POLITYKA ENERGETYCZNA – ENERGY POLICY JOURNAL

2022 ✦ Volume 25 ✦ Issue 4 ✦ 95–114

DOI: 10.33223/epj/155095

Piotr Olczak[1], Dominika Matuszewska[2], Andrii Lishchenko[3], Iryna Zhydyk[4], Viktor Koval[5], Olga Iermakova[6]

The economic efficiency of photovoltaic energy for energy prosumers

Abstract: This article presents an investigation of solar power plants' economic efficiency in the case of energy prosumers. The economic effect of the development of solar energy, the environmental effect of the transition to green energy and the social effect due to lower electricity costs and investment growth from the use of photovoltaic installations (PVI) have been proven. The level of annual savings in PVI due to changes in production and own consumption of electricity are determined. Through use of factor analysis, the grouping method, the method of generalizing indicators, quantitative data collection for solar PV systems and the matrix method, the two main hypotheses were proven: (i) solar energy production should be stimulated by a sound state tariff policy; (ii) prosu-

✉ Corresponding Author: Piotr Olczak; e-mail: olczak@min-pan.krakow.pl

[1] Mineral and Energy Economy Research Institute, Polish Academy of Sciences, Kraków, Poland; ORCID iD: 0000-0002-4926-0845; e-mail: olczak@min-pan.krakow.pl

[2] Faculty of Energy and Fuels, AGH University of Science and Technology, Kraków, Poland; ORCID iD: 0000-0002-8899-012X; e-mail: dommat@agh.edu.pl

[3] Interregional Academy of Personnel Management, Ukraine; ORCID iD: 0000-0003-2332-1328; e-mail: lishchenko777@gmail.com

[4] National University of Water and Environmental Engineering, Ukraine; ORCID iD: 0000-0002-8438-9708; e-mail: i.a.zhydyk@nuwm.edu.ua

[5] National Academy of Sciences of Ukraine, Ukraine; ORCID iD: 0000-0003-2562-4373; e-mail: viktor-koval@ukr.net

[6] National Academy of Sciences of Ukraine, Ukraine; ORCID iD: 0000-0002-9815-3464; e-mail: impeer@ukr.net

mers as players of the electricity market should be considered in the tariff policy. It is revealed that at current interest rates, PVI operational activity is subject to more complex factors, and the main one becomes economic, namely considering the economy of consumers, the level of taxation or grants of PVI activities, as well as productivity and the real state of technical condition of devices. The provided research develops the theoretical and empirical basis for the state policy of solar electricity usage with consideration to the peculiarities of its production and consumption. The process of production and consumption of electricity in PVI is not characterized by uniformity, which is derived from a number of factors, primarily from natural and climatic conditions. It also depends on the technical characteristics of the devices.

Keywords: Poland, prosumer, photovoltaic, energy economics

Introduction

The modern energy industry is undergoing a reformatting stage in the process of growth in the production of autonomous power plants with various forms of ownership. Additionally, the pricing system has formed new principles based on the market economy (Komorowska et al. 2022). However, the system of state regulation focuses exclusively on intensifying the development of alternative energy and mass use both in households and on an industrial scale. At the same time, government policy actively operates the so-called green tariff, which is essentially a “forced rollback” of traditional energy in favor of alternatives.

However, the environmental realities in recent years have shown a trend in the total transition to alternative energy does not being able to cover the needs of electricity consumption, and in extreme situations, alternative energy becomes very vulnerable and almost photovoltaic installations (PVI) its generating function in solar power plants. In the current economic situation, alternative electricity generates capacity that is purchased and consumed by consumers. Thus, there is a problem: what patterns determine the relationship between production and consumption through price parity?

The process of one’s own production and consumption is as the defining factor for being a prosumer. It refers to the process of the joint creation of products and their subsequent consumption (Toffler 1980). The prosumer concept has been further developed in relation to electricity generation, as energy producers also become consumers (Milčiuvienė et al. 2019). Saturation of the energy market is possible due to the growing number of energy consumers who use renewable technologies, which significantly reduces emissions (Sawicka-Chudy et al. 2018).

The implementation of renewable energy technologies such as photovoltaic installation will lead to the development of cooperative energy consumers, which will increase competition in the electricity market (Cader et al. 2021). The sustainable growth of renewable energy is made possible by solar power plants as the cheapest generating capacity at present (Lund 2007). At the same time, there are barriers to the development of the energy prosumer, which is related to a lack of market readiness to use solar-power-plant technologies, low awareness of the potential of the solar-power-plant market, as well as low institutional provisions for this type of energy. The transition to the business model of the prosumer as a consumer, which is also an energy producer, is possible in two ways: (i) a distributed prosumer through the creation of a distributed low power generating installations of PVI; (ii) the creation of energy communities of medium capacity through the unification of consumers (Jasiński et al. 2021; Petrichenko et al. 2022).

The purpose of this study is to investigate the dynamics of the production and consumption of electricity by alternative PVI stations at a favorable price level based on the grouping of volumes of electricity produced and consumed and to determine the level of annual savings of PVI due to changes in the production and consumption of one's own electricity.

The use of alternative and renewable energy sources depends on a range of socio-economic factors: public awareness of the necessity of rational use of fuel and energy resources and the transition to innovative energy-saving technologies; compliance of the national regulatory framework in the field of electricity production with modern world requirements; a sufficient level of financial support for the modernization of the systems of generation and transportation of electricity; import substitution of fuel and the use of alternative renewable energy sources; the correspondence between the cost of services for providing electricity and its quality; the development of a methodical basis for the calculation of tariffs' formation with use of alternative energy sources.

Electricity tariffs are determined within the state policy. It is very important to consider that the price of such electricity is under the influence of market forces (supply and demand), and also a range of specific factors, such as technological, natural and climatic, onsite solar consumption, climate change beliefs that also should be considered in the research.

The second part of the article gives a description of the research methods used that are adopted to the research tasks. The literature review of applications of solar PV systems and the analysis of tariffs for electricity generated by them is provided in the third part. Based on this analysis, two hypothesis were formulated. The main findings of the research, authors' estimations and calculations are presented in the fourth part. Conclusions and further research directions are described in the fourth part.

1. Literature review

1.1. A review of applications of solar PV systems

Based on the results of studies on the implementation of PVI (Byrne et al. 2017; Klaiß et al. 1995; Rukijkanpanich and Mingmongkol 2019; Ulucak et al. 2021), it can be concluded that the development of this type of renewable energy, in addition to environmental benefits, also contributes to an increase in energy security in the following conditions: a greater dependence on the need to intensify the use of natural resources such as gas and coal in the generation of electricity with subsequent deconversion mines; dependence on energy importers (Olczak et al. 2021) EU Member States are developing renewable energy subsidy programs. In Poland, in the years 2019–2020, the "My Electricity" program was implemented, co-financing was up to 50% of eligible costs (max PLN 5000, i.e., EUR 1111. In addition, the growing demand for energy leads to the depletion of fossil (non-renewable) primary energy resources in a short period of time, which necessitates the development of renewable energy sources, including clean and safe sources such as solar energy. Studies have focused on the efficiency and feasibility of using solar energy (Olek et al. 2016). The relevance of solar energy usage has increased under the carbon neutrality challenge. Zhang et al. (2021) analyzed the characteristics of China's existing energy production structure, installed electric capacity, energy consumption, and electric consumption in different sectors based on statistical data to achieve carbon neutrality. Zhu et al. (2021) revealed the nonlinear correlation between solar energy and CO_2 emissions that varies among countries. State policy in solar industry and a sustainable environment should consider this (Latysheva et al. 2020; Koval et al. 2021). Empirical evidence for the research, provided by (Yu et al. 2022), revealed that solar energy should be integrated to achieve sustainable growth and environmental quality. Roux et al. (2016) investigated renewable energy production and electricity consumption in an energy-efficient house and evaluated its potential environmental impacts. Tongsopit et al. (2019) analyzed the economics of electricity self-consumption of distributed solar photovoltaics in Thailand. Their conclusions, namely the assessment of three schemes (no compensation for excess electricity, net metering, and net billing), which showed that all customer classes are profitable and net metering offers the most customer benefits, are useful for the national policy. Solar energy usage varies among countries (United Arab Emirates, Turkey, Spain and Germany, China, USA) owing to different environmental conditions and policy mechanisms (Chang et al. 2003; Chen et al. 2019; Hepbasli and Canakci 2003; Mokri et al. 2013; Sanz-Casado et al. 2014). The methodology, which was proposed by Chen et al. (2019), was based on deep neural networks and was used for the decomposition of solar energy consumption data in the USA in 1983–2017. Their findings provide insights into future demand for solar energy in the United States.

The above considerations led us to the following hypothesis.

Hypothesis 1. Solar energy is under increasing demand due to its impact on sustainable environment. Thus, the state policy should stimulate its production.

One of the barriers to the development of applications of solar PV systems is improper tariff policy. Moreover, countries' peculiarities of solar energy generation also should be considered.

1.2. An analysis of tariffs for solar PV systems

Chesser et al. (2018) revealed the range of correlations about solar electricity pricing, namely the positive relationship between electricity prices and solar PV, the negative relationship between electricity prices and electricity demand. Interesting research was provided by (Sturmberg et al. 2021), devoted to electricity network pricing. The research findings determine clear conditions on local tariff pricing in Australia that is used as the basis for mutually the beneficial arrangement of local network tariffs and community-scale energy storage. The effects of solar power generation forecasts on electricity prices was analyzed by (Gürtler and Paulsen 2018). A peculiarity of their regression model is the simulation-based design of a variable indicating the power generation technology that determines the price at a certain point in time. One of their conclusions is that reducing forecast errors on wind and PV power generation dampens price volatility. Numminen et al. (2018) found that dynamic pricing did not improve technical performance or customer satisfaction.

Using a different approach to energy pricing may not have the same results for consumers (Fikru et al. 2022). There are also risks for electricity retailers due to the rising shares of decentralized solar generation. This problem was investigated by Russo et al. (2022). The conducted study highlights the mechanisms of fair risk sharing between retailers, regular consumers and prosumers in terms of a high penetration of renewable energy source. In this context the interactions among prosumers should be considered while pricing. In the study, provided by Jiang et al. (2020), for these matters a game-theory-based pricing model is proposed in a localized Practical Byzantine Fault Tolerance based-Consortium Blockchain.

The above considerations led us to the following hypothesis.

Hypothesis 2. Prosumers (consumers with self-generation) are players of the electricity market and should be taken into consideration in tariff policy.

For matters of price setting that are vital for tariff policy there is a necessity to do regression analyses considering electricity production and consumption through price parity and to reveal certain consistent patterns, which is the focus of this research.

2. Methods

The implementation of the research goal involves the logical use of factor analysis, which made it possible to form arrays of data on production and consumption, and the grouping method made it possible to systematize and classify everything collected (especially PV solar production data). The generalization method of indicators made it possible to characterize the Solar Energy System processes and determine current patterns from electricity generation to its purchase.

Quantitative Data Collection for Solar PV Systems were used to collect data about the household case study, about its electricity production and consumption. The Quantitative data method allows you to analyze data using statistics with the possibility of the further generalization of the results obtained to other categories of users of solar power plants. The proposed PVI will significantly save money on electricity due to the low cost of purchasing equipment and low operating costs, as well as a short payback period (Olczak and Komorowska 2021). The matrix method was used to calculate the actual consumption of PVI energy to be purchased for the year and annual economic savings.

The study used an approach that analyzed the hourly values of self-consumed energy, produced and consumed energy from PVI by changing them by a given percentage, which allowed the calculation of the coefficient of electricity consumption. The actual electricity consumption is possible in the scale of energy production over 0.001 kWh, so the step of production change was based on this indicator.

In accordance with the above, a matrix of matrix of potential energy results is formed on the basis of these preliminary calculations. All its combinations are calculated according to the following scheme. For each τ (1–8,760 hours):

$$PVP(C.PVP,\tau) = PVP(1,\tau)\cdot C.PVP \tag{1}$$

where:

PVP – hourly energy production in PV installation [kWh],
C.PVP– size factor of *PVP* installation,
τ – time [h]

$$EC(C.EC,\tau) = EC(1,\tau)\cdot C.EC \tag{2}$$

where:

EC – hourly energy consumption [kWh],
C.EC – size factor of prosumer installation energy consumption,
τ – time [h]

$$SC(C.PVP,C.EC,\tau) = Ic + C1\cdot PVP(C.PVP,\tau) + C2\cdot EC(C.EC,\tau) \tag{3}$$

where:

SC – energy self-consumption [kWh],
Ic – interception,
*C*1 – PV energy production factor (for *PVP*),
*C*2 – coefficient of electricity consumption (for *EC*)

$$\begin{gathered} YPE(C.PVP,C.EC)=\sum_{\tau}EC(C.EC,\tau)-\sum_{\tau}SC(C.PVP,C.EC,\tau)- \\ -PF(C.PVP)\cdot\left(\sum_{\tau}PVP(C.PVP,\tau)-\sum_{\tau}SC(C.PVP,C.EC,\tau)\right) \end{gathered} \tag{4}$$

where:

YPE – purchased electricity per year [kWh].

Note that *YPE* cannot take negative values, such energy is lost by the sum during the year.

PF – prosumer coefficient: if *C.PVP* < 2.0 (< 10 kWp) = 0.8, if *C.PVP* > = 2.0 (> 10 kWp) = 0.7

Then the annual savings will be:

$$YEP\left(C.PVP, C.EC, elp\right) = elp \cdot \left(\sum_{\tau} EC\left(C.EC, \tau\right) - YPE\left(C.PVP, C.EC\right)\right) \tag{5}$$

where:

elp – the price of electricity.

The value of elp is based on the electricity price for households in first half of 2022 in Poland (0.14 euro/kWh).

$$SPBT\left(C.PVP, C.EC\right) = YEP / \left(1.2 \cdot PV.EIN\left(C.PVP\right)\right) \tag{6}$$

where:

SPBT – simple payback time [years],

0.2 – is additional costs (1.0 in first year, 1.2 is the sum of 1.0 and 0.2) for the inverter for the ninth year of operation of the power plant and other capital costs;

YEP – the same value is expected every year.

The productivity of panels decrease PVI, but the higher energy value takes into account the fact that there is a natural decrease in the productivity of solar panels and the loss of their energy value.

3. Results

Sustainable energy and its development has become a key component of the new energy paradigm in EU countries in response to climate change and for ensuring energy security. The total capacity of renewable energy generating facilities in the world in 2021 amounted to 3,064 GW, while the European Union accounts for only 16.7% (IRENA 2022a). The main development indicators shown in Figure 1 show a slight increase in renewable energy (a) in average percent and an increase in solar photovoltaic energy (b) from 34% in 2013 to 18.6% in 2021. At that time, the EU had a lower growth rate of solar photovoltaic energy and was 15% from 2019 to 2021.

The main measures for the accelerated growth of solar energy can be identified as government support measures in many countries (Colmenar-Santos et al. 2021; Jenner et al. 2012), as

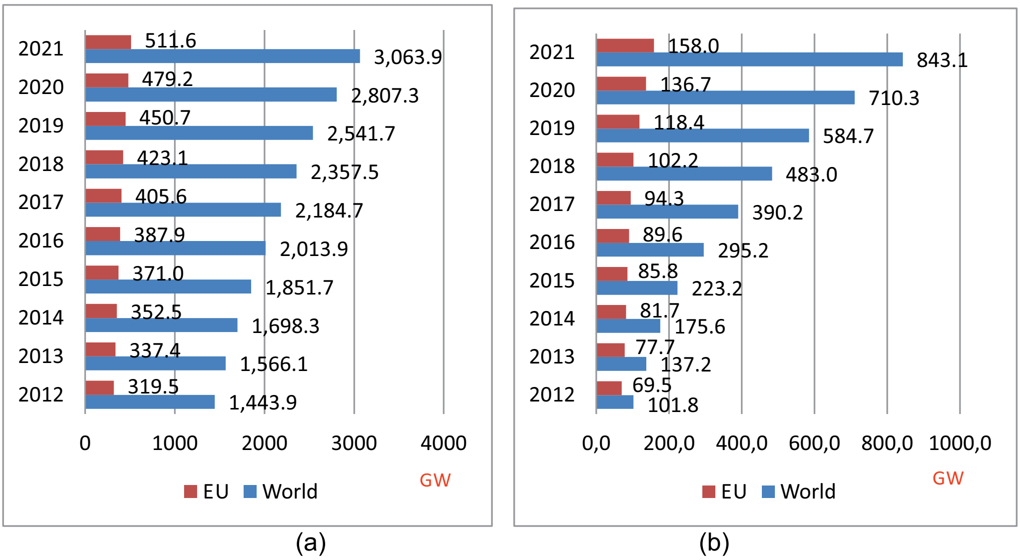

Fig. 1. Total and EU renewable energy (a) and solar photovoltaic energy (b), GW
Source: IRENA 2022b

Rys. 1. Światowe i europejscie wartości mocy zainstalowanej w (a) OZE ogółem, (b) w fotowoltaice

well as through the development of a circular economy and the possibility of reusing components of photovoltaic modules. PVI transform thermal energy from the sun, that is renewable energy source, into electrical energy. Photovoltaic power plants are also known as PV and use photovoltaic cells. There are many benefits of PVI usage. This process is environmentally friendly and meets the sustainable development goals: global warming reduction, public health improvement, the creation of job opportunities, the prevention of power shortage, the reduction of dependence from an electric grid. Solar energy is the future of electricity generation and will experience high growth in the coming years. This is why governments are interested in increasing PVIs in their countries and provide measures for the intensification and promotion of PVI usage.

PVI fully operates within national networks. Thus, the obtained statistical material was developed, which allows the identification of clear patterns in the activities of PVI between energy production and consumption. In general, the annual data of PVI activities for 2020 are shown in Table 1 and Figure 2.

For comparison, the own consumption from production and demand from electricity grid is shown in Figure 3.

The aim of the analysis is to find a function that reflects the relationship between self-consumption, the amount of energy produced and the gross energy consumption in the building. The calculated value of self-consumed energy from PVI must not exceed the current PV energy production or the current energy consumption of the building.

Table 1. Annual measurement results from one PV installation of one household case study (06/01/2020–05/31/2021)

Tabela 1. Roczne wyniki pomiarów z jednej instalacji fotowoltaicznej, tj. jednego gospodarstwa domowego studium przypadku (01.06.2020–31.05.2021)

Marking	Characteristic	Unit	Value
EC	electricity consumption	kWh/year	4,874.8
PVP	PV electricity production	kWh/year	4,671.8
SC	own electricity consumption	kWh/year	1,477.3
YPA	purchased electricity	kWh/year	841.9

Source: own study.

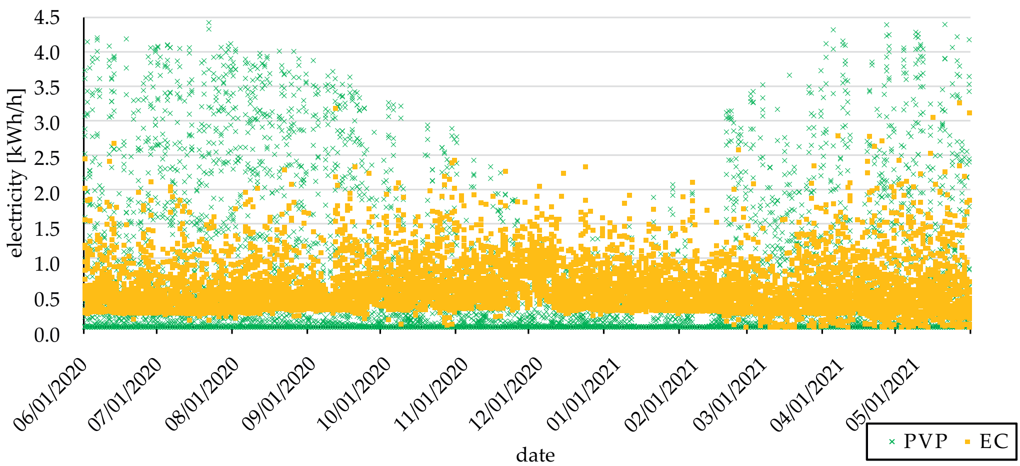

Fig. 2. Annual electricity consumption from PVI of one household case study (PVP – energy production, EC – energy consumption)

Rys. 2. Roczne zużycie energii elektrycznej z PVI w analizowanym gospodarstwie domowym (PVP – produkcja energii, EC – zużycie energii)

The mapping functions should be divided (e.g., a spline function) because at a low value of PV energy production (in relation to the consumption value), the self-consumption value is equal to this production. However, in the case of a high value of PV energy production, the value of self-consumption is closer to the value of consumed energy.

In the first step, the values of produced energy higher than 0.001 kWh were selected, because self-consumption occurs only in the case of energy production. This interval was divided into two in order to calculate the values of the regression coefficient and R2 for the two groups obtained, the aim was to obtain the highest possible mean value of the R2 coefficient. The size of the interval had to be greater than 100 observations. The obtained limits allowed the determination of the distribution of the regression calculation (Table 2).

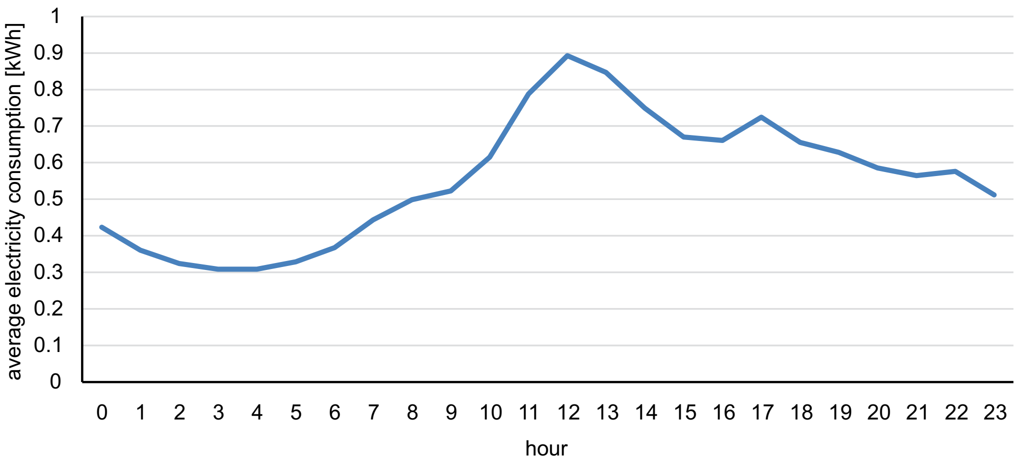

Fig. 3. Profile of energy consumption (from PV production and received from electricity grid)

Rys. 3. Średni profil zużycia energii (z produkcji PV i pobranej z sieci elektrycznej)

TABLE 2. Distribution of regression coefficient (in order to obtain self-consumption values)

TABELA 2. Rozkład współczynnika regresji (w celu obliczenia wartości autokonsumpcji energii)

Parameter	unit	*PVP* [kWh] – range:		
		0.001 – 0.095	0.095 – 3.42	> 3.42
R2	–	0.951	0.746	0.937
Number of observations	–	787	3,321	242
Ic – interception	kWh	–0.001	–0.066	–0.034
*C*1 – *PV* energy production factor (*PVP*)	–	0.950	0.136 th most common	0.035
C2 – coefficient of electricity consumption (*EC*)	–	0.002	0.445	0.733

Ultimately, the functional adjustment was divided into 3 ranges: up to 0.095 kWh/h electricity production, then the auto-consumption value depends only on PV energy production. The power of photovoltaic installation and electricity consumption are shown in Table 3.

Thus, the calculation indicates the actual consumption of solar power plants, energy to be purchased for the year and annual savings (Table 4).

By increasing the power of the installation twice, the value of self-consumption energy is 2,330 (for *C.EC* = 1) kWh/year, while for *C.EC* = 2 and *C. PVP* = 1 self-consumption energy is 1,848 kWh/year.

TABLE 3. The power of photovoltaic installation and values of electricity consumption, production

TABELA 3. Moc instalacji fotowoltaicznej i zużycie, produkcja energii elektrycznej

Electricity consumption, analyzed options:																
C.EC	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0
EC (C.EC) [kWh/year]	4,875	5,850	6,825	7,800	8,775	9,750	10,725	11,700	12,675	13,649	14,624	15,599	16,574	17,549	18,524	19,499
Power of photovoltaic installation, analyzed options:																
C.PVP	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0
PV power [kWp]	5.04	6.048	7.056	8.064	9.072	10.08	11.088	12.096	13.104	14.112	15.12	16.128	17.136	18.144	19.152	20.16
PVP (C.PVP), [kW/year]	4,672	5,606	6,541	7,475	8,409	9,344	10,278	11,212	12,147	13,081	14,015	14,950	15,884	16,819	17,753	18,687
PV.EIB (C.PVP) [Euro]	5,040	6,004	6,967	7,931	8,894	9,858	10,821	11,785	12,748	13,712	14,676	15,639	16,603	17,566	18,530	19,493
PV.EIN (C.PVP) [Euro]	3,630	4,430	5,229	6,029	6,829	8,295	9,095	9,895	10,695	11,494	12,294	13,094	13,894	14,693	15,493	16,293

PV.EIB – investment expenditure for PVI.
PV.EIN – net investment expenditure for PVI, including grants.

TABLE 4. Results of calculation of self-consumption energy value [kWh/year]
(in function C.PVP and C.EC)

TABELA 4. Wyniki wartości autokonsumpcji energii na własne potrzeby [kWh/rok]
(w funkcji C.PVP i C.EC)

C.PVP/ /C.EC	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4
1	1,477	1,662	1842	2013	2,175	2,330	2,476	2,608	2,732	2,849	2,957	3,057	3,150	3,238	3,320	3,396
1.2	1,578	1,784	1,987	2,182	2,370	2,548	2,715	2,877	3,028	3,169	3,301	3,427	3,544	3,654	3,757	3,854
1.4	1,662	1,886	2,108	2,321	2,528	2,725	2,913	3,091	3,260	3,422	3,576	3,723	3,861	3,991	4,115	4,231
1.6	1,733	1,972	2,208	2,435	2,656	2,869	3,073	3,271	3,459	3,639	3,809	3,970	4,126	4,275	4,416	4,551
1.8	1,796	2,047	2,295	2,536	2,769	2,997	3,215	3,428	3,633	3,830	4,018	4,198	4,368	4,530	4,687	4,837
2	1,848	2111	2,368	2,619	2,863	3,099	3,330	3,554	3,772	3,983	4,186	4,382	4,569	4,747	4,918	5,081
2.2	1,896	2,168	2,434	2,695	2,948	3,195	3,433	3,666	3,894	4,114	4,330	4,538	4,738	4,932	5,116	5,294
2.4	1,939	2,221	2,497	2,765	3,027	3,281	3,530	3,771	4,006	4,237	4,461	4,681	4,893	5,098	5,297	5,489
2.6	1,978	2,268	2,553	2,829	3,098	3,359	3,615	3,864	4,108	4,346	4,578	4,805	5,026	5,242	5,451	5,653
2.8	2,012	2,309	2,601	2,884	3,160	3,429	3,691	3,946	4,196	4,443	4,683	4,918	5,149	5,373	5,592	5,804
3	2,045	2,350	2,649	2,940	3,222	3,497	3,765	4,028	4,285	4,537	4,786	5,028	5,264	5,496	5,722	5,943
3.2	2,074	2,386	2,693	2,991	3,279	3,562	3,837	4,105	4,370	4,628	4,882	5,132	5,376	5,614	5,848	6,077
3.4	2,102	2,420	2,733	3,037	3,332	3,618	3,901	4,175	4,444	4,708	4,968	5,222	5,472	5,717	5,956	6,191
3.6	2,128	2,451	2,769	3,080	3,382	3,675	3,961	4,241	4,516	4,785	5,050	5,311	5,565	5,816	6,062	6,302
3.8	2,152	2,479	2,802	3,118	3,425	3,725	4,015	4,300	4,579	4,853	5,123	5,388	5,649	5,904	6,155	6,402
4	2,175	2,507	2,834	3,155	3,467	3,771	4,068	4,357	4,643	4,921	5,195	5,465	5,730	5,991	6,247	6,498

Table 5. Energy to be purchased (from electricity grid) per year including prosumer rules [kWh]

Tabela 5. Energia potrzebna do zakupu (z sieci elektroenergetycznej) rocznie z uwzględnieniem zasad prosumenckich [kWh]

C.PVP/ /C.EC	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4
1	842	57	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.2	1,797	1,008	220	0	0	0	0	0	0	0	0	0	0	0	0	0
1.4	2,755	1,963	1,171	381	0	0	0	0	0	0	0	0	0	0	0	0
1.6	3,716	2,920	2,126	1,333	541	398	0	0	0	0	0	0	0	0	0	0
1.8	4,678	3,880	3,083	2,288	1,493	1,335	615	0	0	0	0	0	0	0	0	0
2	5,643	4,843	4,044	3,246	2,450	2,279	1,556	835	115	0	0	0	0	0	0	0
2.2	6,608	5,806	5,005	4,206	3,408	3,226	2,500	1,776	1,054	333	0	0	0	0	0	0
2.4	7,574	6,770	5,968	5,167	4,367	4,175	3,446	2,719	1,995	1,272	550	0	0	0	0	0
2.6	8,541	7,736	6,932	6,129	5,328	5,126	4,395	3,667	2,939	2,214	1,490	768	48	0	0	0
2.8	9,510	8,703	7,897	7,093	6,290	6,080	5,348	4,617	3,888	3,160	2,434	1,709	986	265	0	0
3	10,478	9,670	8,862	8,057	7,253	7,035	6,300	5,567	4,836	4,107	3,378	2,651	1,926	1,203	481	0
3.2	11,447	10,637	9,828	9,021	8,216	7,990	7,254	6,519	5,786	5,054	4,324	3,595	2,868	2,142	1,418	695
3.4	12,416	11,605	10,795	9,987	9,180	8,948	8,210	7,473	6,739	6,005	5,273	4,543	3,814	3,086	2,361	1,636
3.6	13,386	12,574	11,763	10,953	10,145	9,906	9,166	8,428	7,692	6,957	6,223	5,491	4,761	4,031	3,304	2,578
3.8	14,356	13,543	12,731	11,921	11,112	10,866	10,125	9,386	8,648	7,912	7,177	6,443	5,711	4,980	4,251	3,522
4	15,327	14,513	13,700	12,888	12,079	11,827	11,084	10,343	9,604	8,866	8,130	7,395	6,661	5,929	5,198	4,469

TABLE 6. Annual savings as a results of different capacity PV installation [euro/year]

TABELA 6. Roczne oszczędności wynikające z różnej mocy instalacji PV [euro/rok]

C.PVP / C.EC	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4
1	627	749	758	758	758	758	758	758	758	758	758	758	758	758	758	758
1.2	630	753	876	910	910	910	910	910	910	910	910	910	910	910	910	910
1.4	633	756	880	1,002	1,062	1,062	1062	1062	1,062	1,062	1,062	1,062	1,062	1,062	1,062	1,062
1.6	635	759	883	1,006	1,129	1,151	1,213	1,213	1,213	1,213	1,213	1,213	1,213	1,213	1,213	1,213
1.8	637	761	885	1,009	1,133	1,157	1,269	1,365	1,365	1,365	1,365	1,365	1,365	1,365	1,365	1,365
2	639	763	888	1,012	1,136	1,162	1,275	1,387	1,499	1,517	1,517	1,517	1,517	1,517	1,517	1,517
2.2	640	765	890	1,014	1,138	1,167	1,279	1,392	1,504	1,616	1,668	1,668	1,668	1,668	1,668	1,668
2.4	642	767	892	1,016	1,141	1,171	1,284	1,397	1,510	1,622	1,734	1,820	1,820	1,820	1,820	1,820
2.6	643	768	893	1,018	1,143	1,174	1,288	1,401	1,514	1,627	1,740	1,852	1,964	1,972	1,972	1,972
2.8	644	770	895	1,020	1,145	1,177	1,291	1,405	1,518	1,632	1,745	1,857	1,970	2,082	2,123	2,123
3	645	771	896	1,022	1,147	1,181	1,295	1,409	1,523	1,636	1,749	1,862	1,975	2,088	2,200	2,275
3.2	646	772	898	1,023	1,149	1,184	1,298	1,412	1,527	1,640	1,754	1,867	1,980	2,093	2,206	2,318
3.4	647	773	899	1,025	1,150	1,186	1,301	1,416	1,530	1,644	1,758	1,872	1,985	2,098	2,211	2,324
3.6	648	774	900	1,026	1,152	1,189	1,304	1,419	1,533 p	1,648	1,762	1,876	1,989	2,103	2,216	2,329
3.8	648	775	901	1,027	1,153	1,191	1,307	1,422	1,536	1,651	1,765	1,879	1,993	2,107	2,220	2,334
4	649	776	902	1,028	1,154	1,193	1,309	1,424	1,539	1,654	1,769	1,883	1,997	2,111	2,225	2,338

Table 7. Simply payback time (SPBT) for various electricity consumption factor (C.EC) and PV energy production factor (C.PVP) [years]

Tabela 7. Prosty czas zwrotu dla różnych wskaźników mnożnikowych zużycia energii elektrycznej i produkcji energii fotowoltaicznej [lata]

C.PVP/ /C.EC	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4
1	6.9	7.1	8.3	9.5	10.8	13.1	14.4	15.7	16.9	18.2	19.5	20.7	22.0	23.3	24.5	25.8
1.2	6.9	7.1	7.2	8.0	9.0	10.9	12.0	13.0	14.1	15.2	16.2	17.3	18.3	19.4	20.4	21.5
1.4	6.9	7.0	7.1	7.2	7.7	9.4	10.3	11.2	12.1	13.0	13.9	14.8	15.7	16.6	17.5	18.4
1.6	6.9	7.0	7.1	7.2	7.3	8.6	9.0	9.8	10.6	11.4	12.2	13.0	13.7	14.5	15.3	16.1
1.8	6.8	7.0	7.1	7.2	7.2	8.6	8.6	8.7	9.4	10.1	10.8	11.5	12.2	12.9	13.6	14.3
2	6.8	7.0	7.1	7.2	7.2	8.6	8.6	8.6	8.6	9.1	9.7	10.4	11.0	11.6	12.3	12.9
2.2	6.8	6.9	7.1	7.1	7.2	8.5	8.5	8.5	8.5	8.5	8.8	9.4	10.0	10.6	11.1	11.7
2.4	6.8	6.9	7.0	7.1	7.2	8.5	8.5	8.5	8.5	8.5	8.5	8.6	9.2	9.7	10.2	10.7
2.6	6.8	6.9	7.0	7.1	7.2	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.9	9.4	9.9
2.8	6.8	6.9	7.0	7.1	7.2	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.8	9.2
3	6.8	6.9	7.0	7.1	7.1	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.5	8.6
3.2	6.7	6.9	7.0	7.1	7.1	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
3.4	6.7	6.9	7.0	7.1	7.1	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
3.6	6.7	6.9	7.0	7.1	7.1	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
3.8	6.7	6.9	7.0	7.0	7.1	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
4	6.7	6.9	7.0	7.0	7.1	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.4	8.4	8.4

The use of a sufficiently large *PV* installation means that there is no need to buy additional energy per year, taking into account the prosumer-factor (0.8 up to *C.PVP* 1.8 – less than 10 kWp and 0.7 for *C.PVP* >=2.0 higher than 10 kWp).

The highest annual cash savings were shown for *C.PVP* = 4 and *C.EC* = 4, therefore *SPBT* (simply payback time).

For *C.PVP* <1.8, in most cases, the simple payback time for the installation is less than 7.2. The least favorable case is an oversized installation with *C.EC* = 1. A change in profitability can be clearly seen when increasing the *PV* installation to *C.PVP* = 2 in each of the analyzed cases, *SPBT* increases by at least 1 year (higher values achievable with a relatively low *C.EC*). What is significant, in the case of annual savings, is that a higher value was shown for *C.PVP* = 4 and *C.EC* = 1 (758 euro/year) than for *C.EC* = 4 and *C.PVP* = 1 (649 euro/year); in the case of *SPBT*, the latter case is definitely more financially advantageous (*SPBT* = 6.7 vs 25.8).

Conclusions

The role of prosumers in the use of solar power plants is significant because as players of the solar electricity market, they influence tariff policy. They increase competition and restrain the monopoly of energy companies that decreases consumption tariffs. The sound state policy can increase the involvement of prosumers in solar energy production that meets the sustainable development goals. With regard to price setting, the correlation between electricity production and consumption was determined through price parity and revealed certain consistent patterns.

The process of production and consumption of electricity in PVI is not characterized by uniformity, which is derived from several factors, primarily from natural and climatic conditions. It also depends on the technical characteristics of the equipment, especially energy generation devices (like solar panels and inverters), and also the energy profile consumption for the household/investor.

In real conditions at current interest rates, PVI activity is subject to more complex factors, and the main one becomes economic, namely taking the solvency of consumers into account and the level of taxation of PVI activities, as well as productivity and the real state of the technical condition of the installation. Therefore, the analysis did not indicate that the economic effective version of the PVI is provided with a consumption in the range higher than 1.8–2 (C.PVP). The provided research develops a theoretical and empirical basis for the state policy mechanisms of solar electricity use considering the peculiarities of its production and consumption.

Further research should be similar calculation including net-billing rules instead of prosumer rules (for new PV micro-installation available up to April 2022).

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Piotr Olczak, Dominika Matuszewska, Andrii Lishchenko, Iryna Zhydyk,
Viktor Koval, Olga Iermakova

Efektywność ekonomiczna fotowoltaiki dla prosumentów energii

Streszczenie

W artykule przedstawiono badania efektywności ekonomicznej fotowoltaiki dla przypadku prosumentów. Wykazano ekonomiczny efekt rozwoju energetyki słonecznej, efekt ekologiczny przejścia na zieloną energię oraz efekt społeczny w związku z niższymi kosztami energii elektrycznej i wzrostem skali inwestycji z wykorzystania fotowoltaiki (PVI). Określono poziom rocznych oszczędności w PVI z tytułu zmian wartości produkcji energii (wskutek zmiany wielkości instalacji – *simulation*) i autokonsumpcji energii elektrycznej. Wykorzystując analizę czynnikową, metodę grupowania, metodę uogólniania wskaźników, ilościowe zbieranie danych dla systemów fotowoltaicznych, udowodniono dwie główne hipotezy: (i) produkcja energii słonecznej powinna być stymulowana przez politykę taryfową państwa; (ii) prosumenci jako uczestnicy rynku energii elektrycznej powinni być uwzględniani w polityce taryfowej. Okazuje się, że przy obecnych stopach procentowych działalność PVI podlega bardziej złożonym czynnikom, a ważny staje się czynnik ekonomiczny, a mianowicie uwzględniając wypłacalność konsumentów, poziom opodatkowania działalności PVI, a także produktywność i rzeczywisty stan techniczny instalacji. Przeprowadzone badania rozwijają teoretyczne i empiryczne podstawy polityki państwa w zakresie wykorzystania energii słonecznej z uwzględnieniem specyfiki jej wytwarzania i zużycia. Proces produkcji i zużycia energii elektrycznej w instalacji nie charakteryzuje się jednorodnością, co jest pochodną szeregu czynników, a mianowicie – przede wszystkim warunków naturalnych i klimatycznych. Zależy to również od parametrów technicznych urządzeń.

Słowa kluczowe: Polska, fotowoltaika, prosument, energia i ekonomia