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SAFETY OF PHOTOVOLTAIC INSTALLATIONS AND ANALYSIS OF THE COSTS OF USING PHOTOVOLTAIC PANELS PRODUCING ENERGY FOR THE NEEDS OF CUSTOMERS IN CENTRAL POLAND

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Robert Kruzel[1] – *orcid id: 0000-0002-8534-7286*
Paweł Helbrych[1] – *orcid id: 0000-0001-6907-0363*
[1]Czestochowa University of Technology, **Poland**, *kruzel@bud.pcz.pl*

Abstract: The article discusses the general problem of the use of renewable energy in Poland. The boundary conditions justifying the economic basis for the construction of photovoltaic power plants producing energy for the own needs of customers were determined. The research method uses a standard model of cash flows where revenues are avoided costs of purchase and distribution of energy due to the production of electricity from PV for own needs. The article also presents technical aspects related to the construction of photovoltaic micro-installations. Particular attention has been paid to the protection of photovoltaic installations, the hazards resulting from the operation of photovoltaic installations, and health and safety at work during design and implementation.
Keywords: photovoltaic systems, security, profitability, Poland

1. INTRODUCTION

A large increase in interest in prosumer installations by individual investors in Poland can be observed from 2015, which is connected with changes in the Act on renewable energy sources. It is estimated that currently in Poland 99% of prosumer microinstallations are solar installations. Photovoltaic installations are often used in passive houses. They support ecology and positively affect the environment.
A typical photovoltaic system consists of modules, panels and devices that change direct current, which is produced in cells for alternating current. The inverter is required to supply alternating current devices from photovoltaic micro-installations.
The use of prosumer micro-installations is the most profitable when the electricity produced is consumed immediately. Unfortunately, this is not always possible. With the change of the Law on Renewable Energy Sources of 01/07/2016 introduced a simple system of reception of energy produced from the network – net-metering. Net-metering is based on the fact that a person who produces too much energy will be able to use its excess at a later time in an amount reduced by 20% without additional charges. This solution helps reduce energy costs even in the winter months.

2. SAFETY OF PHOTOVOLTAIC INSTALLATIONS

Prosumerian micro installations can be compared to a working power plant, so anyone who can have access to it must be safe. Installation should be provided with basic protection.

When the panel output terminals are shorted, the current increases. In the case of parallel rows of photovoltaic modules, damage to one or more panels or partial shading of one of the panels causes a short circuit in the panel and flow through a defective reverse current panel, which can cause a significant increase in module temperature, and in extreme cases can lead to thermal destruction and the appearance of DC electric arc.

Security fuses are most often used to protect strings of photovoltaic installations. The fuses break the electrical circuit in case of failure. The rated voltage of the fuse should be higher than the highest voltage in the solar system.

In photovoltaic installations, two levels of protection are designed, which are provided by fuses. Level I disables DC short-circuit currents in the area of the panels in a location closest to the photovoltaic panels. Level II protections constitute the main protection of the photovoltaic installation, and security is usually installed near the inverter input terminals.

Photovoltaic installations are most often installed on open surfaces and are exposed to the risk of damage caused by atmospheric discharges. It is also related to the low impact strength of photovoltaic systems and their size, therefore, to protect photovoltaic installations from the effects of atmospheric discharges, they should be protected using lightning protection solutions.

The inverter, which is an important element of photovoltaic installations, should be particularly protected against the impact of surge voltage. These threats can be minimized by applying basic protection measures: lightning protection, over-voltage protection, earthing, potential equalization system, shielding and proper cable routing.

Photovoltaic installations are exposed to the occurrence of overvoltages not only due to direct lightning, but also to surges induced due to discharges close to the object. The functions of protection against direct atmospheric discharge are met by properly selected and arranged on the building systems of vertical and horizontal air terminals along with discharge ducts, equalizing connections and earth electrodes.

Projects of photovoltaic installations made in accordance with standards and regulations will certainly significantly extend the life of the investment. Proper assembly and proper distribution of cables increase the effectiveness of overvoltage and lightning protection. The use of lightning protection and surge protection systems will eliminate the risk of damage to the photovoltaic installation that may arise due to lightning and overvoltages in power lines.

3. METHODOLOGY OF RESEARCH

The analysis of the cost-effectiveness of photovoltaic prosumer microinstallation was made with the assumptions of the cash flow model for a classical investment project for two existing prosumer microinstallations, located on single-family buildings in the Radomszczański poviat in Poland. The analysis was made on the basis of real data read from the measuring devices of the prosumer micro-installations in question in the period between December 2017 and November 2018.

3.1. Assumptions for analysis

Investment assumptions for micro-installations in the first household:
- a single-family house with an area of approx. 100 m^2,
- roof angle of 45 degrees,
- south orientation of the building
- the type of roofing is sheet metal
- inhabited by two adults
- heating pellet stove
- current annual energy consumption - about 1550 kWh / year
- PV module - JA SOLAR JAM
- number of panels, 6 units, area 9.81 m^2
- Solis Mini 2000 inverter type
- Price of photovoltaic installation with assembly is PLN 12,500 gross

Investment assumptions for micro-installations in the second household:
- a single-family house with an area of approx. 250 m^2,
- roof angle of 45 degrees,
- south orientation of the building
- the type of roof covering is a bituminous shingle
- inhabited by 5 adults and 3 school-age children
- heating furnace for eco-pea coal
- current annual energy consumption - approx. 4550 kWh / year
- PV module - JA SOLAR JAM
- number of panels 18szt o surface 29.43 m^2
- Solis-3P5K-4G inverter type
- Price of photovoltaic installation with assembly is PLN 32100 gross

Boundary assumptions of the analysis:
- the gross costs of electricity and the avoidance of VAT on the energy used are avoided
- running costs of microinstallations are panel washing costs as 0.5% of capital expenditures, cost and cost of accident insurance as 1% of capital expenditures
- Equity - 100%
- Debt share - 0%
- fee for active energy in the analyzed region - 0.30 PLN / 1kWh
- distribution fee in the analyzed region - PLN 0.27 / 1kWh
- fixed costs in the analyzed region - PLN 19.90 / 1 month
- it was assumed that the average annual electricity consumption in the household will be constant.
- due to the rapid technological development, the inverter has been replaced 1 times during the investment period - after 10 years
- duration of the investment for 25 years in accordance with the guarantee period of the PV modules
- the actual inverter warranty time has been adopted as 10 years
- the approximate cost of purchasing a new inverter after 10 years of operation is 3750 PLN
- A 3% drop in the efficiency of the installation in the first year of operation and a 0.7% decrease in efficiency in each subsequent year was assumed.

- Macroeconomic assumptions according to the duration of the investment include: averaged inflation at 2.9%, increase in electricity and distribution prices by 2.6% per annum.
- the analyzed households are located in the Łódź Voivodeship in the Radomsko district.

3.2. Data read from measurements

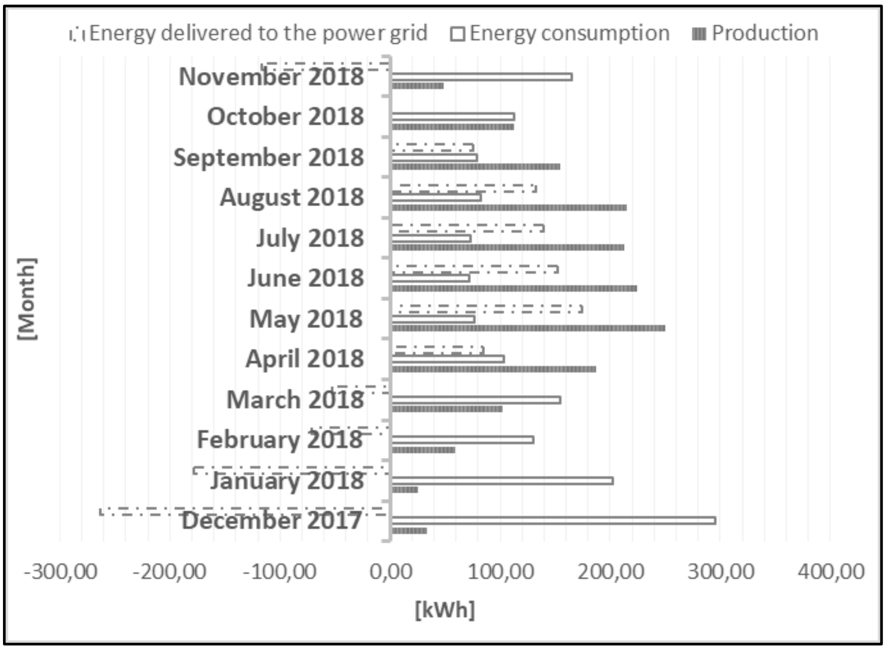

Fig. 1. Production, consumption and energy delivered to the power grid in first household

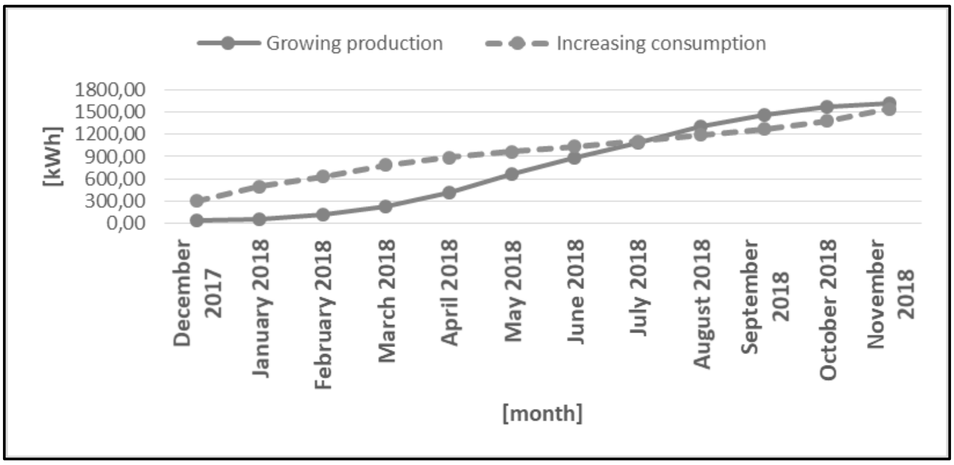

Fig. 2. Chart comparing the growing production and consumption of energy in the first household

The sum of energy produced in the analyzed micro-installations in the first single-family home in the period from December 2017 to November 2018 amounted to 1625.87 kWh, while the energy consumed was 1546,67kWh. The analysis assumes that December 2018 in terms of production and use of energy in this single-family home will be the same as December 2017, it is possible to divide the work period of the analyzed micro-installations into two half-year periods: January - June and July -

December. The energy supplier to which the analyzed micro installation is connected allows for energy settlements in semi-annual periods, where a balanced energy allowance from the first half-year can be used in the second half. In the first period, the investor produced 848.28 kWh (including energy balancing at 0.8) and consumed 738.71 kW, thanks to which in this settlement period, it only incurred fixed and distribution fees, and until the next accounting period it contributed an energy allowance in 87.65 kWh. In the second settlement period, the investor produced 777.59 kWh (including energy balancing at 0.8) and consumed 807.95 kWh, taking into account the energy allowance from the previous accounting period, the investor had to cover the cost of fixed and distribution fees, and the allowance left in the network 57.29 kWh

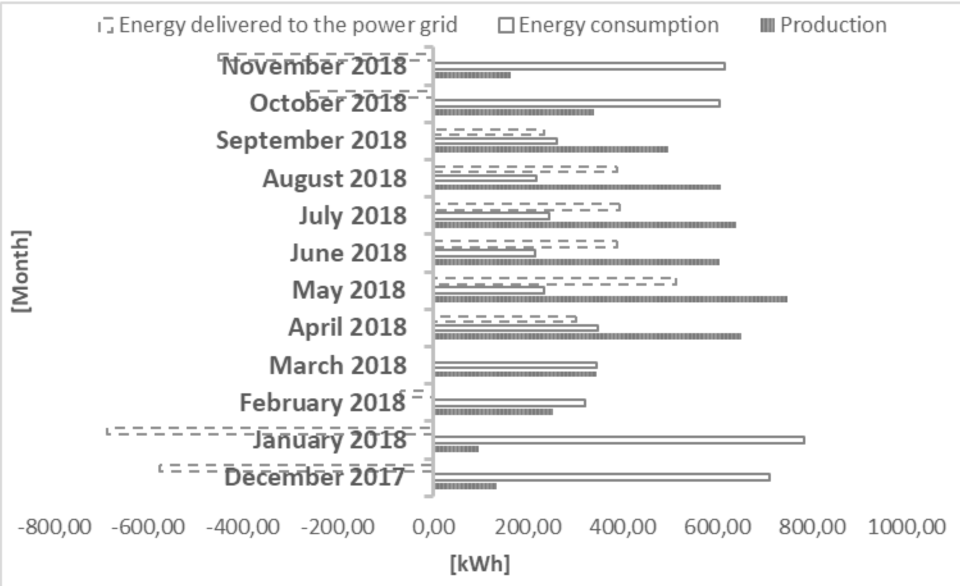

Fig. 3. Production, consumption and energy delivered to the power grid in second household

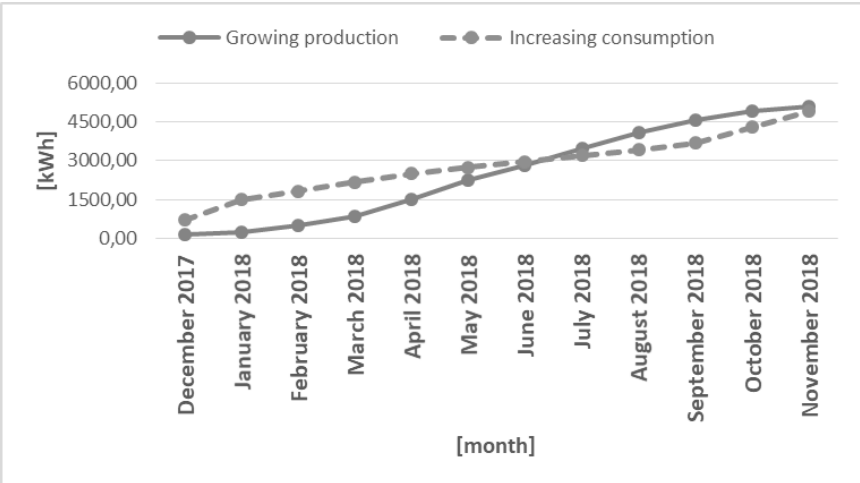

Fig. 4. Chart comparing the growing production and consumption of energy in the second household

In the same way as for the first single-family house, a summary of the produced and consumed energy in the second single-family home was carried out. The sum of energy produced in the analyzed prosumer micro installation is 5089,68 kW, the

energy consumed is 4910.47 kWh. In the first settlement period, the investor produced
2703.01 kWh (including energy balancing at 0.8) and consumed 2250.89 kW, thanks to which in this accounting period, it only incurred fixed and distribution fees, and to the next accounting period it contributed an energy allowance in 361.70 kWh. In the second settlement period, the investor produced 2386.67 kWh (including energy balancing
at 0.8) and used 2659.57 kWh, taking into account the energy allowance from the previous accounting period, the investor had to cover the cost of fixed and distribution fees, and the allowance left in the network 88.80 kWh.

3.3. Analysis

Taking into account the assumptions and boundary conditions of the analysis for the first single-family home, a profitability table for prosumer microinstallation was created (Table 1) and the results were compiled in the graph - Fig. 5.

Table 1
Analysis of the profitability of a prosument photovoltaic micro-installation in first household

Year	Price of electricity	The price of fixed fees	O&M	Insurance	Price of the inverter	The produced energy	Energy used	The cost of energy used and fixed fees	Income
	[PLN]	**[PLN]**	**[PLN]**	**[PLN]**	**[PLN]**	**[kWh]**	**[kWh]**	**[PLN]**	**[PLN]**
2019	0,57	19,9	62,5	125,0	0	1626	1547	426,3	882
2020	0,58	20,5	64,3	128,6	0	1577	1547	438,7	904
...									
2028	0,71	25,7	80,8	161,7	0	1491	1547	591,1	1061
2029	0,73	26,5	83,2	166,4	4000	1480	1547	4615,7	1080
2030	0,75	27,3	85,6	171,2	0	1470	1547	641,1	1099
...									
2042	1,01	38,4	120,6	241,2	0	1351	1547	1019,3	1359
2043	1,03	39,5	124,1	248,2	0	1342	1547	1057,8	1383

Source: own elaboration

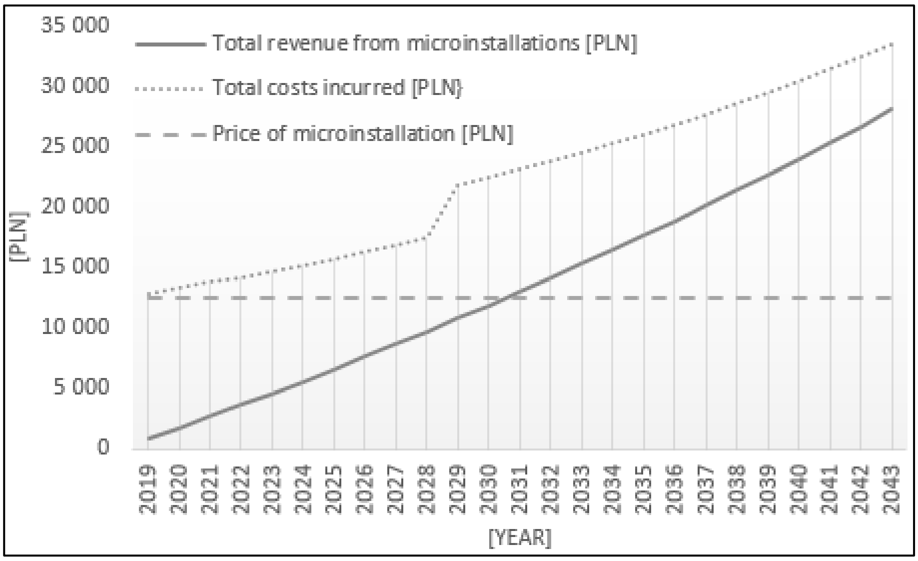

Fig. 5. A summary of the total revenue from micro-installations with the total investment costs and the costs of micro-installations for the first household

Taking into account the assumptions and boundary conditions of the analysis for the second single-family home, a profitability table for prosumer microinstallation was created (Table 2) and the results were compiled in the graph - Fig. 6.

Table 2

Analysis of the profitability of a prosument photovoltaic micro-installation in second household

Year	**Price of electricity**	**The price of fixed fees**	**O&M**	**Insurance**	**Price of the inverter**	**The produced energy**	**Energy used**	**The cost of energy used and fixed fees**	**Income**
	[PLN]	**[PLN]**	**[PLN]**	**[PLN]**	**[PLN]**	**[kWh]**	**[kWh]**	**[PLN]**	**[PLN]**
2019	0,57	19,9	161	321	0	5090	4910	720	2799
2020	0,58	20,5	165,2	330,3	0	4937	4910	741	2869
…									
2028	0,71	25,7	207,6	415,2	0	4667	4910	1105	3322
2029	0,73	26,5	213,6	427,2	3750	4635	4910	5160	3382
2030	0,75	27,3	219,8	439,6	0	4602	4910	1217	3442
…									
2042	1,01	38,4	309,8	619,5	0	4230	4910	2075	4255
2043	1,03	39,5	318,7	637,5	0	4200	4910	2163	4331

Source: own elaboration

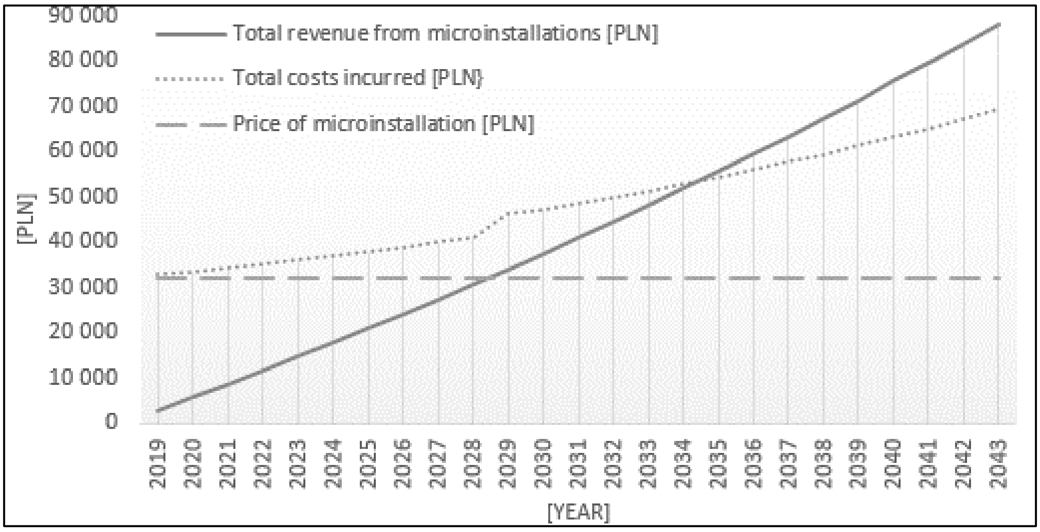

Fig. 6. A summary of the total revenue from micro-installations with the total investment costs and the costs of micro-installations for the second household

4. CONCLUSION

Photovoltaic installations, although environmentally friendly, can be dangerous. Therefore, all safety standards must be observed during the design and installation works of such installations. A damaged photovoltaic installation can be dangerous for people's health and life.

Photovoltaic prosumer microinstallations can already be profitable in Poland without a grant and loan system. The profitability of the investment depends mainly on the household energy demand. The higher the demand, the higher the profitability. The reimbursement of the investment costs for the first household will occur after 12 years (Fig 5), while for the second household after 10 years (Fig 6).

The investment in microinstallations carries additional fixed costs such as insurance and system maintenance, which reduces the income from the installation. In the case of the first household during the installation's lifespan of 25 years, all costs related to the investment and the generated running costs will be higher than the profit (curves on the chart do not intersect - Fig 5), while for the second household the profit from the installation after 16 years will exceed all costs related to the investment and generated running costs (curves on the graph intersect - Fig. 6). In this case, the investment is entirely profitable.

In the case of the first installation, all costs related to the investment and generated running costs after the operational period (25 years) will amount to PLN 33,579 and PLN 28,146, while for the second installation PLN 69,143 and PLN 88242, respectively.

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