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PHOTOVOLTAIC SYSTEMS AS AN EXAMPLE OF ECONOMICALLY JUSTIFIED PROSUMER OPERATIONS

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INSTALACJE FOTOWOLTAICZNE JAKOPRZYKŁAD UZASADNIONEJ EKONOMICZNIE DZIAŁALNOŚCI PROSUMENCKIEJ

STRESZCZENIE: Instalacje fotowoltaiczne są przykładem odnawialnych źródeł energii wykorzystujących energię słoneczną. Zaprezentowano przykładową analizę zastosowania instalacji fotowoltaicznej wykonaną dla rzeczywistego przedsiębiorstwa znajdującego się na terenie Lubina, przedstawiającą efektywną wartość uzyskanej energii oraz rozkład kosztów i zysków. Instalacja fotoogniw to jedna z metod włączenia się do energetyki prosumenckiej, wspieranej między innymi w działaniach 3.1 i 3.2 RPO WD oraz przez NFOŚiGW.

SŁOWA KLUCZOWE: fotowoltaika, energia słoneczna, prosument

Introduction

The progress of civilization is a factor driving the increasing demand for energy. This creates the need to seek alternative energy sources which do not rely on the combustion of organic fossil fuels. Alternative energy can come from renewable and non-renewable sources. Renewable energy is collected from naturally replenished resources such as hydropower, wind power, biomass, biogas, sunlight and/or geothermal heat contained in the environment[1]. The safest source of energy not raising social concerns is solar power. It can be utilized in two ways: in thermal solar panels used primarily for domestic hot water, and in photovoltaic cells, which generate electricity. Photovoltaic cells seem to be a more cost-effective solution.

This study shows the potential benefits to users of photovoltaic systems in the context of prosumer energetics, and is aimed at analysing the legitimacy of photovoltaic cell installation.

Photovoltaic cells

A photovoltaic (PV) cell is a device that converts the energy of visible and infrared light into electricity. The conversion is possible because of the use of semiconductors – solid materials in which charge carriers move within a crystal lattice. There are two types of semiconductors: n-type (negative) and p-type (positive); these can be, for example, silicon semiconductors doped with arsenic and aluminium, respectively. The electrical field on the p-n junctions is formed because of the opposite electrical charges: free electrons on the valence band in the n-type semiconductor and valence holes on the p-type semiconductor. Solar power in the form of photons reaching the p-n junction generates electron-hole pairs in the junction. The separation of these pairs results in an exchange of the excess of electrons and holes between p-type and n-type semiconducting materials. The product of this process is charged ions, which results in an electrical field when the circuit is closed[2].

The performance of PV cells declared by manufacturers is given for standard test conditions (STC), that is irradiance of 1000 W/m^2 and cell temperature of 25^{o}C[3].

1 H. Foit, *Zastosowanie odnawialnych źródeł ciepła w ogrzewnictwie i wentylacji*, Gliwice 2013, p. 17.

2 I. Góralczyk, R. Tytko, *Fotowoltaika: urządzenia, instalacje fotowoltaiczne i elektryczne*, Kraków 2015, p. 191.

3 I. Góralczyk, R. Tytko, op. cit., p. 195.

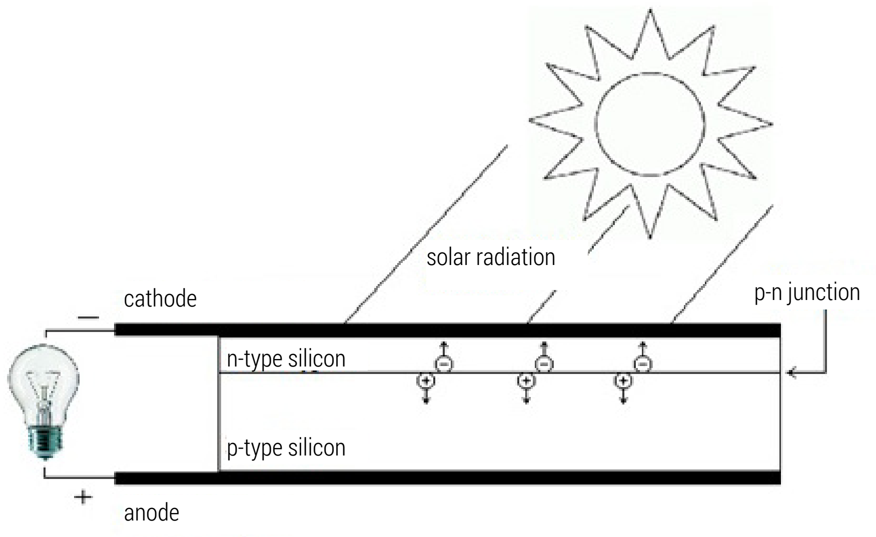

Figure 1. Schematic representation of a photovoltaic cell

Source: authors' own elaboration based on I. Góralczyk, R. Tytko, *Fotowoltaika: urządzenia, instalacje fotowoltaiczne i elektryczne*, Kraków 2015, p. 191.

The performance of different types of PV cells is presented in Figure 2[4].

Modern PV cells are characterized by a decrease in performance over time: in the first year this decline can be up to about 5% (then the device reaches a stable performance level), and in the perspective of 25 years the decline may be as much as 20% of the initial performance rate[5]. The above information should be considered when analysing the cost-effectiveness of a specific system.

The solar radiation that reaches the Earth's atmosphere can be direct, most important for the operation of PV cells, diffuse, which can still be utilised by PV systems on cloudy days when sunlight seems to be completely blocked, and reflected, not considered when designing photoelectric systems because of its unpredictable angle of reflection. The total power of solar energy reaching the Earth is about $81{,}000 \cdot 10^6$ MW. In Poland alone the potential level of energy that can be generated from solar radiation is 1,340 PJ (peta joule, 10^{15} J); however, it has been estimated that after 2020 only 20 PJ will be

4 Ibidem, p. 192.

5 Ibidem, pp. 196–197.

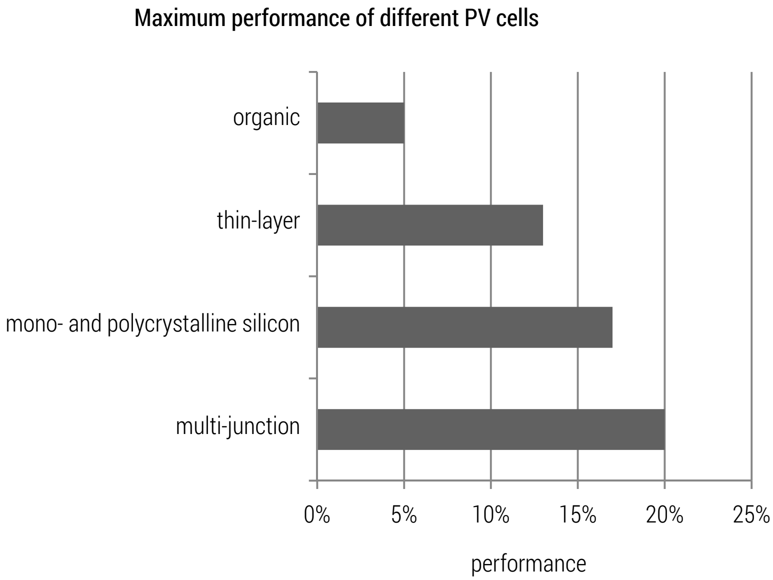

Figure 2. Performance of different types of PV cells

Source: authors' own elaboration based on I. Góralczyk, R. Tytko, op. cit., p. 192.

effectively used (less than 1.5%)[6]. This indicates the theoretically unlimited development of the national solar energy sector. The average level of solar radiation in Poland is about 1,000–1,100 kWh/m^2 with 1,600 hours of sunlight per year. The average radiation power is about 1,000,000/1,600 = 625 W/m^2 [7]. Considering countries with a climate similar to Poland, the greatest interest in photovoltaic systems is observed in Germany, where more than 2 million PV cells of 7 kW each were installed from July 2011 to the end of 2012[8].

One of the environmental benefits arising from the use of photovoltaic cells is about 1,300 tonnes of avoided CO_2 emission per year (for a 1 MW power plant)[9].

6 Ibidem, p. 185.

7 Ibidem.

8 J. Popczyk, *Energetyka prosumencka jako skutek konwergencji postępu technologicznego i rozwoju społecznego*, „Biblioteka źródłowa energetyki prosumenckiej" 2014, p. 2.

9 I. Góralczyk, R. Tytko, op. cit., p. 189.

Types of PV systems

A PV system consists of several components that allow for the supply of electricity to the utility grid (Figure 3).

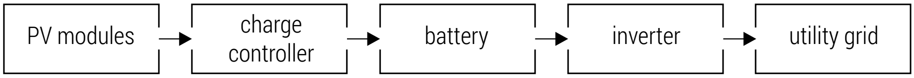

Figure 3. Elements of a PV system

Source: authors' own elaboration based on I. Góralczyk, R. Tytko, op. cit., pp. 241–262.

PV systems can be stand-alone (off-grid) and grid-integrated (on-grid). Off-grid systems can be used when there is difficulty in connecting to the utility grid (e.g. because of large distances). The generated energy is then accumulated and used as needed. An alternative solution is to connect solar panels to the utility grid via an inverter. Then the user can freely use electricity, and is paid back by the operator of the power grid for the unused surplus of energy generated by solar panels[10]. On-grid systems are an example of distributed energy resources, defined by the European Commission as "stand-alone or integrated into the electricity grid small modular conversion units, used by power plants, their clients, private individuals or other parties and offering benefits to the energy sector, specific end-users or both"[11]. Another definition of diffused generation of energy describes these systems as small conversion units (with a rated output of 50–150 kW) integrated directly with the power distribution grid or located within the grid of the user (behind the metering device), also generating energy from renewable sources or electricity in combination with heat[12].

Another beneficial solution involves hybrid solar panels which combine thermal solar panels and PV cells. Increased temperature reduces the performance of photovoltaic cells by about 0.5%/K. To prevent this, a cooling system is used in PV cells (for example water pipes on the bottom of the system working as a heat exchanger), which offers a double advantage: it eliminates the negative effect of high temperature on PV cell and gives the

10 I. Góralczyk, R. Tytko, *Racjonalna gospodarka energią: wybrane zagadnienia, instalacje fotowoltaiczne i elektryczne*, Kraków 2015, pp. 255–256.

11 B. Sedler, *Alternatywne formy generacji rozproszonej, z uwzględnieniem OZE, w tym małej energetyki jądrowej*, in: B. Mickiewicz (ed.), *Najnowsze osiągnięcia z zakresu OZE wraz z przedstawieniem barier we wdrażaniu wyników badań do praktyki gospodarczej oraz sugestiami ich rozwiązań*, Koszalin 2012, pp. 99–128.

12 A. Myczko, A. Kliber, L. Tupalski, *Odnawialne źródła energii a hybrydowe systemy energetyczne*, in: B. Mickiewicz (ed.), op. cit., pp. 81–98.

possibility of using the recovered heat. The performance of hybrid systems depends on the synergy of their components[13].

Prosumer – a new player in the energy market

Prosumer energy is a new sector emerging in the energy market. A prosumer produces and consumes electricity[14]:

Prosumer = **pro**ducer + con**sumer**

According to Popczyk, prosumers are „former end-users who undertake the production of electricity for their own consumption"[15].

Prosumerism is to be promoted primarily by the Act on renewable energy sources passed on 20 February 2015, amending the existing legislation in this area, including the so-called 'small energy tripack'. The Act on RES provides, inter alia, the obligation to purchase electricity from newly constructed, up to 10 kW, RES systems at a feed-in tariff for 15 years, the obligation to purchase the unused electricity at a price of 100% of the average selling price of electricity on the competitive market in the previous quarter, and measuring differences between the amount of electricity used from the grid and the amount of energy supplied by the prosumer to the grid every six months *(*net-metering policy)[16]. The law does not specify whether investors who have received a subsidy for the installation of an RES system will benefit from the feed-in tariff, but after 2016 they can expect profits from the sale of surplus energy (at market price), and the 6-month billing system[17]. The former 'small energy tripack' did not promote the full implementation of EU law, since the proposed price for the purchase of energy from renewable sources generated by prosumers was only 80% of the market price for the previous year[18].

A survey has shown that individual investors (mainly private) are willing to install RES systems because of, for example, the ability to obtain subsidies, the influence of people from their environment, the low failure rate of RES

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13 I. Góralczyk, R. Tytko, *Fotowoltaika…*, pp. 209–210.

14 K. Księżopolski (ed.), *Odnawialne źródła energii w Polsce: wybrane problemy bezpieczeństwa, polityki i administracji*, Warszawa 2013, p. 175.

15 J. Popczyk, op. cit., p. 5.

16 Act of 20 February 2015 on renewable energy sources (Dz.U. 2015 item 478); www.nfosigw.gov.pl [20/11/2015].

17 www.nfosigw.gov.pl [20/11/2015].

18 K. Księżopolski (ed.), *Odnawialne źródła energii w Polsce: wybrane problemy bezpieczeństwa, polityki i administracji*, Warszawa 2013, p. 33.

technologies, as well as trends in the development of RES. Another important factor is that many installation companies assume part of the responsibility associated with obtaining co-financing/subsidies for PV systems[19].

Investments are also stimulated by dynamic changes in the PV market. Statistics from the GTM Research report for September 2015 published at odnawialnezrodlaenergii.pl show that the average price of PV systems is expected to drop by 40% in 2020 compared with the current price, which is associated, among other things, with the introduction of feed-in tariffs in Europe. It was also emphasized that the costs of installation (service) are decreasing more slowly than the cost of the PV module (in 2007 in the United States 'soft' costs accounted for 58% versus 75% today)[20]. The decrease in costs is significantly influenced by the advances in PV technology, and above all, the increased system performance. It should, however, be borne in mind that the high performance obtained in standard test conditions does not immediately translate into an increase in the performance of products offered on the market. Nevertheless, reports on performance parameters seem to be very optimistic – for example the French company Soitec achieved 46% performance for concentrated photovoltaic cells (CPV); Soitec has launched onto the market PV cells with 31.8% performance, and its target is 50%[21].

On the other hand, the development of printed PV cells can bring significant savings on the cost of cells and their installation. The new cells printed in 3D on thin films of any shape and size are being produced on a laboratory scale. The performance of printed perovskite PV cells is up to 20%[22]. In addition, flat and flexible films can be installed without any problems on external walls and roofs, which significantly reduces the investment costs associated with their assembly. Currently, many manufacturers of multilayer sheathing boards are testing in their research centres integrated panels made of flexible film as an integral part of facade and roof structures.

However, long-term speculations on changes in electricity prices are subject to large errors. It is easier to verify the forecast for next year – Paweł Owczarski, CEO for Polski Prąd commented in October 2015 that, for example, the stock exchange prices of electricity in 2016 are lower by 5–6% compared to 2015, but their change will be driven by government policies regarding the coal mining sector. In addition, a 1–3% increase in distribution fees is

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19 A. Hilarowicz, J. Kozioł (eds), *Odnawialne źródła energii – badania oddziaływań społecznych*, Gliwice 2013, p. 53.

20 www.odnawialnezrodlaenergii.pl [01/02/2016].

21 www.gramwzielone.pl [01/02/2016].

22 Ibidem [14/02/2016].

expected, which in turn cannot create any savings for individual consumers (so-called G sector)[23].

The National Fund for Environmental Protection and Water Management is currently operating a programme supporting investments in RES „Prosumer" for the years 2015–2020[24]. Grants are also provided for the replacement of existing systems with new ones; however, no support is provided for systems using only a heat source. It has been estimated that one of the environmental effects of the implementation of the programme will be a 215,000 t annual reduction in CO_2 emissions. The programme's budget for 2014–2022 is 800 million PLN. Funding is offered in the form of a 15-year loan or a credit up to 100% of eligible costs of the system with a 1% interest rate, or a 15 or 30% subsidy, but the eligible costs must be within the range from 100,000 to 450,000 PLN, depending on the beneficiary and the type of system. Private individuals, communities and housing associations can apply for subsidies through banks (Bank Ochrony Środowiska/Bank for Environmental Protection) or Regional Funds for Environmental Protection and Water Management[25].

Regional Operational Programmes are other sources of funding. Their budget is based on European Union funds, and decisions about the type of co-financed investments are made at the provincial level since each province has its own ROP. The detailed description of priority axes of the ROP for Lower Silesia province indicates, among other things, measures in the area of priority axis 3 "Low-emission economy". Particularly noteworthy are measures 3.1 and 3.2, which aim, respectively, at increased levels of energy production from renewable sources in the Lower Silesia province and increased energy efficiency in small and medium-sized enterprises (thermal modernisation).

Applications for funding can be filed by local administration units, their unions and associations, and enterprises. Due to the autonomous nature of the ROP, applicants willing to raise funds for the investment have to check which areas of technology are supported in a given province[26].

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23 www.energiadirect.pl [01/02/2016].

24 www.nfosigw.gov.pl [20/11/2015].

25 www.nfosigw.gov.pl [20/11/2015].

26 Detailed description of priority axes of the Regional Operational Programme for Lower Silesia Province 2014–2020, Project version 1, Wrocław 2015.

Analysis of return on investment for PV systems

The primary criterion for making a decision to invest in PV systems should be their return on investment (ROI). ROI depends on many factors, such as the type of module installed, its surface area, the orientation, the energy demand of the building, the price of commercial electricity, and the level of funding obtained. The calculations should take into account the forecasted changes in the prices of energy from conventional sources, especially in the context of amendments to the laws which are aimed at supporting the prosumer energy sector. To discuss the feasibility of investment in photovoltaic systems we used example data – calculations made for a Lubin-based enterprise operating in production and commerce. The proposal to install PV stems from a report prepared under a project "Firma XXI wieku to ekologiczna firma"/Green business of the 21st century" (POKL.02.01.01-00-055/13), co-financed by the European Union from the European Social Fund. One of the suggested environmental measures was to reduce the use of conventional electricity by installing a photovoltaic system. The proposal was supported by the SWOT analysis (strengths, weaknesses, opportunities, threats), which justified the installation of photovoltaic cells due to the continuous advances in the production technology and operation of PV, virtually eliminating weaknesses and threats indicated in the analysis[27].

The cost estimate for the planned investment included the calculation of the real output of electricity from photovoltaic cells, taking into account parameters such as, among others, cell type, location of the building, the orientation of panels, and various losses in relation to the final gross energy output. The analyzed system consisted of 80 photovoltaic modules and one inverter. The power of a photovoltaic system of 133.1 m^2 total surface was 20 kWp (p – peak). The table below presents subsequent calculation steps for electrical power possible to generate through the use of modules.

27 Ł. Szałata, Prepared under the project „Firma XXI wieku to ekologiczna firma" (POKL.02.01.01-00-055/13), Wrocław 2014.

Table 1. SWOT analysis for energy acquired from solar radiation

POSITIVE	NEGATIVE
Strengths	**W**eaknesses
• no greenhouse gas emissions; • high reliability; • fast implementation of investment; • modern technologies	• lack of systems for the storage of surplus electricity and distribution systems for generated energy; • production of silicon-based cells creates a hazard for the environment; • complicated environmental impact assessment procedures (for Natura 2000 sites)
Opportunities	**T**hreats
• constant and significant growth in the technological potential for the production of PVT and PV panels; • use of roof surface in urban areas; • increasing social awareness about the need for environmentally-friendly investments; • decreasing costs of the production of panels and modules.	• low-quality technologies; • relatively short useful life of panels; • problems with selling energy to a grid operator

Source: authors' own elaboration based on: Ł. Szałata, Opracowanie w ramach projektu "Firma XXI wieku to ekologiczna firma" (POKL.02.01.01-00-055/13), Wrocław 2014.

The level of solar radiation for the analysed area (Lubin) is 1,089.4 kWh m^2.

A PV system with a peak power of 20 kWp can generate 18,032 kWh of energy (AC), which gives about 902 kWh/kWp of specific profit per annum. Of the generated 18 032 kWh/year, the power supply to the system consumes 5,237 kWh/year, so the demand covered by photovoltaic cells is 12 795 kWh/year. Thus, the energy generated by PV cells covers 42.6% of the estimated demand for electricity (30,022 kWh).

The whole system consists of 40 modules oriented to the east (97^o) with an inclination of 10^o and a surface area of 66.5 m^2, and 40 modules oriented to the west (277^o) with an inclination of 10^o and a surface area of 66.5 m^2 (polycrystalline silicon modules, standing on a flat roof). The estimated share of irradiation per module in relation to the angle of global irradiation-total loss does not exceed 10%, as shown in Figure 4. Similar results were obtained for nominal photovoltaic energy (Figure 5).

Table 2. Calculated potential electricity output from the photovoltaic module

Parameters	Energy generated
Global irradiation	**1 089,4 kWh/m^2**
Deviation from the standard spectrum	- 10,89 kWh/m^2
Orientation and inclination of PV modules	- 10,24 kWh/m^2
Reflection from the module surface	- 72,16 kWh/m^2
Irradiation per module	**996,1 kWh/m^2**
Photovoltaic irradiation	996,1×133,07 = **132 554,3 kWh**
STC conversion for η = 15.06 %	- 112 595,49 kWh
Nominal photovoltaic energy	**19 958,8 kWh**
Other losses	- 1 262,1 kWh
Photovoltaic energy – DC	18 696,7 kWh
Voltage range/MPP adaptation	- 102,51 kWh
PV energy (DC)	18 594,2 kWh
DC-to-AC power conversion and other losses	- 562,1 kWh
Generated photovoltaic energy	**18 032,1 kWh**

The values given in the table are rounded values obtained in calculations and may differ slightly from the real values.

Source: authors' own elaboration based on: J. Jurczyk, Projekt 029/2014.

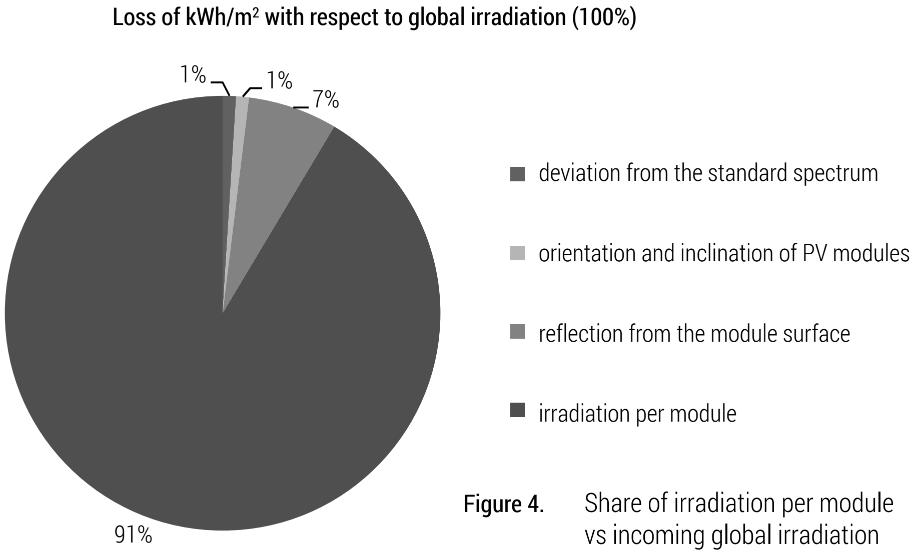

Figure 4. Share of irradiation per module vs incoming global irradiation

Source: authors' own elaboration based on: J. Jurczyk, Projekt 029/2014.

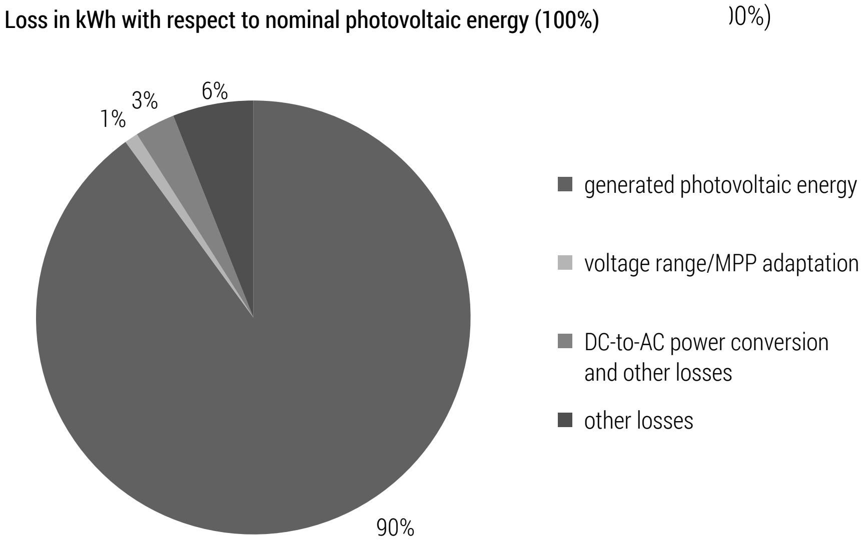

Figure 5. Share of electricity generated by a PV system vs nominal energy
Source: authors' own elaboration based on: J. Jurczyk, Projekt 029/2014.

For the investments valued at 28,400 EUR the estimated amortisation time is less than 10 years, and profit after 25 years of use (producer's warranty) is more than 9,000 EUR[28]. The system can reduce CO_2 emission by 21,613 kg/year, which is roughly consistent with literature data (1,300 t CO_2/year for a 1 MW system, as specified above). The analysis shows that the amount of energy generated by PV cells is always lower than the value given in manufacturer's specifications, and may vary depending on the location of the modules. Therefore, before making a decision on the assembly of a system a detailed cost estimate should be prepared, and the date of payback of expanse should be determined. Undoubtedly, the amortisation time will be much shorter if funding for the project is obtained. The results of analysis of return on investment – the cumulative cash flow for a period of 26 years, taking into account the cost of investment and savings on purchasing electricity are shown in Figure 6.

Major benefits include significant consumer independence from fluctuating electricity prices set by the supplier, as well as reduced risk associated with an increase in additional charges imposed on the users of elec-

28 J. Jurczyk, Projekt 029/2014.

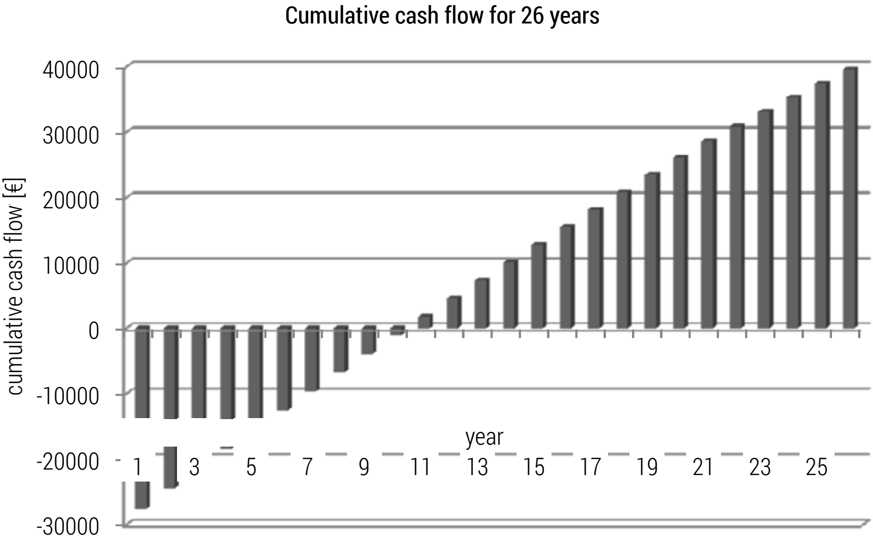

Figure 6. Analysis of return on investment

Source: authors' own elaboration based on: J. Jurczyk, Projekt 029/2014.

tricity. This risk is associated, for example, with unexpected, significant reductions in energy prices, but this is an unlikely scenario.

Investment in PV systems requires the preparation of an individual analysis in a target region to determine the amount of energy that can be generated depending on the orientation of the panels and the incoming irradiation. Less favourable weather conditions may slightly reduce the amount of energy. However, the return on investment can be predicted solely on the basis of geographical location – the orientation of solar panels, their inclination, and the surrounding buildings can be responsible for differences, and thus it is advisable to order a detailed analysis from companies specialized in this field. The value of irradiation in Poland is 900–1200 kWh/m^2, but it is difficult to estimate it precisely for a given location. Meteorological maps can be used for that purpose, but they still may not provide correct information[29].

The forecasted annual savings on purchasing electricity for the analysed company are in the range of 2,148.69 to 2,715.58 EUR. Increase in the costs of electricity (at a 2% growth rate for energy prices) was considered in calculations. The analysis of return on investment by its nature relies on forecasted commercial prices of electricity.

29 www.veelman.com [01/02/2016].

Conclusions

In an era of the depletion of fossil fuels and growing energy prices prosumerism seems to be a favourable solution in economic and ecological terms. The advantages of the installation of photovoltaic cells include the possibility of reselling surplus generated electricity to the grid operator (on-grid systems) and financial support from various sources.

There is a misconception that PV and PVT panels can only work in very sunny climate zones. In fact, PV panels can work even on cloudy days using energy from dispersed sunlight.

Despite all the difficulties, mainly the high investment costs, and regardless of environment-oriented attitudes (or lack of them), one should be aware that due to the general trends in the EU in the coming years, the transition from conventional to renewable energy sources is unavoidable in Poland, and amendments to the law (that of the European Community and Polish) will promote these changes.

Contrary to popular belief, an eco-friendly attitude does not necessarily mean investors have to voluntary cover additional costs for environmental protection. In many cases, the benefits from eco-friendly actions are doubled: profit related to the use of renewable solar energy also means that emissions of harmful gases into the atmosphere are reduced. It should, however, be borne in mind that the whole of human activity has an impact on the natural environment. Reduction in greenhouse gases emission achieved through the use of PV cells must be accompanied by the environmentally friendly technology for their production. For this purpose, a detailed life cycle assessment (LCA) is carried out to demonstrate the stages in the life cycle of the product which have a negative impact on the environment.

A key element influencing the ROI in photovoltaic systems is new technology, which in the coming years may revolutionize the PV market. The price of printed PV cells may be up to 5-fold lower compared to conventional cells, so even if their performance is relatively lower (about 20%), they will be attractive to individual investors.

Summing up:

- subsidies for the installation of PV systems significantly reduce the cost of investment – it is worth applying for subsidies from NFOŚiGW and ROP programmes supporting prosumerism, as well as using other available sources of funding;
- beneficiaries can take advantage of loans, but also non-returnable grants – this gives a chance for a long-term reduction in the cost of electricity, and transition from conventional to renewable energy sources;

- the revised version of the law on RES promotes the use of solar energy and gives prosumers relevant safety solutions ensuring that the surplus of generated energy will be sold to the network;
- in this context criticism has to be expressed about the *Energy policy of Poland until 2030*, where the development of the renewable energy sector based on photovoltaic cells is given very little attention (instead, the share of electricity generated by nuclear power plants is expected to be higher than 10% in 2030), and is particularly marginalised in comparison to energy from biomass and wind power (the policy stresses the need to create at least one biogas plant per municipality before 2020)[30];
- investments in photovoltaic systems can extend the range of diversified sources of energy, and are economically justified prosumer operations.

Authors' contributions to this article:

Łukasz Szałata, PhD Eng. – 33%
Agata Siedlecka, MSc Eng. – 33%
Cezary Lejkowski, MSc Eng. – 33%

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