

INFLUENCE OF ENERGY SELF-SUFFICIENT HOUSING ESTATES ON SUSTAINABLE DEVELOPMENT IN POLAND

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ARTICLE INFO	ABSTRACT
Keywords: sustainable development, green energy, self-sufficient estates	For many years, the increase of energy derived from renewable sources in the total production of electricity, has been an important aim for both central and local authorities in many countries, including Poland. –Many investments undertaken in this area contribute to sustainable development. One of the branches of "green energy" may be prosumer production induced by residential self-sufficient estates. The number of technologies and facilities-related developments have been growing in each EU country every year. The current article, aims to examine the potential influence of self-sufficient estates on "green energy" production and thus on sustainable development in Poland. In order to achieve the above, case studies were undertaken. They showed the profitability of examined photovoltaic installations and capability of the sector in energy production.
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1. Introduction

All over Europe, a lot of attention is paid and great thought is given to implementation of changes which should result in increased gain of electricity derived from renewable sources. It is mainly aimed to limit the usage of natural resources as well as protecting the essentially devastated environment. Electricity production methods diversification is crucial, also from the other point of view, which is the independency of smaller countries from the big world natural resource tycoons. The current geopolitical situation serves as even stronger confirmation of the fact that the greatest problems of the 21st century are not only climate change, but also energetic security (Suman, 2018, pp.166-177).

Countries show different levels of progress towards sustainability, but the number of those changing their priorities in policy design for sustainable development is growing (Basheer et al., 2022, p. 3). The importance derives from the fact that, with every year, each country consumes more energy and excessive energy consumption increases the risk of shortages which are

neither pleasant nor safe (Yaolin et al., 2020, pp. 5-6). A great challenge and well-known problem in domestic energy is rising demand, expected to be no less than 24 % in the next few decades (Hoang et al., 2021, pp. 2-4). Thus, the expansion of "green energy" generation systems issues are concerns not only of governments of individual countries. Societies are more and more aware of the seriousness of environmental threats as well as the need to gain independence from countries rich in natural resources. Thus, they take part in preparations of technological solutions which enable successful transformation from previous traditional energy obtaining sources to renewable ones (Sinha et al., 2018). All actions aimed to improve the energy performance increase the inhabitants' safety and quality of life (Mancini et al., 2016, p. 1118).

The shift away from fossil fuels towards "green energy" is treated with special attention, especially in the European Union, which has been successively pursuing a policy of implementing more and more demanding regulations in this area. According to the

2018 directive, the level of energy obtained in the EU from renewable sources in 2030 should be no less than 32% (Directive, 2018, p. 24). Opinions might be found that „green energy“ doesn't have to be more expensive than traditional ways of energy production (Sali et al., 2021, p. 87). Some, for example, confirm that the costs of energy derived from photovoltaic and wind farms may, in the end, be lower than diesel generators, not mentioning problems with carbon emissions (Malaudzi et al., 2012, pp. 235-236).

In terms of increasing the share of energy derived from renewable sources, there is still a lot to be developed in Poland compared to most European Union countries. Taking into account the above, it should be emphasized that efforts to increase the diversification of energy production in Poland should be treated as a priority. Bearing in mind the possibilities and scope of tasks that are within the competence of state structures, the role of bottom-up initiatives contributing to the construction of such systems that will make a significant contribution to the production of "green energy" cannot be ignored. An example of such investments might be self-sufficient estates. It can be assumed that they can be an important source of electricity, contributing to the sustainable development of the country. Therefore, the main aim of this article has become an attempt to examine the impact of self-sufficient estates on the production of "green energy", and thus on sustainable development in Poland. It was processed in a trial of evaluation whether the implementation of photovoltaic installations in all houses in Poland would play a significant role in energy production and, if so, what the level of such an undertaking could be. The authors also outlined additional research objectives. An inquiry was undertaken in order to compare Poland's energy balance with other European countries, which are believed to be leaders in "green energy" production. In addition, the theoretical cost-effectiveness of photovoltaic installations was examined. The above was done from the private owners' sector's point of view. The research was developed under the assumption that all produced energy may be directly transferred to the energy grid, without need of storing it.

2. Material and methods

The theoretical parts of the article required literature studies, practical studies, statistical data and legal regulations. In the empirical part, case studies were

used, and the internal rate of return (IRR)¹ was used in the calculations. All data presented in case studies were received from properties owners. The provided data consisted of electricity production by three photovoltaic installations with different capacities collected in a one-year period (July 2021 - June 2022) as readings from applications connected with photovoltaic installations. The costs of energy consumption and of the amounts spent on purchasing, assembling and starting up the panels were estimated based on detailed information received from the users.

3. Literature review

3.1. Self-sufficient estates and sustainable development

In order to properly understand the idea of the research problem outlined above, several further concepts should be systematized. This is crucial especially because the literature on the subject provides many various definitions of self-sufficient estates, sustainable development and prosumers. It should be emphasized that, especially in regards to issues connected with the matter of self-sufficient estates, a significant gap of knowledge is still to be encountered². The above makes a systematic literature review challenging.

Prosument possibilities of the self-sufficient estates should lead to eco-development, more often referred to as sustainable development, both in a local and in the wider perspective. The very last is based on the idea that every further economic and industrial development may only take place with simultaneous preservation of the natural environment in the best condition possible. E. Mazur-Wierzbicka defines sustainable development as such social and economic growth that ensures satisfaction of all of the current society's needs along with possibility of freely choosing a kind of a lifestyle and not creating, at the same time, a threat to satisfying the needs of future generations (Mazur-Wierzbicka, 2006, pp. 318). In the context of power engineering as well as social, economic and industrial growth, sustainable development might apply both to urban agglomerations and rural areas. In the first type,

¹The internal rate of return (IRR) is a method that helps to evaluate the profitability of investments widely described in the literature of the subject (Dziworska et al., 1999, p. 131; Rogowski, 2006, p. 520; Damodaran, 2012, pp. 829-830).

² When the "self-sufficient estates" phrase is being searched via Google Scholar, only 131 results are shown.

according to I. Jonek-Kowalska, it would be mainly based on the conception of smart cities perceived as areas where intelligent industry exists and develops (Jonek-Kowalska, 2018, p. 238). In the case of countryside, however, Wlazły believes that it primarily refers to all aspects related to their multifunctional improvement, both in socio-economic and spatial terms (Wlazły, 2018, p. 66). Regardless, self-sufficient estates might play an important role in each of the above-mentioned areas, and thus effectively enhance sustainable development. Its definition in the meaning of stable growth which does not threaten the lives of future generations has been in use for half a century (Kauko et al., 2015, pp. 100-111). Sustainable development, among many others, consists of sustainable housing. The adoption of the former in the housing industry offers undeniable benefits to the environment (Oluleye et al., 2021, p. 85).

The most distinctive discrepancies might be observed in trials to determine the definition of self-sufficient estates. A significant number of researchers use this term to describe groups of buildings equipped with such facilities and services that will ensure their functional or social self-sufficiency (Skowronek, 2021, p. 85). On the other hand, J. Kamiński's definition of "self-sufficient estate" treats them as equals of the concept of ecological estates, meaning that during the process of design, construction and operation, there is an aim to be integrated with the natural environment and cause the lowest possible degradation, both in the immediate vicinity and in the global sense (Kamiński, 2010, pp. 147-149). These types of buildings are meant to create a wider reality of eco-cities which are nowadays growing in popularity (Brodowicz et al., 2015, pp. 15-19). However this field of analysis is not the subject of our research. We would like to focus on energetic issues. Based on the above, we understand the definition of self-sufficient estates closely to Kłusak idea, which relates to mass groups of buildings that meet their own needs in terms of electricity and heat, do not require supply from external units, and are capable of producing and storing such amounts of energy that would cover their total demands (Kłusak, 2012, pp. 262-263). We are aware that this limits the definition to energy self-sufficient estates, but for the purpose of this research, the last definition seems to be the most accurate.

Electricity prosumers are the key components of the efficient development of the renewable energy production sector. Therefore, last but not least, the

meaning of the word prosumer was examined. In European Union countries, individual households first use photovoltaic panels and then wind farms to produce "green energy". According to W. Dołęga, prosumers are entities generating electricity and consuming it for their own needs (Dołęga, 2015, p. 40). Every private person, local society or enterprise can be both a producer and a consumer of the energy they generate. As rightly noted by Okraszewska, in the vast majority of cases, this is closely related to the necessity of connecting to the grid to enable other entities to use the surplus energy produced by the most efficient units (Okraszewska, 2016, pp. 40-41).

3.2. Renewable energy production in European Union countries

The share in the production of renewable energy is very diversified in individual countries of the European Community. Using Eurostat data, Figure 1 shows the percentage level of "green energy" production in relation to the total energy produced for each country. In comparison, the values of targets for the production of renewable energy that individual countries have set for 2020 have been presented.

The above data shows that Sweden, Finland and Denmark are leaders in the production of renewable energy in the European Union. More than 30% of such energy is also produced by: Latvia, Austria, Portugal and Estonia. Classified in a group together with Poland, i.e. less than 11%, are the United Kingdom, Ireland, Belgium, Luxembourg, Malta and the Netherlands. In the remaining 14 countries, the share of energy obtained from renewable sources ranges from 12 to 28%. The high share of renewable energy produced in the Nordic countries requires comment. The main factor that initiated changes in the energy sector in these countries was the crisis of the 1970s and a sharp increase in oil prices. As Frączek notes, the need to reduce dependence on the import of individual resources was associated with the desire to diversify the sources of gaining primary energy (Frączek, 2014, pp. 445-446). According to official information, the goal of the Swedish government is to achieve 100% energy production from renewable sources in less than 20 years. The cut-off date is 2040. Currently, hydrotechnical installations are the main factor generating eco-energy in this country, however to achieve full energy satisfaction from renewable sources, attention has been focused on wind energy. However it should be mentioned that sustainable hydropower is met with some constraints (Bogaart,

2023, p. 22-23). Zhong and others report that a triple increase in the energy production resources from wind farms will allow for the complete satisfaction of energy needs, disregarding the existing traditional forms of electricity production (Zhong et al., 2021, p. 2). Also in Denmark, a lot of emphasis is placed on the

development of wind farms, which, for example, generated as much as 140% of the electricity demand in 2015, which allowed not only internal needs to be satisfied, but also to sell surpluses to neighboring countries (Tomala, 2016, p. 115).

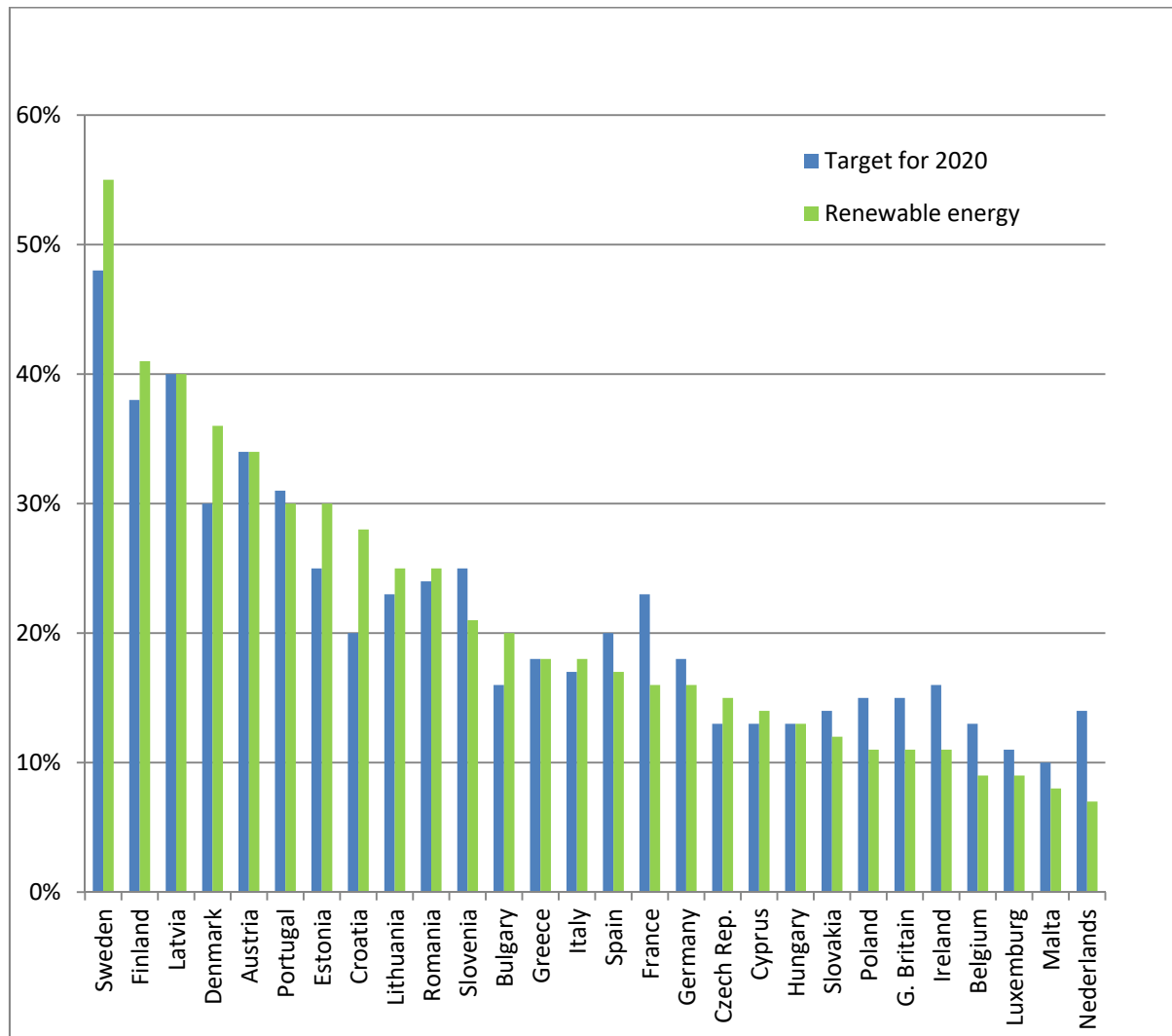


Fig. 1. The share of energy from renewable sources in relation to the total energy produced in individual EU countries in 2018. Source: own study based on Eurostat data.

A considerable group of southern UE countries also strain to reach 70-80% of renewable energy production levels by 2030. Undoubtedly, this may be reached by the simultaneous development of distributed energy assets alongside with those which produce energy in centralized power plants. Roof photovoltaics, which are widely installed in urban agglomerations, can play a very relevant role in this race (Ayadi et al., 2022, p. 2). These options are widely discussed and introduced for example in Spain (Gomes-Exposito et al., 2020, p. 2). In most of the other European Union countries, the production of

renewable energy is based on two sectors. The first is based on energy production by wind farms, the second goes for solar energy processed by photovoltaic installations. Germany is an example of such a country. Kusiak-Winter points out that the intensive development of technology and an increase in the number of installations producing energy from wind and sun is possible thanks to favorable legal regulations, consistently introduced by the German parliament with the broad support of an environmentally conscious society (Kusiak-Winter, 2021, pp. 114-120). Due to the similar geographic

location, Germany can be an example for Poland regarding sources of reaching the required amounts of "green energy". Popczyk therefore rightly points out that the development of distributed energy should be the basic aim of all national structures to accelerate the increase in the share of energy from renewable sources (Popczyk, 2011, pp. 113-116). Table 1 shows the percentage distribution of energy from individual sources in selected countries.

Constructive conclusions can be drawn while analyzing the above data, despite the very different results obtained for individual countries. The major source of renewable energy depends primarily on the geographic and climatic conditions of a given country. The example of Germany, similar to Poland in terms of latitude, shows that it is possible to obtain a 10% contribution to the total country energy production from photovoltaic installations. Paradoxically, the latitude of both countries is safer than of the southern parts of Europe in terms of the risk of overheating installations. Based on the provided data, wind farms could represent the second sector of "green energy" production.

4. Results

4.1. Investigating the possibilities of prosumer photovoltaic installations - case studies

In the design phase of photovoltaic installations, it is assumed that there is an average of one cloudless day per week in Poland. About 1000 hours of sunshine are assumed for the whole year. This means that an exemplary 10kWp installation can produce 10MWh of electricity per year³. The daily energy demand of a household, for a single-family house heated with a heat pump, i.e. a source entirely dependent on electricity, consumption should not exceed 40kWh in winter conditions. These values are at least twice lower in the summer season. The above allows the assumption that a well-selected installation with a properly designed capacity is not only able to meet the needs of a given building, but also to transfer surplus energy to the power grid, which is illustrated by the cases described below.

The production data and the amount of electricity used are presented for three examples of photovoltaic

installations that serve individual households. All three facilities are located in the Pomeranian Voivodeship. The installation in household No.1, located in the estate of 20 buildings in the village of Kielno, Szemud commune, was carried out in June 2021, so the data has been included for the full year, from July 2021 until June 2022. Building No.2 is located in the village of Kowale, in the Kolbudy commune, in an estate of 60 single-family houses. At this property, the panels were installed in May 2020. The data from July 2021 to June 2022 were also adopted to facilitate the comparison of the data. The third farm, with the smallest but longest operating installation (completed in September 2019), is also located in Kowale, in a housing estate of 36 houses, with data collected from the same period. The first and third house's installations are made of monocrystalline panels, whereas the second was equipped with polycrystalline ones. The houses do not possess a means of storing energy. All three buildings use gas heating.

Comparing the data of electricity production by individual installations, it can be seen that the amount of energy produced is directly proportional to the installed capacity in certain months⁴.

The obtained values confirm the correctness of the assumptions made in the design phase of the investment. In fact, the installation with a capacity of 8.25kWp produced 7.67MWh over a period of 12 months. Also the result of 6.03MWh from panels with a capacity of 5.84kWp and 3.3MWh obtained by a 3.5kWp installation operating throughout the year indicates the correctness of the adopted parameters. Annual total energy consumption in houses heated by an air source heat pump, assuming the household is occupied by 4 people, usually does not exceed 10,000 kWh/year, while in a house with a traditional heating source, inhabited by the same number of people, this is approximately 6000 kWh/year. By analyzing the collected results, it can be concluded that both a house equipped with an installation of about 10 kWp, heated with a heat pump, and a building heated with a gas boiler with a set of panels with a capacity of 6 kWh, can both meet their own electricity needs and demand for heating and hot water all year round.

³ Abbreviation kWp (kilo watt peak) is a measurement describing the efficiency which every set of photovoltaic panels can reach under specific measuring circumstances, mainly how much energy measured in kWh it is able to produce.

⁴ A small discrepancy might be seen in Table 2 in December where, by analogy, the amount should exceed 50kWh. The result lower than expected may be an error following to a temporary turn-off of the installation or the connected application. All other results are convergent.

Table 1

Percentage distribution of energy obtained from individual sources in Sweden, Denmark, Germany and Poland in 2020				
Energy source	Sweden	Denmark	Germany	Poland
Nuclear power plants	35%	-	14%	-
Thermal power stations (coal, gas, biomass)	10%	61%	46%	87%
Wind farms	8%	34%	26%	10%
Hydroelectric power stations	44%	-	4%	2%
Photovoltaic installations	3%	5%	10%	1%

Source: own study.

Table 2

Electricity production by the installation with a capacity of 8.25kWp located in household No.1, July 2021 -June 2022													
Installation 8.25kWp													
Month	07 '21	08 '21	09 '21	10 '21	11 '21	12 '21	01 '22	02 '22	03 '22	04 '22	05 '22	06 '22	TOTAL
Production [kWh]	903	760	799	601	160	39	139	347	880	955	1010	1080	7673
Consumption [kWh]	380	430	470	520	610	690	675	605	530	510	440	410	6270
Difference	523	330	329	81	-450	-651	-536	-258	350	445	570	670	1403
Profit/Loss [PLN]	288	182	181	45	-333	-482	-397	-191	193	245	314	369	412

Source: own study.

Table 3

Electricity production by the installation with a capacity of 5.84kWp located in household No. 2, July 2021 -June 2022													
Installation 5.84kWp													
Month	07 '21	08 '21	09 '21	10 '21	11 '21	12 '21	01 '22	02 '22	03 '22	04 '22	05 '22	06 '22	SUMA
Production [kWh]	780	621	518	396	116	47	112	262	683	774	785	945	6039
Consumption [kWh]	300	340	365	400	480	520	510	470	420	400	350	320	4875
Difference	480	281	153	-4	-364	-473	-398	-208	263	374	435	625	1164
Profit/Loss [PLN]	264	155	84	-3	-269	-350	-295	-154	145	206	239	344	365

Source: own study.

Table 4

Electricity production by the installation with a capacity of 3.5kWp located in household No.3, July 2021 -June 2022													
Installation 3.5kWp													
Month	07 '21	08 '21	09 '21	10 '21	11 '21	12 '21	01 '22	02 '22	03 '22	04 '22	05 '22	06 '22	SUMA
Production [kWh]	438	352	293	217	75	34	70	98	377	425	431	535	3345
Consumption [kWh]	170	205	215	250	295	310	305	275	240	225	205	195	2890
Difference	268	147	78	-33	-220	-276	-235	-177	137	200	226	340	455
Profit/Loss [PLN]	147	81	43	-24	-163	-204	-174	-131	75	110	124	187	71

Source: own study.

Table 5

Profitability study for installation No. 1															
Installation 8.25kWp - gross cost PLN 37000, annual energy demand - 6270kWh/year															
Life of installation	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Investment outlays [PLN]	-37000	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Energy costs covered by the panels before installation [PLN]	3480	4640	4640	4640	4640	4640	4640	4640	4640	4640	4640	4640	4640	4640	4640
Profit from the sale of surplus energy [PLN]	309	412	412	412	412	412	412	412	412	412	412	412	412	412	412
Fixed costs after installation [PLN]	-147	-196	-196	-196	-196	-196	-196	-196	-196	-196	-196	-196	-196	-196	-196
Flows for profitability testing	-33358	4856	4856	4856	4856	4856	4856	4856	4856	4856	4856	4856	4856	4856	4856
IRR	11,31%														

Source: own study.

Table 6

Profitability study for installation No. 2															
Installation 5.84kWp - gross cost PLN 33500, annual energy demand - 4875kWh/year															
Life of installation	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Investment outlays [PLN]	-33500	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy costs covered by the panels before installation [PLN]	2706	3608	3608	3608	3608	3608	3608	3608	3608	3608	3608	3608	3608	3608	3608
Profit from the sale of surplus energy [PLN]	274	365	365	365	365	365	365	365	365	365	365	365	365	365	365
Fixed costs after installation [PLN]	-147	-196	-196	-196	-196	-196	-196	-196	-196	-196	-196	-196	-196	-196	-196
Flows for profitability testing	-30667	3777	3777	3777	3777	3777	3777	3777	3777	3777	3777	3777	3777	3777	3777
IRR	8,26%														

Source: own study.

Table 7

Profitability study for installation No. 3															
Installation 3.5kWp - gross cost PLN 20000, annual energy demand - 2890kWh/year															
Life of installation	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Investment outlays [PLN]	-20000	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Energy costs covered by the panels before installation [PLN]	1604	2139	2139	2139	2139	2139	2139	2139	2139	2139	2139	2139	2139	2139	2139
Profit from the sale of surplus energy [PLN]	54	71	71	71	71	71	71	71	71	71	71	71	71	71	71
Fixed costs after installation [PLN]	-147	-196	-196	-196	-196	-196	-196	-196	-196	-196	-196	-196	-196	-196	-196
Flows for profitability testing	-18489	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014	2014
IRR	6.20%														

Source: own study.

A 15-year study⁵ on the profitability of investments in a photovoltaic installation is presented. It takes into account capital expenditure, benefits related to the lack of payments for the energy consumed so far, as well as profits from the sale of surplus energy and fixed costs related to fees for the used installation. Fixed costs were assumed according to the rates set by the energy company for the current year, mainly gross PLN 16.30 monthly for installations with capacities from 2.8 kWp to 10.5 kWp. The calculations assume the new system for billing energy produced by photovoltaic installations, i.e. net-billing, in force in Poland from April 2022. The main difference between this billing method and the previous one (net-metering) is the principle of selling the energy produced by the prosumer at a lower price than the electricity purchased from the energy company. The rule stating that the surpluses are not - as before - in some sense stored to be used in months with low production levels, but are settled on an ongoing basis, is also different. The average cost of selling the energy produced by the panels was assumed to be PLN 0.55/kWh, while the purchase cost in the months of the shortage was PLN 0.74/kWh. For calculations, the prices of energy and costs related to transmission fees were adopted at a constant level throughout the analyzed period (the analysis was made in the indirect model, the so-called implicit cash flow).

The tables above show the results of calculating the internal rate of return (IRR) of 11.31 %, 8.26 % and 6.20 %, respectively. It can be noticed that the profitability of the investment increases in proportion to the capacity of the installed photovoltaic panels, i.e. the higher the rated power of the photovoltaic installation, the higher the rate of return. It should be noted that the analysis was conducted in real conditions (inflation changes were not taken into account). The results of the IRR measure can be confronted with the current cost of capital at the time of making an investment decision.

5. Discussion and conclusions

The literature study shows trends that are now gaining importance all over the world. One of them is the shift

from traditional ways of energy production to ecological ones. Analyzing the data presented above, it can be assumed that, after averaging, each of the installations in question can produce about 5500 kWh per year. Therefore after satisfying its own needs, each of them can transfer over 1000 kWh to the power grid. This means that if, in an exemplary housing estate of 40 single-family houses, each of them had an analogously selected rated power of the installation, such a housing estate would be able to produce 200 MWh, from which it would transfer an electricity surplus of 40 MWh per year to the power grid. According to GUS, there were over 6.64 million residential buildings in Poland in 2020. Approximately 80 % are single-family houses, which amounts to about 5.3 million buildings. Equipping these facilities with a photovoltaic installation would allow for the production of 29150 GWh per year, and after meeting households own needs, supplementing the shortages in other areas with a value of over 5300 GWh. In 2021, over 173583 GWh of electricity was produced in Poland, which covers the country's energy demand. Thus, the estimated value of energy produced by self-sufficient estates of 29,15 MWh would account for 16.7 % of the total amount of energy produced, while the excess energy, reaching up to 5,3 MWh, would account for 3% of the total energy production. In the examined three cases, the effectiveness of monocrystalline installations as well as of the polycrystalline one was confirmed. Moreover, despite the fact that peaks of energy production and energy consumption sometimes overlap, the analyzed examples show that, even without batteries, the installations are efficient and profitable over time. And what should be emphasized once more, the most anticipated model is the prosumer house. Therefore, the production of electricity by commercial self-sufficient estates may constitute a significant potential of "green energy" that could replace the energy currently produced in the country by thermal coal plants. Due to the impossibility of the simultaneous installation of photovoltaic installations on all single-family houses, the presented research results constitute a hypothetical simulation, but nevertheless show the possible direction of the intensification in energy transformations that might take place in Poland. The table below shows how the structure of energy production sources could change if all houses were equipped with panels.

⁵ Purchase, installation and activation of photovoltaic panels along with the formalities which enable the export of surplus energy back to the grid takes about three months. In the first year of prognosis, the realization of the investment was assumed for exactly a 3-month period. Consequently, in this year, only 75% (3/4 of the year) of the costs and profits generated by the installations were taken into the account.

Table 8

Percentage distribution of energy obtained from individual sources in Poland in 2020 and a simulation assuming an increase in "green energy" from photovoltaic installations

Energy source	Current state	Simulation
Nuclear power plants	-	-
Thermal power stations (coal, gas, biomass)	87%	71%
Renewable sources	13%	29%

Source: own study.

Currently, the ratio of traditional to renewable energy is 87% / 13%. Assuming the values from the simulation, the relation would change to 79% / 21%. This means that, with appropriate stimulation at the government and local level, the production of "green energy" in Poland may significantly increase by creating residential self-sufficient estates on a large scale. Thus, with a parallel increase in energy production, e.g. from wind farms, Poland can meet the threshold required by EU regulations for 2030, mainly 32% share of energy obtained from renewable sources. The whole examination done in the article was based on case studies of three samples chosen deliberately. Due to the above, they have the character of a survey. Conducted research might be the foundation of other scientific studies based on a wider sample. The authors are aware of the flaws of the carried out analysis, especially in the area where assumptions regarding the Polish energy power grid sufficiency were made (as in reality, the potential to collect the produced energy from the private sector reveals a multitude of problems and needs to be improved). Therefore, the research should be considered as neither finished nor ultimate. In order to recognize the problem, additional investigations might be carried out, especially that photovoltaic profitability seems to be an area of knowledge just recently introduced in the field of scientific examinations⁶, which confirms that the issues regarding this topic are unsettled. The cost-effectiveness analysis in the article was undertaken with the implicit cash flow approach following the obligatory guidelines. Consequently the IRR results should be referred to the discount rate (capital costs) in the present value.

⁶ When the "photovoltaic profitability" phrase is being searched via Google Scholar, only 32 results are shown, whereas "photovoltaic cost-effectiveness" and "photovoltaic economics" searches provide 44 and 87 sites.

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