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Economic Profitability of a Hybrid Approach to Powering Residual Households from Natural Sources in Two Wind Zones of the Lubuskie Voivodeship in Poland

Piotr Kułyk * and Łukasz Augustowski

Faculty of Economics and Management, University of Zielona Góra, 65-417 Zielona Góra, Poland; l.augustowski@wez.uz.zgora.pl

* Correspondence: p.kulyk@wez.uz.zgora.pl

Abstract: The research was a response to the search for alternative energy sources and the assessment of their profitability and legitimacy of use. The assessment used combined energy sources in the form of wind, solar, and natural gas energy. The research was carried out in various locations with varying degrees of sunlight and in various wind zones, which was motivated by the adopted strategy of increasing the importance of non-conventional energy sources and reducing greenhouse gas emissions. The evaluation was performed using the Homer Grid software. The studies showed the justification for the use of hybrid energy sources, combining renewable and non-renewable sources, at the current stage of development. In the conditions of the Lubuskie Voivodeship, the level of insolation was more important than the more favourable wind zone in such a model. Higher economic efficiency of the hybrid model was obtained in the southern location, with slightly less favourable conditions for wind installations. At the same time, the investments were economically profitable and allowed for their return in the perspective of at least eleven years, even at current prices.

Keywords: hybrid energy; renewable energy; clean energy; energy economics; homer model

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1. Introduction

Renewable energy sources are an important alternative to conventional energy generation methods. However, there is a problem with maintaining their stability in supplying energy and ensuring the economic efficiency of such solutions. This is one of the main goals of managing renewable resources [1]. Traditional methods of obtaining energy have a negative impact on the environment and cause the emission of pollutants to the environment, which is less and less socially accepted and has negative externalities. Nowadays, an upward trend in the emission of environmental pollutants is observed, which requires decisive measures to reduce their emissions. This causes a decrease in the optimal consumption of environmental goods and requires investment in the creation of environmental rents [2]. Conventionally, the source of energy for electricity has been, primarily, fossil fuels. Due to the growing costs of oil and coal exploration and extraction, as well as their environmental footprint, this trend is not permanent and should change in the long run [3].

Moreover, the sustainable exploitation of renewable resources depends on the existence of a reproductive surplus, which is determined by the balance of births and deaths in the population. The environment is also constantly changing, and man has been observing climate change for a long time. Temporary changes in environmental conditions mean that information on sustainable development gathered in the past may be of limited use in the future. There is also a visible pressure to over-exploit resources, which causes negative externalities [4], as well as conflict of interest groups [5]. Although the environmental resource has its own regeneration system, and its stock is a source of utility and input to production, the negative external effect caused by the flow of pollutants may be proportional to this production [6]. Investments of an environmental nature, including renewable

energy sources, also have negative economic consequences. The research by Zhang [7] shows that an increase in the propensity to consume a renewable raw material causes an increase in the interest rate and reduces the state of domestic capital and the production sector, the level of wages and, consequently, the level of consumer goods. Initially, there is a decrease, followed by an increase in the capital resources of the commodity sector and an increase in the consumption and price of a renewable resource, and labour is shifted from the production of goods to the resource sector. On the other hand, the studies by Sachs and Warner [8], Gylfason, Herbertsson, and Zoega [9], or Rodríguez and Sachs [10] show that natural resources have an adverse effect on the rate of equilibrium growth. This is the effect of the fact that they are exhausted, as opposed to other inexhaustible resources, the occurrence of which is constant and does not require capital expenditures for their restoration [11]. Therefore, an alternative in investment processes, related to obtaining energy from renewable sources, is the use of wind and solar energy. Obtaining energy from these sources is associated with an extensive planning process and optimization of the wind farm location to ensure social and economic balance. The main factors taken into account in such a process are: expected power production or energy production, cost of generated energy and production costs, annual profit, or net present value of the wind farm [12]. The cost criterion always plays a significant role in investment projects. In the case of wind farm construction, several types of investment-related costs can be distinguished [13]: the cost of the turbine itself (ex-works), the cost of grid connection, including cables, sub-station, connection and power evacuation systems, the cost of the civil work, including the foundations, road construction, and buildings, other capital costs, operation and maintenance, land and sub-station rental, insurance and taxes, management and administration, cost of producing energy, the discount rate and economic lifetime of the investment, and finally, grid connection costs. This shows the complexity of such investments. The cost characteristics of a renewable energy project depend on the technology used. In the case of wind energy, it is a diverse set of technologies, ranging from small and large onshore and offshore wind farms [14]. The wind farm is subject to power reduction due to losses in the wind energy conversion system and frequent changes in wind speed. Therefore, it is important to properly locate the wind farm, consisting of the optimal placement of turbines within the wind farm as to minimize excitation effects and, thus, maximize the expected energy production [15,16]. The issue of wind energy cost optimization has been analysed in various studies, e.g., in terms of the consequences of wind infiltration into electricity grids and assessing how the energy storage necessary to compensate for interruptions in wind energy can be used [17]. In the search for a meter to quantify the costs of variability of less than one hour of wind farms, and in valuation of wind energy variability reduction [18], profitability of generated energy storage projects, in terms of payback periods with increasing wind penetration levels [19], estimation of optimal wind turbine system configurations with economic analysis, and monthly energy production and evaluation of power potential of wind farms are considered. Using the multi-population genetic algorithm (MPGA), which enables the calculation of the minimum energy cost with the maximum power generation [20], with the use of multitasking evolutionary algorithms (MOEA) in the context of electricity generation, with the choice of variants and combinations of various wind turbine models, with wind speeds varying throughout the day [21], in considering the issue of the micro-location of wind farms to achieve the maximum electric power taken from a wind farm while maintaining the required distance between turbines for operational safety, using the Gauss particle swarm optimization algorithm, ensures the optimization of the position of the turbines in a continuous space [22]. In this approach, a random search algorithm is constructed to optimize the wind farm layout and find optimal wind turbine positions within the wind farm. Such modelling allows for the maximization of benefits and/or minimization of losses, while meeting the existing constraints (boundary conditions) [23]. Another approach is to use the Unrestricted Wind Farm Layout Optimization (UWFLO) method, allowing for the simultaneous optimization of the placement and selection of turbines for commercial wind farms, subject to the influence of variable

wind forces [24]. Attempts were also made to assess the impact of electricity storage on wholesale electricity prices [25]. In many cases, several methods of analysis are combined in order to obtain more accurate results and reduce the significance of each constraint on the final result. The study by Mittal, Kulkarni, and Mitra [26] used hybrid optimization to simultaneously determine the appropriate number of turbines to be installed in the wind farm along with the appropriate location. The hybrid was created from a combination of probabilistic genetic algorithms and deterministic gradient optimization methods, and its application resulted in a higher annual energy production compared to the results when the two existing methods were used separately. The hybrid approach—combining various energy sources—seems to be the most reasonable solution at this stage.

In the case of wind turbines for household needs, the economic profitability criterion of such a project and environmental factors are taken into account. The research indicates significant environmental benefits as a result of using wind energy for households. The wind generator system offers a significant reduction in greenhouse gas emissions compared to the fossil fuel system. Moreover, the wind system produces more electricity than the net energy input obtained from fossil fuels. Additionally, installing larger wind turbines could lead to economic economies of scale [27]. Urban structures, and the nature of buildings, have a significant impact on the local wind speeds and thus on the potential energy efficiency of the turbine. Therefore, the choice of location will have a significant impact on potential economic issues. Installations of wind turbines in households can be profitable only under favourable conditions, where the most important parameters are the dominant wind speeds and the degree of urbanization. Small wind turbines can supply electricity by storing it in a battery and converting it to an AC signal with an inverter or through a power converter (this variant is suitable for urban areas and can operate in off-grid and on-grid modes) [28]. In most cases, the combination of a wind turbine and a storage system will determine the overall profitability of the project [29,30]. The location issue is related to the wind energy potential, which requires the examination of the average wind power on the basis of measurement data [31]. In addition to the location of the turbine itself, the height of its installation is important. The research by Sunderland et al. [32] showed that wind resources available at a height of about twice the average building height in an urban and suburban location can bring greater benefits to households, but when the height is reduced, wind resources are significantly depleted, which makes such solutions economically unprofitable. In turn, the studies by Belmili et al. [33] proved that such a system in urban areas is effective, economically viable, and has a beneficial effect on reducing CO_2 emissions [34–36]. Reducing greenhouse gas emissions in Europe is one of the requirements of sustainable energy consumption and part of many regional strategies. Due to the differences between European countries, there is currently no uniform model illustrating the relationship between economic growth and CO_2 emissions [37]. However, it seems that reducing CO_2 from the household level could be the first step towards reducing greenhouse gases. It is important, from the point of view of sustainable development and the ESG agenda, to respect the continuity of environmental processes.

Nowadays, the main barriers inhibiting the social acceptance of housing projects and small wind companies are: adequate capacity factor, cost efficiency, wind variability, audio aesthetic impact, health and safety, procedural fairness, and transparency. Depending on the chosen location, the principles of implementing small wind projects change. Strategies for overcoming barriers to social acceptance are investigated, as well as recommendations for increased project implementation around the world [38]. The potential impact of operational noise produced by wind turbines is a major concern in the project planning and permitting process [39–42]. In addition, onshore wind turbines affect real estate prices in nearby single-family houses and holiday resorts, reducing their value [43]. In order to fully exploit the possibilities of supplying housing estates, in addition to wind energy, photovoltaics and power supply from an external generator are also used to ensure a constant energy supply [44–50]. The use of natural energy sources (wind and sun) alone can be unreliable due to their unstable nature. In turn, combining these two types of energy

resources will reduce the fluctuation of each and increase overall energy production [51]. This mixed model was used to determine the best approach to meet the electricity demand of a residential building [52]. Wind and photovoltaic systems are used, here, as the main energy sources, and the generator is used as a secondary or backup source of energy. In hybrid installations, even when sun and wind are not available, the system can be reliable and can also provide high-quality energy for a household [53] or for a farm in a rural area [54,55]. It is also associated with shaping appropriate consumer attitudes and preferring a healthy lifestyle, taking into account the environmental factor [56].

Thus, the question arises about the different possibilities of using natural sources for the production of electricity in various wind areas, including the solar factor and the generator. Can households achieve economic benefits from the use of pro-environmental solutions in electricity production, in the long term, in areas with different wind strengths? Research on hybrid models can help a traditional household make the right decision.

The industrial revolution has become a strong growth impulse in the world, and its evolution has resulted in an increase in the consumption of fossil fuels. The increased exploitation of non-renewable resources has led to a sharp increase in green-house gas emissions. This has serious consequences for the global climate, as well as for human health (estimated to result in around 5 million premature deaths each year). In this case, it is difficult to talk about developmental sustainability due to the depreciation of the natural environment. Currently, about three-quarters of the world's green-house gas emissions come from the burning of fossil fuels for energy [57]. Even though the tendency is improving, the emissivity issues are still a big challenge for the pro-environmental policy of many countries in the world. The result is a global reduction in fuel energy consumption by 4.28%. In Europe, it is a 7.56% decline with a simultaneous increase in consumption of energy from renewable sources by 8.5% (in the case of Poland, an 8% increase) [58] This trend is appropriate due to the constantly growing fuel prices and concern for the natural environment, which is in line with national and community policies in the European Union.

This article consists of four parts. First: Introduction, second: presentation of research materials and analytical methods used, third: description of research results, their implementation, and discussion. The fourth section provides conclusions and policy recommendations.

2. Materials and Methods

The aim of the research was to assess the profitability and rate of return on investments in wind turbines, with the possibility of using other energy sources, and the impact of selected natural factors on these effects. The research was carried out in Poland, in the Lubuskie Voivodeship, where the adopted strategy aims to increase the importance of renewable energy sources. The Lubuskie Voivodeship is located in the western part of Poland, where it borders with Germany. It is situated in two wind zones, the conditions of which are favourable (southern part) and very favourable (northern part)—Figure 1.

The analysis used a comparative method, based on the simulation of the benefits and costs of wind and solar farm installations in various parts of the Lubuskie Voivodeship, characterized by different wind conditions. For this purpose, 2 locations were selected: the first one with the following parameters: latitude 51 degrees, 30.00 min N, Longitude 15 degrees, 11.98 min E and the second location: latitude 52 degrees, 52.64 min N, Longitude 15 degrees, 31, 78 min E. The annual insolation of both regions, wind potential, gas prices, generator power, as well as gas and electricity consumption were taken into account. The data came from public statistics and was searched using the Homer Grid program (Version 1.8.7—7 January 2021). The estimation of financial costs and benefits is based on a 20-year horizon, using macroeconomic variables such as the inflation rate and the 10-year bond market rate.

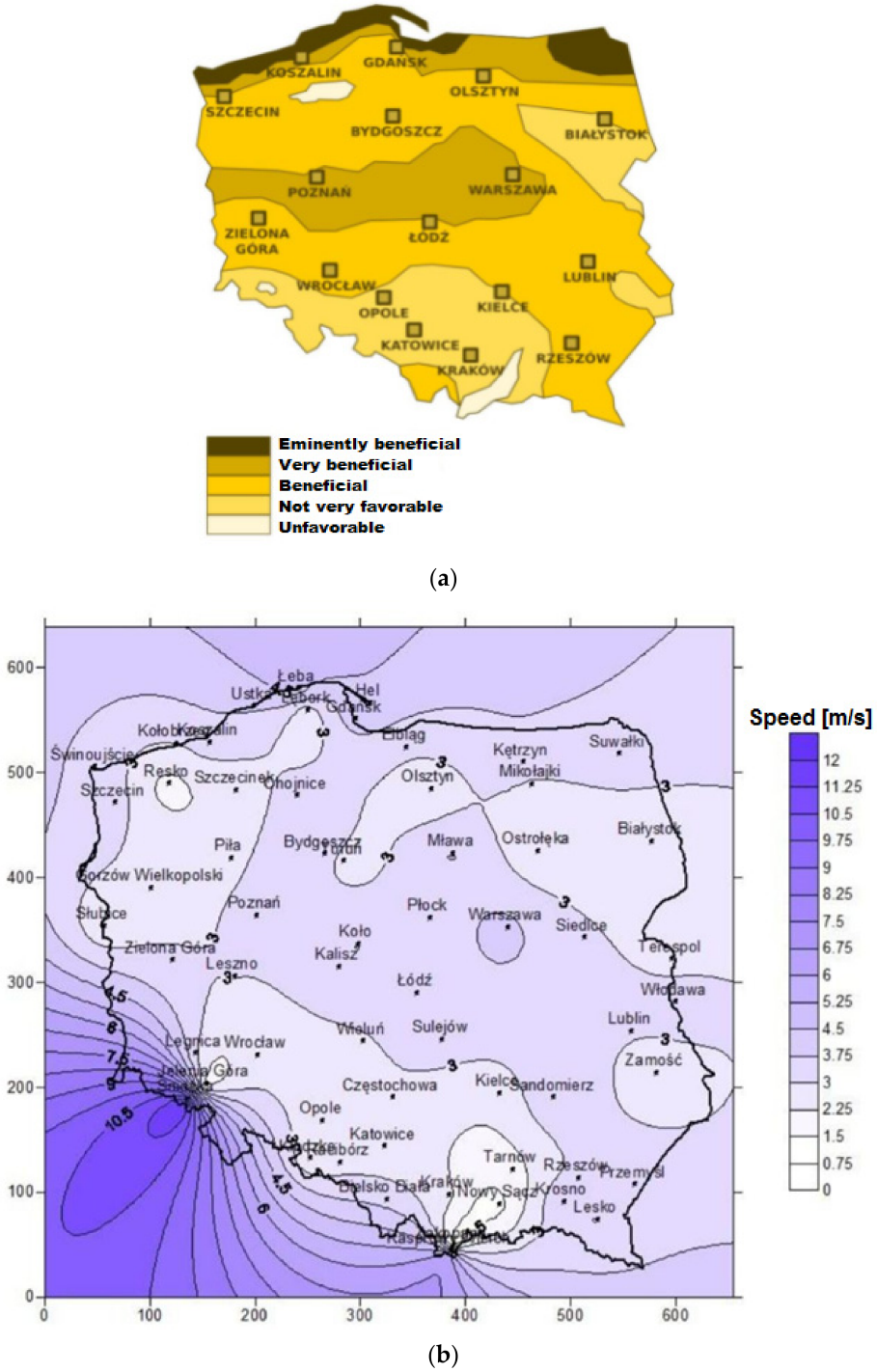


Figure 1. (**a**) Wind conditions in Poland. Source: https://www.instalacjebudowlane.pl/7935-24-87-elektrownie-wiatrowe--wietrznosc-w-polsce.html (accessed on 8 October 2021). (**b**) Wind speeds in Poland. Source: https://remont.biz.pl/energia-odnawialna/zasoby-energii-wiatru-na-terenie-polski-mapa-lokalizacji-w-ktorych-wykorzystamy-wiatrak-do-produkcji-energii-elektrycznej/?fbclid=IwAR2FDyApg_9f3H8blMmpTi_x_BSXgOk7deX5ItihZSu14Vk1_Kzw4PYKLCk (accessed on 8 October 2021).

Due to the location of the Lubuskie Voivodeship in two different wind zones (Figure 1), the question arises about the possibility of supplying energy to households located in separate zones. The analysis of two geographically different locations, in terms of energy production, was widely discussed. The approach used by Becerra et al. [59] for example,

Chile, aimed to identify the economic benefits of wind and solar energy. In turn, the study by Chang and Starcher [60] concerned the identification of the right location for investment in wind and solar energy in Texas. Such analyses show the possibilities of using wind energy to supply a household with electricity by installing wind turbines as an alternative to photovoltaic panels or as a supplement to meet the demand for electricity. The pattern of electricity consumption for the Lubuskie Voivodeship is shown in Figure 2. The annual energy consumption model can be considered sustainable, and the highest energy consumption oscillates between 6:00 p.m. and 9:00 p.m. (Figure 2), which is mainly related to the performance of contract work at earlier times and the activity of household members in the household. This mainly applies to administrative staff, as well as points of sale, repair shops, banks, and other qualified professions. After this time, increased energy consumption occurs due to the operation of many household appliances for hygienic, entertainment, recreational, or professional purposes. At other times, the statistical consumption is lower and often refers only to the provision of energy to devices that constantly require energy supplies (such as pumps). As a rule, people with free time distribute household chores over a longer period of time, so energy consumption is more evenly distributed over time. The lowest consumption falls on the night hours, due to the lifestyle, work, and rest.

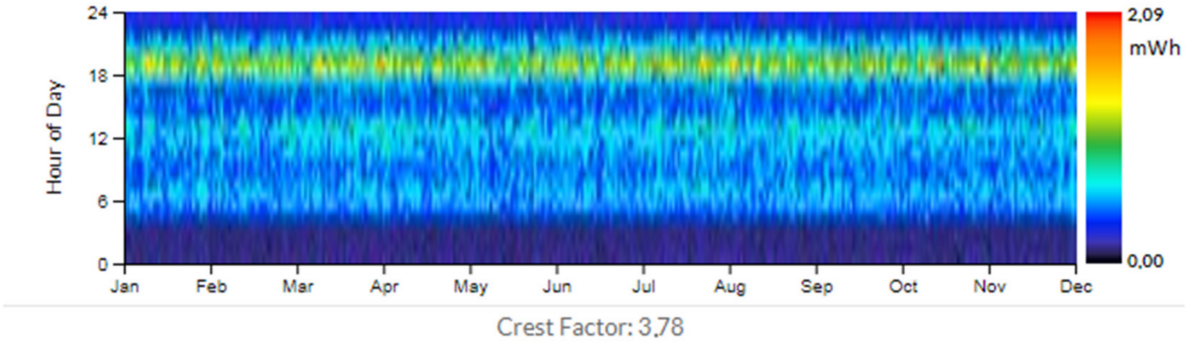


Figure 2. Energy Consumption Patterns in the Lubuskie Voivodeship. Source: own study using Homer Grid software.

Currently, instead of building individual wind farms, there is a tendency to design wind parks with a total capacity of several dozen megawatts, with power plants built on masts 100 m high, where the average annual wind speeds for the area of the Lubuskie Voivodeship range from 6.6 to 7.8 m/s (Figure 3) (open area), with the best insolation conditions in Poland—above 1048 kWh/m^2 [61].

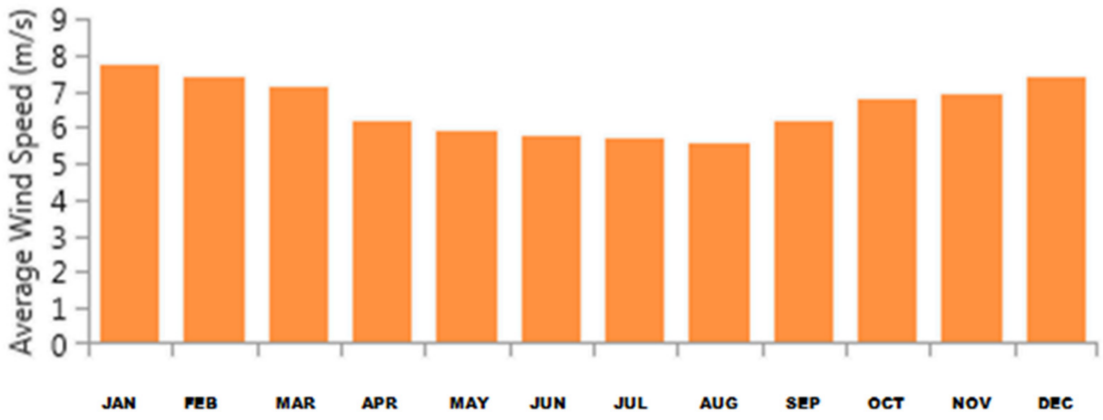


Figure 3. Average wind speeds (m/s) for the Lubuskie Voivodeship. Source: own study using Homer Grid software.

Recorded wind speeds change cyclically—from faster ones in cool periods to slow ones in summer (Figure 3). The level of urbanization is also an important factor. Open areas are a significant determinant for the use of wind potential, which is difficult to implement in dense urban developments. The wind profile of the Lubuskie Voivodeship is shown in Figure 4. This picture shows the existence of clear differences between individual months, the capacity of wind farms to produce electricity, and the need to use other energy sources to ensure the stability of supplies.

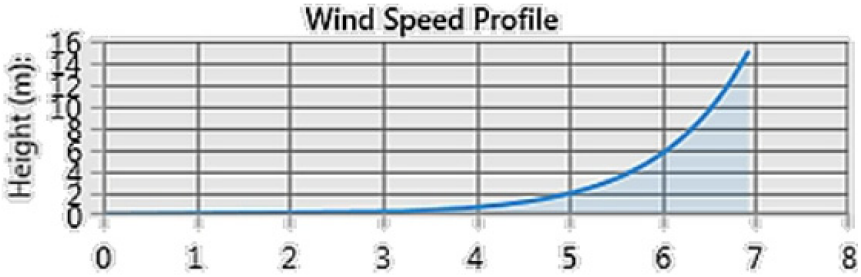


Figure 4. Wind Speed Profile for the Lubuskie Voivodeship—average value. Source: own study using Homer Grid software.

Obtaining energy from natural sources is associated with the need to undertake long-term investments, estimating costs and potential economic profits. The study attempts to estimate the investment of installing a wind turbine with a photovoltaic panel and generator, connected to the grid (Figure 5) for two wind zones of the Lubuskie Voivodeship. The same investment parameters were adopted in both zones, prices for a turbine, photovoltaic panels, batteries, and a generator. In both cases, the turbine was installed at a height of 17 m. Homer Grid software combines engineering and economic information into one comprehensive model. This enables multiple options and outcomes to be compared and provides opportunities to identify points where different technologies become cost competitive. Moreover, it optimizes various options, which reduces the risk of the project and reduces energy costs [62].

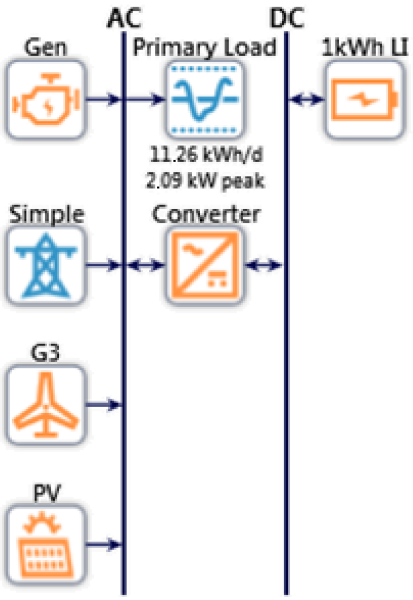


Figure 5. Diagram of the module for obtaining energy from natural sources for the Lubuskie Voivodeship. Source: own study using Homer Grid software.

The adopted diagram of energy sources in the hybrid system is shown in Figure 5. In the model, there are 3 sources of electricity generation (wind, solar, and natural gas), which is transferred to the grid and stored in a battery. The use of the generator, as an external source is necessary, due to the high power consumption in the afternoon, where natural sources alone will not be sufficient to cover the current energy demand. With the time of day, the wind speed, and the intensity of solar radiation also change, which determines the use of additional external power supply for the needs of the household. The Lubuskie Voivodeship is the sunniest area in Poland. Annual average radiation is presented in Figure 6. This creates a favourable perspective for the use of renewable energy sources—especially solar energy in relation to other regions of Poland.

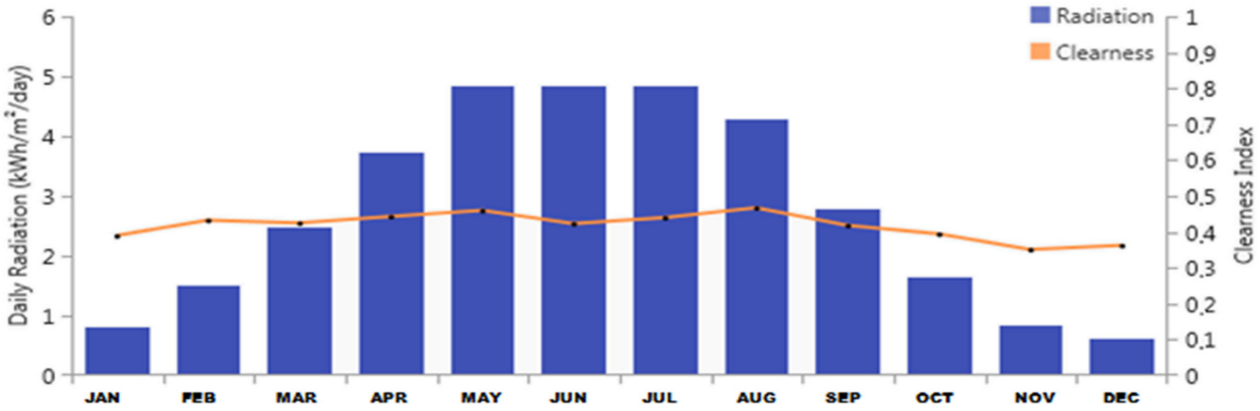


Figure 6. Annual average radiation (kWh/m2/day) in the Lubuskie Voivodeship. Source: own study using Homer Grid software.

For the northern and southern parts of the Lubuskie Voivodeship, the average radiation values are 2.78 kWh/m^2 and 2.76 kWh/m^2, respectively. The clearness index, expressing the relation of global solar radiation intensity measured at ground level to its equivalent estimated at the top of the atmosphere [63], in both cases, was very similar, and its fluctuations over the year are small. The greatest potential for generating energy from the Sun occurs in the summer (Figure 7). As the best time periods for the production of energy from wind and sun are in opposition to each other, it is worth using a combination of their use in order to maximize the production of electricity. This is a clear indication for the hybrid model when planning wind investments.

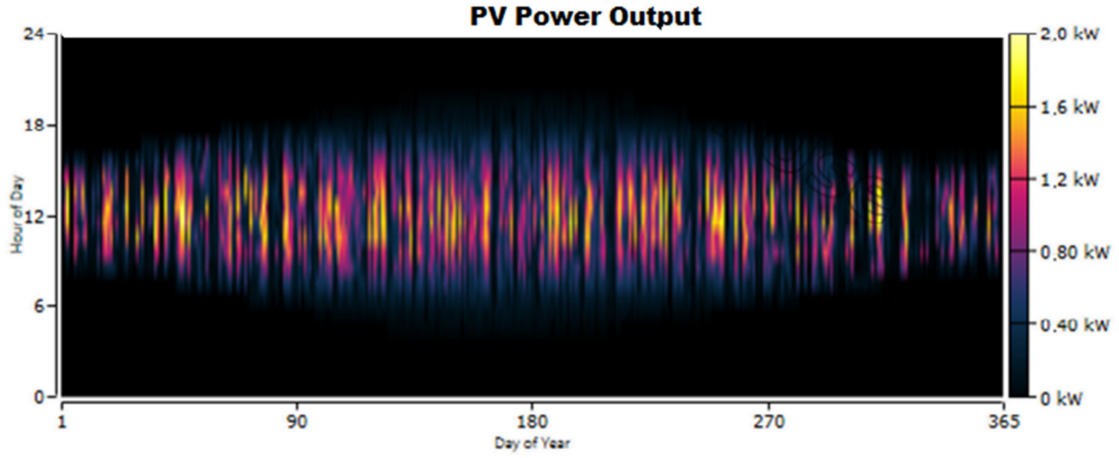


Figure 7. PV Power Output for the Lubuskie Voivodeship. Source: own study using Homer Grid software.

Despite being located in various wind zones, the solar factor also showed differences in both parts of the voivodeship. The values for full facility rated power, output power, total production, and PV penetration (%) are all more favourable in the southern part (Table 1). Moreover, this location showed lower levelised costs, which is a good measure of the average net present cost of generating electricity over the entire life cycle of the plant. Thanks to this, it is possible to combine various investment variants in order to select the appropriate method of electricity generation, depending on the adopted location.

Table 1. Comparison of the possibilities of a photovoltaic panel in two zones of the Lubuskie Voivodeship.

Quantity	Southern Part	Northern Part	Units
	Value		
Rated Capacity	2.00	1.95	kW
Mean Output	0.220	0.216	kW
Mean Output	5.28	5.17	kWh/d
Capacity Factor	11.0	11.1	%
Total Production	1929	1888	kWh/yr
Max. Output	1.98	1.93	kW
PV Penetration	46.9	45.9	%
Hours of Operation	4383	4384	hrs/yr
Levelized Cost	0.249	0.250	PLN/kWh

Source: own study using Homer Grid software.

External power supply is a generator that generates energy from gas, and its forecast consumption is shown in Figure 8. Fuel consumption will change over time, although it is possible to indicate certain regularities of increased consumption during the day, analogically, to the general model of electricity consumption (cf. Figure 2). In addition, gas is used to heat households in the cold months, which is also demonstrated by higher values of average consumption in box charts (Figure 8).

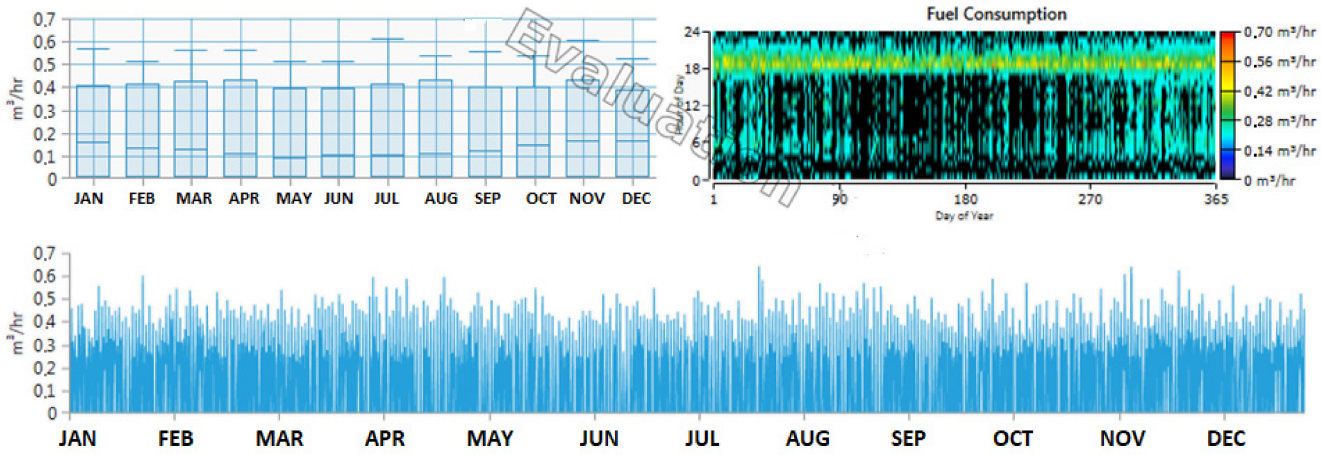


Figure 8. Fuel consumption in the adopted system. Source: own study using Homer Grid software.

Fuel consumption in both locations is similar—slightly higher values are found in the southern part for less favourable wind conditions (Table 2). In the long term, this will be compensation for obtaining energy from natural sources in both zones. The long-term perspective is also associated with the risk of changes in gas prices. In the model adopted, fuel prices are the same in both regions.

Table 2. Estimated fuel consumption for the generator in the northern and southern parts.

Quantity	Southern Part	Northern Part	Units
	Value		
Total fuel consumed	1117	1104	m^3
Avg fuel per day	3.06	3.03	m^3/day
Avg fuel per hour	0.128	0.126	m^3/hour

Source: own study using Homer Grid software.

The calculation assumes a 20-year investment time horizon. According to the forecast of the National Bank of Poland, the assumed inflation rate was 3.4% [64]. The discount rate was estimated on the basis of long-term treasury bonds (10-year), which, after the first year, are, respectively: 1.00% margin plus inflation, with annual interest capitalization [65]. Thus, the discount rate throughout the investment period was 4.4%. Additionally, the G11 tariff in Poland (0.63 PLN/kWh) was adopted as the tariff. In this tariff, the price of electricity is constant around the clock. It is popular in small apartments and houses that are not heated by electricity. The tariff is simple and understandable, giving residents the ability to easily check their invoices and easily predict electricity consumption. The estimated cost of the wind turbine is 18,000 PLN. The wind turbine is mounted at a height of 17 m. Costs and savings were estimated using the Homer Grid (Table 3 and Table 4).

3. Result and Discussion

The analyses carried out with the use of the Homer model allowed for demonstrating the legitimacy of using hybrid solutions. There are significant differences between the results obtained in the northern part of the voivodeship (with more favourable wind conditions) and the southern part (with favourable sunny conditions)—Table 3. As a result of the simulations of the investment implementation, the southern location is more favourable, showing the return on investment with the adopted assumptions in the simple model (8.9 years) and the discounted model (9.7 years). Thanks to this solution, it is also possible to reduce gas consumption in both locations and greenhouse gas emissions, with the reduction being greater in the case of the southern location. In both cases, we are dealing with a significant reduction in economic costs with the adopted, prudent assumptions.

Table 3. Savings Overview: Wind + Generator + Storage: 1kWh LI + Simple.

Description	Southern Part	Northern Part
Economic Metrics		
Average annual energy bill savings	2715.55 PLN	2662.13 PLN
Payback time (simple/discounted)	8.9/9.7 years	10.9/11.4 years
Internal Rate of Return (IRR)	8.67%	7.03%
Project lifetime savings over 20 years	54,311 PLN	53,243 PLN
The levelized cost of energy—LCOE (PLN/kWh)	0.191 PLN/kWh	0.184 PLN/kWh
Net Present Cost (PLN)	31,684 PLN	31,445 PLN
Costs and Savings		
CAPEX (capital expenditures)	20,466 PLN	21,792 PLN
OPEX (operating expenditures)	620 PLN	533 PLN
Annual Total Savings (PLN)	2174 PLN	2056 PLN
Annual Utility Bill Savings (PLN)	2716 PLN	2662 PLN
Annual Energy Charges (PLN/yr)	78 PLN/yr	8 PLN/yr
Environmental Impact		
CO_2 Emissions (metric ton/yr)	0.9 t/yr	1.1 t/yr
Annual Gas Consumption (L/yr)	475 L/yr	578 L/yr

Source: own study using Homer Grid software.

The differences in savings are partly due to the difference in the level of insolation in both areas and thus, in the amount of energy produced at a lower levelised cost. In the case of a 20-year investment, the differences in the total energy production produced by the photovoltaic installation will generate additional savings in the southern part. Additionally, it may reduce generator use and use more renewable energy. As a result, the estimated rate of return is more favourable in the southern location (8.67%) than in the northern one (7.03%) and shows a greater level of resource savings with a slightly higher level of operating costs. These differences made the optimal installation in both regions differ only in the number of batteries in the southern part (Table 4). However, it will be a fixed cost, not affecting the share of the marginal costs of the entire project, which means that these investments can be carried out in both locations for the needs of households.

Table 4. Installation Recommendation.

Component	Price	Installation Size	Total Installed Cost	Annual Expenses
		Southern part		
Generic 3 kW	18,000.00 P LN/ea	1 ea	10,000.00 PLN	180 PLN/yr
Generic 1kWh Li-Ion	550.00 PLN/ea	2 ea	1100 PLN	20 PLN/yr
Autosize Genset (NG)	3150.00 PLN/ea	2.1 kW	3150.00 PLN	217.65 PLN/yr
		Northern part		
Generic 3 kW	18,000.00 P LN/ea	1 ea	10,000.00 PLN	180 PLN/yr
Generic 1kWh Li-Ion	550.00 PLN/ea	1 ea	550 PLN	10 PLN/yr
Autosize Genset (NG)	3150.00 PLN/ea	2.1 kW	3150.00 PLN	217.65 PLN/yr

Source: own study using Homer Grid software.

The hybrid approach to obtaining electricity for households, in both cases, shows the benefits of such an investment. Despite the difference in the level of costs and the rate of return, investments in both locations generate potential savings in the long term. The wind factor alone turned out to be insufficient to provide better conditions for energy generation and return on investment. Hybrid models are more flexible in this respect, and their use is less fluctuating than investing in only one renewable energy source. Similar results were obtained in the Guzelyurt household energy satisfaction survey in Northern Cyprus. As in the case of Poland, the hybrid system is also economically viable, as it provides an energy cost lower than the current price of energy supplied from the national grid. Moreover, it is indicated that the hybrid model can be used globally for various areas with different metrological parameters [66]. In a similar model for Southern Norway, it was noted that, in addition to the potential economic benefits when the producer's gas price does not exceed the threshold level, there are also environmental benefits related to the reduction in greenhouse gas emissions [67]. It is also important to choose an appropriate hybrid model that will perform the function of an energy supplier in the best possible way and will be economically viable. In the case of the Lubuskie Voivodeship, two wind zones were analysed with the use of one hybrid-based model. In turn, in the case of Tehran, five different hybrid models were analysed [68]. The use of hybrid models may also find application in poorer regions. It provides the possibility of using free solar and wind energy, and additionally, it facilitates the mobilization of investments in the direction of natural energy with the increase in the utility of taking advantage of the benefits of electricity [69]. Hybrid systems give a lot of possibilities to choose the appropriate configuration and implementation of energy sources. For the Punjab province of Pakistan, the total load was optimally distributed between wind, photovoltaic, and biomass resources, and excess power was supplied to the national grid in the event of low local load demand [70]. Moreover, there are concepts that indicate the investment profitability of obtaining energy in the absence of government incentives [71]. Nowadays, wind and solar energy are becoming more and more popular due to their availability and abundance, beneficial environmental impact, and reduced use of non-renewable sources,

and the hybrid energy system is suitable for many applications [72]. Although various input parameters significantly translate into the final result, a proper optimization process can reduce the net current costs [73], and in addition, optimal hybrid renewable energy systems take into account the economic and environmental factors of each technology [74]. In the case of the model for the Lubuskie Voivodeship, both of these factors are favourable for the design process.

This article examines hybrid off-grid systems for generating electricity from a variety of renewable and non-renewable energy sources in order to reliably, and cost-effectively, meet household electricity needs. The obtained solution shows that a hybrid combination of renewable energy sources in given locations can be a cost-effective alternative to grid expansion and is sustainable, economically viable, and ecological. It is a practical development of the concept of sustainable development from the regional perspective. At the same time, the conditions that may affect the implementation of the optimal solution are presented, which is an extension of the contemporary theory, and recommendations for solutions for shaping energy policy in the region are proposed. This approach leads to a mitigation of the environmental impact associated with the generation of electricity produced and consumed by households and is an extension of the green economy concept.

4. Conclusions

The conducted research has shown that, in the considered locations, the use of wind farms needs the introduction of the most optimal hybrid model. It requires the simultaneous use of wind, solar, and a main generator (in this case, gas-based). This approach is economically effective, significantly increases the role of renewable energy sources, and reduces greenhouse gas emissions. Other solutions do not ensure adequate energy supply (especially if we would try to base them solely on renewable energy).

Moreover, the combination of obtaining wind and solar energy is the most optimal due to the monthly differences in the possibilities of obtaining energy from these sources, which, to some extent, are complementary to each other. An important observation is also the fact that, in the case of the Lubuskie Voivodeship, a more important factor is a more favourable level of illumination than a more favourable wind zone, which was reflected in the obtained results. As a consequence, the southern part of the voivode-ship in the hybrid model was characterized by a higher rate of return and greater re-source savings, including natural resources.

The obtained results also make it possible to demonstrate the legitimacy of using renewable energy sources, both from an economic and environmental point of view. The return on investment, with the adopted prudential assumptions, does not exceed eleven and a half years. Better results were obtained in the southern location, with slightly less favourable conditions for wind installations. It should also be added that the adopted approach does not take into account the rapid increase in energy prices, based on non-renewable sources, and the health and environmental costs (except for RES rights) resulting from the emission of pollutants. Thus, it can be assumed that the pay-back period is even shorter, especially when we add financial support, which is a kind of environmental rent.

The simulation results show that the best solution is a system based on natural gas consumption with a greater share of the photovoltaic system and, to a lesser extent, wind. This solution is sustainable as well as economically and environmentally beneficial. In addition, the prospect of gaining financial benefits after several years, and the possibility of selling energy to the grid, is an incentive for microeconomic entities to make investments.

The research, carried out with the use of the hybrid model, shows the overall possibility of generating electricity while reducing greenhouse gas emissions. In addition, the prospect of gaining financial benefits after a few years, and the possibility of selling energy to the grid, is an incentive for microeconomic entities to make investments. It may, therefore, be a key aspect of the state's policy, aimed at subsidizing installations using natural sources of energy. It also offers a new look at geographic economics, especially when making comparisons for entities at long distances. The study assumed the hypothesis that, in the

long (20-year) period, the differences in economic benefits will be significantly greater in areas with greater wind and solar factor potential.

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