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Economic and Ecological Efficiency of Solar Systems. A Case Study at the Gorzków and Rudnik Communes

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Abstract

The objective of the study was to assess the economic and ecological efficiency of solar systems used to prepare domestic hot water. The study was carried out at 501 sites in the communes of Gorzków and Rudnik (Krasnystaw County, Lubelskie Voivodship), mainly households, in the years 2014–2015. The results indicate that solar collectors used to prepare domestic hot water and financed by the investors' own resources can be economically efficient, but the payback period for the investment depends on the type and quantity of energy carrier saved. The most beneficial effects were obtained at sites where water was heated using equipment powered by electricity and natural gas. In the case of coal savings, the payback period was longer than the lifespan of the solar installations. The use of solar collectors to heat domestic hot water (DHW) in the Gorzków and Rudnik communes led to a reduction in emissions of CO_2, the primary greenhouse gas, as well as other substances. The study shows that the most beneficial cost-effectiveness of CO_2 emission reduction was obtained by reducing the use of electricity, while the highest cost-effectiveness indicator was noted for gas installations.

Keywords: economic efficiency, solar installation, renewable energy sources

Introduction

The amount of solar energy reaching the Earth in one year is a thousand times greater than the global demand for energy (Ney 1994; Odum 1996). This energy, however, is diffuse and difficult to exploit directly and efficiently, but methods are continually undergoing improvement. 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 observed for energy obtained from solar cells (a 120-fold increase) and solar thermal collectors (a 20-fold increase).[1] In the European Union, exploitation of solar energy more than doubled in the years 2010–2013, and in 2013 its percentage share of renewable energy acquisition was 5,5%.[2] Among European countries its role is most important in Greece, Spain and Cyprus, where it is not only a major source of renewable energy, but also meets from 2,1% to 3,2% of the final energy demand. Among other countries, solar energy plays the largest role in Germany, where it accounts for about 10% of energy acquisition from renewable sources — twice the share of hydropower and comparable to that of liquid biofuels. In Poland, while exploitation of solar energy doubled in the years 2010–2014, from 350 TJ to

1. See: European Biomass Statistics 2009 — A statistical report on the contribution of biomass to the energy system in the EU 27 by Peter Rechberger et al., Aebiom: Brussels, 2009.

2. See: Supply, transformation and consumption of renewable energies — annual data. [@:] http://ec.europa.eu/eurostat/en/web/products-datasets/-/NRG_107A.

[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.]

720 TJ, its contribution to renewable energy acquisition was only 0,21% (Berent-Kowalska et al. 2015). In 2014 over 96% of solar energy was acquired using solar thermal collectors, with a combined surface area of 1 741 000 m^2.

Because its production costs (mainly of electricity) are considerably higher than in sources exploiting non-renewable fuels, the growth of this market depends on the size of subsidies (Żylicz 2012). Individual countries choose to support renewable energy production because it is currently the primary means of achieving national indicative targets arising from the climate and energy package, and in the near future also the global climate agreement negotiated in Paris during the 21st Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC), held from 30 November to 12 December 2015. The choice of methods and the scope of support, even in the case of an ample budget, should be consistent with the principle of sound management, which in practical terms is based is on the criterion of efficiency.

1 Material and methods

The study was a continuation of long-term analyses of the efficiency of exploitation of renewable energy, mainly biomass and solar power (Gradziuk 2012a, 2012b, 2013, 2014, 2015). It was carried out in 2014–2015 at 501 sites in the communes of Gorzków and Rudnik (Krasnystaw County, Lubelskie Voivodship), mainly households. The objective was to assess the economic and ecological efficiency of solar systems used to prepare domestic hot water. The economic measure was the value of the savings obtained by their users. The ecological outcomes were the reduction in emissions of CO_2, CO, SO_2, NO_x, and particulates, expressed in Mg. Estimations of empirical data on the consumption of energy carriers prior to realization of the project were based on statements by the potential beneficiaries. The volume of thermal energy production was obtained from readings of meters after the first year of installation, and investment costs were provided by the individuals responsible for carrying out the project in the two communes. Calculations were based on the following assumptions:

- contribution of investors' own capital in the investment: 100%
- available interest rate on a deposit in the banking market: 2%
- operation period: 25 years
- decrease in efficiency of collectors: 0,7% per year
- maintenance and service costs: 3% initial value per year
- price of coal: 28 PLN/GJ
- price of electricity: 360 PLN/MWh (100 PLN/GJ)
- price of natural gas: 66 PLN/GJ
- increase in energy prices: 2% per year

2 Study area

A study conducted by Roszkowski (2001) indicates that the main renewable energy sources in Poland will be biomass and solar energy. This assertion is supported by statistics on acquisition of primary energy. In 2005–2014 the main renewable energy source was biomass, but its contribution has decreased, while the role of solar and wind energy is growing; their consumption has increased 70-fold and 30-fold, respectively. The main reasons for such a pronounced increase in the use of solar energy were subsidization of this energy sector and the increasingly lower costs and higher energy efficiency of photovoltaic and solar installations. In 2013 alone wholesale prices of monocrystalline panels in Poland were 25% lower than in the previous year, and prices of polycrystalline panels were 38% lower (Rosołek, Santorska, and Więcka 2013). Similar tendencies were observed in the global market (fig. 1).

Systems for preparation of domestic hot water, mainly in households, have accounted for the largest share of existing solar installations in Poland. A major contributor to the popularization of this means of energy acquisition has been the National Fund for Environmental Protection and Water Management (NFEP&WM), which in 2009 began implementation of a programme of bank

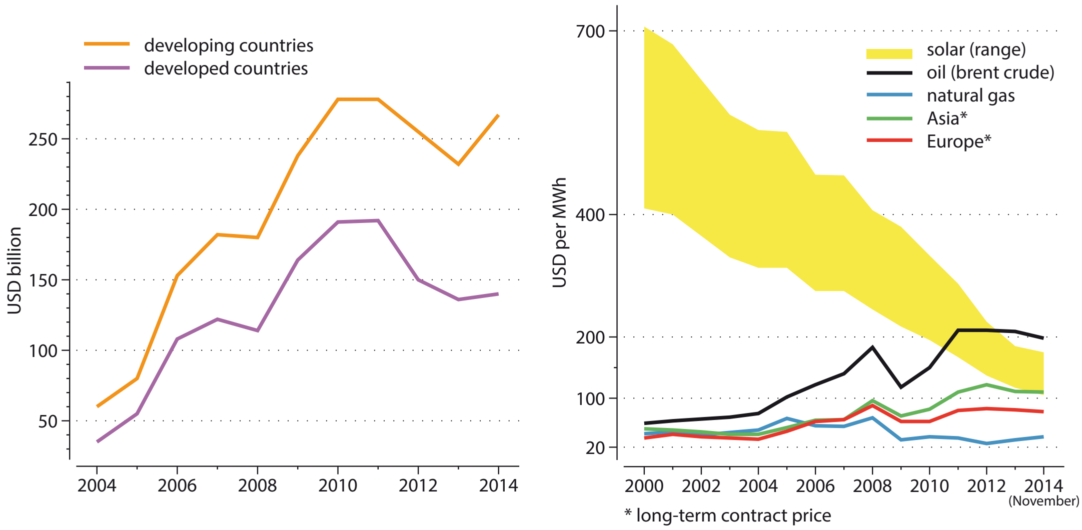

Fig. 1. The value of investments in renewable energy and electricity generation costs in selected sources

Source: Own elaboration based on UNEP, Bloomberg New Energy Finance; IHS Energy publication

loan subsidies (in the amount of 45% of eligible costs) for the purchase and installation of solar thermal collectors. The offer was available to individuals and homeowners' associations having the power of disposal of the building and unconnected to the district heating system (Walczak 2014). A sum of 450 million PLN was allocated for its implementation in 2010–2014, which enabled financing of installations with a combined surface area of 483 800 m^2.[3]

Considerably more favorable financial conditions for renewable energy investments were available under Regional Operational Programmes (ROP)—financial perspective for the 2007/2013 period. An analysis performed at the Institute for Renewable Energy (Wiśniewski 2011) showed that successful applicants were most interested in solar thermal energy (in particular solar thermal collectors for heating domestic water). The share of funds granted for such installations was 45% of the total pool of funds allocated to support development of the use of renewable energy.

The project "Solar energy in the Gorzków and Rudnik communes" was co-financed by the European Regional Development Fund under the Regional Operational Programme of the Lubelskie Voivodship for 2007–2013, Priority Axis VI: Environment and clean energy, Measure 6.2 Environmentally friendly energy. The project involved the installation of solar systems for preparation of domestic hot water in 492 individual residential buildings (Gorzków Commune—296, Rudnik Commune—196) and 9 public buildings in the Gorzków and Rudnik communes. The primary goal of the project is to improve the state of the natural environment in the Gorzków and Rudnik communes while increasing the economic attractiveness of the region and its appeal to tourists, as well as raising the quality of life of local communities.

3 Results

To assess the economic efficiency of an investment a comparison is made of incurred or planned expenditures with anticipated revenues. In the case of the project analysed, its outcomes are the savings obtained as a result of partially replacing conventional energy carriers used to prepare domestic hot water (DHU) with solar yield, as solar installations can only supplement traditional systems. At the sites analysed water was heated mainly by coal (62%), electricity (37%) and to a small degree natural gas (Rudnik Commune), so these energy sources were used in the calculations.

The total costs of heating DHU consist of expenses incurred for the purchase and installation of the necessary equipment and maintenance costs. At the sites studied the capacity of the equipment

3. See: Załącznik do Uchwały nr 33/15 Rady Nadzorczej NFOŚiGW z dn. 27 kwietnia 2015 r. Sprawozdanie z działalności 2014. Zainwestujmy razem w środowisko. Warszawa, kwiecień 2014, [@:] https://www.nfosigw.gov.pl/gfx/nfosigw/userfiles/files/o_nfosigw/sprawozdania_z_dzialalnosci/2014/sprawozdanie_z___dzialalnosci_nfosigw_w_2014_r.pdf.

Tab. 1. Investment costs in relation to the size of the solar installation and the amount of thermal energy produced during the operation period

Type of installation	Collectors (in PLN)	Installation kits (in PLN)	Storage tanks (in PLN)	Pumps (in PLN)	Automation (in PLN)	Fittings and heat-transfer fluid (in PLN)	Installation (in PLN)	Total (in PLN)	Number of installations	Total costs (in PLN)	Energy production (in GJ)	Costs (in PLN/GJ)
Two-panel with 250 liters storage tank	2 929,30	539,61	1 773,00	462,52	385,43	616,70	1 002,13	7 708,70	126	1 002 131,00	20 238,3	49,5
Three-panel with 300 liters storage tank	3 317,92	611,20	2 008,22	523,88	436,57	696,51	1 135,08	8 731,37	67	541 344,94	16 002,4	33,8
Four-panel with 400 liters storage tank	3 962,18	729,88	2 398,16	625,61	521,34	834,14	1 355,48	10 426,80	264	2 752 675,20	65 758,3	41,9
Five-panel with 500 liters storage tank	4 515,53	831,81	2 733,08	712,98	594,15	950,64	1 544,79	11 882,97	41	510 967,71	13 726,9	37,2
Six-panel with 600 liters storage tank (2 × 300)	4 829,41	889,63	2 923,06	762,54	635,45	1016,72	1 652,17	12 708,97	2	2 417,94	849,0	29,9
Nine-panel with 900 liters storage tank (400+500)	7 348,96	1 353,76	4 448,05	1 160,36	966,97	1 547,15	2 514,12	19 339,37	1	19 339,37	1 548,5	12,5
Total									501	4 851 876,16	118 123,4	

installed depended on the calculated demand for DHU. Over half (52,7%) were four-panel installations with a 400 l storage tank, while the others were two-, three-, five-, six-, and nine-panel installations (tab. 1).

The purchase of solar collectors (38%), storage tanks (23%) and installation (13%) accounted for the largest share of investment costs. Although the same type of collectors and equipment were installed at all sites, the unit investment costs in relation to the thermal energy produced were quite varied, ranging from 12,49 PLN/GJ for the nine-panel installations to 48,00 PLN/GJ for two-panel installations. The main reason for this variation was the amount of DHU used at the sites. Table 2 presents a basic statistical characterization of thermal energy produced in the 2014/2015 season in relation to the capacity and type of solar installation. The greatest variation in the use of solar energy was noted in the two-, three- and four-panel installations, in which the differences were 17-fold, 25-fold and 37-fold, respectively. This means that at some of the sites the demand for DHU was overestimated, in part because some individuals registered as residents of the building and taken into account in the estimate were temporarily residing elsewhere.

Tab. 2. Statistical characterization of thermal energy generated in the 2014/2015 season in relation to the capacity and type of solar installation (in GJ)

Type of solar installation	Average	Median	Minimum	Maximum	Stand. dev.
Two-panel	0,539	0,497	0,096	1,670	0,231
Three-panel	0,801	0,760	0,108	2,742	0,367
Four-panel	0,835	0,768	0,071	2,626	0,381
Five-panel	1,123	1,035	0,384	2,278	0,509
Six-panel	1,422	1,422	1,222	1,622	0,200
Nine-panel	5,193	5,193	5,193	5,193	0,000

Maintenance costs included expenditures for the purchase of electricity to power circulator pumps, service, and changing heat-transfer fluid, according to the manufacturer's recommendations. Their annual volume is estimated at 3% of the initial value of the investment outlays.

The data presented above were used to calculate the total costs of heating DHU in the solar installations, which were considered in relation to the value of the savings on conventional fuels. It was assumed that the efficiency of electric and gas water heaters was 90% and that of coal heaters was 70%. The data in table 3 indicate that the use of solar thermal collectors at the sites where electricity was used to produce DHU yielded savings ranging from PLN 235,95 PLN in the case of two-panel installations to 6 124,02 PLN in the nine-panel system. In the case of natural gas, the results achieved were only slightly less favourable. Only in comparison with coal were the savings higher than the costs (except for the nine-panel installations). These outcomes were mainly due to differences in the prices of the energy carriers, ranging from 28 PLN/GJ (coal) to 100 PLN/GJ (electricity).

Tab. 3. Savings or losses resulting from installation of a solar system and the payback period for the investment

	Size of solar installation — number of collectors											
	2		3		4		5		6		9	
	PLN	Years	PLN	Years	PLN	Years	PLN	Years	PLN	Years	PLN	Years
Coal	−260,41	36	−196,00	32	−296,68	39	−249,81	35	−152,08	29	1 338,24	11
Natural gas	−27,74	28	150,00	22	64,32	24	235,19	22	462,25	17	3 581,58	8
Electricity	235,95	20	542,14	15	473,46	19	784,86	16	1 158,50	13	6 124,02	6

Table 4 shows the threshold values for DHU consumption at which the costs of generating it would be equal to the savings on each of the energy carriers in the season analysed. This condition was met by over 80% of installations in which DHU was heated using electricity. In the case of natural gas and coal, these indicators were 38,1%–61,2% and 2,4%–17,1%, respectively, for the most frequently installed systems. Thus the greater the reduction in consumption of conventional energy carriers and the higher their purchase price, the greater the savings obtained and the shorter the payback period.

Tab. 4. Threshold values and the percentage of installations for which the cost of producing DHU in solar installations was equal to the savings on the energy carriers they replaced

	Size of solar installation — number of collectors											
	2		3		4		5		6		9	
	GJ	%	GJ	%	GJ	%	GJ	%	GJ	%	GJ	%
Coal	13,490	2,4	15,280	11,9	18,247	8,7	20,795	17,1	22,232	0,0	33,844	100,0
Natural gas	7,358	38,1	8,335	61,2	9,953	49,2	11,343	56,1	12,127	100,0	18,460	100,0
Electricity	4,856	82,5	5,501	81,0	6,569	85,2	7,486	95,1	8,004	100,0	12,184	100,0

One of the main reasons for the increased interest in the use of renewable energy is the desire to reduce pressure on the environment, as intensive exploitation and processing of traditional energy resources exert a highly detrimental effect on natural resources. The use of solar thermal collectors to heat DHU in the Gorzków and Rudnik communes led to a reduction of about 3% in emissions of CO_2, the primary greenhouse gas, and other substances[4] (tab. 5). The results of the study show that the most favorable cost-efficiency of CO_2 emission reduction (131 PLN/ton) was obtained by reducing consumption of electricity, while the highest cost-efficiency indicator was noted for gas installations (790 PLN/ton).

Tab. 5. Reduction in emissions of selected substances as a result of decreased consumption of conventional energy carriers in the Gorzkow and Rudnik communes in the 2014/2015 season

	Coal (4 546 GJ)		Electricity (2 111 GJ)		Natural gas (57 GJ)		
	EF	ER	EF	ER	EF	ER	Total ER
SO_2	0,65	2,95	0,868	1,83	0,001	0,00	4,78
NO_2	0,16	0,73	0,386	0,81	0,053	0,00	1,54
CO	4,70	21,37	0,000	0,00	0,008	0,00	21,37
CO_2	95,00	431,87	331,000	698,74	55,000	3,14	1 133,75
Dust	0,16	0,73	0,032	0,07	0,001	0,00	0,80

EF — emission factor (in kg/GJ); ER — emission reduction (in tons)

Conclusion

The study demonstrates that solar thermal collectors used to prepare domestic hot water and financed by the investors' own resources can be economically efficient, but the payback period for the investment depends on the type and quantity of energy carrier saved. The most beneficial effects were obtained at sites where water was heated using equipment powered by electricity and natural gas. In the case of coal savings, the payback period was longer than the lifespan of the solar installations. This variation is due to the prices of the carriers, which were highly varied: 28 PLN/GJ for coal, 66 PLN/GJ for natural gas, and 100 PLN/GJ for electricity. Taking into account trends in the market of solar system components and comprehensive services in this area, as well as the increase in the price of energy carriers over a long period of time, it should be concluded that the payback period will decrease in the near future. The use of solar collectors to heat DHU in the Gorzków and Rudnik communes reduced emissions of CO_2, the primary greenhouse gas, and other substances. The study shows that the most favorable cost-effectiveness of CO_2 emission reduction (131 PLN/t) was obtained by reducing consumption of electricity, while the highest cost-effectiveness indicator was noted for gas installations. The very high value obtained for gas is due to the fact that CO_2 emissions associated with this fuel are three times lower than in the case of coal and six times lower than in the case of electricity generated in coal plants.

4. Data from Low Emission Economy Plans were used as the basis for reference.

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