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TECHNICAL AND COST COMPARISON OF SELECTED TECHNOLOGIES FOR ENERGETIC CONVERSIONS OF RENEWABLE ENERGY SOURCES

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The authors of this article were guided by the desire to show the profitability of using renewable energy sources and to facilitate decisions for future investors as to their choice. The article classifies energy sources and methods for converting renewable energy sources (RES) and presents a technical comparison of two electricity supply systems: a photovoltaic system and a household wind farm for a selected building. A residential, single-family building, inhabited by a family of three, was adopted for analysis. Photovoltaics, the use of solar radiation energy to produce electricity, is classified next to wind farms as the most dynamically developing renewable energy technology. When analysing in terms of technology renewable conversion methods that provide us with electricity, the better installation is the photovoltaic installation. By analysing the cost of renewable energy conversion technologies that provide us with electricity, the photovoltaic system becomes more beneficial, because with a similar investment price we get a much shorter payback period than in the case of a backyard wind power station.

Keywords: renewable energy sources (RES), conversion methods, photovoltaics, wind farms, comparison.

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1. INTRODUCTION

The basic factors necessary for human life are reduced to food and energy. Unfortunately, all efforts to acquire these goods cause environmental pollution. So there is a conflict between the need to provide human needs and preserve an uncontaminated environment. However, modern technology gives the opportunity to combine comfort, safety and economical use with an environmentally friendly approach, and the annual increase in energy demand and shrinking deposits of conventional fuels lead to the discovery of ever newer renewable energy sources. Issues related to the acquisition and practical use of renewable energy sources are increasingly addressed in available publications [1, 2, 3, 4.]. We can also find a comparison of the most popular installations based on conventional fuels with renewable energy sources [5].

The authors of this article were guided by the desire to show the profitability of using renewable energy sources and to facilitate decisions for future investors as to their choice. This article classifies energy sources and methods for converting renewable energy sources, and attempts to compare two of them in technical terms and the cost of providing electricity to a selected residential building,: photovoltaics and wind power plant.

Photovoltaics, the use of solar radiation energy to produce electricity, is classified next to wind farms as the most dynamically developing renewable energy technology. Given that solar radiation is available almost everywhere, this technology can be used almost anywhere. Photocells are made of semiconductor materials and are used as durable and reliable energy sources. Mass-produced cells achieve efficiency of around 20%, but cells with efficiency above 40% are already known. Research is also carried out on polymer and organic cells that, despite lower efficiency, would have a more favourable energy-price ratio.

Wind farms are mainly used to power large state networks, in professional power industry, but they can be used both in small, local power plants and in home wind farms. There are many technical solutions for wind turbines on the market. We can distinguish both motors with vertical and horizontal axis of rotation, depending on its location and slow or high-speed, depending on choice. Currently turbines produced are 50 times stronger than those from 20 years ago.

2. CLASSIFICATION OF ENERGY SOURCES

Primary energy is chemical energy generated during the combustion of primary fuels, as well as that can come from natural sources, such as solar energy, wind energy, and geothermal energy. Primary energy carriers include natural fuels: solid, gaseous and liquid, as well as thorium and uranium compounds. On the other hand, secondary energy is energy obtained during primary processes of secondary fuels, energy of other secondary carriers and electricity. Secondary energy carriers are gaseous and liquid fuels, as well as nuclear fuels originating from primary energy carrier processing. Secondary energy carriers also include: hot water, steam, geothermal energy, and electricity [8]. The distribution of energy sources is shown in Figure 1.

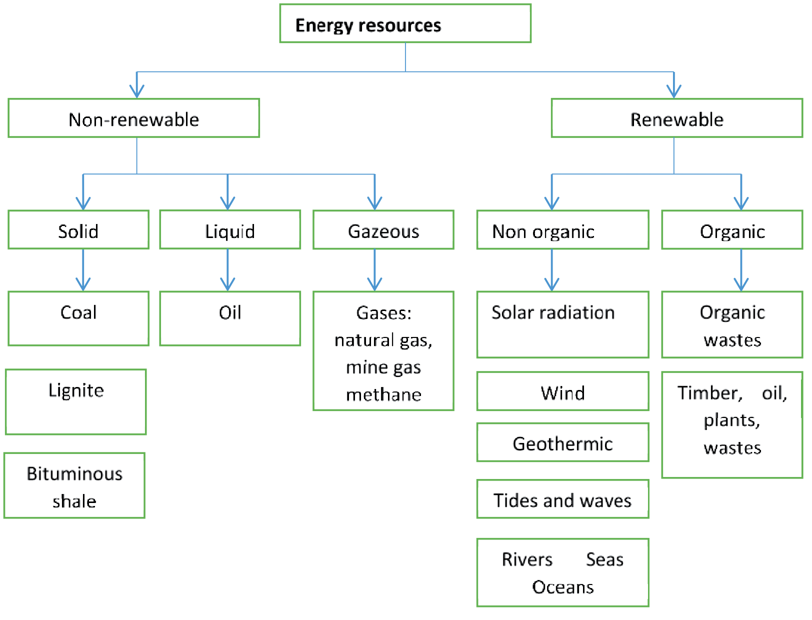

Fig. 1. Division of primary energy carriers [8].

Resources of renewable energy are practically unlimited. The only difficulty lies in its dispersion. There is a need to concentrate the potential of a given source, which is combined with higher costs of obtaining such energy. Therefore, often the investment costs of producing renewable energy are higher than, i.e., the extraction and processing of fossil fuels [7].

In turn, renewable energy sources alone are not enough to ensure an optimal amount of energy. For this you need appropriate energy technologies that allow you to receive electricity, heat and chemical energy (Fig. 2).

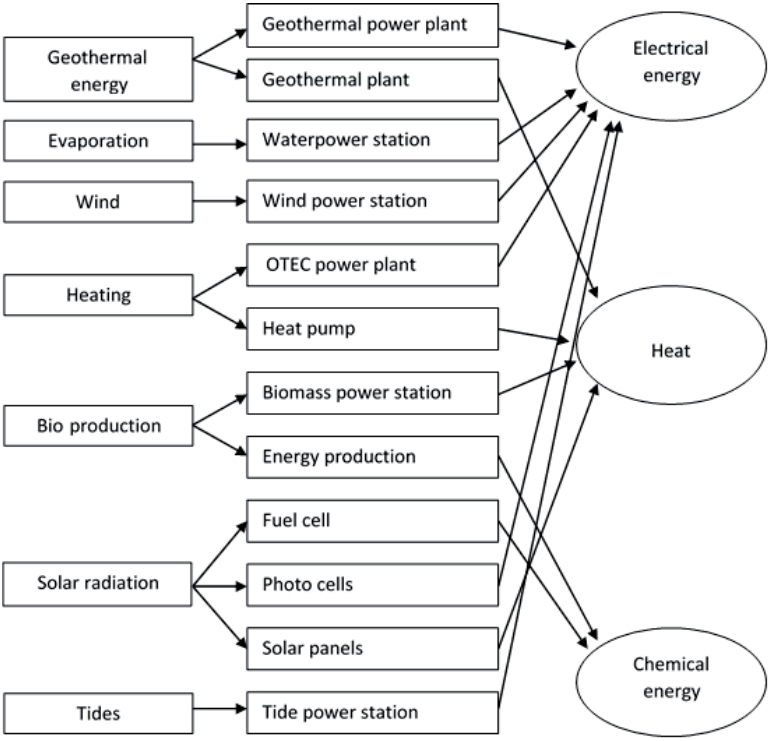

Fig. 2. Energy technologies of renewable energy sources [8].

3. TECHNICAL ANALYSIS OF SELECTED RENEWABLE ENERGY CONVERSION TECHNOLOGIES PROVIDING ELECTRICITY

This article presents a technical comparison of two electricity supply systems: a photovoltaic system and a household wind farm for a selected building.

A residential, single-family building, inhabited by a family of three, was adopted for analysis. An annual electricity demand of 3500 kWh was adopted, which is equal to the European average annual energy demand for a household [7]. At home, we have a traditional electrical installation, to which we connect the proposed solutions.

3.1. Photovoltaic system

Photovoltaics, the use of solar radiation energy to produce electricity, is classified next to wind farms as the most dynamically developing renewable energy technology. Given that solar radiation is available almost everywhere, this technology can be used almost anywhere.

With an annual demand (for the building) of 3500 kWh of electricity, a 3kW set will be a sufficient set in the solar system.

The set adopted for analysis is an off-grid set, not connected to the public network. It works autonomously and consists of:

- solar panels,
- battery inverter,
- battery system,
- energy meter produced,
- monitoring system.

The basic and most important element of such a set are photovoltaic panels, mounted on the roof as autonomous elements, and not as elements of roofing. In this set there are 12 panels with a power of 250W and their total power gives us 3000W. These are panels with polycrystalline modules, dimensions 1650 x 992 x 45 mm, operating at temperatures from -40 to 85 ° C. The cells of such panels have an acid textured surface, thanks to which the sun rays are even better absorbed. The efficiency of one such panel accepted for analysis is 15.3%.

The battery pack inverter is another very important element of the system. The solution adopted for analysis is a 3kW inverter, equipped with a WLAN port, thanks to which it is possible to connect it to a third device and control or control its work from outside, via the Internet. The task of the inverter is to change the current generated in the panels to a current that is suitable for supplying the electrical network. It also controls the charging and discharging of the battery system: its purpose is to recharge when the solar system produces more energy than it is consumed, and similarly, when the energy demand is greater than its production, the battery system is discharged by the battery inverter.

In the analysis, a battery system consisting of 4 batteries with a capacity of 100Ah was proposed as a battery system. This system aims to increase the consumption of household energy with photovoltaic components installed. It is characterized by space saving, very high efficiency, large battery capacity as well as long life and high operational safety.

In the set, one meter registers the amount of energy produced by the solar panel system, and the other - electric, measures the energy produced by the inverter.

As mentioned above, it is possible to use an intelligent monitoring system that informs about the solar system operation data and the system power at the moment. It can also provide information on the estimated energy production using meteorological data.

3.2. HOUSEHOLD WIND FARM

Wind energy, apart from energy obtained in the process of wood burning, was the most commonly used renewable energy. Owing to historical records we can determine that it was already used in the 18th century B.C. Fuel crisis caused an increase in interest in this type of energy.

The energy supply by a wind turbine is dependent on the wind speed and is not even. Therefore, the on-grid home wind farm was adopted for analysis, i.e. connected to the public power supply network, supplying excess energy to the public network.

In case of energy shortage - it is taken from the public network. The on-grid system is characterized by:

• continuity of electricity supply, regardless of weather conditions,
• lower investment costs obtained by eliminating batteries,
• no need to interfere with existing installation circuits,
• additional source of income (possibility of selling excess energy to the public grid).

The main assumption in the analysis is the annual energy demand, equal to 3500kWh.

Therefore, a 1.5kW turbine was adopted. The whole set consists of:

• 1.5kW wind turbine,
• charging controller with inverter for 1.5kW turbine
• 9m high steel mast with guy ropes.

The adopted household power plant has a power of 1.5kW, so we classify it into small power plants with a power of 100W to 50kW. Its turbine has a horizontal axis of rotation. The rotor consists of 5 very durable blades, 2.05m in diameter, made of fiberglass. The rotor's rotation surface is 3.3 m2. The turbine has a system regulating the angle of attack of the blades. A very important element of the turbine is the brake that stops the turbine in adverse weather conditions. The adopted turbine is equipped with two brakes: aerodynamic and electromagnetic. The turbine element, visible to the naked eye, is the directional rudder regulating the horizontal angle of attack of the turbine. The generator inside the turbine changes the kinematic energy of rotation of the shaft on which the rotor is mounted to electricity. In the adopted set we deal with a brushless 3-phase motor, with a neodymium magnet, with constant high performance. The wind start speed at which the rotor starts working is 2m / s. It is a quiet turbine, generating noise at a wind speed of 5m / s, at a level of only 20dB. The rated wind speed is 12m / s and the maximum turbine power is 1800W. It works at 48-110V. The turbine operating temperature is between -20 and 60 ° C. The entire turbine weighs 35 kg, its service life is 20 years, with a 5-year warranty.

The turbine is mounted on a 9 m high steel mast to which it is connected by a flange connection. The steel mast has guy ropes in the form of steel cables fixed in the ground for greater stability and safety of the entire structure.

The charging controller with an inverter for a 1.5kW turbine decides whether to deliver the produced energy to the house (when there is a shortage) or to send it back to the public network (when there is an excess). It also changes direct voltage to variable voltage, adapted for use in the household.

3.3. TECHNICAL COMPARISON OF SOLAR FARMS - HOME WIND FARM

First of all, pay attention to the dependence of the installation on atmospheric conditions. In both cases, installations depend on weather conditions. The photovoltaic system does not produce energy at night and during heavy cloud cover. A household wind farm, on the other hand, does not work during windless weather, but also when the wind speed is too high. It begins to produce energy at 2m / s, and the maximum survival wind, i.e. the wind speed at which the installation will be destroyed is 60m / s.

The adopted solar installation works in an off-grid system, i.e. without connection to the public network. In this case it was necessary to use a battery system.

In the case of a home wind farm, an on-grid system was used, which in the case of energy shortage draws it from the public network. In the case of overproduction of energy, it is also possible to sell it to the operator. This option is not available for solar installations. In both cases, assembly and installation times are comparatively short. The advantage of a photovoltaic system may be that we do not need additional space next to the house, as in the case of a home wind farm. For many, a mast with a turbine may seem unsightly. With a solar system, it is possible to remotely control the operation of the entire installation. In a home wind farm this is not possible.

Both installations have no negative impact on the environment. Only for a home wind farm a negligible noise is generated, usually lower than ambient noise.

Photovoltaic works in the temperature range from -40 to 85 ° C, in the case of a household wind installation this range is from -20 to 60 ° C, which can be associated with problems during severe frosts.

The durability of a photovoltaic installation is much longer and amounts to 20-30 years, while a home wind farm installation amounts to 15-20 years.

The above comparison is illustrated in Table 1.

Table 1. Photovoltaics and a backyard wind power station. Source: own study

Criterion	**Photovoltaics**	**Backyard wind power station**
Dependence on weather conditions	Considerable	Very high
Type of installation	Off-grid	On-grid
Possibility of selling energy through the grid	None	Yes
Construction time	Short	Short
Area needed	None (on the roof)	Needed (near the building)
Aesthetics	Aesthetic look	Unsightly (turbine mounted on the mast protrudes over the roof)
Remote control option	Yes	None
Negative impact on the environment	None	None
Noise	None	Insignificant
Operating temperature range	From -40 to 85°C	From -20 to 60°C
Plant durability	20-30 years	15-20 years

4. Cost analysis of selected renewable energy conversion technologies providing electricity compared to traditional technology

The cost analysis of renewable energy conversion methods providing electricity (solar system and home wind farm) was compared to a traditional power connection to the public grid, comparing different indicators and aspects such as:

- cost and assembly of the entire installation,
- annual cost of operating the installation,
- savings compared to a traditional installation,
- simple payback period,
- investment profitability after 20 years.

The following assumptions were made to simplify the analysis:

- the investor does not bear any costs related to capital, because he has an infinite amount of capital,
- demand for electricity was assumed equal to 3500kWh / year,
- when calculating the annual operating costs of installations, the operating costs of devices such as controllers were assumed to be negligible,
- all installation maintenance costs have been omitted,
- the investor wants to calculate the profitability of the investment after 20 years.

The costs of the analysed installations are presented in Table 2. It includes the costs of individual elements making up the installation and assembly costs. The residential building, on the example of which the analysis was carried out, is located at a distance of 100m from the nearest power line, and the required connection power is 11kW. The price for making this connection is € 1324.

Table 2. Costs of installations providing electricity. Source: own study

Name of installation	**Installation components**	**Gross price**	**Total**
Solar photovoltaic system	A system consisting of panels and an inverter	2533 €	5638 €
	Battery system manufactured by Haze	2528 €	
	Power energy meter	21 €	
	Installation assembly cost	556 €	
Backyard wind power station	Turbine 1,5kW	2036 €	5134 €
	Turbine charging controller with a 1,5kW inverter	606 €	
	9m high steel mast with guy ropes	757 €	
	Network connection to Ttauron (11kW)	1324 €	
	Assembly and conionstruction	411 €	
Connection to grid	Network connection to Ttauron (11kW)	1324 €	1324 €

From Table 2 it can be concluded that the most expensive is the solar system, but comparable with the system of a backyard wind farm. The cost difference is just over € 500. The costs of connecting to the public network are definitely lower, just over € 1,300.

Table 3. Annual operating costs of individual systems, saving of renewable energy conversion systems compared to traditional technology. Source: own study

Name of installation	Annual cost of operation	Saving as compared to traditional installation
Solar photovoltaic system	0,00 €	412 €
Backyard wind power station	202 €	210 €
Connection to grid	412 €	-

Table 3 presents the operating costs of individual systems and the saving of renewable energy conversion systems compared to traditional technology. It should be noted that the annual cost of energy consumption by a household, via the connection, was calculated according to the energy supplier's tariff. By contrast, the cost of household energy consumption, in the case of a household Wind Farm, has been expertly determined at 2/5th of the entire annual energy demand. The highest annual operating costs are generated by the connection to the public network: € 412. The cost of maintaining a backyard wind farm is approximately € 200, and the solar system costs us nothing. We get the largest annual savings when we opt for a photovoltaic system and it is 412 €.

The concept of a simple payback period means the period of time after which our investment will become profitable. In practice and in the case of our analysis, this concept means the number of years needed to pay back the costs of our investment, covered by annual savings compared to traditional technology. We calculate it for both RES conversion methods by dividing the costs of individual installations by saving the installation compared to traditional technology. As can be seen in Table 4, presenting simple payback periods for individual investments, the installation of a photovoltaic system will pay for itself back after 14 years, and the backyard wind farm system after 25 years, which is definitely a much higher value and a negative assessment of this investment.

Table 4. Simple return periods for individual investments. Source: own study

Name of installation	**Total cost**	**Saving as compared to traditional installation**	**Simple payback period (years)**
Solar photovoltaic system	5638 €	412 €	**14**
Backyard wind power station	5134 €	210 €	**25**

Then the profitability of investments after 20 years was calculated (Table 5). This was done using the NPV (Net Present Value) indicator, which allows calculating the value of investments after n years. The value of the investment in the zero period was the cost of the entire investment, including assembly. The next columns give the annual investment savings compared to traditional technology, i.e. connection to the power grid. The interest rate is 0, because the investor does not bear any costs associated with capital. Table 5, which presents the method of calculating the NPV indicator for individual RES conversion methods, shows that the value of the photovoltaic system investment after 20 years will be equal to € 2590, i.e. this investment will be profitable. The value of the backyard wind farm investment will be -928 €, which means it won't be profitable.

Table 5. Cost of the entire installation Savings compared to traditional installations. Source: own study

	Number of years					
Name of installation	**0**	**1**	**2**	**....**	**20**	**NPV**
Solar photovoltaic system	-5638 €	412 €	412 €	412 €	412 €	**2590 €**
Backyard wind power station	-5134 €	210 €	210 €	210 €	210 €	**-928 €**

A general summary of indicator values & costs for the above analysis is presented in Table 6.

Table 6. General list of costs and values of indicators for electricity solutions. Source: own study

Name of installation	**Cost of installation**	**Annual cost of operation**	**Saving as compared to traditional installation**	**Simple payback period (years)**	**NPV after 20 years**
Solar photovoltaic system	5638 €	0,00 €	412 €	14	**2590 €**
Backyard wind power station	5134 €	202 €	210 €	25	**-928 €**
Connection to grid	1324 €	412 €	-	-	-

5. Conclusions

When analysing in terms of technology renewable conversion methods that provide us with electricity, the better installation is the photovoltaic installation. It is characterized by work independent of the electric grid operator, aesthetics, no need to install outside the house, no negative impact on the environment, the ability to remotely control the system and no noise.

By analysing the cost of renewable energy conversion technologies that provide us with electricity, the photovoltaic system becomes more beneficial, because with a similar investment price we get a much shorter payback period than in the case of a backyard wind power station. This investment is also profitable after 20 years, unlike a backyard wind power station.

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List of figures and tables:

PORÓWNANIE TECHNICZNO KOSZTOWE WYBRANYCH TECHNOLOGII ENERGETYCZNYCH KONWERSJI ODNAWIALNYCH ŹRÓDEŁ ENERGII

*Słowa kluczowe***:** odnawialne źródła energii (OZE), metody konwersji, fotowoltaika, siłownie wiatrowe, porównanie..

STRESZCZENIE:

Autorzy niniejszego artykułu kierowali się chęcią pokazania opłacalności wykorzystywania odnawialnych źródeł energii i ułatwienia podjęcia decyzji przyszłym inwestorom, co do ich wyboru. W niniejszym artykule sklasyfikowano źródła energii i metody konwersji odnawialnych źródeł energii oraz podjęto próbę porównania, w aspekcie technicznym i kosztowym dostarczania energii elektrycznej do wybranego budynku mieszkalnego, dwóch z nich: fotowoltaiki i siłowni wiatrowej.

Przedstawiono porównanie techniczne dwóch systemów dostarczania energii elektrycznej: systemu fotowoltaicznego i przydomowej elektrowni wiatrowej, do wybranego obiektu budowlanego. Do analizy przyjęto budynek mieszkalny, jednorodzinny, zamieszkiwany przez 3 osobową rodzinę. Przyjęto roczne zapotrzebowanie na energię elektryczną równe 3500 kWh, co jest równe średniemu europejskiemu rocznemu zapotrzebowaniu na energię dla gospodarstwa domowego. W domu posiadamy tradycyjną instalację elektryczną, do której podłączamy zaproponowane rozwiązania.

Analizę kosztową metod konwersji OZE, zapewniających energię elektryczną (system fotowoltaiczny i przydomowa elektrownia wiatrowa) przeprowadzono w porównaniu do tradycyjnego przyłącza energetycznego do sieci publicznej, porównując różne wskaźniki i aspekty, takie jak:

- koszt i montaż całej instalacji,
- roczny koszt eksploatacji instalacji,
- oszczędności w stosunku do instalacji tradycyjnej,
- prosty okres zwrotu instalacji, opłacalność inwestycji po 20 latach.

Przyjęto następujące założenia, upraszczające analizę:

- inwestor nie ponosi żadnych kosztów związanych z kapitałem, gdyż dysponuje on nieskończoną ilością kapitału,
- zapotrzebowanie na energię elektryczną przyjęto równą 3500kWh/rok,
- podczas obliczania rocznych kosztów eksploatacji instalacji, koszty działania urządzeń, takich jak sterowniki, przyjęto za pomijalnie małe,
- pominięto wszelkie koszty konserwacji instalacji,

- inwestor chce obliczyć opłacalność inwestycji po 20 latach.

Analizując pod względem technologicznym metody konwersji OZE, dostarczające nam energię elektryczną, lepsza jest instalacja fotowoltaiczna. Cechuje ją praca niezależna od operatora sieci elektrycznej, estetyka, brak konieczności instalacji poza obrębem domu, brak negatywnego wpływu na środowisko, możliwość zdalnego kontrolowania systemu oraz brak wytwarzanego hałasu.

Analizując kosztowo technologie konwersji OZE, zapewniające nam energię elektryczną, bardziej korzystnym jest obecnie system fotowoltaiczny, gdyż przy podobnej cenie inwestycji, otrzymujemy dużo krótszy okres zwrotu, niż w przypadku przydomowej elektrowni wiatrowej. Inwestycja ta jest także opłacalna po 20 latach, w przeciwieństwie do przydomowej elektrowni wiatrowej.

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