Amorphous silicon solar…, 2019).

Ukraine was the main region for the production of high-purity silicon for many years. The country has reserves of all types of raw materials for the production of silicon. Among the already existing industries suitable for the production of crystalline silicon are high-quality quartzites and sandstones. A special grade in terms of obtaining silicon for use in the production of solar panels corresponds to quartzite with a content of: $SiO_2 > 99\%$; $Al_2O_3 < 0.10–0.25–0.50\%$; $CaO<0.10\%$.

Even in quartzites for the production of low-grade crystalline silicon, the sum of these impurities cannot exceed 1.65–3.00%, and the SiO_2 content cannot be less than 96.5–98.0%. Only quartzites and sandstones of unique quality can meet such requirements.

In Ukraine, quartzites with a SiO_2 content of more than 96% were previously used for silicon production. The state balance of mineral resources of Ukraine includes four quartzite deposits (Dnipropetrovsk, Zhytomyr, Kirovohrad regions, the reserves of which exceed 180 mln tons) and one deposit of quartzite-like sandstones (Sumy region – reserves of more than 9.5 mln tons) (Gursky et al., 2006).

In Ukraine, the total reserves of the main raw material for the production of silicon – quartzites – exceed 180 mln tons. Their deposits are located in the Dnipropetrovsk, Zhytomyr, Kirovohrad regions (Ovruch, Tovkachivske, Bilokorovychi, Vasylkivske and Ivanivske). At the same time, the Ovruch quartzite deposit has no analogues in Europe in terms of the quality of crystalline quartzites and reserves.

The content of SiO2 is 98.8%, the explored reserves are more than 150 mln tons, and the probable reserves are 500 million tons. In 1936, an enterprise for the extraction, processing and enrichment of quartzite was established on the basis of this deposit. Today it is JSC "Ovruch Mining and Concentrating Integrated Works "Quartzite".

The company specializes in open pit mining using drilling and blasting. Currently, up to 2 mln tons of crushed quartzites, up to 0.3 mln tons of ground quartzites and 1 million tons of crushed stone are mined and enriched here. The total reserves of quartzite-sandstones in Ukraine are more than 9.5 mln tons. Their deposits are located in the Sumy region (Banychi deposit). The reserves of the Banychi deposit amount to more than 0.6 mln tons (Fomina, 2011).

As was already mentioned, there are three types of solar panels: monocrystalline, polycrystalline and film or flexible (amorphous). The first two types occupy the main share of the solar energy market. The production of flexible solar panels is innovative, because they have a number of significant advantages (they absorb scattered light, do not overheat, are more practical, have fewer defects). For flexible panels, not a crystalline, but a powdered form of a chemical element is used – amorphous silicon, sprayed onto solar panels.

The use of solar panels for electricity generation is impossible without the use of batteries, inverters and charge controllers, which affects the development of the market for related products, the creation of new industries and jobs.

A breakthrough in the domestic photovoltaic market was the opening in 2019 of the KNESS PV plant, the history of which began in 2009 and which should provide the production of 100% of its main components for residential, commercial and industrial solar power plants (KNESS PV, 2023).

It is also extremely important to manufacture and upgrade related products that can affect the performance of solar panels. For example, solar regulators or charge controllers control the amount of charge supplied to the battery from the solar panel.

If this is not done, the fluctuations caused by the rise and fall of the sun's temperature can damage the batteries. Some charge controllers also convert excess voltage into current. This allows you to quickly charge the batteries (TOP-18 advantages…, 2022).

It should be noted that the development of the photovoltaic market has an impact on the development of other markets. For example, the use of solar panels in real estate increases its value, and the presence of a constant supply of electricity speeds up the sale.

The development of agrivoltaics is promising for Ukraine, since 70% of the total land fund of the country is occupied by agricultural land. Agrivoltaics is an innovative approach in the agricultural sector that makes it possible to profitably combine energy from solar stations and farming on the same plot. Thus, there is an optimization of the use of the area and an increase in productivity.

After all, the partial shading of the field contributes to the growth of some plant crops and double cooling. Plants protected by panels carry away carbon for photosynthesis, water comes out of the leaves, which creates a cooler microclimate. It promotes plant growth and cools the solar modules themselves – further reducing losses of produced energy.

If agricultural enterprises install solar panels on the roofs of farms, this protects buildings from overheating from the sun's rays. It is important for livestock to keep

the heat balance indoors. Photovoltaic modules lower the temperature, which reduces the use of electricity for air conditioning / ventilation (Benefits of installing…, 2021). Researches by scientists (Doroshenko *et al.,* 2022) make it possible to draw conclusions about the feasibility of using the electricity produced by solar power plants to produce hydrogen, and hydrogen itself can be used to fuel cars and other purposes.

In addition, hydrogen can be stored as a mixture in existing underground gas storage facilities; it is possible to store hydrogen in the cavities of existing gas pipelines decommissioned due to a reduction in transit; it is possible to upgrade existing compressor stations that are decommissioned for the production of hydrogen using solar panels; it is possible to use vast territories in the zone of land acquisition for gas pipelines, where limited land use is in effect, to install SPP panels.

Threats: Among the threats, the impact on the soil environment should be highlighted. It is known that the influence of solar concentrators can change the nature of the earth and land plants. The air associated with the reflection of solar radiation can change the direction of the wind, heat balance and humidity of the places where the panels are installed. In addition, solar panels placed on the ground or on surfaces near drinking water sources can contaminate drinking water over time due to low temperature boiling liquids.

What remains unresolved at the global level is the lack of technology for recycling solar panels at the end of their useful life. The vast majority of materials that make up solar panels can be recycled and reused. However, the panels also contain asbestos, non-recyclable polymers and plastics, as well as toxic resins, old unused paint and adhesives. It should be noted that the legislation on the disposal of solar panels in most countries of the world is still under development (Yaloviy, 2021).

SWOT Analysis Matrix:

Table 6 shows the extended SWOT matrix developed by the authors of this publication for the photovoltaic market of Ukraine.

Table 6. *Photovoltaic SWOT Analysis Matrix*

Strengths	**Weaknesses**
1. The development of solar energy technologies has positive environmental consequences: it helps to reduce carbon dioxide (CO_2) emissions, reduce air pollution, and protect the environment. 2. A “green” tariff system has been introduced in Ukraine, stimulating the development of photovoltaics and helping to reduce the payback period of investments. The "green" tariff, at which the state buys electricity produced by solar	1. The nature of photovoltaic power generation is unstable, in particular, depends on cloud cover, season, time of day, therefore, the solar panel system must work in parallel with traditional sources of electricity. 2. Solar energy is most needed in the morning and evening when it is not available, thus, it is necessary to ensure the storage of electricity from solar energy during the day and move its consumption to

power plants, has long been one of the highest in Europe. 3. Solar panels convert the sun's energy into electricity using silicon. Significant deposits of raw materials from which silicon is produced are found in Ukraine, and silicon production has also been established. 4. In Ukraine, there is a practice of combining solar stations with other renewable energy sources, which allows creating hybrid energy systems and eliminating some of solar power plant disadvantages. 5. There is a trend towards the formation of large players on the market that ensure the production of solar panels and related components, in particular, a KNESS PV plant has been opened in Ukraine, capable of providing 100% of the need for solar stations component parts. 6. The loss of solar panel performance due to natural conditions and UV radiation on the territory of Ukraine is practically absent due to its geographical location. 7. The entire territory of the country is suitable for the development of solar energy. 8. Ukraine has considerable experience in the construction of solar power plants, the history of which reaches 1985.	the evening. 3. Silicon panels are still the most used, but the cost of single crystals is quite high, which leads to high prices for monocrystalline solar panels. 4. The efficiency of polysilicon solar panels remains low (14-18%), prevailing among other types (80%). 5. Tandem and perovskite technologies still do not solve cell strength problems and are expensive. 6. Solar panels are most efficiently installed at height or in open areas, which require the use of large areas. 7. Until now, the high cost of solar cells and insufficient efficiency remain. 8. The need for periodic cleaning of photovoltaic panels from contamination. 9. Reduced efficiency of photocells when they are heated, which requires the use of cooling systems. 10. The market for insurance of solar panels against natural and other damages is underdeveloped. 11. The market for servicing solar panels, consulting services for the purchase, installation and maintenance of solar panels and power plants is underdeveloped.
Opportunities	**Threats**
1. Development of the silicon mining industry to reduce the cost of panel production technologies. 2. Production of flexible (amorphous) solar panels, characterized by greater adaptability to a changing environment. 3. Application of tandem and perovskite technologies to increase the efficiency of solar energy generation. 4. Development of agrivoltaics in Ukraine. 5. Using solar panels to make environmentally friendly vehicles. 6. Development of market entities for the production of related products: batteries, inverters and charge controllers. 7. Ukraine has the scientific potential for the production of hydrogen from solar	1. Damage the environment of the earth. 2. Solar panels contain asbestos, polymers and plastics, which are very difficult to recycle. 3. The air associated with the reflection of solar radiation can change the direction of the wind, heat balance and humidity of the places where the panels are mounted. 4. Lack of measures for the processing of cadmium when it is used in solar panels. 5. Decreased efficiency of photocells over time. 6. Absence in Ukraine of normative regulation of the process of utilization of solar panels and their elements.

electricity, its transportation through the gas transmission system and storage. 8. Due to the war, the closure and destruction of many industries in the war zone, the unemployment rate has increased in Ukraine. The development of the photovoltaic market will create new jobs. 9. It is possible to use the existing infrastructure of gas transportation facilities (pipelines, compressor station sites, underground gas storage facilities) for the joint use of photovoltaic and green hydrogen technologies.	

Source: *Created by the authors.*

4. Conclusions, Proposals, Recommendations

The main advantages of solar energy are the general availability and inexhaustibility of the energy source, as well as the almost complete safety of the environment. The entire territory of Ukraine is suitable for the development of heat and power supply systems using solar energy.

The main disadvantages are the relatively low specific solar radiation, which requires the use of large areas. The flow of solar energy on the Earth's surface significantly depends on the geographic latitude and climate, as well as on the average number of sunny days per year, the value of which can vary significantly in different regions.

The development of the photovoltaic market in Ukraine will contribute to the development of the silicon mining and processing industry, because Ukraine has silicon reserves both to meet its own needs and for export. And this is a positive trend. The markets for related products will also develop. The development of photovoltaic technologies can also be a driving force for the development of electromobility, which in recent years has become a priority for the development of the automotive industry, especially in the EU.

Since Ukraine plans to join the European community, it should already take care of the legislative regulation of the recycling of solar panels. In addition, it should strive to increase the share of renewable energy in the structure of electricity produced, especially since it has the opportunity to use the infrastructure (one of the largest in Europe) of the gas transmission system and underground gas storage facilities.

The formation of motivational mechanisms for business, government, population and scientists will accelerate the growth rate of the share of solar electricity in the energy balance of Ukraine. Today, the motivational mechanism is only the introduction of a „green tariff", but this is not enough. It is necessary to expand the

toolkit of motivation, for example, by:

- creating utility companies that will help to account for and transfer electricity to the grid;
- abolishing fees for the transmission of electricity generated from solar energy by electricity networks;
- contributing (at the level of state programs) to the development of large power generating capacities of electricity using photovoltaics;
- facilitating the development of technologies for the extraction and purification of silicon;
- generating interest and support among households in the decision to install solar panels.

Of course, the main driver is the flow of investments in the development of the photovoltaic market. Therefore, based on the above material and our own considerations, we present in table 7 the advantages and disadvantages of investing in the field of photovoltaics.

Table 7. *Advantages and disadvantages of investing in the field of photovoltaics in Ukraine*

Advantages	**Disadvantages**
energy independence	high price
replacement of imported energy resources with local ones	long payback period
reduction of greenhouse gases and pollutants	energy production only during daylight hours
creation of many thousands of jobs: sale, installation, service of solar stations, requiring specialized local companies	the impossibility of using solar panels on cloudy days, the need to install rather expensive additional equipment (batteries, inverters, etc.)
attractive conditions for investors and ordinary citizens	low energy efficiency
lack of licensing	
a long service life of solar panels, as a result – their 100% payback	
ease of scaling, that is, you can buy a small installation with several panels, and over time buy more	

Source: *Created by the authors.*

The main solutions used today in practice to compensate for the existing shortcomings of solar energy, including in Ukraine:

- at large solar power plants, photovoltaic cells are placed at a height of 1.8-2.5m, which makes it possible to use the land under the power plant for agricultural needs;

- photo panels are placed on the roofs of houses, warehouses, industrial and logistics complexes;
- a method of using solar balloon stations, suitable for both ground and sea and high-altitude placement;
- to compensate for the uneven production of electricity at SPPs, special electric accumulators and pumped storage stations are used;
- SPP operation is combined with other types of power generating capacities and energy infrastructure facilities;
- new technical solutions for photocells are applied, in particular, based on the use of film materials.

It should be noted that under the influence of the development of engineering and technology, the quality and efficiency of photovoltaic cells are constantly being improved. This leads to a gradual reduction in the cost of solar panel production and expands the field of practical use of photovoltaics.

The results of the analysis of the origin, development and functioning of the solar energy (photovoltaics) market in Ukraine in the pre-war period showed that this market is a segment of the national energy market. This market covers such segments as hydrocarbon (oil, natural gas and products of their processing), carbon (coal), electricity (nuclear power plants, thermal power plants, combined heat and power plants, hydroelectric power plants, pumped storage power plants) and renewable energy sources (which includes photovoltaics proper).

These segments are closely interconnected within the national economy, and are also combined and interact with international energy markets, in particular the energy market of the European Union. This necessitates consideration of the prospects for the development of photovoltaics in Ukraine from the standpoint of a systematic approach within the framework of developing a unified balanced strategy for the development of energy in Ukraine in the post-war period.

The mission, principles and goals of the Energy Strategy of Ukraine 2050 published on the website of the Ministry of Energy of Ukraine on February 8, 2022 should be considered as strategic guidelines (Energy strategy, 2022). At the same time, it is important to take into account the existing realities that have developed as a result of the war with the Russian Federation in 2022-2023.

It should be noted that the leaders in terms of installed capacity of solar power plants are the Dnipropetrovsk region (the largest in Ukraine Pokrovska SPP with a capacity of 323.3 MW of the DTEK company is located there) and the Mykolaiv region (the largest in the region Prohresivka SPP with a capacity of 148 MW, owned by the Norwegian company Scatec). The total capacity of these areas is 1139 MW and 909 MW, respectively (Vodyaniy, 2022).

Therefore, we believe that in the post-war period we should expect a significant development of the photovoltaic market in Ukraine, since:

- geographical location of Ukraine is favorable,
- significant deposits of silicon are located on the territory of Ukraine;
- Ukraine has a strong scientific potential for the development of photovoltaic technologies.

In addition, the restoration of cities and villages will need to be carried out according to the principle of a "smart" city (village), taking into account the principles of sustainable development, including the generation of energy from renewable energy sources.

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