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ORIGINAL PAPER

FEASIBILITY STUDY OF THE USE OF RENEWABLE ENERGY SOURCES IN HOUSEHOLDS

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Abstract

The present study presents an estimation of the effectiveness of photovoltaic panels and a heat pump installation. The objective of the research was to evaluate the economic feasibility of investing in combined systems relying on renewable energy sources. The research results corroborated the first hypothesis, namely that the use of photovoltaic panels fully supplies the energy needs of the heat pump installed in the household. The other hypothesis, however, was not supported; namely that a combined investment in photovoltaic panels and a heat pumps will pay back in a period shorter than the half of the project's lifetime. The period of financial return slightly exceeded the assumed time. This means that a combination of a heat pump and a photovoltaic installation is economically feasible, but some forms of support with external capital should be applied.

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OCENA OPŁACALNOŚCI ZASTOSOWANIA ODNAWIALNYCH ŹRÓDEŁ ENERGII W GOSPODARSTWIE DOMOWYM

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Słowa kluczowe: odnawialne źródła energii, opłacalność, gospodarstwa domowe.

Abstrakt

W opracowaniu przedstawiono ocenę efektywności ekonomicznej zainstalowania instalacji fotowoltaiczno-ciepłowniczej oraz pompy ciepła. Celem badań była ocena opłacalności ekonomicznej inwestowania w połączone systemy odnawialnych źródeł energii. Wyniki badań pozwoliły potwierdzić pierwszą hipotezę, że zastosowanie paneli fotowoltaicznych zaspokaja potrzeby energetyczne pompy ciepła wykorzystywanej na potrzeby gospodarstwa domowego. Nie potwierdzono jednak hipotezy drugiej, że łączona inwestycja paneli fotowoltaicznych oraz pompy ciepła zwróci się w okresie krótszym niż połowa przewidzianej żywotności projektu. Okres zwrotu przekroczył nieznacznie założony czas. Oznacza to, że połączenie pompy ciepła z instalacją fotowoltaiczną jest opłacalne ekonomicznie, ale warto zastosować bardziej rozbudowane formy wsparcia kapitałem zewnętrznym.

Introduction

In Poland, access is available to various types of renewable energy, which may create a safe and economic energy mix (Świdyńska & Witkowska-Dąbrowska, 2020, p. 194, 195). Photovoltaic panels and heat pumps have become the most popular options for households seeking to utilize renewable energy. For the energy independence of households, these are very attractive solutions. An installation of photovoltaic panels of suitable capacity lowers the household's energy bills, while the use of heat pumps helps bring down the cost of heating. This is a substantial financial relief over the years. However, the heat pump requires electricity for operation. Therefore, a question arises about the short term economic benefits of using photovoltaic panels and the heat pump in the household, and the time of return on such investment. The aim of this research was to evaluate the economic viability of investing in combined systems of renewable energy.

Methodology of research

Two hypothesis were posed for the research:

H1: the use of photovoltaic panels fully covers the energy needs of a heat pump operating for the needs of a household,

H2: the combined investment in photovoltaic panels and a heat pump will pay back in the period shorter than the assumed half time of the project.

The analyzed period included 24 months between 2020 and 2022.

The source of data were internal documents obtained from the subject of the research: the cost estimation of the investment, incoming electricity bills for years 2020-2022, readings from measuring devices for photovoltaic panels and heat pumps. The source data was processed with selected simple and complex methods (Pastusiak, 2003, p. 85-95).

The calculated simple period of return (PP - payback period) was defined as the time needed to refund the expenditure incurred (Sobczyk, 2011, p. 172); DPP (discounted payback period) means the number of periods upon the sum of which the discounted net cash flows will equal zero (Herman & Koroblowski, 2003, p. 51-56).

The simple ROE (return on equity) shows the profitability only from the owner's point of view, including the net profit:

$$\mathrm{ROE} = \frac{Z_n}{K_w} \cdot 100\%,$$

where:

K_w – own equity,

Z_n – net profit.

The results show how much operational profit (ROI) and net profit (ROE) falls for every zloty of the investment expenditure (total and own) in every period.

Another non-discounted method is ARR (accounting rate of return). This is the average annual return (sum of the net profit divided by the length of the project expressed in years) divided by the average yearly investment understood as the sum of the initial and final net accounting value of the investment.

$$\mathrm{ARR} = \frac{\bar{Z}_n}{N} \cdot 100\%,$$

where:

$\bar{Z}_n$ – average net profit,

N – average yearly investment.

The approach described above works under the assumption that the capital financing the initial investment expenditures is engaged until the last year of the investment project. As this assumption is not always real, the accounting rate of return can be calculated based on the condition that the invested initial capital is returned on an ongoing basis along with the write-off of the created assets (Świdyńska & Witkowska-Dąbrowska, 2020, p. 197, 198). The complex or discounted methods allow one to eliminate the shortcomings of simple methods, taking into account the changing value of money depending on the timing of cash flows incurred for the estimated investment (Pastusiak, 2003, p. 85-95). The NPV (net present value ratio) allows the estimation of investment projects with reference to the main objective of the company's operation, which is maximizing the value of the owners' income through maximizing of the company's value. NPV is the difference between the sum of discounted future cash flows generated by the project and the total value of expenditure (Brodziński *et al.*, 2021, p. 2087).

$$\mathrm{NPV} = \sum_{t=1}^{n} \frac{\mathrm{CF}_t}{(1+r)^t} - \sum_{t=0}^{n} \frac{N_t}{(1+r)^t},$$

where:

t – given period of the total number n of the project periods; $t = 0, 1, 2, 3\ldots, n$; n – duration of the project,

CF_t – cash flow generated in period t,

r – discount rate,

N_t – expenditure in the project.

Decision criterion applied for this project: NPV > 0 PLN: the project is profitable, i.e. it covers the cost of the capital needed to invest in the project and brings surplus income; when NVP = 0, the project is acceptable; when NPV < 0: the project must be rejected (Mielcarz & Paszczyk, 2013, p. 22, 23).

The IRR (Internal Rate of Return) is a rate expressed in percentage, for the value of NVP = 0.

$$\sum_{t=0}^{n} \frac{\mathrm{CF}_t}{(1+\mathrm{IRR})^t} = 0.$$

This method is applied to calculate the real rate of profitability of the estimated investment, which allows one to compare the threshold rate of profitability with the real profitability of the investment.

Justification for the use of renewable energy sources in households in relevant literature

The demand for energy has been growing rapidly, which calls for the introduction of processes which would satisfy the needs of the growing world's population and avoid energy crises. RE sources can play an important role in the light of the exhaustion of fossil fuel deposits and the global warming.

At the current rate of energy consumption, forecasts see an increase in demand by 65% until year 2030 (Metz *et al.*, 2007, p. 268). At present, most of the energy consumed worldwide is generated from non-renewable sources, like coal power plants. It is evident that this leads to serious problems, like emissions of greenhouse gases and global warming (Sharvini *et al.*, 2018, p. 257-266). As the levels of greenhouse gasses are growing at a hazardous rate, besides the strategies for the reduction of carbon dioxide, new energy sources are needed based on renewables (Behrouzi *et al.*, 2016, p. 1270-1281). In contrast to fossil fuels, renewable energy offers alternative sources of clean energy. It is also expected that RES will limit the future energy crises, playing a key role in satisfying the future demand for electricity. As the awareness of the clean environment is on the rise, it is now considered that the traditional dependence on fossil fuels has led to an excessive emission of greenhouse gases and damage to the environment (Lucas *et al.*, 2018, p. 449-445). RES may cover the domestic need for energy with the potential of providing energy services at zero or near zero emission of air pollutants and greenhouse gases (Fornara *et al.*, 2016, p. 1-10; Borovik & Albers, 2018, p. 33-39; Keramitsoglou *et al.*, 2016, p. 1332-1337; Bhowmik *et al.*, 2017, p. 796-813). It is therefore important to shape the policies and popularize RES also among households (Qazi *et al.*, 2019, p. 63837-63851; Wierzbicka, 2022, p. 1-16).

The market for photovoltaic collectors has an enormous potential in Poland; as yet, it seems that this potential has not been exploited. In 2025, the total installed capacity of PV collectors is to reach 7.8 GW, which means that this capacity will exceed the capacity assumed in the Domestic Plan for Energy and Climate until year 2030 (*Rynek fotowoltaiki w Polsce…* 2020).

To a large extent, the observed and forecast growth in the installed capacity of solar power is possible due to the government subsidies from programs like “My Electricity,” “Clear Air,” “Energy Plus,” and “Agroenergy,” as well as changes in the regulations which let the households engage in energy production and feed it into the grid, introduced in 2016 (Ustawa z 19 lipca 2019 r. o zapewnianiu dostępności osobom ze szczególnymi potrzebami), which should trigger interest in the production of green energy. Thanks to the government subsidies, support from EU programs, and new legal regulations, the RES industry was the only sector of the economy which managed to fetch more investment capital in years 2019-2020 than the sector of conventional energy.

Besides the lower electricity bills, another important factor which determines the return of investing in solar panels is the adequate level of sun exposure over the area of Poland (Żelazna *et al.*, 2020, p. 3978-3994).

Each region of Poland has different conditions, such as cloud cover, terrain shape, longitude and latitude. Meteorological conditions have a vital influence on the efficiency of solar collectors and impact the basic parameters determining the potential of solar energy use, like insolation [W/m^2], total solar radiation [J/m^2]. These parameters determine both the total radiation and its components, which is direct and dispersed radiation. At Poland's longitude, the sum of direct and dispersed radiation reaching the land surface can achieve the maximum instantaneous value of 1 kW/m^2 (*Global Solar…* , online). The month when the land is most exposed to the sun is June, when the sky is clear and the sun is in the highest point over the horizon. On the other hand, this energy is much lower in December, when the sun is at its lowest point (Chwieduk & Chwieduk, 2020, p. 3232-3249). Summer months have the largest number of insolation hours. Direct radiation can correspond to as much as 90% of the total radiation reaching the Earth, with the value of 1,050 W/m^2. At the same time, when the sky is completely clouded, only dispersed radiation reaches the land surface, and its value is between 50 and 150 W/m^2. From October to March, the number of insolation hours is the lowest; moreover, the absorption of this energy is further inhibited by strong winds and lower temperatures (Niekurzak & Kubińska--Jabcoń, 2021).

A heat pump makes it possible to use thermal energy from sources of low temperatures. It uses the heat from ground waters, surface waters, and atmospheric air. Its function is to absorb heat from the source of a lower temperature and pass it on to the source of higher temperature. Heat pumps use low temperature heat, which is difficult to utilize otherwise. The most common way of using heat pumps in Poland is to take advantage of the ground heat through the so-called ground collector. We distinguish heat pumps of vertical and horizontal heat exchangers. There are two types (*Odnawialne źródła…* online):

– horizontal heat exchangers (horizontal collectors) – laid 1.0-1.6 meters under the surface; a collector laid in the ground does not affect plant vegetation and gives most heat when placed in moist soil;

– vertical heat exchanger (vertical pump) – a vertical exchanger placed in a drilled well, which constitutes a closed loop in which non-freezing glycol-water solution circulates. The absorbed heat is exchanged by the heat pump into energy.

Geothermal energy in Poland is competitive in terms of ecology and economy against other energy sources; we have relatively large supplies of geothermal energy, potentially used for thermal purposes (*Energia geotermalna*, online).

Estimation of the feasibility of installing panels and pumps in a household

The study investigated the data obtained from a household fitted with a PV installation and a heat pump. The house is located in Skierniewice municipality, in łódzkie voivodship. The house area is 190 m^2 and is occupied by 4 residents. The łódzkie voivodship belongs to zone 3 of insolation, where solar radiation reaches 1,100 W/m^2. The studied household has a PV installation made up of 26 panels of the total 8.85 kWp capacity, installed in 2020. The panels are mounted on the roof and inclined towards the south, which is the most common recommendation in Poland. The roof inclination is 35 degrees. The vicinity of the house does not have trees or high rise buildings, which means that in no time during the day the panels are in shade, which would unnecessarily degrade their effectiveness. The installed panels are of high quality and their average longevity is estimated to be 40 years.

The cost of the PV installation, including workload and additional equipment, amounted to PLN 40,000, of which PLN 5,000 was granted by the government as part of "My electricity" program. The cost of the heat pump 10 kW F-1245 All-In-One, after the producer's discount of PLN 5,000, was PLN 30,000 plus the cost of the design and drilling to the depth of 240 meters of PLN 17,000, and installment with other materials priced at PLN 9,000, which composed the total cost of the investment equal PLN 56,000. The total cost of the installation was PLN 96,000. The annual production from the PV installation averages 8,800 kWh, while the annual demand for energy of the household reaches 10,000 kWh; the heat pump itself needs 4,000 kWh. The missing kWh is bought in the inexpensive tariff G12W, where the present price is PLN 0.39; there is also a fixed monthly payment of PLN 25. At present, the PV installation satisfies 88% of the energy needs of the household, the remaining 12% comes at the cost of PLN 885.

The total annual cost of energy and heating the water incurred by the household reaches approximately PLN 10,667, while the cost for the household fitted with the PV installation and the heat pump is just PLN 885 per year. This sum follows from the need to supplement the missing kWs and the fixed payment of PLN 25 per month; however, the night tariff G12W means that the household buys extra energy at just PLN 0.39/kWh. What follows from this is that the household makes an annual saving of PLN 9,782 and this sum is considered the annual return from the investment in the PV installation and the heat pump. The longevity of the investment was assumed to be 25 years, the discount rate 5%, and the fixed rates of payments for additional energy for the whole period of the investment.

Table 1 shows the production output from the PV installation of 8.8 kW capacity and the use of energy by the household in years 2020-2022. It can be seen that the data from 2020 and 2020 are incomplete, but when we combine them, they represent a full calendar year. The navy blue color in the table shows the months included in the heating season, the warm months are in green, and the transitory months between the heating season and the warm season are given in the salmon pink color. It is evident that the warm and the transitory months are characterized by the production higher than the energy use. During seven months of the year, the PV installation produced 5,341.85 kW, while the simultaneous energy consumption was 4,650.4 kW, which means a surplus of 691.45 kW produced in that period. In 2021, the installation was in operation throughout all year and yielded 8,816,41 kW, while the simultaneous consumption of energy by this household was 10,050,67 kW, which necessitated the purchase of the remaining 1,234,26 kW. In the first five months of 2022, the installation managed to generate 3,855,84 kW while the energy use of the household was 4,605,83 kW, which again shows that the remaining nearly 750 kW had to be bought. The highest production of energy was measured in June 2021 at 1,445,11 kW, and the lowest - in January 2021, at 97,12 kW. The largest consumption of energy by the household was in December 2021, the smallest in August 2020.

Table 1

Production of electric power from the PV installation and energy consumption in the household

Month	PV 8.8 kW					
	production [kWh]			consumption [kWh]		
	2020	2021	2022	2020	2021	2022
January	-	97.12	187.69	-	1,151.36	1,210.56
February	-	445.69	403.38	-	1,027.91	989.67
March	-	694.14	1,102.66	-	972.38	896.42
April	-	984.9	873.63	-	894.5	841.55
May	-	1,141.95	1,288.48	-	709.82	666.63
June	1,083.03	1,445.11	-	512.62	599.2	-
July	1,352.71	1,117.31	-	525.02	535.24	-
August	1,184.35	897.97	-	475.59	551.86	-
September	935.89	864.84	-	509.41	607.75	-
October	387.83	747.69	-	667.63	828.32	-
November	263.22	244.9	-	866.26	921.59	-
December	134.82	134.79	-	1,093.87	1,250.74	-
Total	5,341.85	8,816.41	3,855.84	4,650.4	10,050.67	4,604.83

Source: the authors, based on data obtained from the household submitted to the study.

The average annual production of energy by this installation amounts to approximately 9,000 kW, while the simultaneous demand for energy reaches 9,653 kW, which means that the PV installation satisfies 93.3% of the average annual demand for energy in this household. Table 2 presents energy consumption in the given periods by the heat pump installed in the household.

The average annual consumption of energy by the heat pump reached 4,050.47 kW at the annual working time of 1,460 units, which includes 501 work units for heating the household water. The share of hot water in the pump's working time was 34.3%. The remaining 65.7% was used to supply the household with central heating. The average work use of kW/h in the studied period was 2.93 kW/h; the lowest consumption of work energy was 2.49 kW/h, the highest reached 4.48 kW/h. The total value of energy consumed within 2 years of the

Table 2

Data on the heat

Dates of measurements	Heat pump 10 kW F-1245 All-In-One					
	energy consumption in kW	working time		percent share in working time		kW/h of work
		total	cwu	cwu	co	
2020.04.04	-	-	-	-	-	-
2020.08.01	777.28	235	149	63.40	36.60	3.31
2020.12.05	1,004.84	335	145	43.28	56.72	3.00
2021.01.02	527.71	211	45	21.33	78.67	2.50
2021.02.02	671.17	270	49	18.15	81.85	2.49
2021.03.02	574.15	227	51	22.47	77.53	2.53
2021.04.03	484.65	188	55	29.26	70.74	2.58
2021.05.02	390.2	147	49	33.33	66.67	2.65
2021.06.01	211.6	66	46	69.70	30.30	3.21
2021.07.06	192.16	49	68	138.78	-38.78	3.92
2021.08.31	241.93	54	36	66.67	33.33	4.48
2021.11.03	451.72	142	72	50.70	49.30	3.18
2021.12.09	554.28	214	53	24.77	75.23	2.59
2022.01.11	690.38	274	55	20.07	79.93	2.52
2022.02.05	527.8	205	40	19.51	80.49	2.57
2022.03.01	406.82	156	38	24.36	75.64	2.61
2022.04.02	394.25	146	51	34.93	65.07	2.70
Total	8,100.94	2,919	1,002	–	–	–

Source: the authors, based on data obtained from the household submitted to the study.

heat pump's use would have amounted to PLN 5,590 if the above mentioned G11 tariff had been applied. Hypothesis One, marked as H1, which assumed that the use of photovoltaic panels would cover the power needs of the heat pump utilized for the energy needs of the household was confirmed. The studied PV installation produces the average of 9,000 kW per year, while the annual power consumption by the heat pump stands at 4,050 kW, which means its demand for power is covered twice over.

The simple payback period calculation is a method that is easy to apply, but this is a non-discounted approach, namely it does not account for the impact of time on the evaluated project; however, it can be used as an additional instrument. PP indicated for this project is 9.81 years, which is a satisfactory length given that the project's life span is set to be 25 years. This means that the whole investment will pay back after 9.81 years, which is less than half the time of the project. The discounted period of return was also calculated to eliminate the fault of the previous calculations, which did not take into account a change in the value of money over time. It differs from the previous indicator as the cash flows are discounted, which makes the financial result more realistic, and lengthens the period of return. The DPP indicator for the studied investment was set at 13.83 years, which is still satisfactory performance. This period is slightly longer than the halftime of the project, but still indicates high profitability.

Table 3 presents the indicators calculated for the estimated project. The ROI indicator shows how much operational profit is generated by every PLN of the investment. The ROE for the studied period reached PLN 1.55 of profit for every PLN 1.00 invested in the project. The ROE indicator, on the other hand, shows how much net profit was made per every PLN invested, and for this particular project the ROE amounted to PLN 1.63 of profit per PLN 1.00 invested. The investment was also estimated with the accounting rate of return, which is a different approach. It determines the difference between the average annual net profit and the capital spent to generate that profit. This indicator came up to 10.19%, which is a very satisfying result for an investor. The most important method for decision makers is the net present value (NPV). It is considered valuable in accounting as it allows for the factor of time on the value of money. The value of the studied investment, at the rate of return set by the investor to be 5%, was found to be PLN 41,866.93. The NPV > 0 value means that the investment is profitable considering the surplus of the discounted revenue over the discounted expenditure. This NPV value is satisfactory for the investor.

The investment will reach a positive value of return within 14 years of its commencement. This means that the investment will pay back after 14 years, and the remaining years of the project will generate profit. The second most important indicator of the economic viability of the project is the internal rate of return (IRR). This indicator was calculated with a spreadsheet and reached 9.01%, which means that the investment is profitable and attained a satisfactory IRR. The last method used to calculate the profitability of the investment was the profitability index (PI), which took the value of 1.4361, which means an acceptable level above PI>1. All of the calculations were based on the average rates of year 2021.

The second hypothesis, H2, assumed that the combined investment in the photovoltaic panels and the heat pump will pay back in a period shorter than half the time of the forecast life of the project. This hypothesis was not confirmed, as the maximum discounted return period should not have exceeded 12.5 years. It should be also noted that H1 shows that the project should have been launched even though it was not backed up by H2; the investment is still economically attractive, as the DDP only slightly exceeds the payback time assumed in H2. This is even more so given that the longevity of the project exceeds the payback time by over 11 years.

Table 3

Indices of the investment's economic profitability

Index	Result
Payback period (PP)	9.81 years
Discounted payback period (DPP)	13.83 years
Accounting rate of return (ARR)	10.19%
Return on Investment (ROI)	155%
Return on Equity (ROE)	163%
Net Present Value (NPV)	PLN 41,866.93
Internal Rate of Return (IRR)	9.01%
Profitability Index (PI)	1.4361

Source: the authors.

Summary

The conducted analysis of the economic profitability is particularly important to the investor, who in this case is a house owner. However, it should be taken into account that the estimation was based on average values for the period of only 2 years and the future years may differ from the assumed values. Savings were made by covering the energy consumption with own production, which turned out very beneficial for the household. The estimation indicated a high value of NPV and a satisfactory value of IRR. The discounted payback period of the investment was estimated to be around a dozen years; other indicators also point at the profitability if the realized investment. The PV installation satisfies the average annual energy consumption of the household in 93%. There is also a possibility to add more PV panels to render the household completely independent fro the grid power; however, the covering of the energy needs of the household at this point is satisfactory. It should also be noted that there are environmental benefits of this type of installation. The use of this hybrid system allowed the household to almost completely decouple the cost of heating from the market prices, which can be very volatile. A house fitted with such installations becomes more modern and eco-friendly, and more attractive in the real estate market. The awareness of the need to protect the environment is rising, and the use of such installations is a personal contribution to combating global warming.

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