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Economic Efficiency of Photovoltaic Installations

(A Case Study at the Zwierzyniec–Biały Słup Research and Education Centre of the Roztocze National Park)

Piotr Gradziuk
University of Life Sciences in Lublin, Poland

Abstract

The paper presents an assessment of the economic efficiency of a 21 kW photovoltaic system consisting of 92 Viessmann Vitovolt P230RA modules and an SMA Sunny Tripower 17000TL inverter, installed at the Zwierzyniec-Bialy Słup Research and Education Centre of Roztocze National Park. The study was carried out from 1 January 2012 to 31 December 2014. The total investment cost associated with the purchase and assembly of the photovoltaic system was PLN 505 489,67. The annual value of the electric energy produced, including revenue from the sale of certificates of origin during this period, was PLN 6 793,48. The payback period for the investment was calculated at 74 years, which is more than double the anticipated exploitation period (30 years), with a present net value (NPV) of PLN 229 000. The paper also presents the results of a simulation-based calculation of the economic efficiency of such a system for three levels of investment costs: PLN 6 000 per kWp — variant 1, PLN 7 000 per kWp — variant 2, and PLN 8 000 per kWp — variant 3. The payback period ranged from 19 to 25 years, depending on the variant, and the NPV was positive for all variants.

Keywords: economic efficiency, photovoltaic installation, renewable energy sources, green power, grid-connected

Introduction

Except for tidal energy (85 EJ/a), which is the result of gravity, mainly lunar, and geothermal energy (672 EJ/a), all other forms of energy begin with absorbed solar radiation – 3,93 x 106 EJ/a (Odum 1996). Solar energy reaching the geobiosphere enables hydrological, biological, chemical and physical processes, as a result of which thermal energy, hydroelectricity, wind energy and biomass energy are produced. Fossil fuels (coal, petroleum and natural gas), which were first exploited in about the 14th century, are the result of the effect of the sun, as they arose from the slow transformation of biomass (Smil 1994).

The amount of energy reaching our planet over the course of a year exceeds the world energy demand 1000 times (Ney 1994). In practice, however, energy from solar radiation is diffuse and difficult to exploit directly and efficiently, but methods are continually being improved. According to a study by Roszkowski (2001), the main sources of renewable energy in Poland will be biomass and solar energy acquired in photothermal processes. The best conditions for exploiting solar energy are found in eastern Poland, from Białowieża to Zamość, and on the west coast (Tymiński 1997). The rate at which these resources are exploited will depend on the economic efficiency of their acquisition (Fetliński and Juźwik 2011).

Until recently, energy acquired in this manner was more expensive than conventional energy in most applications, but as foreseen by Woś and Zegar (Woś and Zegar 2002), “time works in favour of renewable resources,” and while the process is slow at first, it can be accelerated by the development of new technologies and by increases in the price of non-renewable fuels (Ney 1994).[1] Nevertheless, the payback period of investments in photovoltaic systems exceeds the guaranteed lifespan of photovoltaic modules, which is usually 20–30 years. Hence in order to encourage investors to use technologies based on exploitation of renewable energy sources, including photovoltaics, a variety of initiatives have been undertaken at the international or national level. One such measure in Germany was a pilot programme for installing photovoltaic systems on the roofs of residential buildings. In 1998 an even more serious challenge was taken up — the "100 000 roofs programme," the idea of which was to create an economic system encouraging investment in such installations.[2] The mechanism involved the introduction of "Feed-in Tariffs" (FIT), because the prices of energy produced from zero-emissions sources were higher than the prices of energy from conventional sources. Currently such regulations are in effect in most EU countries (Olchowik 2011).

A Feed-in Tariff is a regulated price for a unit of energy from renewable sources which the power distribution company is required pay the producers in the area where it operates. The amount of the FiT is determined by public authorities, which guarantee the producers sale of energy for a specified time period (usually 20 years). The amount of the tariff depends on the type of technology (wind, solar, biomass, etc.) and on the specific character of the resources of the country (e.g., the level of insulation). In Poland, to support the production of energy from renewable sources a system was introduced in 2006 establishing the obligation to acquire certificates of origin and submit them for collection, the obligation to pay a compensation fee, and the obligation to purchase electric energy and heat generated from renewable energy sources.[3] However, owing to the European Union Climate and Energy Package adopted by the European Parliament on 17 December 2008, member countries were required to implement renewable energy decisions by January 2010. In Poland, as of 4 December 2014, a bill regarding renewable energy had been sent to the appropriate committees of the Sejm after the first reading.

According to an estimate by experts from the European Biomass Association, as early as 2010–2020 the highest growth dynamics in exploitation of renewable energy will be in energy from solar cells (120-fold increase) and solar thermal collectors (20-fold increase).[4]

1 Material and methods

The study is a continuation of a long-term analysis of the efficiency of exploitation of renewable energy sources, mainly biomass and solar power (Gradziuk 2012a, 2012b). It was conducted at the Zwierzyniec-Biały Słup Research and Education Centre of Roztocze National Park from 1 January 2012 to 31 December 2014.

The aim of the study was to assess the economic efficiency of a photovoltaic system, determined using the indicators NPV and IRR. The NPV (net present value) is defined as the difference between the present value of net cash inflows and the initial investment. The IRR (internal rate of return) is the interest rate for which NPV = 0, and is a measure of the profitability of an investment. As the Centre received substantial financial support from the National Fund for Environmental Protection and Water Management, a simulation-based calculation of the efficiency of such a system was performed for actual costs.

The task was carried out during the initial period of the formation of this market in Poland, so the prices of components of photovoltaic systems and associated comprehensive services (e.g., consulting, sales, assembly, start-up, and service) were substantially higher than current prices. The Institute for Renewable Energy, conducting a study commissioned by the Ministry of Economy, identified six economic entities operating in this branch of industry in 2007, and as many as

1. See also: Communication from the Commission. Energy for the Future: Renewable Sources of Energy. White Paper for a Community Strategy and Action Plan. COM(97)599 final (26/11/1997), s. 48–52, [@:] http://europa.eu/documents/comm/white_papers/pdf/com97_599_en.pdf.

2. 100.000-Dächer-Programm; more information at http://www.100000daecher.de/.

3. See: Rozporządzenie Ministra Gospodarki z dnia 19 grudnia 2005 r. w sprawie szczegółowego zakresu obowiązków uzyskania i przedstawienia do umorzenia świadectw pochodzenia, uiszczenia opłaty zastępczej oraz zakupu energii elektrycznej i ciepła wytworzonych w odnawialnych źródłach energii, DzU z 2005 r. nr 261 poz. 2187.

4. See European Biomass Statistics 2009 at webpage of European Biomass Association, http://www.aebiom.org/.

198 in 2013. In 2013 alone wholesale prices of monocrystalline panels had fallen by 25% since the previous year, and polycrystalline panels by 38% (Rosołek, Santorska, and Więcka 2013). Hence in this article the economic simulation of the efficiency of the photovoltaic system was performed on the assumption that the unit investment cost was PLN 6 000 per kWp in variant 1, PLN 7 000 per kWp in variant 2, and PLN 8 000 per kWp in variant 3 (approximate market value including the purchase of apparatus and system components: modules, power inverter, mounting structure, accessories, wiring, and installation design and assembly).[5]

Empirical data concerning the production and sale of electricity from the photovoltaic system was obtained on the basis of meter readings. Investment and exploitation costs were obtained from the accounting department of Roztocze National Park. The price of electric energy was based on a statement by the President of the Energy Regulatory Office (ERO) (29/2013) on the average selling price of electricity in the competitive market in 2013 (PLN 196,35 per MWh). The value for the unit compensation fee (PLN 297,35) was also based on information from the President of the ERO (3/2013).

2 Characterization of the site

The Zwierzyniec-Biały Słup Research and Education Centre of Roztocze National Park was set up under the project 'Thermo-modernization using renewable energy sources', partially funded by the National Fund for Environmental Protection and Water Management (agreement no. 860/2009). The main objective of the project was to improve energy efficiency by means of thermo-modernization and the use of a control system for thermal energy receiving installations (heating coils in air handling units, a heating and hot water system) and renewable energy sources:

- Vitosol-type flat plate solar collectors (32) with 74 m^2 absorbers
- Vitocal 300-G BW/BWS 145 brine/water heat pumps—Viessmann (4) with total capacity of 171,2 kW
- A 150 kW biomass-fired plant with a Pyrot 150 boiler for two types of fuel—biomass and heating oil

The control system was programmed so that heat supplied by the solar thermal collectors would be used first, and then heat supplied by the heat pumps or biomass-fired plant.

Also installed in the building was a photovoltaic system consisting of 92 Vitovolt P230RA modules (Viessmann), with nominal power of 220 Wp (peak Watt). This is the power output that can be obtained from a given model in STC (Standard Test Conditions)—i.e., a module temperature of 25°C, 1000 W/m^2 irradiation, and AM 1,5 spectral distribution of irradiation (clear sky at noon).

The system was installed on the south side of the roof and divided into 4 circuits of 21 modules each and one circuit consisting of 8 modules, with a total capacity of 21,16 kW. An SMA Sunny Tripower 17000TL solar inverter with a maximum power rating of 20 kW was used to supply energy with the necessary parameters from the solar cells to the electrical grid. The inverter was connected to a TF1 dashboard and a metering system. The energy obtained from the system is first used to power the Centre's machinery, and the surplus is sent to the Local Metering and Billing System of PGE Dystrybucja.

Resale of energy surpluses required not only the installation of suitable metering devices (a meter for active and passive power in networks with two-way power flow) and transmission devices (a module enabling transmission of meter data from the main and back-up metering systems to the PGE Dystrybucja system via a GSM network), but also the fulfilment of legal requirements. One of the most important of these was to obtain a licence to produce energy, issued by the President of the ERO. Then the management of Roztocze National Park applied to the operator of the local electricity grid (PGE) for issuance of connection terms and an annex to the agreement on connection to the grid. A producer of electricity from renewable sources has the right to apply to

5. [In the journal (in both Polish and English texts) European practice of number notation is followed—for example, 36 333,33 (European style) = 36 333.33 (Canadian style) = 36,333.33 (US and British style). Furthermore in the International System of Units (SI units), fixed spaces rather than commas are used to mark off groups of three digits, both to the left and to the right of the decimal point.—Ed.]

the President of the ERO, by the agency of the grid operator (PGE OBRÓT), for the issuance of certificates of origin, which can be sold off at the Towarowa Giełda Energii commodity exchange. The management of Roztocze National Park submitted such an application in July 2012. During the period covered by the study 36 certificates of origin were obtained.

3 Results

Table 1 presents quantitative data on the production and sale of electricity from the photovoltaic system. It is worth noting the substantial differentiation in production, from 12,4 MWh in 2013 to 16,0 MWh in 2014. According to a specialist supervising the functioning of the system, the main reason for this was the highly favourable weather conditions in 2014 (little snowfall in winter and many days with high insulation in March, September and October).

Tab. 1. Production and sale of electricity for the 21 kW photovoltaic system (kWh)

	2012		2013		2014	
Month	**production**	**sale**	**production**	**sale**	**production**	**sale**
January	72	0	33	0	151	1
February	75	11	171	24	431	93
March	1 335	612	308	112	1 331	549
April	1 329	649	1 425	717	1 602	638
May	1 840	936	1 821	714	1 921	347
June	1 477	670	1 956	935	2 151	633
July	2 133	1 103	2 138	996	2 206	672
August	1 869	994	1 912	702	2 088	790
September	1 343	634	1 172	492	2 121	894
October	937	348	953	242	1 458	532
November	351	44	322	22	429	73
December	40	1	228	6	160	4
Total	12 801	6 002	12 439	4 962	16 049	5 226

Source: Zwierzyniec–Biały Słup Research and Education Centre of Roztocze National Park

The total investment cost associated with the purchase and assembly of the photovoltaic system was PLN 505 489,67. The average annual value of the electricity produced, including revenue from the sale of certificates of origin during the period studied, was PLN 6 793,48. The payback period calculated on the basis of this information is about 74 years, and thus over twice the anticipated period of exploitation (30 years). On the basis of the analysis it can be concluded that in the conditions described above electricity production is economically inefficient, and that the enterprise was possible due to a subsidy from the National Fund for Environmental Protection and Water Management in the amount of PLN 501 380. The nearly 100% subsidy was due to the research and educational goals to be met by the beneficiary.

Presented below (tab. 2) are the results of the simulation-based calculation of the efficiency of the system, for the actual expenditures and for variants 1, 2 and 3. The calculation was carried out based on the following assumptions:

- financing — 20% from the entity's own funds, 80% from a loan by the Voivodship Fund for Environmental Protection and Water Management, 2% interest per annum
- reduction in output of photovoltaic modules — 0,5%/year
- service costs — 2% of revenue from the installation
- increase in energy prices — 5%/year
- price of certificates of origin — PLN 297,35

Tab. 2. Economic results of the photovoltaic system (21 kW)

	Payback period (years)	NPV (PLN)	IRR (%)
Actual	74	–228,555	0,0
Variant I	19	146,825	2,5
Variant II	22	125,825	2,1
Variant III	25	104,825	1,6

Given the changes in the price of energy and of certificates of origin in the years 2010–2013 (fig. 1), the assumptions regarding future prices may raise certain doubts. The values for these indicators result from the costs of implementing climate policy.

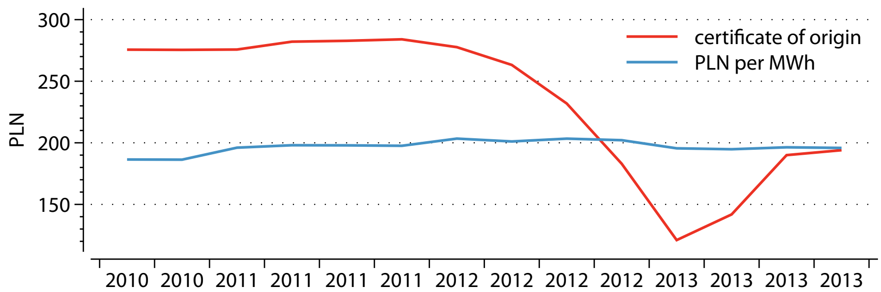

Fig. 1. Prices of certificates of origin and electric energy in the years 2010–2013

Source of data: Energy Regulatory Office and Towarowa Giełda Energii

The research and simulation-based calculation conducted using the example of a photovoltaic system installed at the Zwierzyniec-Biały Słup Research and Education Centre of Roztocze National Park show that given the cost incurred, the production of electricity is economically inefficient. The payback period is 74 years and the NPV: PLN 229 000. Since the decision was made and the winning tender was selected for construction of this experimental system, significant changes have taken place in the market for components of pholtovoltaic systems and associated comprehensive services, resulting in lower prices. Hence in current conditions each of the three variants analysed would be economically efficient. The payback period ranged from 19 years to 25 years, depending on investment costs, the NPV values were positive, and the IRR ranged from 1,6% to 2,5% (tab. 2).

Conclusion

Among the many methods of exploiting solar energy, the greatest interest is raised by its direct transformation into electricity via the photovoltaic effect. During this process no harmful substances resulting from chemical reactions are produced; it is a zero-emissions process. Moreover, no other undesirable effects occur, such as noise or radiation. Conversion of solar energy into electrical energy based on the photovoltaic phenomenon requires no conventional intermediate thermodynamic or mechanical stages. Hence in order to encourage investors to use technology based on the exploitation of renewable energy sources, including photovoltaics, various types of initiatives have been undertaken at the national and international level. In Poland, to support the production of energy from renewable sources a system was introduced in 2006 establishing the obligation to acquire certificates of origin and submit them for collection, the obligation to pay a compensation fee, and the obligation to purchase electric energy and heat generated from renewable energy sources. The study carried out using the example of the photovoltaic system installed at the Zwierzyniec–Biały Słup Research and Education Centre of Roztocze National Park showed that while production of electricity given this level of support is economically efficient, the payback period is very long — about 20 years.

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