

Management of the solar power development in households of Ukraine

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Abstract. *Solar power is one of the fast-growing promising areas of renewable energy use. The article is devoted to the use of solar radiation energy in private households of Ukraine. It is noted that the amount of solar radiation is high enough to create solar power facilities throughout Ukraine.*

Based on the results of the research, it was found that households that have installed photovoltaic power station are fully self-sufficient in electricity and are the most energy efficient, as the surplus of environmentally clean electricity produced is sold at a "green" tariff. Based on the data of the study of the state of installation of solar power plant in private households, has been made a forecast of the development potential of this electricity sector for the period up to 2024.

On the basis of the conducted research, it can be stated that the use of solar power in private households has a sufficiently large perspective to ensure which it is advisable to introduce a net-metering system in Ukraine, which includes the free sale of surplus energy produced on the market with the possibility of "taking" it from this market later.

Keywords: *solar power, photovoltaic power station households, financial model, "green" tariff*

I. INTRODUCTION

In recent decades, there has been a trend in the world to abandon traditional energy sources and switch to alternative ones, where an important place is given to solar power. This is the most promising source of electricity, since solar power can be obtained constantly,

for free, and anywhere on the globe. In particular, solar power has been extremely popular in Ukraine in recent years. The advantages of this type of energy are its availability, as Ukraine has the possibility of its free use due to its geographical location. Modern technologies make it possible to use the potential of the sun's energy with sufficiently high efficiency. However, in contrast to the large amount of literature and research conducted on solar power, less attention has been paid to qualitative assessments of the strengths and weaknesses of its use in private households.

The purpose of the article is to study aspects of solar power development in Ukraine in the context of providing private households with electricity and legislative regulation of this process.

A review of the literature.

A number of scientists' works are devoted to the aspects of effective development of solar power in private households.

Y. Dzyadykevych, M. Buryak and I. Lyubezna point out that the use of solar power in everyday life provides an opportunity to meet the needs of electricity and at the same time become independent of generating companies and external conditions. Electric energy produced in the country from solar power is of particular importance for Ukraine's energy security [1].

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S. Matyakh, T. Surzhik, and V. Ryeztsov claim that the power indicators of incoming solar radiation are high enough for the creation of solar power facilities throughout the territory of Ukraine. The thermal energy of solar radiation can be effectively used in private households for hot water supply and heating [2].

V. Bodunov believes that one of the ways to stimulate the development of renewable energy is preferential electricity tariffs for business entities, consumers of electricity, including energy cooperatives and private households, whose generating plants produce electricity from alternative energy sources. Such a state policy exists in Ukraine as a "green" tariff [3].

Some research authors pay attention to the fact that on the basis of solar power it is possible to easily build distributed systems of the future - disconnected from the central network, independent clusters within communities. It is in this direction that the development of the energy industry is moving. Today, at the current tariff, home solar stations are paid for in 4-5 years. After 9-10 years, they should be occupied due to the net-metering system, which Ukraine should implement and which includes the free sale of surpluses to the market with the possibility of "taking" energy from this market later [4].

The report on the solar electricity market in Western Europe [5] notes that the Western European solar electricity production market consists of its sale and related services. As the cost of using solar power to generate electricity falls every year, many users are increasingly switching to solar power. Some of the major additional benefits of going solar include cost savings that depend on electricity usage, the size of the solar electric system, and a number of other factors.

II. MATERIALS AND METHODS

This study is included in the general subject of the research laboratory "DAK GPS" of the Higher Education Institution "Podilskyi State University", whose activity is based on the study of the potential of effective use of renewable energy sources [6-11]. The theoretical and methodological basis for the article were the scientific works of scientists, which became the basis for researching the development of solar power in private households. Data from official sources were used for the analysis. The information base of the study was the materials of the State Agency for Energy Efficiency and Energy Saving of Ukraine, analytical materials, reviews and calculations of domestic experts and companies in the field of solar power and its use in private households.

To achieve the goal, the article uses the method of statistical observation for collecting primary statistical material and its analysis. Tabular and graphical methods were used to present the results of the study, which made it possible to analyze the dynamics of the installation of photovoltaic power station in private households, their capacity and the amount of energy they realized under the "green" tariff in the period 2014-2021. A modeling method is used to build a financial model of a solar power plant of a private household. The forecasting method made it possible, with the help of correlation analysis, to calculate the forecast indicators of the installation of photovoltaic power stations and their capacity in private

households, and the volume of energy sales under the "green" tariff for the future

III. RESULTS AND DISCUSSION

Solar power is a relatively new industry in Ukraine. The entire area here is suitable for the location of photovoltaic power stations. The rate of its development is extremely high compared to other sectors of the domestic economy. Thus, according to the results of 2021, solar power accounted for more than 5% of the total electricity production in Ukraine [12].

Some research authors indicate that the thermal energy of solar radiation can be effectively used in private households for hot water supply and heating. From an environmental point of view, solar electricity may have very few limitations in its implementation as there is no significant negative impact on the environment. Social characteristics include the creation of additional jobs [13].

Y. Dzyadykevych, M. Buryak and I. Lyubezna believe that the development of solar power in Ukraine will make Ukrainian energy more competitive. The International Renewable Energy Agency (IRENA) has concluded that the increased use of solar power in the period up to 2030 will reduce the total costs of the Ukrainian energy system. With this in mind, there will be a positive impact on the environment and the health of the population, as the level of smog decreases and the volume of emissions of harmful substances decreases [1].

S. Matyakh, T. Surzhik, and V. Ryeztsov note that with the help of solar power, it is possible to provide electricity to residents of the private sector, which is also possible in parallel with the operation of the electrical network. The most common are photovoltaic power stations located on the roof of buildings. [2].

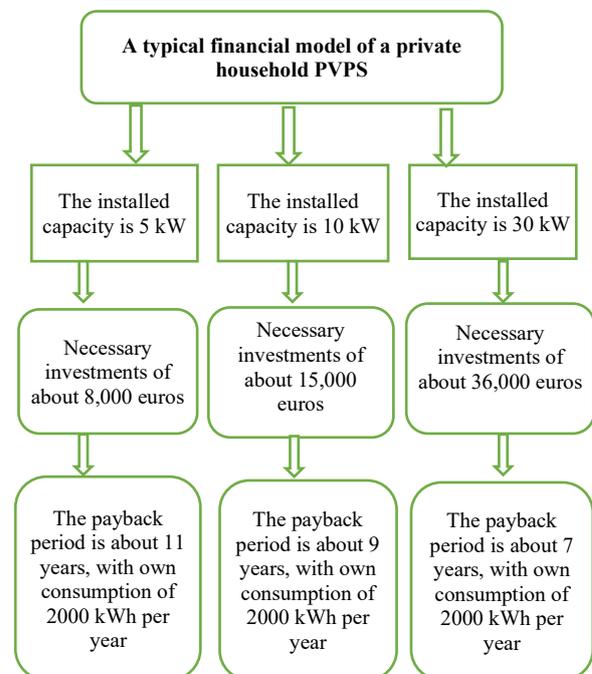


Fig. 1. A typical financial model of a private household photovoltaic power stations [14]

For the installation of solar power in the private sector, typical financial models of photovoltaic power stations for private households (PVPSH) have been developed, which, based on a given volume of energy consumption, determine the required installed capacity, payback period and necessary investments, taking into account the size of the "green" tariff (Fig. 1) [14, 15].

It is worth noting that the vast majority of households install solar plants with a capacity of 30 kW, since they are more efficient from the point of view of investment return. For comparison: the payback period of a 5 kW PVPSH is 11 years with an investment of 8 thousand euros, and the most popular 30 kW roof PVPS is 7 years with an investment of 36 thousand euros [16].

The main benefit for households in the Western European solar market is cost savings, which depends on electricity consumption, the size of the solar electric system, whether users buy or lease solar systems, hours of direct sunlight, roof size and angle, and local electricity tariffs. Some of the other benefits include increased housing costs. A study by Lawrence Berkeley National Laboratory found that, on average, solar added about \$15,000 to the value of a home [5]

The legislation of Ukraine [17] clearly regulates who, where exactly and under what conditions can set up the PVPSH. A household consumer has the right to install in his private household a generating plant intended for the production of electricity from the energy of solar radiation. The size of such an installation should not exceed 50 kW. Production of electricity from such an installation is possible without a corresponding license. Households that have installed PVPSH are fully self-sufficient in electrical energy and are the most power efficient, as the surplus of environmentally clean electricity produced is sold at a "green" tariff [17], [18].

V. Bodunov draws attention to the fact that according to Article 63 of the Law of Ukraine "On the Electric Energy Market", the universal service provider is obliged to purchase electric energy produced by the generating units of private households, the installed capacity of which does not exceed 50 kW, according to the "green" tariff in the amount exceeding the monthly consumption of electric energy by such private households. However, in accordance with Article 58 of this law, the connection of generating plants of consumers, including private households, should not lead to a deterioration of the regulatory parameters of the quality of electric energy in the network and the security of supply. [3].

More and more private households are choosing solar power. Installed photovoltaic power stations in households provide an opportunity to independently meet their power needs, reduce dependence on the import of traditional energy resources, save on electricity bills, be autonomous, and stimulate the local economy [19].

In 2021, Ukrainians set a new record for the number of domestic PVPSH, during which nearly 15,000 Ukrainian families installed solar panels, which is twice as many as in 2020. This is a record number of installed home heating systems for a year, informs the press service of the State Agency for Energy Efficiency and Energy Saving of Ukraine with reference to the results of quarterly

monitoring. In total, as of the end of 2021, there were approximately 45,000 households in Ukraine that had installed photovoltaic power stations. (fig. 2) [20], [21].

It should be noted that the active rate of development of domestic PVPSH in 2021 allowed to increase their capacity by 426.1 MW, which is 36.4% of the new renewable energy sources capacities put into operation last year. Thus, the total installed capacity of all household solar systems reached 1,205.1 MW at the end of the year. (Fig. 2). Home solar stations make up only 11% of the total installed capacities of PVPSH (Fig. 2). [4], [22].

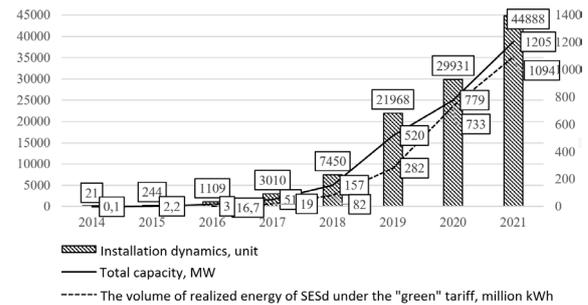


Fig. 2. The dynamics of the installation of photovoltaic power stations in private households [14]

Based on the materials of State Energy Efficiency of Ukraine, one can notice that the development of photovoltaic power stations in private households has positive dynamics. Over the period 2016-2021, the rates of sales of electricity sold to the European Union under the "green" tariff are characterized by stable growth. The highest numbers were achieved in the period 2019-2021. During this period, the sales volume increased by 4 times from 282 million kW*year in 2019. up to 1094 million kW*year in 2021. It is important to note that private households favor the transition to natural electricity (Fig. 2) [14].

The State Agency for Energy Efficiency and Energy Saving assessed the regions of Ukraine and established a rating for the number of installations of ESSD as of 01/01/2021. The top three regional leaders, due to the number of establishments by the EU PVPS, have increased: Dnipropetrovsk - 4184 PVPS, Ternopil'ska - 2512 PVPS, Zakarpattia - 2082 PVPS regions. (Table 1) [23].

The decision to install a solar installation is influenced by the economic factor, which allows selling excess electricity to the grid. Since 2008, the "Green Tariff" has been in effect in Ukraine, which is a policy of stimulating the production of electricity from alternative sources by the state. The basis of the system is the purchase of excess produced alternative electricity from private households. "Green" tariff for electric energy produced from the power of solar radiation by generating units of private households, the installed capacity of which does not exceed 50 kW, provided they are located on the roofs and/or facades of buildings and other capital structures [24], [25].

TABLE 1. RATING OF REGIONS REGARDING THE NUMBER OF INSTALLED PVPSH AS OF 01.01.2021

№	Region	Number of PVPSH	Number of population, persons	number of PVPSH per 1,000 people
1	Ternopil	2512	1081418	2,32
2	Zakarpattia	2082	1256802	1,66
3	Kirovohrad	1550	945549	1,64
4	Ivano-Frankivsk	2149	1373252	1,56
5	Khmelnyska	1508	1037640	1,45
6	Kyiv	2350	1767940	1,33
7	Dnipropetrovsk	4184	3206477	1,30
8	Odesa	1273	1131096	1,13
9	Chernivtsi	1231	1206351	1,02
10	Volyn	754	1035330	0,73
11	Vinnytsia	1094	1560394	0,70
12	Cherkasy	811	1264705	0,64
13	Kherson	1693	2675598	0,63
14	Kharkiv	652	1045879	0,62
15	Zhytomyr	758	1220193	0,62
16	Sumy	628	1157301	0,54
17	Lviv	1175	2522021	0,47
18	Rivne	519	1400439	0,37
19	Chernihiv	256	904374	0,28
20	Mykolayiv	805	2950819	0,27
21	Poltava	606	2380308	0,25
22	Zaporizhzhia	397	1705836	0,23
23	city of Kyiv	222	1005745	0,22
24	Donetsk	637	4165901	0,15
25	Luhansk	85	2151833	0,04

According to the specialists of the Solar System installer company, relying on the statistical data of the State Agency for Energy Efficiency and Energy Saving of Ukraine, the interest of Ukrainian households in "clean" sources of energy is growing. In order to further promote the development of this direction, the State Agency for Energy Efficiency and Energy Saving of Ukraine wants to start a trend and mechanism that is already popular in Europe - #NetEnergyMetering. In addition, as more and more households use "clean" energy, the market for solar installation materials and services is growing. To date, photovoltaic power stations installed by families are primarily investments in the amount of about 640 million euros in the development of the Ukrainian energy industry [16]

TABLE 2. DYNAMICS OF INSTALLATION OF PHOTOVOLTAIC POWER STATIONS BY PRIVATE HOUSEHOLDS

Indicators	2017	2018	2019	2020	2021	2022	2023	2024
Number of PVPS, units	3010	7450	21968	29931	44888	x	x	x
Trend line	202	10826	21450	32074	42698	53322	63946	74570

Based on the data from the conducted research, I will establish the installation of photovoltaic power stations in private households for the period 2017-2021. (Fig. 2), a forecast of the development potential of this electricity sector for the period up to 2024 has been compiled. Using the Excel spreadsheet editor, a graph of a linear trend was drawn, which illustrates the duration between periods and

the number of installations of photovoltaic power stations and the coefficient of determination (R^2), which is calculated automatically. In the presented graph, $R^2 = 0.975$, which classifies the relationship between values as high, so that the model generated is adequate to the real data (Fig. 3).

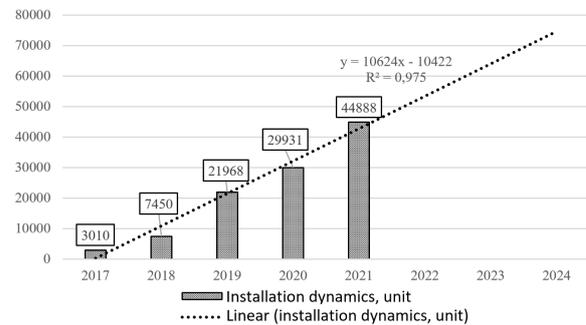


Fig. 3. Trend model for forecasting the development of solar power in private households (Covered by the authors)/

Taking into account the received trend equation $y = 10624x - 10422$, the forecast indicators of the installation of photovoltaic power stations in private households for 2022-2024 were calculated, according to which the state of their coverage in 2024 will be at the level of 74,570 units. Compared to the actual indicators of 2021, the projected growth in 2024 will be 66%.

Research shows that the potential for the development of solar power is provided by our own scientific and industrial bases, design bureaus that design solar collectors, production of mono- and polysilicon, nanotechnology, the availability of necessary metal products, etc. Photoenergy projects have been actively implemented in Ukraine since 2010. The advantages of solar power are the general availability and inexhaustibility of the energy source.

At present, solar power is used mainly for household lighting and private use by households. By extending the hours of available light, it creates additional time for productive activities. Now, many different devices have appeared in the private use of the population, which consume a large amount of energy. Therefore, electricity consumption in Ukraine is growing, and every household needs a reliable and modern source of energy. Therefore, energy independence and reliability in the fact that there will always be a current are important above all. There are also environmental benefits, each kilowatt-hour of solar power generated will significantly reduce greenhouse gas emissions such as CO_2 as well as other dangerous pollutants. Solar power also reduces water consumption and abstraction

Further expansion of the scale of use of solar power for the production of electricity and thermal energy in the private sector of Ukraine will contribute to raising the standard of living, especially in rural areas. Inexhaustibility and ecological purity, as the main properties of solar power, are expected to provide greater stability of the energy sector of households and improve the state of the environment than is possible when using traditional fuel resources.

IV. CONCLUSIONS

During the studied period, the development of photovoltaic power stations in private households has a positive dynamic, and the active rate of installation of domestic PVPSH by the end of 2021. allowed to increase their number and power, and the amount of electricity sold by them under the "green" tariff is characterized by stable growth. Based on the research conducted on the state of installation of photovoltaic power stations in private households, a forecast of the development potential of this electricity sector was made.

On the basis of the conducted research, it can be stated that the use of solar power in private households has a sufficiently large perspective to ensure which it is advisable to implement a net-metering system in Ukraine, which includes the free sale of surplus energy produced on the market with the possibility of "taking" it from this market later.

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