THE ASSESSMENT OF THE FUNCTIONING OF PHOTOVOLTAIC INSTALLATION UNDER SMALL HOUSEHOLD CONDITIONS

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Abstract

The aim of the study was to present the mechanism of operation and to assess technically and economically a typical household photovoltaic installation. The study included the data on the construction of the PV installation panels and the aspects connected with the profitability of the investment. The energy consumption and production from the existing photovoltaic installations was analysed and the project was assessed as well.

The polycrystalline panels, the monocrystalline panels and the CdTe panel were selected for the analysis. The value of the savings was calculated on the basis of the energy production from the photovoltaic installation multiplied by the average energy cost and the coefficient for the prosumers in the settlement with the distribution system operator.

The discussed photovoltaic installation used the photovoltaic polycrystalline panels which allowed for the achievement of the most beneficial yield-price relationship under Polish conditions. The economic analysis determined a degree of the covered energy demands in the discussed case. It amounted to 29,44% per year and allowed for the obtainment of the savings at the level of over PLN 1200 per year.

Keywords: photovoltaic installation, energy production, energy consumption, renewable energy sources
JEL Codes: Q20, Q43, Q50

Introduction

The photovoltaics market in Poland has been developing more and more dynamically year after year (Marecki et al., 2012; Miciuła, 2015). The facts that the prices of panels were reduced (Mirowski and Sornek, 2015) and the state tries to launch programmes of subsidies (Bartnikowska et al., 2017) have a positive impact on its development.

At present, the support is addressed mainly to the projects reducing low emission in rural areas, inter alia, through the construction/modernisation of local coal-fired boiler plants and household heating furnaces towards ecological ways of heating in local and household boiler plants (including: the use of biomasses, solar installations, heat pumps). This results from the fact that in the Polish rural areas the buildings mainly are heated by solid-fuel boilers. The storage systems for the preparation of domestic hot water during the heating season are commonly used. The alternative heat sources - in most cases - electric boilers are used after heating season. Now the highest dynamics of the investments in solar installations are noted in the voivodeships of South-Eastern Poland – low-urbanised areas, urban-rural municipalities (Hektus et al., 2015).

The renewable energy sources may constitute a material share in the energy balance of individual urban-rural municipalities (Graczyk, 2017; Łada et al., 2015). The intensive development of renewable energy sources can be observed in the global energy balance. In 2004-2014, more than fourfold growth of investment expenditures for renewable energy sector was reported in the world (Kujda et al., 2016; Sektor Energetyczny w Polsce, 2012).

Furthermore, the energy and climate policy of the European Union (ENERGY ROADMAP 2050) encourages the member states to support the energy efficiency and the renovation of buildings with a view to the decarbonisation of the building stock (Maśnicki and Lisowski, 2017; Clerens, 2015, Szczerbowski, 2015). Besides, energy independence, raising ecological awareness of the population and using local potential of RES (Renewable Energy Sources) are the most efficient ways to limit CO_2 and improve energy security (Habiera and Dyjakon, 2017; Szczerbowski et al., 2016).

The total capacity installed in the photovoltaic systems in Poland in 2016 amounted to approx. 199 MW of which microinstallations connected to the grid represent 100 MW (Rynek fotowoltaiki w Polsce, 2017). They are mostly used by individuals but the interest among entrepreneurs is growing as well. Despite the continuous growth from 2014 the share of photovoltaics is insignificant and represents 2,3% of the national system using the renewable energy sources and 0,5% of the entire energy system at the same time (Rynek fotowoltaiki w Polsce, 2017). The forecast of the development of the photovoltaic microinstallations in Poland assumes the growth of the installation capacity from 2016 to 2030 by approx. 13 000 MW, including 3; 40; >40kWp (Krajowy Plan Rozwoju, 2015).

Depending on the needs as well as the location of the project the installation can operate as off-grid or on-grid one (Gużda and Szmolke, 2017; Niechaj, 2016). The efficiency of energy production in the installed stationary modules depends on their performance and air temperature as well as on the position in relation to the direction and inclination angle of their planes (Maśnicki and Lisowski, 2017; Poddaniec, 2016). In Poland the incident radiation (insolation) reaching the horizontal surface amounts to approx. 1000 kWh/m² over the year (Buriak, 2014; Bogacki et al., 2010). The use of the tracking systems of the sun movement and the positioning systems of the PV modules increases the efficiency of energy production in relation to the stationary system by over 20% in winter months and by almost 40% in summer months (Maśnicki and Lisowski, 2017).

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The study covers not only the economic aspects of energy production but also social and ecological dimensions of the photovoltaic installation under typical conditions of a small household.

Materials and methods

A residential building (single-family terraced house) located in central Poland was selected for the analysis. The surface of the roof is 30,08 m^2. The building is inhabited by two adults. The especially energy-consuming additions to the building include: air conditioning system, heated garage driveway and electric underfloor heating in the bathroom. The building is equipped with a gas system which is used to heat rooms and water. The use of the underfloor heating and heated garage driveway determines the increase of energy consumption in winter periods. The operation of the air conditioning system in summer months means the higher energy consumption in summer. The average annual consumption amounts to 9,5 MWh.

The article discusses the household photovoltaic installation. The installation was put into service in 2016. For the proper assessment of the installation three solutions with different types of panels were proposed. An inverter of the same parameters was used in the discussed variants of the photovoltaic installation.

The photovoltaic installation consisting of panels was technically and economically assessed (efficiency and cost installation) – the polycrystalline panels, the monocrystalline panels and the CdTe panel, generally available on the Polish market, were selected for the analysis (table 1). The surface of photovoltaic installation was defined by investor from 18m2 to max 20m2 (an even number of panels) (table 1). The value of the savings was calculated on the basis of energy production from the photovoltaic installation multiplied by the average energy cost which is the average cost achieved on the basis of the data from several years and which amounts to PLN 0,54 per kWh and the coefficient for the prosumers in the settlement with the distribution system operator which amounts to 80%.

Table 1. Technical data of selected photovoltaic panels

Catalogue parameters	Variant I (Polycrystalline panels)	Variant II (Monocrystalline panels)	Variant III (Photovoltaic o panel CdTe)
Maximum power Pmax [W]	260	300	75
Voltage of open circuit Voc [V]	37,7	39,7	61,6
Voltage of maximum power Vmpp [A]	31,0	32,5	46
Short-circuit current Isc [A]	8,9	9,7	1,91
Current intensity of maximum power Impp [A]	8,45	9,26	1,66
Efficiency%	15,8	18,3	10,9

Results

Pursuant to the calculations, the variant II, consisting of the monocrystalline panels of the highest performance amounting to 18,3%, is the best solution, taking into account the possible power of installation (table 2).

Table 2. Calculated power of photovoltaic installations

Parameter	Variant I	Variant II	Variant III
The surface of the one photovoltaic panel [m2]	1,64	1,57	0,72
The number of panels that will fit on an area of 18-20m2	12	12	26
The total surface of the photovoltaic panels installation [m2]	19,68	18,84	18,72
Power of installation [kWp]	3,12	3,60	1,95

This installation could produce 3796,07 kWh per year at the discussed geographical latitude. The installation consisting of the polycrystalline panels - variant I - is ranked second. In this case it is possible to produce 3289,93 kWh per year. It should be noted that the difference is not significant in these two proposals, therefore, the economic criterion should be taken into consideration in order to decide which variant is more profitable. The third presented solution consisting of CdTe thin-film panels could produce 2056,21 kWh per year which is the lowest value of the presented ones and which means that it is the least favourable possibility and it should be rejected - the cost of the entire installation consisting of 26 panels would amount to PLN 11570.

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Taking into account the prices of panels (table 3) the use of polycrystalline panels characterised by the less performance and slightly less yield can reduce the cost of the panels by PLN 1560 in comparison with the cost of the same number of monocrystalline panels. Considering that it is a household installation the difference in price of the panels is a determining factor for choice.

Table 3. Profitability comparison of photovoltaic polycrystalline and monocrystalline panels

Variant	Technology	Price for one panel [PLN]	Number of used panels	Total cost of panels [PLN]
I	Polycrystalline	*989,00*	12	11 868
II	Monocrystalline	*1 119*	12	13 428
			DIFFERENCE	1560

*Variant III was rejected, total cost of panels 11570 PLN.

The installation cost is PLN 25000 net. The user received a subsidy under the programme operated in the central of Poland in 2016 in the amount of PLN 9500. The installation cost after the subsidy amounted to PLN 15500 net (PLN 19065 with VAT).

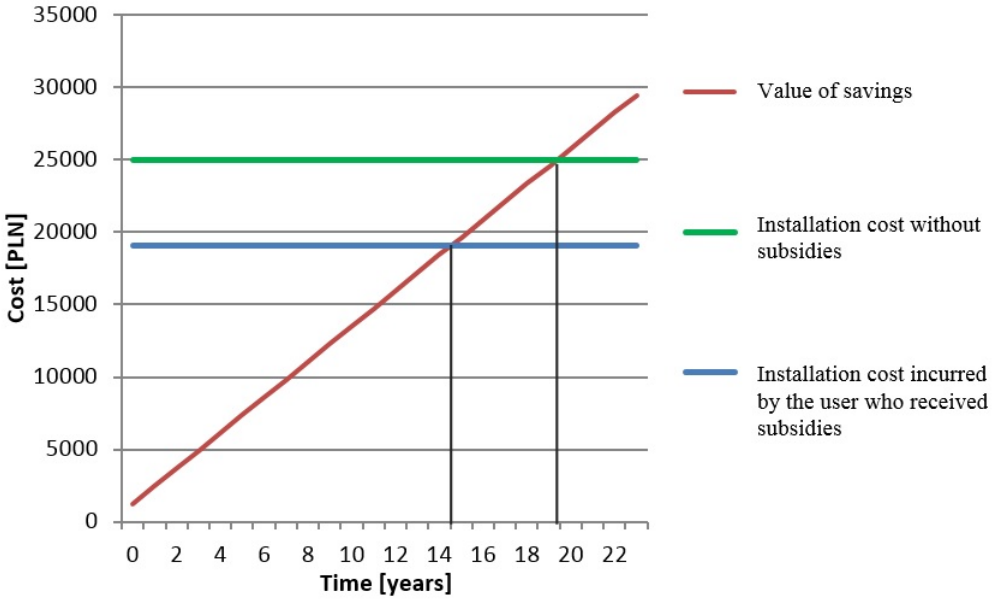

Figure 3. Payback period for investment of photovoltaic installation

The payback period for the investment without subsidies is 20 years (fig. 3). The period is shortened to 15 years with subsidies. The situation with subsidies is beneficial and encouraging from the user's point of view. It significantly shortens the payback period for the investment.

The energy production was analysed as well (fig. 4). The highest production can be observed in June, typical of the discussed geographical latitude, and the lowest production - in December. The total energy production for the full year is 2791,57 kWh. The theoretical production (calculated on the basis of literature formulas) is 3289,93 kWh.

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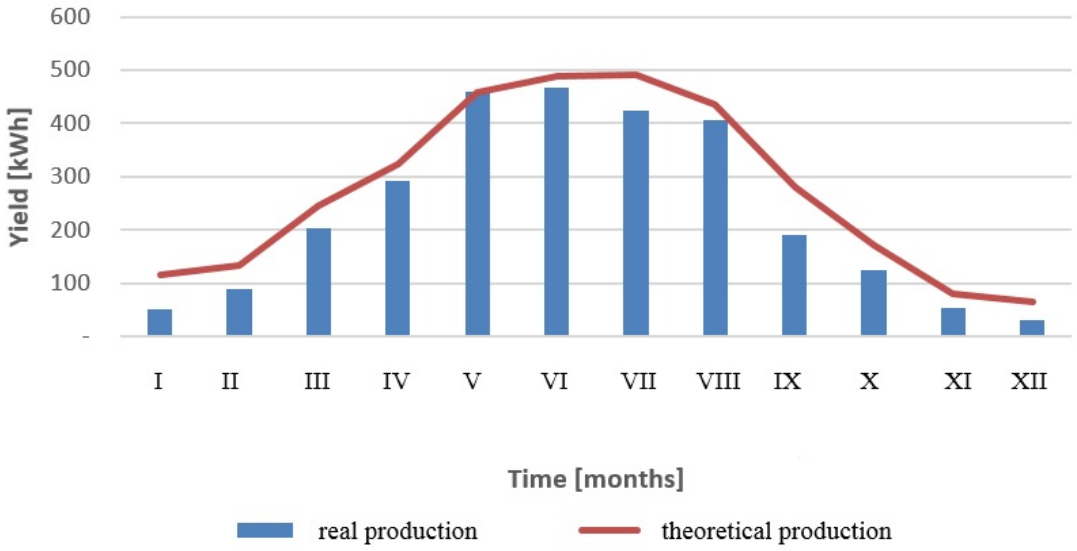

Figure 4. Real and theoretical energy production throughout the year

The average annual energy consumption in the building amounts to 9482,43 kWh. The energy production was 2791,57 kWh in 2017. The installation therefore covers 29,44% of the annual consumption. Taking into account the energy consumption and the price of PLN 0,55 per kWh for the consumed energy the user would pay PLN 5215,34.

The value of the produced energy is reduced by 20% (the coefficient for the prosumers in the settlement with the distribution system operator is 80%) and it amounts to PLN 1 228, 29. This allows for the savings of the energy costs at the level of 23,55% per year.

Conclusions

In connection with the obligation to meet the European Union criteria on the renewable energy and the protection of the environment the solar energy can have a significant impact on the composition and operation of the Polish distribution network. Furthermore, the photovoltaic systems will continue to become cheaper thus their use will ensure the higher energy security and the reduction of carbon emissions. The application of the PV panels on a broader scale can contribute to the reduction of emissions of harmful gases to the atmosphere and to the sustainable development of the national economy.

Importantly, before starting to execute the investment works, it is necessary to check the appropriateness and profitability in order to properly plan the costs and works. It should be analysed whether it was worthwhile investing additional funds if the values of the yields do not differ significantly from each other.

On the basis of the survey it can be observed that:

1. The yields calculated in accordance with the formulas and averaged parameters differ by 15% from the real production.
2. The economic analysis determined a degree of the covered energy demands in the discussed case. It amounted to 29,44% per year and allowed for the obtainment of the savings at the level of over PLN 1200 per year.
3. The discussed photovoltaic installation used photovoltaic polycrystalline panels which allowed the achievement of the most beneficial yield-price relationship under Polish conditions.
4. The monocrystalline panels allow for the achievement of the highest calculation yields but this is connected with the higher investment costs than in case of the polycrystalline panels.
5. The programmes of subsidies and aids can shorten the payback period for the investment which is a positive phenomenon from the investor's point of view. The newly developed installations have also a positive impact on the structure of the national energy system.

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