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Assessment of Photovoltaic Systems in Public Utility Facilities in Light of the European Parliament Directive Requirements on Energy Efficiency

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Abstract

A public utility facility underwent an energy and economic efficiency audit regarding the photovoltaic system generating electricity for its own needs. The audit included an analysis of the amount of energy produced by the PV generation system, the calculation of the amount of the energy conserved, as well as the economic viability of the project in accordance with the guidelines contained in the Regulation of the Minister of Economy on energy efficiency. Two options for the financing of investments were considered: own resources of the public body or the purchase of the system with the financing from the EU funds — ROP Measure 7.2 – Improving air quality and increase in the use of renewable energy sources. On the basis of the economic analysis, it was determined that the installation of a photovoltaic system is economically justified only if the public body receives funding from external sources — such an investment (taking into account the changing value of money over time) may be recovered after 13 years of use, and the cost incurred to conserve energy will be twice lower than the cost of purchasing electricity from the grid.

Keywords: energy efficiency audit, photovoltaic system, public utility facility

JEL: Q28, Q42

Introduction

According to the Law on Energy Efficiency[1] which implements the Directive of the European Parliament and of the Council on Energy Efficiency[2], public sector entities are required to introduce "Energy efficiency improvement measures." Art. 8.1 of this Act determines the types of projects aimed at improving energy efficiency that should be carried out and financed by the public sector bodies, and in particular: purchase of energy-efficient products or outsourced service — they purchase energy-efficient products or commission services the performance of which is related to energy consumption; they purchase or rent energy-efficient buildings or parts thereof that meet at least the minimum requirements for energy efficiency and the thermal insulation of partitions, or implement other measures to improve energy efficiency within the energy performance of buildings. The products or services purchased by public authorities must meet the criteria for their inclusion in the highest energy efficiency class, if it is possible to achieve it — in the case of energy-using products, if they comply with the criteria of cost-effectiveness and technical suitability, and it is

1. See: Ustawa z dnia 20 maja 2016 r. o efektywności energetycznej. DzU z 2016 r. poz. 831.
2. See: Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC Text with EEA relevance. OJ L 315, 14.11.2012, pp. 1–56.

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economically justified. The proposed legislation maintains the Regulation of the Minister of the economy on the detailed scope and method of preparation of the energy efficiency audit, template form of audit and the methods for calculating energy savings.[3]

According to the regulation, the energy efficiency audit drawn up includes in particular:

- indication of the limit, according to the technical and economically viable types and variants of the project aimed at improving energy efficiency, including the use of different technologies
- a detailed description of the different types and variants of the project aimed at improving energy efficiency
- indication of the possible energy savings, including an assessment of the economic viability of each of the viable projects aimed at improving energy efficiency, in particular:
  - assumptions and data sources used to calculate energy savings
  - the manner of performing data analysis, the computational methods and mathematical models used and a detailed description of the templates, indicators and ratios used in the calculations,
  - assessment of the economic viability of individual types and options for the implementation of the projects aimed at improving energy efficiency, including in particular: the types of investment costs, the current assumed and projected prices of fuels and energy and the expected return on investment

Public authorities can use various options to enable greater energy efficiency in public buildings. One of these variants is to install a photovoltaic micro generation system which will generate energy for its own needs and thus reduce the energy demand from the grid. Additionally, there is the possibility of financing the purchase of this type of a system with the funds from the EU programs, therefore, the aim of the study was to perform an energy efficiency audit of the existing photovoltaic system operating for the needs of a public facility located in the Wieliczka County, Małopolskie Voivodship. The analysis has been prepared in accordance with the requirements enshrined in the Regulation on the detailed scope and method of preparation of the energy efficiency audit.

1 Subject of the study

The necessary studies for the implementation of the research have been carried out on the photovoltaic system operating for the needs of a public facility in the Małopolskie Voivodship. The PV generation facility operated in a standalone system in which the energy was produced only for the own needs of the facility without the possibility of introducing the produced surplus to the public grid. It consisted of 206 polycrystalline photovoltaic panels with a total nominal power of 53,56 kWp,[4] two inverters (the first with a capacity of DC 30,5 kW/AC 27,6 kW, the second with a capacity of DC 22,4 kW/AC 20,0 kW) and a system monitoring the operation of the system and preventing the outflow of the energy generated by the PV facility to the external energy grid (current transformers SolarLog CT 100A-o and monitoring devices SolarLog 1200 METER). The tasks related to the design and performance of the photovoltaic system were financed from the Regional Operational Programme for the years 2007–2013 under Measure 7.2 – Improving air quality and increase in the use of renewable energy sources.

2 Methodology

The research on the operation of the photovoltaic generation facility was carried out in the period from 1 September 2015 to 31 October 2016. It consisted of recording the consumption of electricity from the public grid in specific time zones in accordance with the requirements specified in the electricity sales tariff, group B23 and the volume of electricity generation by the PV facility with daily frequency.

3. See: Rozporządzenie Ministra Gospodarki z dnia 10 sierpnia 2012 r. w sprawie szczegółowego zakresu i sposobu sporządzania audytu efektywności energetycznej, wzoru karty audytu efektywności energetycznej oraz metod obliczania oszczędności energii. DzU z 2012 r. poz. 962.

4. [In the journal 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). — Ed.]

The cost of charges for the energy from the public grid were determined on the basis of the charges for the given tariff group, according to the relationship:

$$O_{poi} = O_s + O_z\,, \tag{1}$$

$$O_s = S_{SV_n} \cdot P_i + S_{op} \cdot P_i + O_a\,, \tag{2}$$

$$O_z = \sum_{k=1}^{r} C_i \cdot E_{pik} + \sum_{k=1}^{r} S_{ZV_nk} \cdot E_{pik} + S_{oSJ} \cdot E_{ok}\,, \tag{3}$$

where:

O_{poi} — charge for electricity and distribution services calculated for a given customer in PLN,
O_s — fixed charges associated with the value of the contracted energy and the subscription fee,
O_z — variable charges dependent on electricity consumption,
S_{SV_n} — fixed component of the grid rate in PLN/kW per month,
P_i — contracted capacity specified in the contract for the consumer in kW,
S_{op} — transition fee rate in PLN/kW per month,
O_a — subscription fee in PLN,
C_i — price for the electricity in a given time zone in PLN/kWh,
E_{pik} — amount of energy taken from the grid by the consumer in time zone k in kWh,
S_{ZV_nk} — variable component of the grid rate for the time zone k in PLN/kWh,
S_{oSJ} — quality rate in PLN/kWh,
E_{ok} — amount of electricity consumed by the consumer and other consumers connected to the grid using the national energy system in kWh,
r — number of clearing zones.

3 Indicators of economic evaluation

The choice of a particular system should be based on objective criteria. It is widely believed that the surplus of costs over effects is such a criterion — including both the initial costs and all costs incurred within a given period of the operation of the system (Szul 2015). The economic analysis was performed on the basis of complex methods of the evaluation of investment property, based on the interest rate (discount rate), taking into account the change in time value of money. These methods are (Laudyn 1999):

- net present value of the project (NPV), it is the sum of all future revenues for the lifetime of the investment brought to the current year less capital expenditures (in thousands of PLN):

$$NPV = \sum_{n=1}^{n=t} \frac{WRK_n}{(1+i)^2} - NI\,; \tag{4}$$

- discounted pay-back period (PBP), the period of time in which the discounted cash flows cover capital expenditures; the discounted pay-back period takes into account the variable value of the amount invested in time (in years):

$$PBP = \frac{\ln\left(\frac{1}{1-\frac{NI}{WRK}\cdot i}\right)}{\ln(1+i)}\,; \tag{5}$$

- internal rate of return (IRR), this is the value of the discount rate at which the net present value NPV is zero; the condition of investment profitability criterion is met $IRR > i$:

$$\sum_{n=1}^{n=t} \frac{WRK_n}{(1+IRR)^n} - NI = 0\,; \tag{6}$$

- cost of conserved energy (CCE); if the cost of the energy conserved is less than or equal to the price paid for energy, there are indications that the investment is profitable (in PLN/kWh):

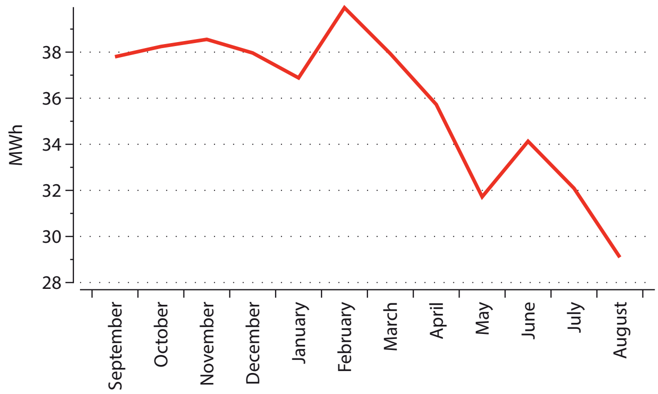
(7) $$CCE = \frac{NI \cdot \frac{i}{1-(1+i)^{-n}} + K_{e,o}}{\Delta E};$$

where:
WRK — value of annual benefits (in thousands of PLN),
NI — initial costs (i.e., the cost of purchase and deployment) (in thousands of PLN),
$K_{e,o}$ — annual operating costs of the system, in thousands of PLN,
ΔE — annual energy conserved (in kWh),
n — ($n = 1, 2,..., 25$) another year of costs (the assumed number of the years of the life cycle of the system: 25),
t — another year of the use of the system,
i — discount rate (3% assumed according to).[5]

4 Findings

4.1 Technical analysis

In the studied public utility facility, the average annual electricity consumption was at approximately 430 MWh. whereas the monthly energy consumption (fig. 1) in the period under consideration varied from 29 MWh in August to almost 40 MWh in February. The design assumptions for the construction of the micro generation PV system under consideration for the public utility facility stated that the energy generated will be used solely for the needs of the facility and its energy, due to the daily limit load profile, was 53,56 kWp.



Tab. 1. Monthly electricity consumption in the studied public utility facility (September 2015 – August 2016)

The efficiency of the photovoltaic generation facility is, to the greatest extent, influenced by the intensity of solar radiation and the time in which its value exceeds the threshold value allowing the generation of electricity by the photovoltaic module. Long-term data shows that the average monthly value of the radial intensity at the location of the generation facility fluctuated in a range from about 200 W/m^2 in the winter months to more than 350 W/m^2 in the summer months. In the summer months, there are favorable working conditions for the PV system not only because of the higher intensity of radiation (fig. 2), but also because of the triple extended period of time in which it can operate (fig. 3).

Based on many years of meteorological data and data sheets of the used PV modules, the theoretical amount of electricity production was estimated. Assuming that, at the location of the generation facility, annual solar radiation is 1 040 kWh/m^2, diffusion radiation is 566 kWh/m^2 and the surface of the modules with a capacity of 53,56 kWp is 344 m^2, the estimated annual DC electricity output will be 51,3 MWh. Once converted, sinusoidal variable voltage will be available at the level of 49,4 MWh of electricity. In the study period, the monthly theoretical and actual

5. See: Stopa referencyjna i archiwum. [@:] https://uokik.gov.pl/stopa_referencyjna_i_archiwum.php.

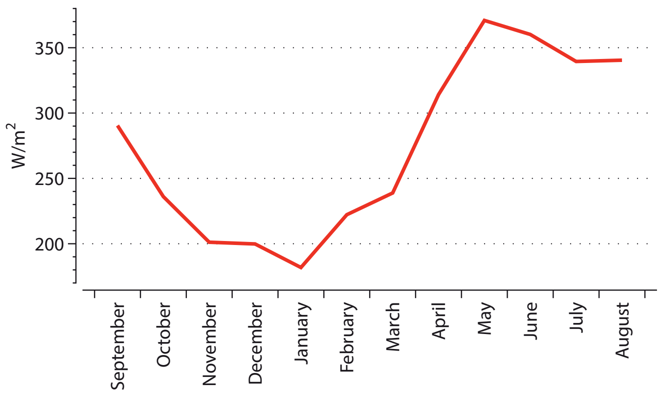


Fig. 2. Average monthly solar radiation at the location of the PV system (September 2015 – August 2016)

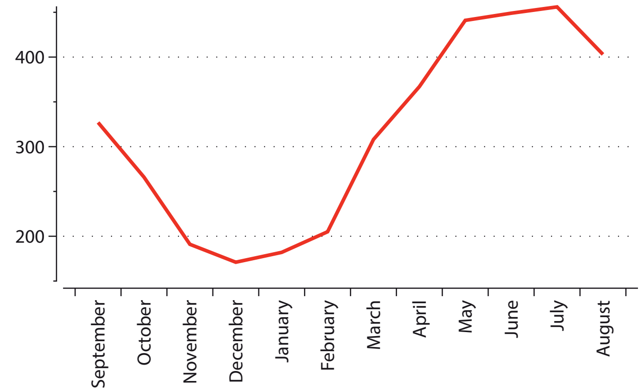


Fig. 3. Monthly number of hours in which solar radiation exceeds 50 W/m^2 (September 2015 – August 2016)

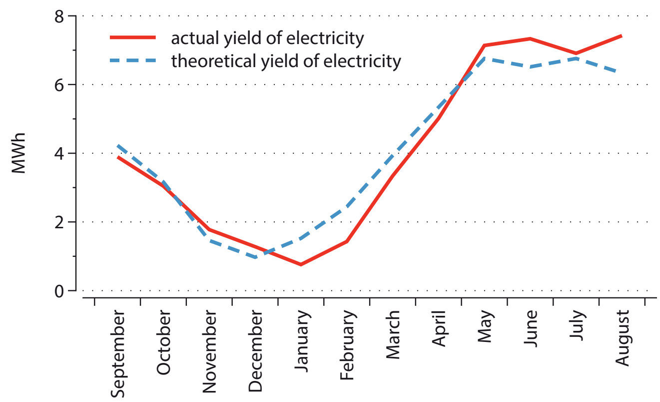


Fig. 4. Theoretical and actual yield of electricity from the PV facility (September 2015 – August 2016)

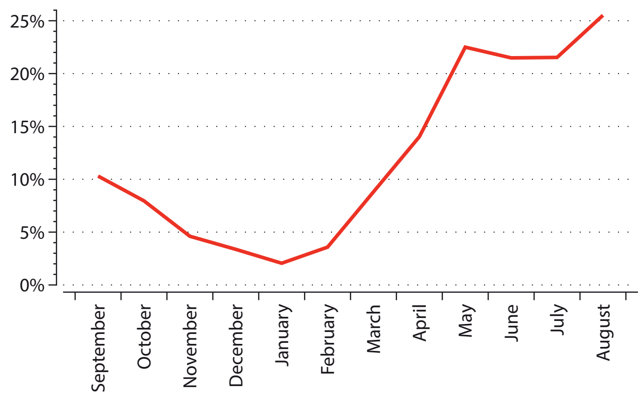


Fig. 5. Coverage of electricity demand from the PV generation facility (September 2015 – August 2016)

amounts of the electricity produced vary by the average of 500 kWh but, in the case of yearly intervals, the difference is at the level of only 90 kWh. Thus we consider the period representative for the operation of the PV facility and use it to further economic analyses. During the study, the PV facility generated 49,3 MWh. Most of the energy was acquired in the summer months (May–August) and its share accounted for almost 60% of the annual production. For such a system, the coverage of the monthly demand for energy varied from only 2% in January to over 25% in August.

4.2 Economic analysis

In order to conduct an economic analysis of the studied photovoltaic system in the public utility facility, the actual costs were assumed (obtained from the investor), as incurred for the purchase and installation of the photovoltaic system in the facility, the cost of electricity, the cost of reducing the value of the asset (depreciation), the insurance and handling (inspection) of the system. The economic analysis will be performed for two scenarios, that is:

- a public authority finances the whole investment from its own resources, and
- a public authority obtains funding from the Regional Operational Programme Measure 7.2 – Improving air quality and increase in the use of renewable sources of energy, in the amount of 85% of the eligible investment costs.

The economic assumptions for the calculation along with the estimated value of annual benefits (TRC) arising from the use of the micro generation photovoltaic system are summarized in table 1.

On the basis of the economic analysis (tab. 2), it can be determined that any public authority which would install a photovoltaic system based solely on its own resources would suffer a loss — despite the fact that the system leads to annual savings (TRC) at the level of PLN 8,13 thousand, due to the high investment costs, it will not lead to real savings — as all of the values of economic indicators prove. The net present value (NPV) is negative and amounts to PLN −127 thousand and thus that will be the loss amount incurred by the authority within the assumed period of operation — the investment will never be recovered. The CCE indicators also suggest that the cost incurred to save energy is greater than the cost of purchasing energy, and ranges from 0,56 PLN/kWh.

Tab. 1. Basic assumptions for the economic calculation

Specification	Value	
N — capital expenditures net (thousands of PLN)	221,5 [a]	188,27 [b] 33,23 [c]
VAT (thousands of PLN)	50,9 [a]	50,90 [d]
NI — gross fixed capital expenditure (thousands of PLN)	272,4 [a]	272,40 [d]
n — total number of years of operation	25	
o — maintenance costs, costs of repairs and insurance 0,5% net of investment costs (per year) (thousands of PLN)	1,10	
a — depreciation of the photovoltaic system (thousands of PLN)	10,90	
unit price (gross) of electricity (PLN/kWh)	0,4546	
i — discount rate	3%	
P_b — avoided costs of purchasing electricity (thousands of PLN)	20,13	
$K_{e,o}$ — annual operating costs of the system ($o + a$) (thousands of PLN)	12,00	
WRK — value of annual benefits ($P_b - K_{e,o}$) (thousands of PLN)	8,13	

[a] own resources, [b] purchase of funding — funding; [c] purchase of funding — own contribution; [d] purchase of funding

Tab. 2. Results of the economic analysis

	Own resources	Purchase with funding
NPV (thousands of PLN)	−127,00	55,70
PBP (years)	177,00 (not recovered)	13,00
IRR	–	8,36
CCE (PLN/kWh)	0,56	0,34

The only solution to the profitability of investments in the construction of photovoltaic system in public utility facilities is a scenario that assumes the reimbursement of eligible costs to the maximum of 85 percent of the cost of the project. In this case, the values of economic indicators point to the desirability of constructing the system. The investment can be returned in the period of approximately 13 years. It the assumed operation period, the benefits of the public authority in this respect may be approximately PLN 56 thousand. The cost of the energy conserved CCE is approximately 30% lower than the purchase price of energy. The IRR value (8%) also testifies to the profitability of this type of investments.

Similar conclusions can be found in the works (Dąbrowski et al. 2014; Główand Kurz 2013; Szul 2015) where photovoltaic systems in residential buildings were subjected to the profitability analysis. Depending on system power and energy consumption profile, payback for the system was 15–25 years, assuming that the system will be financed from external resources at the level of 40%–45%. The office building (Nawrot 2014) payback period with a similar level of financing is 9 years. All authors pointed out the unprofitable investment for the use of its own resources — this is due to the high cost of investment in the construction of the photovoltaic system and the relatively low energy yield from the plant during the winter when demand is highest.

Conclusions

On the basis of the energy efficiency audit conducted for the photovoltaic system in the public utility facility, the following conclusions can be drawn:

- At the location of the photovoltaic system, the monthly average value of the intensity of solar radiation fluctuated in the range from about 200 W/m^2 in the winter months to more than 350 W/m^2 in the summer months which are, at the same time, characterized by a period in which electricity can be generated which is three times longer.
- The photovoltaic system installed in the public utility facility can reduce energy consumption by approximately 49 MWh per year, which represents 12% of the demand for electricity. The annual benefit (including the cost of the system use) amount to PLN 8,13 thousand.
- The public authority that would install a photovoltaic system based solely on its own resources would suffer a loss — as proven by the value of all economic indicators.
- The energy efficiency of the project will be achieved only in the case of subsidizing the eligible costs to the maximum of 85 percent of the cost of the project. In this case, the values of economic indicators point to a return on investment which can be recorded after 13 years of use and the savings that can result are approximately PLN 56 thousand. The cost of the energy conserved is lower by approximately 30% than the cost of purchasing electricity from the grid.

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