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Solar Energetics in Ukraine and the Experience of the Visegrad Group Countries

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Abstract. The urgency of investigating the improvement of solar energy industry efficiency in Ukraine is conditioned upon the exhaustive nature of conventional energy sources and their polluting effect, the availability of the potential for efficient use of solar energy and lower than possible level of its implementation, and by the opportunities of applying the practices of V-4-countries, which are connected with Ukraine geographically, economically, and naturally. The purpose of this study was to identify the main positive elements of the said practices and devise possible development vectors for solar energy industry in Ukraine. The main methods employed in this study are general methods (analysis and synthesis combined with scientific abstraction and generalisation, induction) and special economic and statistical methods (analysis of dynamic series, indexes, comparison). The main results of this study: the author identified the methods for obtaining and using solar energy, established its advantages and disadvantages, trends, rates, and potential of branch development; identified the share of solar energy in the structure of renewable energy on the level of 10 %; outlined the importance, state, and trends of solar energy development in Ukraine, its leading role in greening the entire economy using the available favourable conditions, and how this development is relatively low and hampered by the lack of national support, energy accumulation and storage systems, clear and understandable national strategy of its development, outdated practices of green tariffs, instability of public investment policy in the industry, high level of wear of electric networks. In this regard, the aforementioned practices concern the consolidation of the solar energy market to increase its level of regulation; the normalisation of national energy policy and investment climate; the development of the practice of creating solar parks and systems of cogeneration of different types of energy and energy storage systems; replacement of green tariffs by the mechanism of green auctions and other schemes

Keywords: solar power, practices of V-4 countries, green tariff, green auction, solar energy market

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INTRODUCTION

The period of carefree interaction between humankind and the environment is long gone, and the ignorance of this fact has led to a rising tendency for the quality of this environment to deteriorate. One of the main factors in this is the pollution of the environment with waste from the production and use of energy from conventional sources.

It will be difficult or even impossible to obtain energy from non-renewable sources in the foreseeable future, as explored fossil fuels will only last for another 30-50 years (Semena, 2009). Therefore, the only way out is to diversify energy sources towards maximising the share of renewable sources — heat, wind, tides, biogas, solar radiation, etc. Nuclear energy provides almost 7% of the world's energy and 16% of the world's electricity. The total number of operating nuclear reactors in the world (in more than 30 countries) exceeds 440 units. Most nuclear energy in the structure of domestic production is produced in the United States — 20%, while in France nuclear energy has the largest share in electricity production — 80%. In Europe as a whole, the index of the latter is 30% (Mikhailov, 2008). But the rapid development of nuclear energy that humanity had hoped for was not as halcyon as it seemed because of a series of catastrophes at nuclear power plants. The most promising of possible renewable sources of energy is currently the solar energy. Solar power is the source of all energy sources used by man (renewable and non-renewable) (Golashevski, 2011) and can be produced while the Sun is shining. The amount of energy consumption by humankind today is 6 thousand times less than the magnitude of the potential of solar energy, which is 200 times greater than the potential of the wind energy (Mikhailov, 2008). The rate of development of solar energy in the world is one of the highest, comparing to other types of green energy, but differs region from region (Sadik-Zada, 2021).

The features and effects of solar energy use are quite fully described in the studies of some Ukrainian and foreign researchers. According to A. Dolinskii, from the standpoint of physical economy, the use of solar energy in technological processes is the most effective vector of energy industry due to the simultaneous solution of environmental, economic, energy, and social issues (Dolinskii, 2006). In this context there is an interesting idea about the large potential of solar energy in North Africa, which theoretically meets the world's energy demand manifold (May, 2005). Researchers also note that the highest conversion coefficient of solar energy can be provided in its conversion into heat using solar collectors without concentration of light flux in the temperature range from 50 to 2,000°C directly in the technological processes of drying, steaming, space heating and water heating (Savchenko, 2013). A special place in the use of solar energy is occupied by cold formation from radiant solar energy using photovoltaic panels based on the Peltier effect (Science Direct, 2016). To date, even S2P (Solar To Petrol) technology has been developed, which can use the heat from the sun to split carbon dioxide from the air into oxygen and carbon monoxide, and the latter component — to produce artificial gasoline (Mikhailov, 2008). The method developed by E. Savchenko to quantify the prevention of damage to health and the development of environmental effects from the sale quotas by reducing CO_2 emissions is also noteworthy due to the introduction of solar power in technological processes (Cherevko & Savchenko, 2016).

In Ukraine, solar energy industry is a relatively new vector, but its development is rapid, which, however, could be even more rapid. For Ukraine, solar energy industry is, on the one hand, a forced step due to the extremely low level of efficiency of the available energy system, and, on the other hand, there are conditions for its development in the country, which are not worse, than, for instance, in Germany. Thus, the study and application of the practices of developing this industry by Ukrainian neighbours — the V-4 countries — can positively affect the development of solar energy industry in Ukraine, as can be seen from the results of relevant studies (Sadik-Zada, & Gatto, 2021).

Effective development of solar energy in Ukraine can be important for V-4 countries too, as Ukraine is geographically the nearest neighbour to this region and will then be capable of constructively fitting into the possible energy market. The development of mutually beneficial approach to shaping relations between Ukraine and the V-4 countries is necessary to improve and strengthen regional cooperation, as well as to prevent differences between them in the future, which is a necessary prerequisite for facilitating the regional stability and unity, and for promotion of the Visegrad Four values given the existing security threats and challenges in the region.

Thus, the relevance of investigating the efficiency improvement of solar energy industry in Ukraine is conditioned upon the exhaustive nature of conventional energy sources and their polluting effect, the potential for efficient use of solar energy and lower than possible level of its implementation and the opportunities of applying the practices of the V-4-countries, which are connected with Ukraine geographically, economically, and naturally. Accordingly, the *purpose of this study* was to identify the main positive elements of the solar energy industry development practices of V-4 countries and devise possible vectors of implementing these practices for the effective development of solar energy industry in Ukraine.

MATERIALS AND METHODS

The general methodological approach to this study was based on the understanding of the economic importance of solar energy development through its positive impact on the environment and, the social aspect of population welfare, as environmental impacts are ultimately expressed in social effects, but the economy remains the basis of its achievement. Methodological aspects of this study also relate to the main reasons for choosing V-4 countries to identify elements of positive practices in

solar energy industry related to the geographical proximity of these countries to Ukraine, to the same level of surface insolation, to economic and cultural relations, and to some extent — to close mentality due to a fairly similar "socialist" past.

The methodological approach to this study was based on the perception of the economic importance of solar energy through its basic positive impact on the environment and the social sphere. The main research methods were applied based on the known dialectical approach to the study of economic phenomena: general methods (analysis and synthesis combined with scientific abstraction and generalisation — to investigate the development of solar energy and to generalise the results; induction — to predict possible prospects based on the facts) and special economic and statistical methods (analysis of dynamic series — to examine the available trends and determine the pace of their changes; indexes — to determine the values of relevant indicators; comparison — to identify positive practices of solar energy industry in different countries).

The materials used for this study were obtained mainly from information sources relevant to the subject under study, namely the State Agency for Energy Efficiency and Energy Saving of Ukraine — DerzhEnerhoEfektyvnist, Solar Energy Association of Ukraine — SEAU, Avenston Group; Energy Watch Group; OECD Statistics; International Renewable Energy Agency — IRENA, Bloomberg NEF, McKinsey&Company, Mordor Intelligence, Proper Power Supply company, Global Solar Atlas, Green System Company, Global Renewable Energy Community REN21, Solar Power Europe Association, Energy Watch Group.

The study used information sources that contain data mainly for the period from 2010, as feed-in tariff (FIT) for renewable energy support schemes has been introduced in Ukraine since 2010, although most intensive solar energy development in Ukraine began only in 2018-2019. The development of solar energy in Ukraine in this period took place against the background of no less intensive development of this energy sector around the world, specifically in European countries, including Visegrad Four. Some aspects of the problem were investigated based on the widest possible period, as well as more recent available data.

RESULTS AND DISCUSSION

Solar energy industry: Types and advantages and disadvantages

The Sun emits 881,024 calories of heat every second, which is equivalent to 1.25.1016 t.o.eq. or 1.02.1020 kWh. Only a part of this energy reaches the Earth — about 1.1018 kWh (123.1012 t.o.eq.) per year, which is about 100 times more than the energy resources of all explored combustible minerals on Earth (Cudria, 2020). Solar energy can be generated in two main ways (Fig. 1): by direct conversion of solar radiation into electricity using photovoltaic cells (PV), which, firstly, is most convenient for the consumers, and secondly, is considered an environmentally friendly means of obtaining electricity; by solar power concentration (SPC) method, using special mirrors. Figure 1 shows that the shares of electricity produced by two different methods are vastly different due to the presence of certain advantages and disadvantages in these two methods.

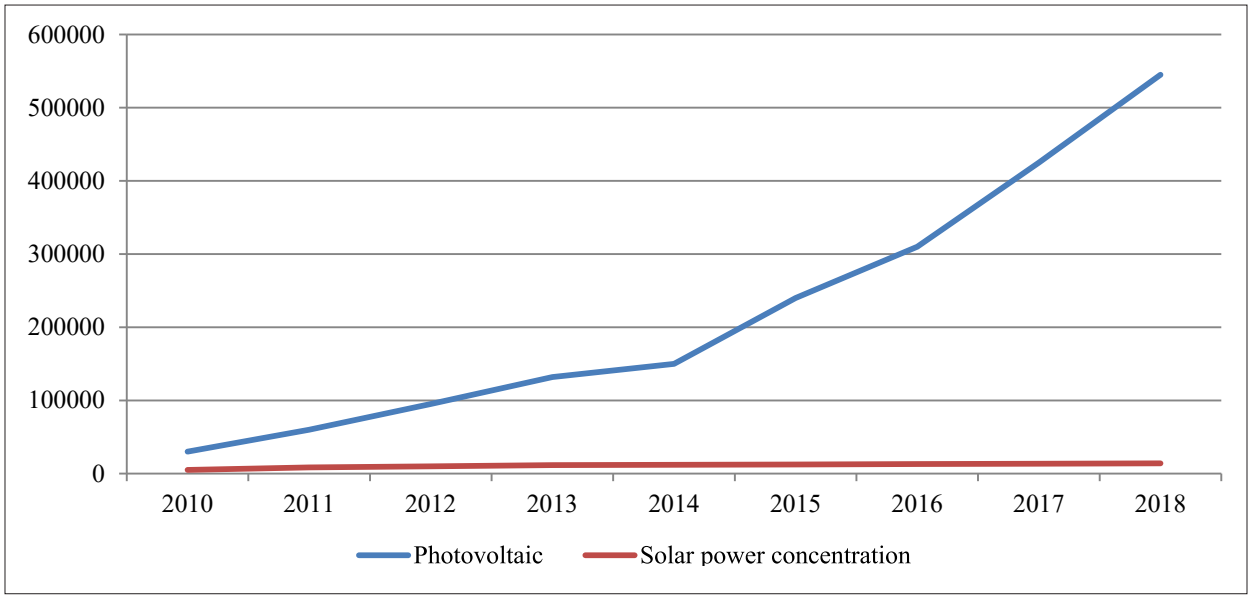

Figure 1. *Production of solar electricity in the world in terms of technology, GWh/year*
Source: *constructed by authors according to IRENA (2019)*

One of the main advantages of the SPC over a solar power plant is that it can be supplemented with tanks with molten salts, which can store heat. Concentration SES (Solar Energy Stations) are mainly spread in the United States and Spain due to their high cost (Weiss & Spörk-Dür, 2020). About 2.3 GW of concentrated solar power has been installed in the EU since 2013, but most new projects take place in Africa and the Middle East (European Commission, 2019). The world's largest SPC power plant, Noor Energy, built in Dubai, combines

100 MW of SPC tower, 200 MW of three parabolic systems that concentrate solar energy and create a heating effect, 250 MW of photovoltaic power and a capacity of molten salt for 15-hour storage of accumulated heat (Reve, 2020).

Solar energy, like any other method of obtaining energy, has its advantages and disadvantages. The advantages include practical inexhaustibility (the solar energy may remain unchanged for another 5 million years), fast return of investment, environmental friendliness, quietness, possibility of installing SES utilities anywhere, safety, ease of operation, independence, durability of the equipment, the minimum care and service, fast modernisation of branch and the corresponding reduction in price of the equipment, no need for expensive power lines and fuel storage, no need for fuel delivery, rapid reduction in price — since 2009, the price of solar energy has dropped by almost 90%. During the life cycle, the solar panel produces 30 times more energy than it needs for its manufacture (Lazard, 2019).

One of the positive effects of solar energy is the generation of employment (Sadik-Zada, 2021). Each TWh of electricity generated by SES allows creating 1,100 jobs — much more than in other energy industry sectors, resulting in, for example, 3.4 million jobs created in the world in 2017, all thanks to solar energy industry, and the global solar-related industry may employ over 18 million people until 2050 (IRENA, 2019). The number of jobs in photovoltaic solar energy in the world in 2020 is about 3.97 million — 33% of renewable energy sector worldwide (IRENA, 2020). Most jobs in solar energy industry are provided by small solar utilities — three times more than the large ones, as most small utilities (2/3) are roof-type utilities, the installation of which requires more workforce. About a third of all jobs in the sector are needed in maintenance and operation of such utilities. The technological features of solar energy industry require maintenance for the entire lifetime of solar power utilities, and therefore fluctuations in the labour market do not directly affect employment in this sector (Solar Power Europe, 2019).

The relative disadvantages of solar energy are quite easy to solve: the instability of equipment productivity, dependence on weather conditions, time of day and year, excessive cost of batteries, impossibility of precise forecasting. Solar energy industry is scattered — the power, removed from 1 m^2 of sunlit surface does not exceed 100 W on average (Bliznyuchenko & Smerdov, 2010). It means that 1 MW of SES capacity requires the allocation of at least 1.5 hectares of land (State Agency for Energy Efficiency..., 2018). These disadvantages are more than offset by such an effect of solar energy as the environmental friendliness of the energy obtained. Moreover, according to the report by the IRENA, in 2019 alone, the cost of solar electricity dropped by 13%, and since 2010 the cost of equipment for solar power plants in the world has dropped by 82% (IRENA, 2019) due to innovations in the solar energy sector. Further innovative development of this sector will ensure the introduction of innovative technologies for the production, accumulation, and storage of energy and reduce its value in all links of the chain of its formation. Solar energy is becoming inexpensive in comparison to other conventional energy sources due to innovations in the solar sector that have reduced the global average selling prices of solar power. With the predicted technological advance and increased supply of panels from China/Europe, the capital costs are expected to stabilise at lower levels. As a result, investors/developers are expected to focus on the commercial viability of solar projects.

Solar energy: The dynamics of development in the world and in Europe

The clear plenitude of the advantages of solar energy over its disadvantages is a factor of its rapid development — the annual increase in solar energy capacities put into operation, is about 40-50% (IRENA, 2019). Accelerated growth of solar power combined with deep electrification can yield 21%-reduction of CO_2 emissions (almost 4.9 gigatons per year) by 2050. Solar electricity could cover a quarter of the world's electricity needs. Global capacity could exceed the current one by 18 times, reaching over 8,000 GW by 2050. The share of solar energy in the total amount of renewable energy is also growing and amounts to one tenth of all renewable energy already (REN21, 2020) (Fig. 2).

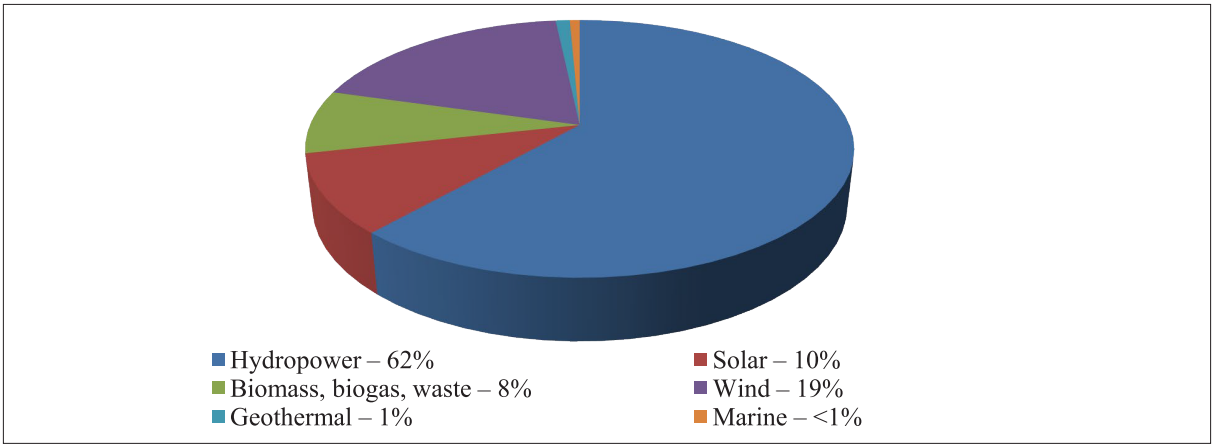

Figure 2. *Structure of electricity production from RES in the world, 2018*
Source: *constructed by authors according to IRENA (2019)*

To a considerable extent, the rapid growth of solar energy industry is explained by the elevated dynamics of the proper investments because of the high investment attractiveness of this sector (Fig. 3), which have amounted to about $300 billion over the past 10 years.

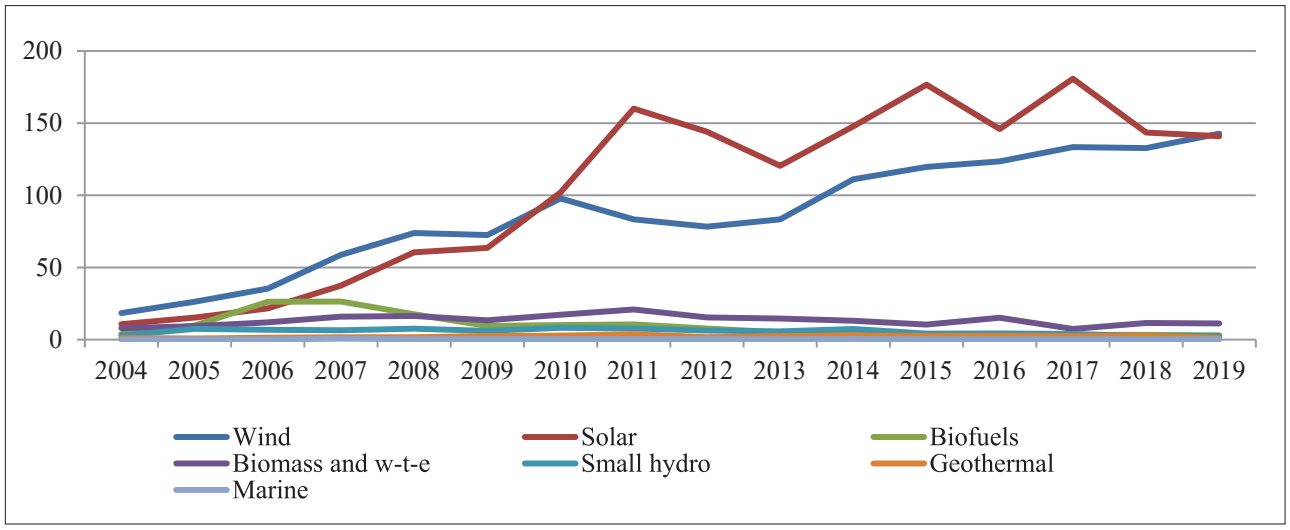

Figure 3. *New annual investments in electricity generation from RES in the world, $ billion*
Source: *constructed by authors according to Bloomberg (2021)*

In Europe, the installed capacity of solar power generation reaches 121.5 GW (2018); 140.9 GW (2019) and SES electricity production — 131.753 GWh (2018). Therewith, the share of solar energy in renewable energy in the EU is the same as in the world — 10% (IRENA, 2019) (Fig. 4).

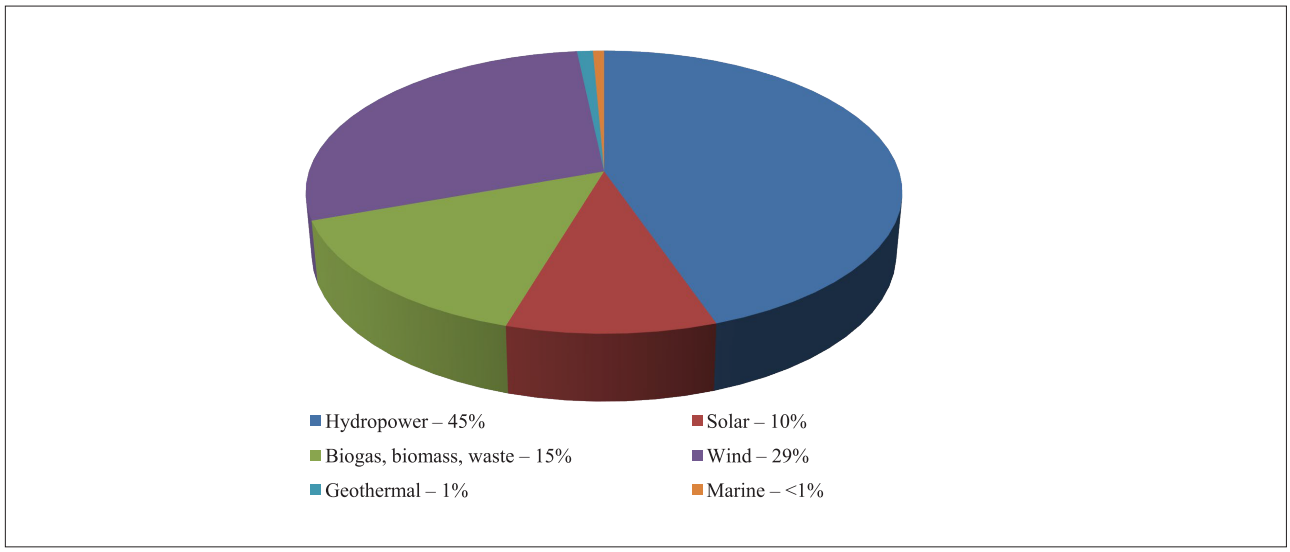

Figure 4. *Structure of electricity production from RES in Europe, 2018*
Source: *constructed by authors according to IRENA (2019)*

The potential of solar energy is impressive. An area of 254 kmx254 km (1% of the Sahara Desert) would be enough to meet the total electricity demand of the world. The amount of electricity needed by the EU-25 states could be produced on an area of 110 kmx110 km. For Germany, with a demand of 500 TWh/year, an area of 45 kmx45 km is required, which amounts to 0.03% of all suited areas in North Africa (May, 2005).

According to nearest prospects for the development of solar energy in the EU, to keep the growth of the average temperature on Earth not more than 2°C from the level of the pre-industrial period, in contrast to the scenario of continuation of the current practices, by 2050, the greenhouse gas emissions should reduce by 70%, which will affect all sectors of economy, and 75% of this reduction should be ensured by the use of RES (IRENA, 2019). Thus, in December 2019, the European Commission introduced an ambitious proposal to make the bloc climate-neutral by 2050 (McKinsey & Company, 2020). According to McKinsey & Company (2020), the most cost-effective decarbonisation pathway in Europe illustrates the technical feasibility of reducing the European Union's emissions by 55% by 2030 from 1990 levels and reaching zero by 2050, providing broad

economic benefits, including GDP growth, lower cost of living and generation of employment.

In 2020, 132 GW of SES capacities in the world were added. According to the conservative scenario, another 160 GW will be added in 2021, according to the optimistic scenario — 209 GW (Bloomberg NEF, 2021).

Solar energy: Development and its problems in Ukraine

For Ukraine, diversification of energy sources is a particularly pressing issue. In 2018, Ukraine topped the list of countries with the most inefficient and most expensive heat generation in the world. Most thermal power plants in Ukraine were built 60-70 years ago, and some — in the 1930s. They are obsolete morally and technically, which affects not only the cost of the electricity they generate, but also their environmental friendliness. 68 out of 75 thermal power plants in Ukraine operate beyond their designated service life (Accounting Chamber, 2021). And the most promising of renewable sources in terms of the availability of proper conditions in Ukraine is solar energy, which is developing quite dynamically in this country (Table 1).

Table 1*. Dynamics of solar energy development in Ukraine*

Year	Installed (MW)	Growth rates compared to the previous year, %	Generation (million kWh)
2010	3	–	n/a
2011	196	653	n/a
2012	326	166	n/a
2013	616	189	563
2014	411	67	485
2015	432	105	475
2016	531	123	492
2017	742	140	715
2018	1,388	187	1,101
2019	4,925	355	2,412
2020	6,320	128	4,740

Source*: calculated by authors according to Global Market Outlook for Photovoltaics (2015), State Agency on Energy Efficiency (2017) (2019a)(2019b)(2020), Radio Liberty (2021), Ovcharenko (2018), National Commission for State Regulation…(2019)*

As calculation results above show (Table 1), the dynamics of solar energy development in Ukraine is very uneven, but the general trend is quite understandable. Preferential ("green") tariff for renewable energy in Ukraine was introduced in 2010 as an incentive for its development, but it has been developing most dynamically in 2018-2019 — in 2019 alone, the solar energy sector increased by 1,169 MW of commercial and 226 MW of household photovoltaic capacities. As a result, the total capacity of SES in Ukraine amounted to 6,873 MW, of which 11% were formed by household photovoltaic power utilities (Aventson Group, 2021).

The main producer of solar electricity in Ukraine is DTEK VDE, which is currently operating the Trifanivska SES — its pilot project in the solar energy industry sector equipped with 37,000 solar panels (DTEK, 2018). In addition, in March 2019, DTEK VDE launched the Nikopol SES, which has 750,000 solar panels with a total capacity of 200 MW and is the largest solar power plant in Ukraine (DTEK, 2019). Focusing on the "green" tariff, the Ukrainian solar energy market also includes such foreign companies as "China National Building Material Company" (n.d.), "TIU Canada Ltd." (2019), Recom LLC (2019) and Scatec Solar (n.d.).

However, the current development of solar energy in Ukraine is at a stage that Europe passed 7-10 years ago. Therewith, favourable conditions for the development of solar energy have been created in Ukraine: the availability of resources and land plots, preferential tariffs, even insufficient national support aimed at achieving 25% of clean energy production by 2035. As a result, interest in renewable energetics in Ukraine continues to grow. As of the end of 2020, SES with a total nominal capacity of 6,320 MW has been installed, generating 1,265 billion kWh of electricity. The share of SES for the first quarter of 2021 of the total power generation of Ukraine was about 6%. Such active development of the industry has allowed Ukraine to rise from 34th to 23rd place in the world ranking of solar energy industry.

About 30,000 families in Ukraine have already switched to solar power stations. € 600 million has already been invested in domestic solar power stations in Ukraine (State Agency for Energy Efficiency…, 2022). At the beginning of 2014, when there were only 20 households with connected solar power stations, it was quite difficult to predict such a rapid development. But presently such a mechanism as the "green tariffs" has been successfully integrated into the economy of Ukraine.

Ukraine already has the Solar Energy Association of Ukraine, which unites 45 companies and 43 solar stations, whose capacity exceeds 400 MW. Additionally, according to DerzhEnerhoEfektyvnist (State Energy Efficiency) and Solar Energy Association of Ukraine, over the past three years, the dynamics of the development

of SES in Ukraine is fully consistent with the nature of the dynamics of SES in Europe; in 2050 there will be at least 17 GW of solar stations; in 2019, Ukraine got into the top 10 countries with high added capacity in the SES — 8th after Australia and Germany (Avenston Group, 2015). According to Global Solar Atlas, potential of solar energy in Ukraine as solar radiation potential is similar to V-4 countries (Global Solar Atlas, 2020).

According to Solar Power Europe and Solar Energy Association of Ukraine, installed capacities of SES per capita (Watts/capita) in 2019 are as follows: in Ukraine — 164; in Germany — 651 (maximum from top-10), in Spain — 283 (minimum from top-10) (Solar Industry Reports, 2019).

Ukraine's climate and geographical location, even its northern regions are favourable for the development of solar energy and the construction of SES, which is not inferior to conditions in most European regions. The average annual amount of total solar radiation energy that enters the territory of Ukraine annually is in the range from 1,070 kWh/m^2 in the northern part of Ukraine up to 1,400 kWh/m^2 and higher in the Crimea (State Agency for Energy Efficiency, 2018). The theoretical potential, or the total annual inflow of solar radiation into the territory of Ukraine is estimated at 720·1012 kW·h, which is equivalent to 88.4 billion tons o.eq. (State programme..., 1997). Term of effective operation of solar energy equipment in the southern regions of Ukraine — 7 months (from April to October), in the northern regions — 5 months (from May to September) (Cudria, 2020). The level of intensity of sunlight per unit of land area in Ukraine exceeds such index of the flagship of solar energy — Germany. According to scientific research, considering not only the value of solar radiation, but also the area available for the construction of stations and power factor of SES, which depends on the type and location of photovoltaic panels, distance between rows of panels, etc., the estimated capacity of SES in Ukraine and the annual potential of SES electricity generation is about 100 billion kWh/year (Cudria, 2020).

The available stocks of raw materials in Ukraine, sufficient human capital, technical and technological receptivity and the legal framework are sufficiently favourable for strong investments in the alternative energy sector of the country in general. In addition, production capacity of such giants of microelectronics as production associations "KVAZAR", "IRVA" (Kyiv), "Graviton" (Chernivtsi), "Hartron" (Kharkiv), "Gamma" and "Elektroavtomatika" (Zaporizhzhya), Dnipro (Kherson) allow for a full technological cycle of solar elements creation. Ukraine also has a highly qualified scientific potential in this field (Institute of Physics of Semiconductors and Institute of Electrodynamics of NASU, Taras Shevchenko National University of Kyiv, Yu. Fedkovych National University of Chernivtsi, "KPI" National Technical University).

There is enough reason to expect an accelerated development of the solar energy industry capacity in Ukraine in the nearest future because of plenty of examples of efficient functioning of solar energy equipment and stations, which forms foreign investors' interest in investing into this branch (Avenston rou, 2015). It remains to wait for real state support for solar energy. Otherwise, in the near future, along with foreign cars, appliances and household waste, Ukraine will start intensively receiving foreign solar panels.

Feed-in tariffs (FITs), which have been in force in Ukraine since 2008, are prevalent support policies for scaling up renewable electricity capacity. They are market-based economic instruments, which typically offer long-term contracts that guarantee a price to be paid to producers of a pre-determined source of electricity per kWh fed into the electricity grid, which is no longer extremely popular in other countries. From the 47 countries that had a Feed-in Tariff since 2000, only 9 countries kept the opportunity to receive it in 2019 (including Ukraine) (OECD Stat, 2020).

The green tariff, at which the state buys all the electricity produced by SES, is one of the highest in Europe in Ukraine, but not as high as one might expect, especially since it is steadily declining over the years. As of January 1, 2021, 8,516 MW of RES have been installed in Ukraine, which operate at a "green tariff" and capacity structure of RES facilities operating at the green tariff (01/01/2021) is as follows: SES — 6,094 MW — 71.6%; SES (roof) — 779 MW — 9.1%; WPS — 1,314 MW — 15.4%; biomass — 109 MW — 1.3%; biogas — 103 MW — 1.2%; MHPS — 117%; MW — 1.4%. The unpredictable actions of the government to reduce the green tariff due to the lack of funds to pay for it have had a considerable negative impact on the development of solar energy industry in Ukraine, because it has shaken the confidence of foreign investors in the government.

One of the most vulnerable factors in Ukraine that reduces the efficiency of any type of energy production, including the solar power, is aging power lines. 95% of electrical distribution networks in Ukraine are in poor condition (90%). Therefore, due to changes in climatic conditions in recent decades, a sizeable number of lines built in the 1970-80s are vulnerable to increased climatic loads. The designated service life (40 years) of most of them has already expired, which causes considerable losses of electricity in the grid. Depreciation on distribution networks is about 60%, of which 36.7% transformer substations have exhausted their resources, on main and interstate networks — 45%, of which about a third have been in operation for over 40 years, 260 thousand km of overhead power lines require replacement, with switchgear equipment being obsolete (Sadik-Zada & Gatto, 2021).

Considering the practices of introducing solar power plants in EU countries with levels of solar radiation similar to Ukraine, as well as given the global trends of constant reduction of SES construction costs due to technological development, due to technology improvement and commissioning of new capacities, production of solar energy in Ukraine can be significantly increased. The presence of favourable climatic conditions, significant reserves of raw materials, industrial and technological base for the manufacture of

photovoltaic devices can fully meet not only the needs of domestic consumers, but also allow exporting more than two-thirds of the energy produced (State Agency for Energy Efficiency..., 2018).

Solar energy: The practices of V-4 countries and the possibilities of its application

Ukraine is also in the European space and the general course of its development is officially recognised as European integration. Thus, the development of solar energy in Ukraine is necessarily associated with the development of the SE of the world and specifically of Europe. For Ukraine, when it comes to the possibility of using foreign practices in the development of solar energy, the experience of countries around the world is important — especially the V-4 countries as the closest neighbours to Ukraine geographically, which have natural conditions similar to those in Ukraine.

Notably, that the V-4 countries, like all EU Member States, are developing their energy sector, including renewable energy sources, according to NECPs (National Energy and Climate Plans), which were introduced by the Regulation on the governance of the energy union and climate action (EU) 2018/1999, agreed as part of the Clean energy for all Europeans package which was adopted in 2019 (Energy and Climate Plans, 2020). Solar energy industry in Poland is growing rapidly, with a current 3.9 GW capacity. Poland on an EU level currently has a 12% solar market share. Increasing solar photovoltaic (PV) deployment is likely to drive the Poland renewable energy market in the forecast period. The country is planning to increase its solar power share, to meet its target of 15% renewable energy in its energy mix by 2020 (Mordor Intelligence, 2020c). The country is well on track to reach its NECP goal of 7.8 GW of solar energy industry by 2025. The Institute of Renewable Energy has reported that by December 2020, 10 GW worth of preliminary grid project permits were acquired, marking the sustained growth of solar energy sector in Poland. It is predicted that by 2024, Poland's annual solar capacity will increase by 46% as renewable energy prices continue to drop and newer innovations take over the market (Solar Industry Reports, 2019).

However, there is the potential for a 300% increase in Poland's solar capacity by 2024. Solar capacity here is expected to reach 7.3 GW by 2030 with about half installed by 2025. Poland's renewable energy market is expected to grow at a CAGR (Compound annual growth rate (CAGR) is the rate of return that would be required for an investment to grow from its beginning balance to its ending balance, assuming the profits were reinvested at the end of each year of the investment's life span (Gartner Glossary, 2021)) of more than 8% (Mordor Intelligence, 2020c). Poland has a large potential to install solar utilities on former coal sites. There is an interest from Polish grid operators in large photovoltaic projects to fill in the summer peak demand, partly resulting from the higher capacity of air-conditioning systems. To foster the deployment of solar energy, the government announced a corresponding policy in November 2019. The VAT applied to residential PV in Poland was reduced from 23% to 8%. The programme is open to residential PV projects with a generation capacity of 2-10 kW and grants rebates of up to PLN 5,000 per project. The Polish government is currently supporting solar through net metering (up to 40 kW) and the auction mechanism for large-scale projects over 40 kW — two schemes, which replaced the green certificate mechanism. The Polish renewable energy market is moderately fragmented. Some of the key players in the market include PGE Polska Grupa Energetyczna SA, Akuo Energy SAS, Engie SA, Dalkia Polska, and SGS SA Mordor Intelligence, 2020b).

Solar power generation continues to be the most popular technology in Hungary. Solar energy grew here significantly in 2018, and it is likely to increase during the forecast period. Hungary, due to its number of sunny days in the country, has good solar potential, so renewable energy market is expected to grow at a CAGR of over 4% during the forecasting period. Very good practice of solar energy industry in Hungary is Solar Parks, which are something like clusters. One can mention Dunai Solar Park, Felsőzsolca Solar Park, Solar Park near Parks Nuclear Power Plant. In 2018, MET Group completed its Dunai Solar Park project with a total capacity of 17.6 MW and ability to provide electricity to 9,000 houses. In In addition, MVM Group built the Felsőzsolca Solar Park, which has the capacity of 20 MW and can generate up to 21 GWh of electricity per year. In 2019, a new Solar Park near Parks Nuclear Power Plant was opened. The facility has a capacity of 20.6 MW and can generate electricity for 8,500 households. The Hungarian renewable energy market is moderately consolidated. Some of the key actors in this market include E.ON SE Sponsored ADR (Germany), China National Machinery Import and Export Corporation, MVM Group, MET Holding AG, and Solarpro Holding AD (Mordor Intelligence, 2020b).

Slovakia plans to support renewables that can replace fossil fuels in a way ensuring the safety of electricity and heat production without any great added costs. After replacing solid fossil fuels with renewable energy sources, Slovakia is expected to become one of the cleanest countries in the entire EU. Solar energy in Slovakia provides an essential contribution to meet energy needs in the electricity sector. According to the latest statistics published by the International Renewable Energy Agency, Slovakia had around 472 MW of installed solar power generation capacities in 2019. Solar power is expected to claim 44% of the clean energy capacity required to generate 2.4 TWh of electricity by 2021. The electricity generated by solar power has reached 585 GWh in 2018. In addition, the quantity of installed solar power capacity is expected to reach 600 MW by 2020 and 750 MW by 2030. Slovakia solar energy market is expected to grow at a CAGR of more than 1% during the forecasting period. Slovakian solar photovoltaic is mainly driven by the residential sector. Since March 2010, Slovenské elektrárne has been operating two photovoltaic power plants: Mochovce photovoltaic power plant and Vojany photovoltaic power plant. The Slovakian renewable energy market is consolidated.

Some of the major companies include Slovenské elektrárne AS, Axpo Holding AG, CONTOURGLOBAL PLC, VP Solar, and Acrosun SRO (Mordor Intelligence, 2020d).

Czech Republic's renewable energy shares around 12% of the total electricity generation in the country. The primary driver for the market includes the government initiatives that involve the use of clean and alternative sources of energy to protect the environment from the growing carbon emission. With increasing carbon emission, the government of the Czech Republic is expected to increase its renewable energy share in total electricity production. With 15% share of renewable sources in electricity generation in 2019, the country is estimated to increase this share to nearly 22% by 2030. Solar energy has considerably grown from negligible levels in 2009 to around 0.5% in 2015, primarily due to generous subsidies. In December 2016, the Czech Republic reached a cumulative installed solar power capacity of about 2.08 GW. During 2010-2014, the growth of renewable energy sources was supported by several different mechanisms, including feed-in tariff (FIT) system (guaranteed price), feed-in premiums (an amount paid on top of the market price for electricity, or green bonuses), investment subsidies, and fiscal measures. Two-third of the subsidies for RES were allocated to solar power, which produces only 5% of renewable energy. In 2019, Czech Republic had installed a solar power capacity of around 2,071 MW, with an electricity generation capacity of around 2.3TWh. The Czech Republic solar energy market is expected to grow at a CAGR of around 2.5% during the forecasting period (Mordor Intelligence, 2020a). Solar energy is becoming inexpensive in comparison to other conventional energy sources due to innovations in the solar sector that have reduced the global average selling prices of solar power. With the expected improvements in technology and increased supply of panels from China/Europe, the capital costs are expected to stabilise at lower levels. As a result, investors/developers are expected to focus on the commercial viability of solar projects. The Czech Republic solar energy market is moderately consolidated. The key players in the market include CEZ Group, Senvion S.A., EP Energy, Scatec Solar, Solar Global AS Burke, M.J., & Stephens.

Common to the V-4 countries is the presence of the same factors inhibiting the development of solar energy, the main of which is the resistance of conventional fossil energy companies. "In a time of climate emergency, weak forms of democracy may also delay the transition or elicit centralisation, and thus persistent local resistance to renewable energy sources may reflect a missed opportunity to redistribute political and economic power" (Burke & Stephens, 2018).

A positive experience that deserves attention is the creation of combined energy systems, which allows for a more stable balance of energy production with needs and provides a cogeneration and synergy effect. An example is the Matra Power Plant in northern Hungary: 100 MW are obtained by biomass + 60 MW are obtained by SES + 50 MW are obtained by ESS. This practically confirmed the conclusion of scientists at the Centre of Alternative Technologies in the mountains of Wales made 20 years ago, that a mixed system of renewable energy sources is the most optimal and reliable for environmental and economic reasons (Konechenkov, 2004).

The practice of the V-4 countries also confirmed the results of the research that energy storage systems (ESS) increase the efficiency of solar (and wind) power plants by 30-50% (Avenston Group, 2021). In 2019, such capacities in Poland were already producing 1 MWh; in the Czech Republic — 3 MWh; in Hungary — 7 MWh; even small Slovenia — 13 MWh (UK – 570 MWh, Germany — 406). This answers the question why Germany managed to develop solar energy industry so quickly — because 406 MWh work primarily on balancing the conventional network and RES.

In the future, Ukraine may also adopt a few more elements of successful practices of foreign colleagues to expand the prospects of solar energy. In V-4 countries, photocells are placed on the roofs of trains, thereby providing them with electricity during operation. This technology can be used on ships and planes. Thermal energy is a way to convert solar energy by heating water in containers made of heat-conducting materials (Avenston Group, 2015).

Thus, the results of the practices of the V-4 countries under study, where the natural conditions for the development of solar energy are similar to the Ukrainian ones, give grounds for identifying certain possible ways to improve the solution of solar energy development in Ukraine: consolidation of the solar energy market — in each of the V-4 countries the solar energy market has only about 5 key operators, which makes this market more regulated; creation of the favourable government regulatory and supporting policies and improvement of investment attractiveness; development of the practice of cogeneration of different types of energy; development of the practice of building energy storage systems; creation of solar parks; auction mechanism and other effective schemes (feed-in premium, simplified taxation, direct subsidies, etc.) replacing the green certificate mechanism. These solutions outline the immediate tasks for Ukraine: updating of Ukraine's Energy Strategy with more ambitious SES development targets; elaboration of new goals of the National Action Plan on RES Climate 2020-2025 at least at the medium level for EU countries; development of the concept of "green" energy transition and "Ukrainian Green Deal; construction of additional 25 GW SES, considering the growing share of roof and hydrogen SES.

Some elements of the European practices, including experience of V-4 countries are already implied in Ukraine. Thus, in April 2019, the "Law on Green Auctions" was adopted (State Agency for Energy Efficiency, 2019). According to that, the implementation of projects with a capacity of more than 1 MW in the solar energy sector from 2020 makes provision for mandatory prior participation in "green" auctions, which should prevent the emergence of monopolies in the RES market in Ukraine. An inherent feature of such auctions is their transparency, and they are expected to be held twice a year

through the ProZorro electronic trading system. The level of the "green" tariff was clearly prescribed in the Law, and in the case of auctions, the amount of support for each project will be determined at the auction, and this will considerably reduce the cost of such energy. The adoption of this law preceded the conclusion of a memorandum with RES producers on June 10, 2020 (National Commission for State Regulation..., 2020). Under the terms of this memorandum, it is planned to reduce tariffs by 15% for SES and shift to an auction model of tariff setting from July 1, 2020. "Green" auctions were supposed to be introduced in 2019-2020, but this was not done due to problems with the mentioned payments under the "green" tariff. Provision of national support to economic entities in renewable energy sector exclusively through auctions for the distribution of quotas will ensure the development of alternative energy sources, including solar power, in a more controlled and efficient way and reduce the financial burden on consumers and the threat of violating the operational security of the United Energy System of Ukraine in the future.

The Verkhovna Rada of Ukraine also adopted the Draft Law of Ukraine No. 5436-d "On Amendments to Certain Laws of Ukraine on the Development of Energy Storage Facilities" (Draft Law on Amendments..., 2020). The drafting of the document considered the fundamental principles of legal regulation of energy storage systems in EU countries, including V-4 countries. Its adoption will ensure the use of energy storage systems, balance the operation of the energy system, facilitate the synchronisation of the Ukrainian energy system with the European ENTSO-E, as well as increase the stability of electricity supply to consumers. However, these measures are only the first individual steps.

Countries, combined with geographical proximity, common history, and long-term prospects, have traditionally focused on active multifaceted cooperation. Various similarities, related interests and aspirations form the basis that eventually determines the mutually beneficial coexistence and interaction (Chorna, 2012). In the field of renewable energy, such cooperation is objectively possible by integrating the United Energy System of Ukraine into ENTSOE (European Network of Transmission System Operators for Electricity), which will allow for more efficient use of the solar energy capacity of Ukraine and V-4 countries, organically balancing local needs for clean solar energy within the region.

CONCLUSIONS

Solar energy resources can be used to produce energy both by directly converting solar energy into electricity, which is user-friendly and environmentally friendly, and by concentrating solar energy (SPC) with special mirrors, what has its advantages but is much more expensive.

Advantages of solar energy industry are practical inexhaustibility, fast return on investment, environmental friendliness, quietness, the ability to install SES everywhere, safety, ease of management, independence, durability of equipment, minimal care and maintenance, rapid modernisation of technology and cheaper equipment and energy, intensive generation of employment; disadvantages include instability, high cost of batteries, difficult forecasting, spatial scattering. Due to the considerable advantages of positive features of solar energy over its drawbacks, it is developing at a fairly high rate, but so far, its share in the structure of renewable energy in the world and in Europe is only 10%, although the potential of solar energy industry in terms of clean energy is impressive.

Ukraine's energy industry is currently one of the least efficient and the most environmentally harmful and dangerous. Thus, for Ukraine, solar energy industry is, on the one hand, a forced step due to the extremely low level of efficiency of the available energy system, and on the other hand, there are favourable conditions for its development in the country. In this regard, the study and application of the development practices for this industry by Ukraine's neighbours — the V-4 countries — can positively affect the development of solar energy industry in Ukraine.

The general trend and motives for the intensive development of solar energy in Ukraine in 2018-2020 are quite clear, although the legal and economic conditions for this have been created as early as 2010, and natural conditions have always been favourable and are not worse than in countries that are leading solar energy producers. The available human capital, production capacities, and investment attractiveness also contribute to this. But the current level of solar energy development in Ukraine was surpassed by Europe 7-10 years ago, because of numerous negative aspects holding Ukraine back. The main problems are a lack of support from state institutions; high level of wear of electric networks; delay in the development of systems for accumulation and storage of energy received by SES; delay in the introduction and dissemination of the practice of "green" auctions in the renewable energy sector, instability of national policy towards investors in solar energy industry; lack of clear and understandable governmental strategy of solar energy industry development.

Therefore, the practices of developing the solar energy industry in the V-4 countries can be practically useful for Ukraine due to the similarity of conditions and the geographical proximity of these countries to Ukraine. The most valuable elements of these practices for Ukraine are the consolidation of the solar energy market, which makes this market more regulated; creation of a favourable state regulation and proper investment climate; development of practices of cogeneration of different types of energy and construction of energy storage systems; creation of solar parks; development of an auction mechanism and other effective schemes instead of a green tariff mechanism. Therefore, the immediate tasks for Ukraine include the updating of Ukraine's Energy Strategy; development of new goals for the National Action Plan on Climate Resistance and the concept of transition to green energy and the Ukrainian Green Course; construction of additional SES utilities; integration with ENTSOE, which together will positively affect both Ukraine and the V-4 countries through

the development of mutual electricity exchange. Prospects for further research relate to creating proper conditions for the implementation of specified elements of the V-4 countries' practices in solar energy industry development.

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Сонячна енергетика в Україні та досвід країн Вишеградської групи

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Анотація. Актуальність дослідження шляхів підвищення ефективності розвитку сонячної енергетики в Україні зумовлюється вичерпністю конвенційних джерел енергії та їх забруднюючим ефектом, наявністю потенціалу ефективного використання енергії Сонця і нижчим від можливого рівнем його реалізації та можливостями використання досвіду країн V-4, які пов'язані з Україною географічно, економічно та природно-екологічно. Метою дослідження було визначення основних позитивних елементів названого досвіду та на цій основі — можливих напрямів подальшого розвитку сонячної енергетики в Україні. Основні методи дослідження застосовуються на основі діалектичного підходу до вивчення економічних явищ: загальні методи (аналіз і синтез у поєднанні з науковою абстракцією та узагальненням, індукцією) та специфічні економіко-статистичні методи (аналіз динамічних рядів, індексів, аналізу, порівняння). Основні результати дослідження: визначено методи отримання та використання сонячної енергії, її переваги та недоліки, тенденції, темпи та потенціал розвитку галузі; визначено частку сонячної енергії в структурі відновлюваної на рівні 10 %; окреслено значення, стан і тенденції розвитку сонячної енергетики в Україні, її провідну роль в екологізації всієї економіки, використовуючи існуючі сприятливі умови, але зараз цей розвиток є відносно низьким і гальмується відсутністю державної підтримки, систем накопичення та зберігання енергії, чіткої та зрозумілої державної стратегії її розвитку, застарілими практиками зелених тарифів, нестабільністю державної інвестиційної політики у галузі, високим рівнем зношеності електричних мереж. У зв'язку з цим згаданий вище досвід стосується консолідації ринку сонячної енергії з метою підвищення рівня його регульованості; адекватизація державної енергетичної політики та інвестиційного клімату; розвиток практики створення сонячних парків та систем когенерації різних видів енергії та систем зберігання енергії; заміна зелених тарифів механізмом зелених аукціонів та іншими схемами

Ключові слова: слова: енергія Сонця, практика країн V-4, зелений тариф, зелений аукціон, ринок сонячної енергетики