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The Potential of Ecological Distributed Energy Generation Systems, Situation, and Perspective for Poland

Piotr Senkus [1,*], Waldemar Glabiszewski [2], Aneta Wysokińska-Senkus [3], Szymon Cyfert [4] and Roman Batko [5]

1 Faculty of Social Sciences, Siedlce University of Natural Sciences and Humanities, 08-110 Siedlce, Poland
2 Faculty of Economic Sciences and Management, Nicolaus Copernicus University, 87-100 Torun, Poland; waldemar.glabiszewski@umk.pl
3 Faculty of Management and Command, War Studies University Warsaw, 00-910 Warsaw, Poland; a.wysokinska-senkus@akademia.mil.pl
4 Institute of Management, Poznan University of Economics and Business, 61-875 Poznan, Poland; s.cyfert@ue.poznan.pl
5 Faculty of Management, Military University of Land Forces, 51-150 Wroclaw, Poland; roman.batko@awl.edu.pl
* Correspondence: piotr.senkus@uph.edu.pl; Tel.: +48-604-645-154

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Citation: Senkus, P.; Glabiszewski, W.; Wysokińska-Senkus, A.; Cyfert, S.; Batko, R. The Potential of Ecological Distributed Energy Generation Systems, Situation, and Perspective for Poland. *Energies* **2021**, *14*, 7966. https://doi.org/10.3390/en14237966

Academic Editors: Bartlomiej Iglinski, Antonio Rosato and Michał Bernard Pietrzak

Received: 4 October 2021
Accepted: 23 November 2021
Published: 29 November 2021

Abstract: Poland needs to fulfill its climate goals and become "climate neutral" by 2050. The plan is intricate for the Polish Government because coal-powered power plants generate about 80 percent of electricity in the country. Although policymakers are making an effort to redesign the energy sector, a lot still remains to be done. The viral trend in that transformation involves installing photovoltaic (PV) panels by private, corporate, and self-government investors. For example, the "My energy" support program of the National Fund for Environmental Protection and Water Management has helped finance 220,000 micro-PV installations. The achievement is significant but constitutes only partial success. PV powerplants will not simply replace coal powerplants. That is why the research on the ecological distributed energy generation systems has to be executed. The article presents the research results on ecological distributed energy generation systems, making the transformation of the Polish energy sector possible. The study's primary objectives were to review the energy situation with particular attention paid to the technologies that could be used as the ecological distributed energy generation systems and draw the scenarios for the sector development. The authors used Desk research, the Delphi method supported with the Computer Assisted-Web Interview (CAWI) technique, and the Weighted SWOT analysis to fulfill the objectives. The findings showed that photovoltaic (PV) systems would be the fastest-growing energy sector even in the perspective of doubling the energy consumption by 2050. Private investors investing in ecological distributed energy generation systems, especially the PV systems mentioned above, and biomass or biogas systems, would significantly help policymakers, including those in Poland, fulfill the climate goals.

Keywords: alternative energy sources; photovoltaic systems; wind systems; hydropower systems; biogas; biomass systems

1. Introduction

> "*Energy cannot be created or destroyed; it can only be changed from one form to another.*" (Albert Einstein)
>
> "*Nothing is lost, nothing is created, everything is transformed.*" (Antoine-Laurent de Lavoisier [1])

Energy has become one of the most strategic resources for countries to retain their sustainable development ability. Human beings require more and more electricity and heat to perform their daily activities, which leads to increased energy consumption. If the current trends continue, global energy demand will double by 2050 [1]. Polish policymakers face that demand-driven challenge and must also fulfill the climate goals, including becoming "climate neutral" by 2050. Achieving this is even harder because coal-powered facilities have about eighty percent of electricity in Poland, and the country is under growing pressure from the EU to reduce emissions as soon as possible.

Luckily, science and practice show that a strong innovation wave is growing in the energy sector, resulting in a disruptive change in the efficiency of clean energy facilities and cutting the unit cost of energy production [2–7].

Some energy sector analytics, such as Lovins A., declare that achieving the energy transformation goal is possible. He said that "dependence on oil and coal could be eliminated by 2050 while switching to efficient use and renewable supply", implementing only existing technologies [3,7]. Other inventors and scientists such as McDonough W. and Braungart M. claim that it can be achieved even without reducing the quality of life. The authors have declared using clean and renewable energy as one of the fundamental issues of their "Cradle to cradle" concept: "Living things thrive on the energy of current solar income. Similarly, human constructs can utilize clean and renewable energy in many forms—such as solar, wind, geothermal, gravitational energy and other energy systems being developed today—thereby capitalizing on these abundant resources while supporting human and environmental health".

The article presents the research results on ecological distributed energy generation systems, making the transformation of the Polish energy sector possible.

The main objectives of the study included:

1. To review the global energy situation with particular attention on the technologies that could be used as the ecological distributed energy generation systems;
2. To review the technologies that could be used as ecological distributed energy generation systems from the perspective of Poland.

The following research questions were asked:

(a) If the renewable energy sources could provide sufficient energy to replace the conventional energy sources (from global and Polish perspectives)?
(b) What renewable energy sources are suitable as ecological distributed energy generation systems in Poland?
(c) What are the most Strengths, Weaknesses, Opportunities, and Threats for the essential technologies to replace conventional energy sources in Poland?
(d) What are the scenarios for energy production in Poland?

The novelty of this study is the use of the weighted SWOT analysis method to analyze the Polish energy sector and individual electricity production systems. When one enters the phrase "weighted SWOT" into the Google Scholar search engine, one only finds about 70 results, of which about 30% are associated with energy. "Google Scholar" returned more than one and a half million results after searching "SWOT". The application of the above analysis was the basis for achieving the research goals set by the authors. The following study applied a weighted SWOT to Poland, but it can also be used on a voivodeship, city, or commune scale.

This study may be of interest to politicians, local government officials, managers of public, private, and non-profit organizations, and environmental activists, and engineers in the field of environmental protection. Genuine care for the planet, expressed, among other things, through the optimization of energy production processes, should be part of the typical activities of the stakeholders mentioned above and, just like ordinary people, should not be dominated by any field of science.

Another novelty of this study is showing the reader the so-called "big picture"; that is, a bird's-eye view, which allows people specializing in a vase in their fields to have a different look at the issues of energy production own business.

2. Materials and Methods

The authors used the following methods to achieve the objectives and outlines in the introduction:

- Desk research—a literature review was performed on reports and academic publications obtained mainly from the digital libraries. The desk research results were used to prepare the global energy situation review, characteristics of the different energy sources that could be used in distributed power plants, and partly the current state of production and prognosis of energy in Poland. The desk research results were also used to prepare the CAWI survey used in the Delphi method to collect the information from participants.
- The Delphi method—was developed by RAND Corporation in 1950 [7]. The Delphi approach makes use of an interactive iterative technique to look for professionals in assess or behavior predictive research. The classical Delphi approach consists of 4 key features: anonymity, iteration, managed feedback, and statistical summary [8–11]. The CAWI method became used to guide the Delphi approach. The CAWI technique was used to support the Delphi method.
- The Computer-Assisted-Web Interview (CAWI) technique—authors used the method to collect experts' opinions on energy sources in ecological distributed energy generation systems, especially their strengths, weaknesses, opportunities, and threats. A mostly five-point scale was used. The data were collected in two rounds. In the first round of the survey, mainly open-ended questions were included. Then in the second round, the survey included five-point scale questions to evaluate the most frequent factors from the first round. Finally, the authors analyzed the collected data to prepare the weighted SWOT
- The Weighted SWOT analysis—SWOT analysis is a widely used technique to map out the present Strengths (S), Weaknesses (W), Opportunities (O), and Threats (T). The SWOT Analysis has two main steps: listing the key internal strengths and weaknesses and listing the key external opportunities and threats. Because SWOT analysis is often subjective, the authors prepared a weighted SWOT score matrix, where the metrics are defined as below:
    - Weight (W)—the relative importance of a given factor in the range from 0.00 to 1.00 (0.00—insignificant factor; 1.00—significant factor). The total weight -1.00;
    - Rating (R)—on a scale from 1 to 5. The higher rating, the more like to attain;
    - Weighted score—that was computed by multiplying each factor's weight by its rating;
    - Total Weighted Score (TWS) = (W) $\times$ (R);
    - Internal Factors Ratio (IFR) = (S TWS)/(W TWS).
    - External Factors Ratio (EFR) = (O TWS)/(T TWS) [12–15].

The template of the Weighted SWOT analysis is presented in Table 1.

Table 1. The example of the Weighted SWOT analysis.

		Weight	Rating	Score
Strengths		1.00		
1	Strength 1	0.40	5	2.00
2	Strength 2	0.30	4	1.20
	Total weighted score			3.20
Weaknesses		1.00		
1	Weakness 1	0.30	5	1.50
2	Weakness 2	0.30	5	1.50
	Total weighted score			3.00
Internal Factors Ratio (IFR)				1.06
Opportunities		1.00		
1	Opportunity 1	0.60	5	3.00
2	Opportunity 2	0.40	5	2.00
	Total weighted score			5.00
Threats		1.00		
1	Threat 1	0.50	5	2.50
2	Threat 2	0.30	5	1.50
	Total weighted score			4.00
External Factors Ratio (EFR)				1.25

The authors have described the most popular energy sources in the following aspects:

- General characteristics;
- Current usage;
- Possibility to use as a distributed powerplant;
- Usage potential;
- Levelized cost of energy (LCOE).

The LCOE is calculated and discussed in this section from an economic point of view (excluding transfers such as grants, taxes, or other financial incentives (e.g., the LCOE calculated from a financial or investor's point of view include these transfers)). The LCOE is calculated as follows: (3)

$$LCOE = ACC + VOMC + FC + FOMC \tag{1}$$

- "ACC, VOMC, FOMC, and FC—annualized capital costs, variable O & M costs, fixed O & M costs, and fuel costs.

All these costs are expressed in terms of energy ($/MWh). ACC and FOMC are calculated as presented below" (4):

$$ACC = (OC * CRF * 1000)/(CAF * 24 * 365) \tag{2}$$

$$FOMC = (FXC * 1000)/(CAF * 24 * 365) \tag{3}$$

- OC means a lump-sum investment of a facility ($/kW), and FXC is the annual fixed costs $/kW. CRF is the capacity recovery factor that converts the costs expressed in terms of capacity to the related costs in terms of energy. CAF is the capacity availability factor.

The fuel cost does not apply to renewable technologies, except biomass. It is determined based on the heat content of a fuel (HC), fuel prices (FP), and the heat rate of the system (HR). Fuel prices are in USD per metric ton of coal. Heat content—the amount of heat, in kilocalories (Kcal) or megajoules (MJ), divided by one physical unit of the fuel (MJ/kg). "Heat rate is the inverse of the thermal efficiency of a power plant; it refers to the amount of heat needed to produce one unit of electric power (MJ/kWh). Thus, the fuel cost (FC) was calculated as:

$$FC = (FP/HC) * HR \tag{4}$$

Finally, the CRF is derived by using the discount rate (r) and the economic life (n) of a plant as follows" [15,16]:

$$CRF = \{r * (1 + r)n\}/[\{(1 + r)n\} - 1] \tag{5}$$

3. Global Energy Situation Review

Human beings have always used energy to fulfill needs and to transform the world around them. When considering energy consumption from 1800 to 2019, its growth is exponential and could be described with a function. e = 2.71828 is Euler's number. The "x" occurs as an exponent (1). The R^2 indicator—0.9671 is very high in that case and shows that the curve equation almost perfectly fits the analyzed data (2).

$$y = 0.1449e^{0.1329x} \tag{6}$$

$$R^2 = 0.9671 \tag{7}$$

When considering the energy sources' mix, traditional biomass gave 5653 TWh in 1800, and 11,111 TWh in 2020. That means over 100% growth, but it was the slowest growing energy source (Figure 1).

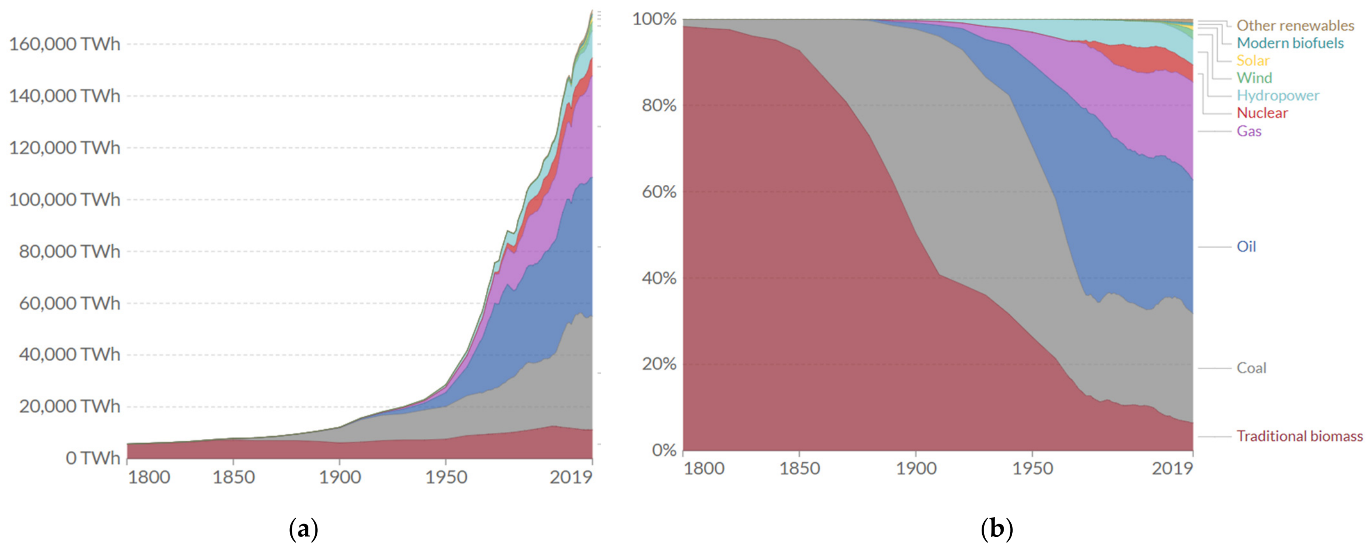


Figure 1. Global primary energy consumption by source: (**a**) In Twh; (**b**) relative (%) [17].

Coal was the second traditional primary energy source. It delivered about 97 TWh in 1800, and 44,109 TWh in 2019. In the 19th century, coal was the primary energy source to enable the "1st Industrial Revolution" and was 55.23% of the global energy mix in 1910. Since then, no primary energy source achieved such a significant share in the world energy mix. The percentage of coal in the global energy mix has been declining and now is about 25.7%.

Oil was the third primary energy source that has appeared in the 19th century and has become the essential energy source. The history of oil began in occupied Poland. The Polish pharmacist, engineer, businessman, inventor, and philanthropist Ignacy Łukasiewicz was the pioneer who designed the world's first modern oil refinery in 1856. "His achievements included discovering the methods of distilling kerosene from seep oil, the invention of the modern kerosene lamp, the introduction of the first modern street lamp in Europe, and the construction of the world's first modern oil well" [18,19]. Oil has provided 53,620 TWh in 2019, and was the first most crucial energy source, but its share was about 31% at that time. It obtained its highest share—43.3% in the global energy mix in 1973.

Natural gas was the fourth most crucial energy source in 2019. The history of gas also began in the 19th century. The popularity of natural gas is still growing. In 2019, gas provided 39,292 TWh, which constituted 22.5% of the global energy mix.

Hydropower was the fifth most crucial energy source in 2019. It has provided 10,455 TWh, making 6.05% of the global primary energy mix—the most significant share of the renewables.

Nuclear fusion was the sixth most important primary energy source in 2019. It provided 6923 TWh and about 3.99%.

Recently, the most popular renewables: wind, solar, and modern biofuels, and other sources provided 4.64%, merely 1.64% more is considered a statistical error in the analysis. It has to be mentioned that all of the four primary energy sources used in 2019 were fossil fuels that have provided around 147,876 TWh, making 85.31% of the global energy mix.

This is the perfect time to ask about the possibility of the total reconstruction of the global energy mix by 2050. However, please wait a little bit for the answer and scenarios for the future related to Poland.

Other statistics are even more interesting, such as the energy consumption per capita. Qatar was the first place according to primary energy consumption in 2020—200.00 MWh per capita. The rest included: Iceland—181.38; Singapore—171.23; Trinidad and Tobago—143.26; United Arab Emirates—138.42; Kuwait—108.99; Canada—106.38; Norway—91.97; Saudi Arabia—90.17; and Oman—85.21. The average energy consumption was 21.19, and the median value—28.71 MWh per capita. That means that the average use of primary power sources is about 9.4× lower than the consumption in Qatar. Poland with 31.61 was between median and average. Almost all countries in that ranking acquire their energy primarily from fossil fuels they possess and excavate. That means that the countries' governments could not be particularly interested in energy transformation. According to the UN, there is one exception—Iceland, which could be the model energy transformation for the world because over 85% of the energy consumed there was acquired from renewable energy sources [20,21].

The factor that encourages the investment in renewable energy sources is the combination of the cost of energy generation and the market price of the electricity. According to the authors, this relationship is essential in encouraging potential investors to invest in distributed power plants. Figure 2 presents the average wholesale baseload electricity prices for the first quarter of 2021 [21].

Compared to the previous year, the average electricity prices in the EU have grown 57% compared to the preceding 12 months. The highest growth has been observed in (a) Norway (about 190%), (b) Sweden (about 160%), (c) Denmark (about 130%), and (d) Finland (about 100%).

Although that situation means higher prices and enabling inflation, it will still boost investment in the eco-distributed power plants.

Will the growing trend continue? It depends. EU citizens might remember when in 2009, the EU called for withdrawing traditional halogen light bulbs [22]. The only developed lightning technology at that time was compact fluorescent lamps (CFL). Unfortunately, that technology was much more expensive than traditional halogen lightbulbs. Light emitting diode (LED) technology was marginal at that time. Nowadays, consumers prefer LED instead of CFL [22–24]. The same case could be with energy generation, and that is why relying only on statistical data referring to changes in the technology, including energy technology, is useless. Statistical information has nothing to do with "destructive technologies" that appear on the market and are changing it dramatically. The exact mechanism could be seen in other sectors, too [25,26]. This is why the authors treat the statistical analysis as background for further additional analysis like expert panels with the Delphi method and CAWI surveys.

Figure 2. Average wholesale electricity prices, for the first quarter of 2021.

For those who think that the status quo in which fossil fuels burned traditionally will still be the leading source of energy, the words of Don Huberts should be recalled. He was "convinced that fuel cells, which generate clean energy from hydrogen, would soon replace power stations and cars that mostly burn coal, oil, or natural gas" [26]. The Royal Dutch/Shell manager said: "The stone age did not end because the world ran out of stones, and the oil age will not end because we run out of oil".

4. Characteristics of the Different Energy Sources That Could Be Used in Ecological Distributed Energy Generation Systems

The following energy generation systems are characterized in that section: • Photovoltaic systems; • Concentrating Solar Power (CSP) system; • Wind systems; • Natural Gas; • Geothermal systems; • Hydropower systems; • Coal systems; • Nuclear systems; and • Biomass and biogas systems.

Photovoltaic systems are designed to provide usable solar energy through photovoltaic cells. The system consists of various modules, including • solar panels that absorb sunlight and convert it into electricity; • solar inverter to convert direct current to alternating current; • plumbing; • cables; and • other equipment. PV systems range from an integrated roof or building systems with several kilowatts to large power plants of several hundred megawatts. Nowadays, most photovoltaic systems are on-grid, while off-grid systems make up a small market [27–37]. In the publication year, PV systems are mostly made from crystalline silicon (c-Si), and the most popular on the market are:

- Monocrystalline silicon (mono-Si) solar cells feature a single-crystal composition;
- Polycrystalline silicon cells that are made from cast square ingots—large blocks of molten silicon carefully cooled and solidified.

It has been estimated that the silicon-based PV systems efficiency is limited to about 30%, which outputs about 330 (Pmax) W/m^2. According to respondents who took part in the survey, PV systems have become "disruptive technologies" and could be most suitable for distributed power plants [38,39]. According to the respondents or literature sources, the popularity of PV systems will grow because the systems are becoming cheaper and cheaper over time [40,41].

The photovoltaic systems are very elastic in terms of their application, for example, (a) rooftop and building integrated systems; (b) photovoltaic thermal hybrid solar collector; (c) power stations; (d) agrivoltaics; (e) rural electrification; (f) spacecraft applications; (g) indoor photovoltaics (IPV); and (h) spacecraft applications [41]. In the future, this technology will be even cheaper and more accessible due to research on Perovskite solar cells (PSC). "PSC is a type of solar cell that includes a perovskite-structured compound, most commonly a hybrid organic–inorganic lead or tin halide-based material, as the light-harvesting active layer. The researchers have estimated that solar systems based on PSC could gain efficiency about 66%" [42–49]. That means the potential output is about 1200 (Pmax) W/m^2. It is even more important that perovskite PV systems, according to Saule Technologies, can be placed on almost every surface that makes them perfect for building distributed powerplants [44,45]. The advantages of PV systems include: (a) high reliability; (b) strong persistence; (c) low maintenance costs; (d) zero fuel consumption; and (e) strong independence. The most important disadvantages of photovoltaic systems are (a) high start-up cost, (b) available solar radiation instability, and (c) have energy storage requirements. According to the IRENA photovoltaic system, even based on silicone, in 2019, it had the lowest LCOE—618.00 USD/kW (Table 2). That makes it one of the most economic-efficient energy systems. The cost per unit in 2019 was about 0.25 USD/kWh and competed with hydropower systems and biofuels. The experts predict that with upcoming perovskite and mix silicon-perovskite in no more than five years, photovoltaic systems will be the most economically effective from the others discussed in the paper.

Concentrating Solar Power (CSP) systems—sunlight is focused by mirrors or lenses on the receiver generating a large amount of energy. When sunlight is converted into heat (solar heat), electricity is generated, connecting a heat engine (usually a steam turbine) with an electricity generator, or carrying out a thermochemical reaction. "The CSP had a total installed capacity of 5500 MW worldwide in 2018, compared to 354 MW in 2005" [34–36]; in 2020, 133 powerplants in 22 countries [45]. According to the experts' system, concentrating solar power (CSP) is also a "disruptive technology", but technical aspects are not accessible for individuals or small businesses. This is why the potential of using solar power (CSP) as distributed powerplants is more limited than photovoltaic systems. It is not very popular technology.

Wind systems—onshore wind is the type that blows straight from the sea. On the other hand, an offshore wind is composed of waves that blow from the ground. In 2019, wind power provided 1430 TWh of electricity, equivalent to 5.3% of global electricity production, with a worldwide installed wind capacity of over 651 GW, an increase of 10% compared to 2018. According to the experts, the onshore and offshore wind systems are also "disruptive technologies." Offshore wind systems, due to technical aspects, are not so accessible for individuals or small businesses. Onshore wind systems are very scalable and more accessible for smaller investors. The experts predict that due to ongoing research on wind turbines, they will be more effective. Figure 3 presents different wind turbines that could have been in various industrial, commercial, or residential installations. The LCOE of the onshore wind turbine systems is second-lowest from analyzed energy generation systems—Table 2.

Figure 3. Different types of small wind turbines.

Natural Gas systems—Natural gas belongs to fossils but burns more cleanly than others. The systems that transform energy are mainly gas turbines and steam turbines. Natural gas burns. Natural gas could support future renewable energy sources. Natural gas is used in nearly every country and is traded on every continent. The LCOE of the natural gas made it the most attractive energy—Table 2. Technologies like micro-combined heat and power (CHP), which produce power and heat from natural gas, could be the disruptive technology that keeps natural gas as one of the most important energy sources, and makes the technology very important in ecological-distributed powerplants [50,51].

Geothermal systems—is the thermal energy from Earth's crust. In 2019, 13,900 MW (MW) of geothermal energy were retrieved worldwide. Since 2010, 28 gigawatts of direct geothermal heating systems have been installed. Geothermal power generators have been used in 26 countries and heating facilities in 70 countries [52–55]. Although the LCOE of the geothermal systems was above the average for renewables (Table 2), they are promising alternatives for fossil fuels depending on the individual counties' physical conditions. According to the experts, small-scale geothermal energy systems could build ecological distributed powerplants in countries that are rich in geothermal sources. This point of view has also be seen in recent publications [56,57].

Hydropower systems—Hydropower systems installed capacity was 1308 GW in 2020, making over 71% of all RES in 2020. Hydropower generated [2] and was expected to increase by about 3.1% each year for the next 25 years. As can be seen by LCOE analysis, the cost of hydroelectricity was low. When natural conditions are available, hydropower systems are the most compatible of RES. Traditionally, hydropower systems are related to rivers or water reservoirs [58–60]. According to the experts, small-scale hydropower energy systems could even be used as power accumulation for PV or wind turbines to store energy when more energy from renewables is produced than used and retrieved when it is needed.

Table 2. The cost of different RES (USD/kW, 2019 price).

No.	Source	Value	Solar PV Systems	CSP	Wind Systems		Natural Gas Systems	
					Onshore	Offshore	Gas-CC	Gas-GT
1	EIA		1331.00	7191.00	1319.00	5446.00	1017.00	710.00
2	IEA	Min	1005.00	3831.00	1287.00	3973.00	673.00	536.00
		Avg	1877.50	6283.00	2252.00	5169.00	1028.00	768.50
		Max	2750.00	8735.00	3217.00	6365.00	1383.00	1001.00
3	IRENA	Min	618.00	3704.00	1039.00	2677.00	n.a.	n.a
		Avg	1706.00	5415.50	1760.50	4114.00	n.a.	n.a
		Max	2794.00	7127.00	2482.00	5551.00	n.a.	n.a
4	Lazard	Min	900.00	6000.00	1100.00	2350.00	700.00	700.00
		Avg	1000.00	7550.00	1300.00	2950.00	1000.00	825.00
		Max	1100.00	9100.00	1500.00	3550.00	1300.00	950.00
5	NREL	Min	1142.00	6574.00	1678.00	3145.00	944.00	937.00
		Avg	1142.00	6574.00	1678.00	4231.50	944.00	937.00
		Max	1142.00	6574.00	1678.00	5318.00	944.00	937.00
No.	Data Source	Value	Geothermal Systems	Hydropower Systems	Coal Systems	Nuclear Systems	Biomass Systems	
1	EIA	Min	2680.00	2752.00	3661.00	6317.00	2831.00	
2	IEA	Min	1602.00	1282.00	1072.00	2805.00	630.00	
		Avg	4355.00	n.u.	2181.00	4736.50	4964.00	
		Max	7108.00	n.u.	3290.00	6668.00	9298.00	
3	IRENA	Min	2020.00	680.00	n.a	n.a	422.00	
		Avg	4650.00	2409.00	n.a	n.a	4582.00	
		Max	7280.00	4138.00	n.a	n.a	8742.00	
4	Lazard	Min	3950.00	n.a.	3000.00	6900.00	n.a.	
		Avg	5275.00	n.a.	4600.00	3456.10	n.a.	
		Max	6600.00	n.a.	6200.00	12.20	n.a.	
5	NREL	Min	4557.00	3974.00	3867.00	6460.00	3988.00	
		Avg	n.u.	5696.00	4046.00	6460.00	4085.00	
		Max	n.u.	7418.00	4225.00	6460.00	4182.00	

n.a.—not available because the study does not include the particular technology, n.u.—not used as the values are outliers. Data from the sources were transformed to 2019 prices using US GDP deflators.

Coal systems—traditional coal transformation is conducted by burning coal to generate heat or electricity. Coal-fired power plants are responsible for one-third of the world's electricity, "but cause hundreds of thousands of early deaths each year, mainly from air pollution" [60,61]. According to the experts and current literature, there are technologies to burn coal cleanly [62,63]. There are also technologies to transform coal into gas underground [64,65]. Coal in the future may be treated as a clean energy source because of the proper transformation process that coal will undergo. The possibility of using coal as ecological distributed powerplants strongly would depend on the technology applied to transform coal into energy.

Nuclear systems—atomic energy can now be produced by nuclear fusion and decay. At present, the great majority of electricity is generated through nuclear fission of uranium and plutonium. In 2019, civilian atomic power generated 2586 TWh, or in other words, nearly 10% of worldwide energy output. That made nuclear systems the second-largest low-carbon power source. At the beginning of 2021, there were 442 civilian facilities, with 392 GW.

Moreover, there were 53 facilities under construction and 98 planned. There is a popular hypothesis regarding cold fusion [66–68]. That it is only a matter of time that clean fusion generators would be in nearly every home [68]. Temporary in many countries, there is a fear of implementing this type of technology because of spectacular nuclear catastrophes such as the Chernobyl Nuclear Power Plant—1986, and the Fukushima Daini Nuclear Power Plant—2011.

Biomass and biogas systems—The facilities use green or animal wastes to produce heat or electricity. Although biomass technically can be used directly as a fuel, some people use biomass and biofuel interchangeably [69,70]. According to the experts, biomass systems are excellent solutions for the ecological distributed powerplants, especially in rural areas.

5. The Current State of Production and Prognosis of Energy in Poland

5.1. Polish Energy Sector—Overview and Limitations

Every analysis should start with the demand side, followed by the supply analysis. It is good to put the study in context to understand the upcoming trends better. This idea highlighted the following analysis. The data from Poland were presented in the context of Germany and the EU or the world average. The previous research performed by the authors on different economic branches ensured that analyzing trends in Germany was helpful to predict changes in Poland.

The primary energy consumption in MWh per capita changed from 1965 to 2019. While the consumption of primary energy per capita in the world was growing over the analyzed period, the energy consumption per capita in Germany and Europe (average) was maximum in the early 1990 of the XX century and then started to fall. In 2019, the consumption in Germany was 78.3% of its maximum and 85.1% in Europe. The consumption in Poland dropped rapidly from 1990 to 2001 due to the fall of communism (Figure 4). From 2002, energy consumption had started to grow again. The period from that year should be taken into consideration to predict the consumption for the future. In 2019, the consumption in Poland was 71.7% of the consumption of Germany. The authors have estimated that the consumption in Poland and Germany would be equal in the statistical scenario in about 2040.

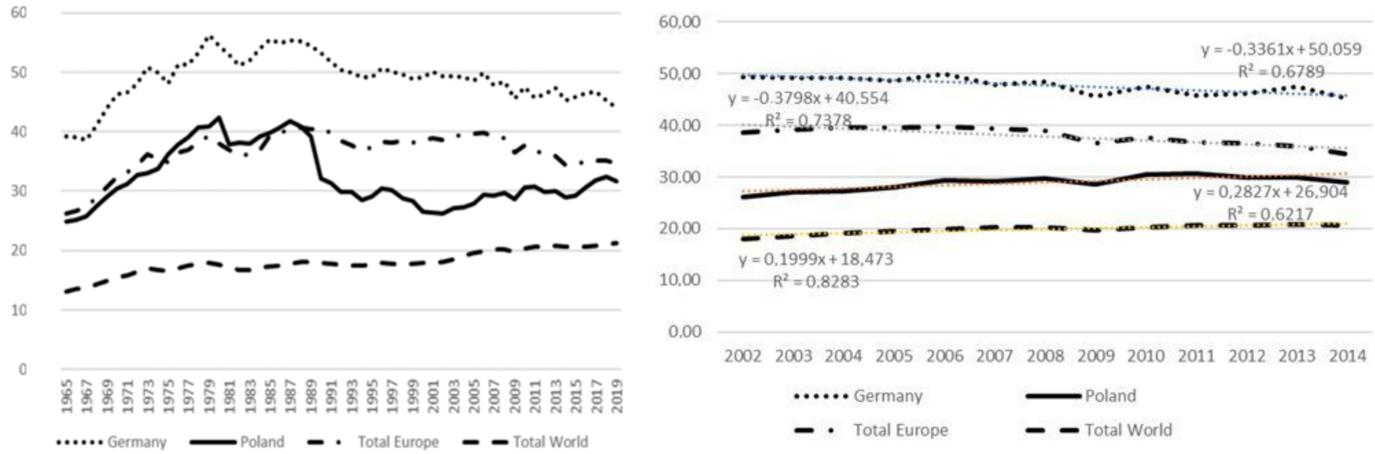


Figure 4. Energy consumption per capita in 2019 in Poland (in MWh), based on [17].

The change in primary consumption in Poland can be described by the equation below. The R-Squared (R^2) indicator over 0.5 is acceptable.

$$y = 0.2827x + 26.904 \quad (8)$$

$$R^2 = 0.6217 \quad (9)$$

The costs of fuel and energy in Poland constitute a significant share of household expenditure. According to Jurdziak and others [71–73], this share may be over 20%. That means that an increase in energy prices contributes to the impoverishment of society.

When analyzing the energy balance of Poland (Figure 5) from 2014 (except 2015), it turns out that electricity production in Poland did not cover the demand. Unfortunately, the experts predict that without a restructuring program of the Polish energy sector, the gap between demand and supply will increase, which is dangerous for the country's energy security.

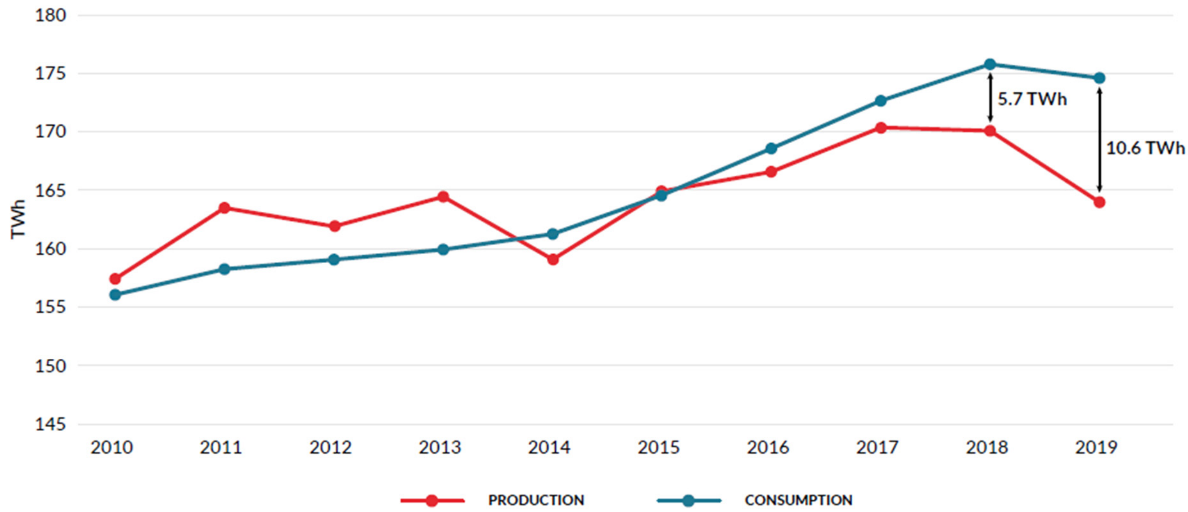


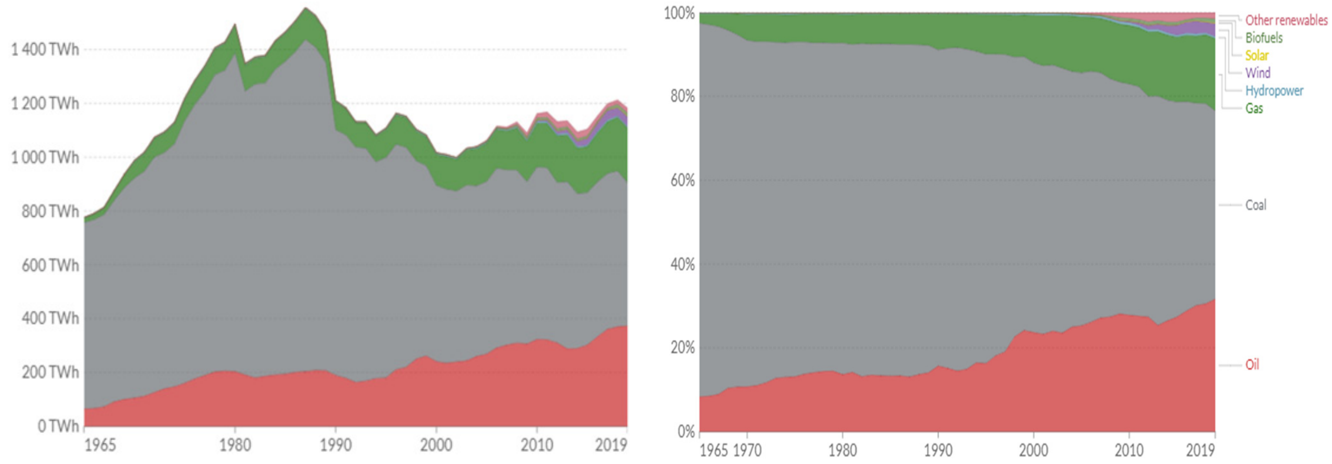
Figure 5. Balance of domestic electricity production and consumption [73].

The supply of the Polish energy system in 2019 was one of the largest in Europe [71,72] was covered mainly by coal-fired power plants—about 70% of the installed capacity [71,72]. Unfortunately, many outdated power plants and combined heat and power plants operate in Poland.

Agencja Rynku Energii S.A. (ARE) has reported in 2019 that hard coal systems with 23.9 GW had 50.4% of Poland's total installed capacity, which output 78.9 TWh of energy production and was 48.1% of total energy production in Poland. The second biggest share in the installed capacity was lignite—9.3 GW; 19.6% made 41.7 TWh; 25.5% of energy production. The other were natural gas systems—2.7 GW (5.7%) installed capacity and 14.5 TWh (8.8%) production; other industrial systems 0.6 GW (1.2%) installed capacity and 3.0 TWh (1.8%) production; pumped-storage systems 1.4 GW (3.0%) installed capacity and 0.7 TWh (0.4%) production. The total renewable energy systems had 9.5 GW (20.1%) installed capacity and 25.2 TWh (15.4%) production (hydropower systems 1.0 GW (2.0%) installed capacity and 2.0 TWh (1.2%) in production; onshore wind systems 5.9 GW (12.5%) installed capacity and 15.1 TWh (9.2%) production; biogas systems 0.2 GW (0.5%) installed capacity and 1.2 TWh (0.7%) production; biomass systems 0.9 GW (1.9%) installed capacity and 6.3 TWh (3.9%) production (including co-firing); and photovoltaics systems 1.5 GW (3.2%) installed capacity and 0.7 TWh (0.4%) production [73–76].

The structure of the energy facilities in Poland correlated to the structure of primary energy consumption by source (Figure 6).

Based on the opinion of the experts and the previous studies, the weighted SWOT analysis of the Polish energy sector has been made (Table 3). It has to be said in terms of the world energy transformation that the Polish energy sector does not fit those trends. A lot has to be done to build a future Polish energy sector that fulfills the EU policy regulations and demand requirements.



(**a**) (**b**)

Figure 6. Poland primary energy consumption by source: (**a**) in TWh; (**b**) relative (%) [1].

Table 3. Weighted SWOT matrix for the Polish energy sector.

		Weight	**Rating**	**Score**
	Strengths	1.00		
1	Little diversification of the Polish energy sector	0.40	5	2.00
2	Polish energy sector is one of the largest in Europe	0.30	4	1.20
3	Sufficient number of potential clients	0.20	5	1.00
4	Research centers and universities are researching energy issues	0.10	4	0.40
	Total weighted score			4.60
	Weaknesses	1.00		
1	Equipment to produce and to distribute energy is old	0.30	5	1.50
2	Polish power grids require general modernization	0.30	5	1.50
3	The Polish energy system is not ready to absorb energy from distributed sources on a larger scale	0.20	5	1.00
4	The sector is not currently self-sufficient	0.10	4	0.40
5	Power plants in Poland are not well distributed to cover demand needs	0.10	4	0.40
	Total weighted score			4.80
	Internal Factors Ratio (IFR)			0.96
	Opportunities	1.00		
1	Citizens of Poland are eagle to invest in the ecological distributed powerplants	0.60	5	3.00
2	When making buying decisions related to home appliances, consumers consider energy efficiency as one of the main factors	0.40	5	2.00

Table 3. *Cont.*

		Weight	Rating	Score
	Total weighted score			5.00
	Threats	1.00		
1	Unstable domestic law	0.50	5	2.50
2	The most crucial power source is coal; the ban on coal would be a vital issue for Polish energy security	0.30	5	1.50
3	Small micro-sources at the level of one circuit, without appropriate technical solutions, may harm energy parameters	0.20	5	1.00
	Total weighted score			5.00
	External Factors Ratio (EFR)			1.00

The conclusion from the weighted SWOT matrix for the Polish energy sector (Table 3) was not very optimistic. The internal factors ratio (IFR) was below 1, meaning the weaknesses were more critical than strengths. Opportunities and threats were balanced, which means that development perspectives of the Polish energy sector are not favorable. The ratio between internal factors ratio (IFR) and external factors ratio EFR) was 0.96:1.00. The strategy of the Polish policymakers should be focused on building or better allowing private investors to build distributed energy generation systems, especially photovoltaic systems, wind systems, hydropower systems, biogas, and biomass systems [27,77–79]. The Polish policymakers' strategic activity should also modernize and keep good quality energy distribution grids.

In Poland, the sources of distributed energy generation systems are classified as follows according to the "installed capacity:

- Microgeneration systems—from 1 W to 5 kW;
- Small generation systems—from 5 kW to 5 MW;
- Medium generation systems—from 5 MW to 50 MW;
- Large generation—from 50 to 150 MW" [70].

5.2. Photovoltaic Systems

Private investors, especially prosumers, have noticed the advantage having of PV systems in Poland. Installed capacity in photovoltaics at the end of 2020 was almost 4 GW, which means a 200% increase year on year. According to experts, PV is one of the most flexible systems to establish many ecological distributed powerplants. Its growth was exponential and could be described with the Equation (10). The R^2 indicator—0.9672 was very high in that case and showed that the curve equation had described the analyzed data very well (11) (Figure 7).

$$y = 8E - 5e^{1.0858x} \tag{10}$$

$$R^2 = 0.9672 \tag{11}$$

The experts make a remark that, unfortunately, the situation on the PV systems market is highly dependent on politicians' decisions. Currently, there is information that the rules for collecting energy from prosumers will change dramatically; investing in PV systems will be unprofitable for the prosumers.

According to the Energy Regulatory Office, the number of photovoltaic installations at the end of 2020 was around 460,000. The average capacity of the installed PV system was 5.78 kWp. Photovoltaic installations account for 99.89% of all RES micro-installations. Since 2018, the share of monocrystal PV systems has hit 98% in the year-to-year sales.

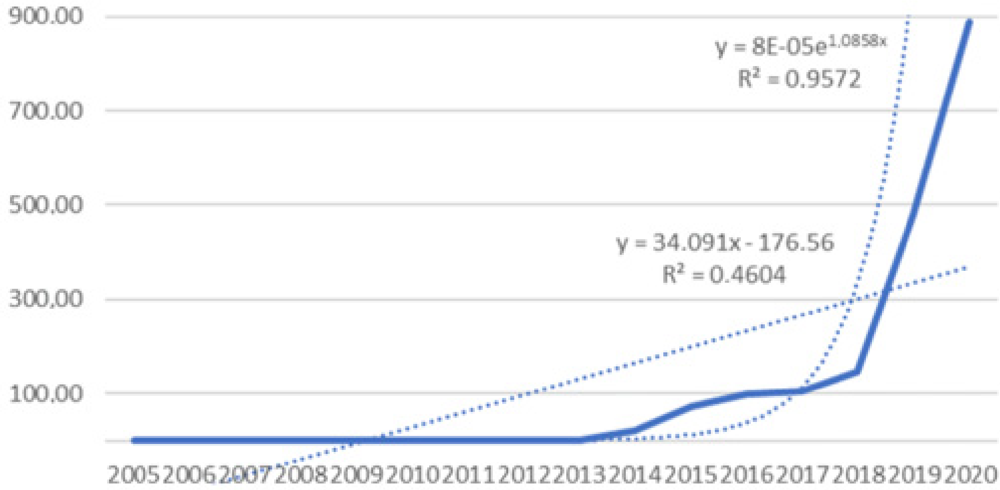


Figure 7. Photovoltaic systems—installed capacity (MW) and trends.

The PV systems have tremendous potential for growth. It is estimated that there are 5,522,000 residential buildings in Poland that are suitable for PV systems. The size of the average roof of a residential building is about 100 m^2. That gives about 552,200,000 m^2 of estimated area for PV systems to be installed. The total area could be from 182.23 GWp capacity installed from silicone PV systems to 662.24 GWp from hybrid or perovskite PV systems. That potential could be even more considerable because PV systems can also be installed on facades.

It is estimated that the PV system could fulfill from 4.0 to 10.0% of electricity demand in Poland.

The efficiency of PV systems could be upscaled 2–3 times by combining them with heat pumps, depending on the COP of the heat pumps.

The conclusion from the weighted SWOT matrix for the photovoltaic systems in Poland (Table 4) was also not very optimistic as for the weighted SWOT matrix for the Polish energy sector presented in Table 3. The internal factors ratio (IFR) was above one, meaning that the strengths were more critical than the weaknesses. The opportunities to threats ratio was 0.86, which means that the photovoltaic systems' development perspectives are not favorable because of extreme dependence on political decisions. The balance between the IFR and EFR was 1.10:0.86. The Polish policymakers' only strategy should be to not disturb the private sector and to provide energy distribution grids to handle the new installations. As shown in Figure 7, Polish private investors are very eager to build PV systems and understand the need to convert to a "zero-emissions" policy, but they have to see an economic reason to do it.

This vital activity should also be able to provide affordable and effective solutions to store energy, which requires further research and funding.

5.3. Wind Systems

Out of 6.35 GW of the installed capacity, onshore wind power supplies 12.6 percent of electricity in Poland. New onshore and offshore wind energy development will lead to at least double these figures in the coming years.

The Energy Regulatory Office reported 1239 wind farms in operation in the country in 2020 (including 1111 with a capacity below 10 MW (89.7%) and 128 with a capacity greater than or equal to 10 MW).

The electricity produced from wind sources in the Polish power system has also been systematically growing. In 2020, wind systems delivered 14,174 GWh of energy (compared to 13,903 GWh in 2019).

Wind energy accounted for ca. 8.2 percent of the energy consumed in the country in 2019.

Igliński believes that considering all the limiting criteria, the area excluded from the possibility of locating wind energy is 311.657 km^2, i.e., 99.92% of the land area of Poland, i.e., 311.904 km^2. That means that only 247 km^2 is available for the construction of wind farms, i.e., 0.02% of the country's territory. Therefore, since introducing the distance act, wind energy systems in Poland have practically stopped being developed [75]. The analysis of Figure 8 clearly shows that the slowdown in the development of wind systems is abnormal in Poland and confirms the claims of Igliński's thesis claims.

Table 4. Weighted SWOT analysis for photovoltaic systems in Poland.

		Weight	Rating	Score
	Strengths	1.00		
1	Roi from 8–17%	0.30	5	1.50
2	Very low operating costs for the installation	0.10	5	0.50
3	Its use does not emit harmful gases (including CO2)	0.10	5	0.50
4	Very low maintenance and operating costs for the installation	0.10	5	0.50
5	Can be used in off-grid locations	0.10	5	0.50
6	Scalable efficiency in combination with other installations, e.g., heat pump	0.10	4	0.40
7	Relatively low failure rate of the solar installation	0.10	4	0.40
8	Ability to combine with energy storage systems	0.10	3	0.30
	Total weighted score			4.60
	Weaknesses	1.00		
1	More energy is generated in spring–summer than autumn–winter	0.50	5	2.50
2	Energy from PV systems is produced only when the sun shines	0.20	4	0.80
3	Big initial costs of photovoltaic installations	0.30	3	0.90
	Total weighted score			4.20
	Internal Factors Ratio (IFR)			1.10
	Opportunities	1.00		
1	High social acceptance	0.30	5	1.50
2	Big potential of growth	0.30	4	1.20
3	Perovskite based solar cells are produced in Poland	0.20	5	1.00
4	Market is adopting new technologies very fast	0.20	3	0.60
	Total weighted score			4.30
	Threats	1.00		
1	Unstable domestic law	0.50	5	2.50
2	Small micro-sources at the level of one circuit, without appropriate technical solutions, may have a negative impact on energy parameters	0.30	5	1.50
3	Bad condition of national grid	0.20	5	1.00
	Total weighted score			5.00
	External Factors Ratio (EFR)			0.86

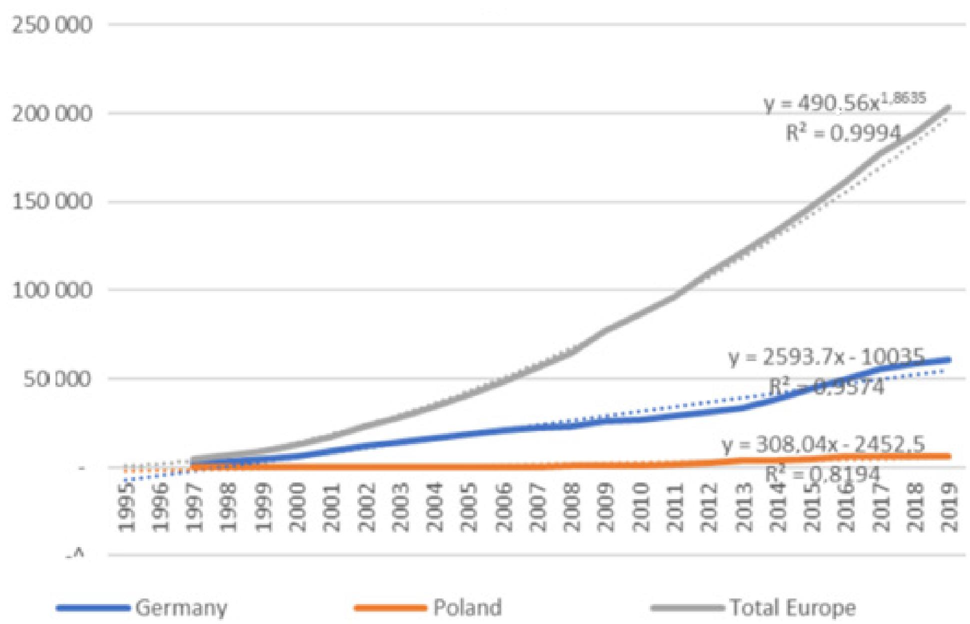


Figure 8. Wind systems—installed capacity (MW) and trends.

Table 5 presents the the Weighted SWOT Analysis for Wind Systems in Poland.

Table 5. Weighted SWOT analysis for wind systems in Poland.

		Weight	Rating	Score
	Strengths	1.00		
1	Well known technology	0.40	5	2.00
2	Wind is a source of clean energy	0.20	5	1.00
3	Wind farm require less space than solar farms or hydroelectric generation	0.20	3	0.60
4	Availability of resource in Poland	0.20	4	0.80
	Total weighted score			4.40
	Weaknesses	1.00		
1	The speed of wind is dependent on the metrological conditions	0.30	5	1.50
2	High initial investment costs in wind systems	0.30	4	1.20
3	Wind turbines could be harmful for migrating birds	0.20	3	0.60
4	The wind turbine blades are made of had to recycle material	0.10	4	0.40
5	Noise pollution is one of the setbacks of the wind technology	0.10	3	0.30
	Total weighted score			4.00
	Internal Factors Ratio (IFR)			1.10
	Opportunities	1.00		
1	Big potential of growth	0.50	5	2.50
2	Many producers of the systems are located in Poland	0.30	4	1.20
3	Research and development in the sector boost the efficiency of the wind systems	0.20	4	0.80
	Total weighted score			4.50
	Threats	1.00		
1	Unstable domestic law, unfavorable for the wind systems	0.40	5	2.00
2	Bad condition of national grid	0.40	4	1.60
3	Low social acceptance	0.20	3	0.60
	Total weighted score			4.20
	External Factors Ratio (EFR)			1.07

The conclusion from the weighted SWOT matrix for the wind systems in Poland (Table 5) was also quite optimistic. The IFR was above one, meaning that the strengths were more critical than weaknesses. The opportunities to threats ratio was 1.07, which means that the wind systems' development perspectives are pretty favorable, but one must remember extreme dependence on political decisions. The balance between the IFR and EFR was 1.10:1.07. This means moderately positive prospects for the development of these systems. The only strategy of the Polish policymakers should be, like in the case of the PV systems, not to disturb the private sector and to provide energy distribution grids that can handle the new installations. The Polish policymakers did precisely the opposite, as was mentioned by Igliński and others [75–81].

5.4. Hydropower Systems

In Poland, compared to other countries, the use of the water energy potential is incomparably lower, which is primarily due to the climatic conditions, average rainfall, and topography. Traditional hydroelectric power plants could be built in places with large natural slopes or where water could be artificially dammed. Hydropower systems require high initial investment costs (mainly due to construction costs). It was estimated that the share of hydropower in primary energy was about 1.5%. Poland's hydropower resources alone are estimated at 13.7 TWh per year. If it were possible to fully use Poland's hydropower systems potential, it would be possible to achieve even ca. 11 GW of capacity in big, and ca. 1.2 GW in small and medium, hydropower plants. In 2020, there were only 18 hydroelectric plants in the country with more than 5 MW.

The conclusion from the weighted SWOT matrix for the hydropower systems in Poland (Table 6) was also quite optimistic. The IFR was above 1–1.45, meaning that the strengths were more critical than weaknesses. The opportunities to threats ratio was 0.98, which means that the hydropower systems' development perspectives are not favorable because of extreme dependence on political decisions. The balance between the IFR and EFR was 1.45:0.98. This means a favorable situation because strengths and opportunities are more critical than weaknesses and threats. The things that Polish policymakers should do are to manage the potential resistance of society and to promote the building of micro- to medium hydropower power stations primarily in the places where watermills operated over 100 years ago.

5.5. Biogas and Biomass Systems

Poland has considerable resources of biomass and biogas available in every region. It has been estimated that biomass and biogas could fulfill about 15% of the demand for electricity in Poland. Additionally, the facilities could supply 28% of the heat demand. Figure 9 shows the actual number of biogas and biomass systems in Poland in 2020. Their distribution was correlated to the level of agricultural technology.

The conclusion from the weighted SWOT matrix for the analysis for biogas and biomass Systems (Table 7) was also, such as in the case of wind and hydropower systems, quite optimistic. The IFR was above 1–1.04, meaning the strengths were more critical than weaknesses. The opportunities and threats ratio was 1.27, which means that development perspectives of the biogas and biomass systems are the most favorable of the analyzed cases. The balance between the IFR) and EFR was 1.04:1.27. That means an extraordinary situation because strengths and opportunities are more critical than weaknesses and threats. The things that Polish policymakers should do is not to disturb and allow farmers to use the waste they produce as the source of clean energy.

Table 6. Weighted SWOT analysis for hydropower systems in Poland.

		Weight	Rating	Score
	Strengths	1.0		
1	Well known technology	0.20	5	1.00
2	Availability of resource	0.20	5	1.00
3	Easy and precise control of energy produced	0.15	4	0.60
4	Much lower operating costs than in conventional power plants	0.15	4	0.60
5	Means the access to a stable energy source (unlike, e.g., solar and wind energy electricity production is independent of weather and time)	0.10	5	0.50
6	Possibility of using energy locally or sending it to grid	0.10	4	0.40
7	Its use does not emit harmful gases (including CO2)	0.10	4	0.40
	Total weighted score		4.50	
	Weaknesses	5.00		
1	Construction of hydropower plants constitutes a serious interference with the natural environment	0.20	4	0.80
2	Inability to work during prolonged drought	0.20	5	1.00
3	The construction costs of this type of power plant are 2–3 times higher than the expenditure for the construction of conventional power plants	0.20	3	0.60
4	Reduction in reservoir capacity through sediment accumulation	0.10	3	0.30
5	Noise and pollution during construction	0.10	4	0.40
	Total weighted score		3.10	
	Internal Factors Ratio (IFR)			1.45
	Opportunities	1.00		
1	Water reservoirs could be used for tourist and recreational purposes	0.50	5	2.50
2	Pumped storage plants could be widely used energy storage	0.30	5	1.50
3	New directions of owe development	0.20	5	1.00
	Total weighted score		5.00	
	Threats	1.00		
1	Unstable domestic law	0.50	5	2.50
2	May cause secondary effects in the form of barrage cracking and water disasters	0.30	4	1.20
3	Moderate social acceptance	0.20	4	0.80
4	Resistance of ecological groups (large hydroelectric plants)	0.10	3	0.30
5	Damming of water in reservoirs may lead to flooding of settlements and agricultural lands, which may result in the necessity of displacement of the population	0.10	3	0.30
	Total weighted score		5.10	
	External Factors Ratio (EFR)			0.98

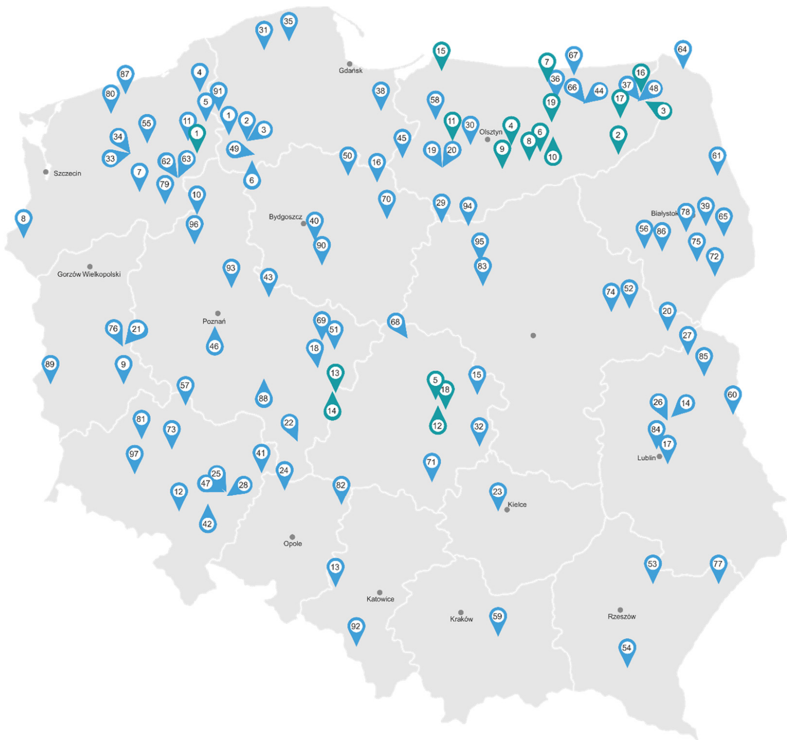


Figure 9. Location of biogas and biomass systems in Poland.

Table 7. SWOT analysis for biogas and biomass systems in Poland.

		Weight	Rating	Score
	Strengths	1.00		
1	Well known technology	050	5	2.50
2	Availability of resource	0.30	5	1.50
3	Possibility of using energy locally or sending it to grid	0.20	4	0.80
	Total weighted score			4.80
	Weaknesses	1.00		
1	Heat unused directly from the biogas is waste	0.60	5	3.00
2	Big initial costs of biogas and biomass systems	0.40	4	1.60
	Total weighted score			4.60
	Internal Factors Ratio (IFR)			1.04
	Opportunities	1.00		
1	High social acceptance	0.30	5	1.50
2	Combining high energy-intensive greenhouse cultivation could make the technology more efficient	0.20	5	1.00
2	Big potential of growth	0.30	3	0.90
3	Fast development of the technology	0.20	4	0.80
	Total weighted score			4.20
	Threats	1.00		
1	Volatility in the prices of resources from agriculture	0.50	3	1.50
2	Unstable domestic law unfavorable for the biomass and biogas systems	0.30	4	1.20
3	No guarantee of stable feedstock supplies in agricultural biogas and biomass plants	0.20	3	0.60
	Total weighted score			3.30
	External Factors Ratio (EFR)			1.27

In Poland, in 2020, were about 110 biogas plants. That was eight biogas plants per 1 million inhabitants, while in the Czech Republic, for example, this number was 54. The massive slowdown in biomass and biogas development was the effect of administrative and legal barriers.

The thesis about bad legislation was verified positively by experts and the historical data—Figure 10. Figure 10 presents two scenarios about developing the installed capacity of biogas and biomass systems in Poland. The higher line represents the prediction based on the period from 2005 to 2016, and the lower line is based on the period from 2005 to 2018. The actual number of the biogas and biomass systems followed, unfortunately, the worst scenario.

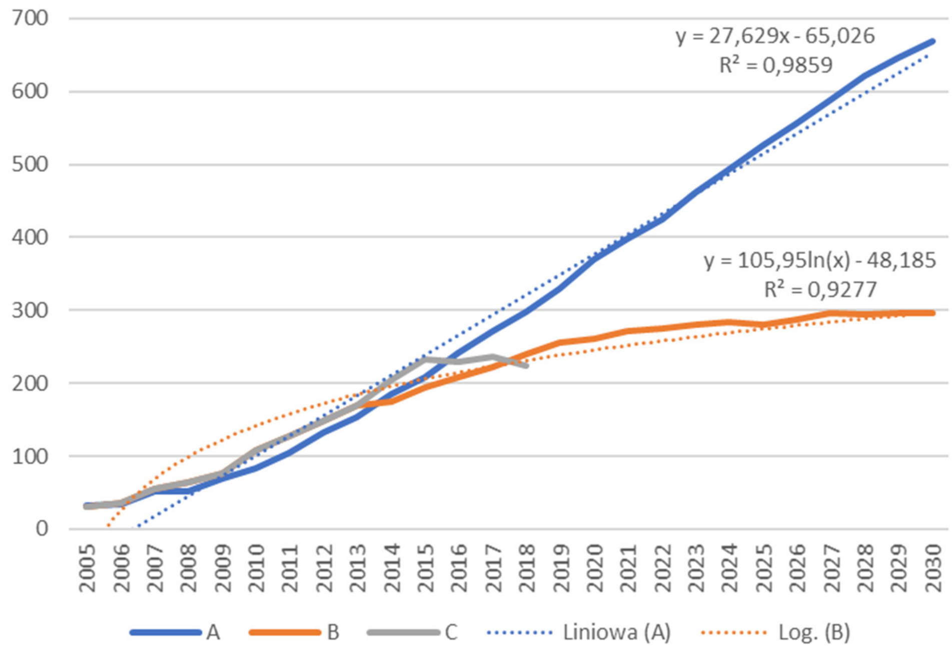


Figure 10. Biogas and biomass systems in Poland (MW) [28,82].

5.6. Other Energy Systems

Some other energy systems that were less popular or not considered as ecological-distributed energy generation systems have to be mentioned—especially geothermal and small nuclear systems.

- Geothermal systems—according to the Polish Geological Institute, National Research Institute Poland, it has great potential. According to estimates, the geothermal resources of Poland, available in 80 percent of the country, would be enough to meet the country's heat needs by 30 percent [83]. It has to be noticed that usability of geothermal resources in Poland is limited by their temperature: (1) level—low-level geotherm—down to 100 m +10 °C temperature could be obtained, which would provide an excellent possibility to set up "water to water" heat pumps, which are more effective during winter than "air to water systems"; (2) level—average temperature geotherm—down to 3 km—the temperature of about +100 °C could be obtained—which is a suitable temperature for a geothermal heating plant; (3) level—high-temperature geotherm—down to 6 km—the temperature of about +200 °C could be obtained—which is a suitable temperature for a geothermal electricity plant. The considerable advantage of geothermal systems is that the systems could be used to heat or cool the facilities.
- Nuclear systems—"As nuclear power generation has become established since the 1950s, the average size of reactor units has grown from 60 MWe to more than 1600 MWe, with corresponding economies of scale in operation" [84,85]. One can see the growing popularity of small and medium reactors (SMRs), more commonly recognized as "small modular reactors". SMRs are typically under 15 MWe. There are designed mainly for remote communities. The units can be set up independently or like LEGO

bricks, combined in a larger complex. There are also plans to construct tiny self-contained units for distant locations. SMRs are viewed as far more manageable than large ones, especially in terms of costs. Another reason for interest in SMRs is that they may be located in closed coal-fired power plants. “The World Nuclear Association outlines the characteristics of an SMR, which include (a) modest power and compact architecture; (b) modularity of construction; and (c) the possibility for sub-grade siting of the reactor unit, which provides better protection from natural or man-made risks”. Once, the IBM engineers had believed that the world needed five computers a year. They were wrong. Who knows, maybe the SMR for energy generation will be the same for which the Apple II was for the information revolution and will be used instead of classic high pollutive coal power plants in Poland.

5.7. Scenarios for Renewable Energy Sources Development in Poland

Based on the information above and discussion with experts, the following main scenarios for Poland could be drawn:

- Catastrophe—due to Polish legislation, the current state of the energy sector would be preserved. The government wants to protect the national grid, so for it to change the way to enable and use small on-grid power plants to build new energy systems would be economically unjustified. Some investors decide to set up off-grid, but that would be a margin in the energy consumption scale. The electricity prices mainly due to emission prices go up. The energy to fulfill growing demand would be imported. High energy prices would make the Polish economy uncompetitive;
- Full RES—that could be treated as a mix of scenarios that the RES technologies would fulfill the demand for electricity and heat. This scenario can be believed because it is estimated that in a single hour, the amount of power from the sun that reaches the Earth is more than the entire world consumes in a year. The RES energy systems, like wind or photovoltaic, do not provide the energy constantly. Currently, there are not efficient enough energy storage systems developed to store enough energy produced to provide reliable power. Only biomass, biogas, and geothermal systems could provide energy regularly. Still, substantial technological development has to be achieved to make them more efficient and ready to fulfill the growing energy demand. For the scenario to succeed, severe investments into the national grid have to be built. The lesson learned from the Grand Ethiopian Renaissance Dam project shows that financing of the dam could be in a public–private partnership.
- Clean coal and RES—a lot of research has been done on coal gasification [86,87]. Hydrogen, for example, could be the final product of the process. The gasification process could be done underground and in a remote installation. The process would be done in distributed locations. The facilities could be placed near the demand site because the final product would be electricity or heat to provide society or industry. To succeed in this scenario, substantial investments into the national grid have to be made.
- Nuclear MIX—as time goes and as the Polish energy companies take no action, the only way to fulfill international agreements would be to install SMRs instead of disabling coal plants. To succeed in this scenario, substantial investments into the national grid would need to be made.

6. Discussion

Most Polish researchers and politicians agree that the country faces significant challenges related to the energy sector. The challenge is even more challenging because the Polish economy relies on coal as the primary energy source. Nearly everybody agrees that “something has to be done”. Most of these people also agree that future technology should help to build a low-carbon economy. The papers related to the subject mainly highlight the possibilities and advantages in using RES as a substitute for coal. Of course, physicists argue that it is possible; but still, researchers do not mention the disadvantages and threads that should be considered in constructing a new energy mix for Poland. As the problem affects the entire economy, industry and economists should take part in the discussion and estimate the economic efficiency of the proposed solutions from designing to the utilization of the wastes. This should be an idea for further research. For example, the authors strongly recommend using PV systems as ecological distributed energy generation systems because of their flexibility, use, and growing efficiency. Still, it has to be mentioned that millions of solar panels installed in the last two decades will soon be ready to be disabled and recycled. Recycling is also a considerable problem of wind turbine blades, batteries used as energy storage, and nuclear waste. Making the total cost calculation could change the efficiency of the proposed solutions. This is why further research has to be carried out.

7. Conclusions

The main objectives of the paper were completed:

(1) Based on literature studies and LOCE analysis, photovoltaic systems would be game-changers to allow the globe to switch to the "zero-emission" economy. The PV systems would be supported with wind systems and biogas systems located mainly in rural areas. In some areas nuclear systems would also play an important role;

(2) The review of the technologies that could be used as the ecological distributed energy generation systems from Poland's perspective showed that the PV systems supported with wind systems and biogas systems located predominantly in the rural areas would help achieve the Agenda 2030 goals.

Additionally, the research questions were answered:

(a) Renewable energy sources could provide sufficient energy to replace the conventional energy sources (from global and Polish perspectives). As mentioned before, the only energy that comes from the sun would fulfill all current and future consumption. The only problem is developing more efficient systems that would transform solar energy and develop energy storage systems that would minimize the weaknesses, especially of the PV and wind systems. From the Polish perspective, the ideal energy mix, in the authors' opinion, would be PV systems, wind, biogas, and hydropower systems supported with energy storage systems (hydropower systems could also be used as energy storage). The remaining energy could be obtained from natural gas, which also comes from the environmentally friendly coal gasification process.

(b) PV systems, as well as wind, biogas, and hydropower systems are suitable as ecological distributed energy generation systems in Poland.

(c) In general, the main strength of the technologies to replace conventional energy sources in Poland is that all systems require low maintenance costs. Unfortunately, these systems require high initial costs, and this is the most important weakness. The most important thread of the development of alternative energy systems in Poland is government policy. However, theoretically, a society interested in financing ecological distributed energy generation systems could change the policy or policymakers.

(d) Unfortunately, the "Catastrophe scenario" mentioned above is coming true—due to Polish legislation, and the current state of the energy sector will be preserved.

Author Contributions: P.S.—Conceptualization, formal analysis, writing—original draft; W.G.—conceptualization, formal analysis, writing—review and editing, funding acquisition; A.W.-S.—conceptualization, formal analysis, writing—original draft; S.C.—conceptualization, formal analysis, writing—initial draft; R.B.—conceptualization, formal analysis, writing—original draft. All authors have read and agreed to the published version of the manuscript.

Funding: Funded by Faculty of Economic Sciences and Management, The Nicolaus Copernicus University in Toruń (NCU).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The primary statistical data https://data.worldbank.org/; https://stat.gov.pl/; https://data.europa.eu/en.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. De Lavoisier, A.L. *Traité Élémentaire de Chimie*; Forgotten Books: Maxtor, France, 2019.
2. Ghiani, E.; Serpi, A.; Pilloni, V.; Sias, G.; Simone, M.; Marcialis, G.; Armano, G.; Pegoraro, P.A. Multidisciplinary Approach for the Development of Smart Distribution Networks. *Energies* **2018**, *11*, 2530. [CrossRef]
3. Lovins, A.B.; Ürge-Vorsatz, D.; Mundaca, L.; Kammen, D.M.; Glassman, J.W. Recalibrating climate prospects. *Environ. Res. Lett.* **2019**, *14*, 120201. [CrossRef]
4. Binz, C.; Tang, T.; Huenteler, J. Spatial lifecycles of cleantech industries—The global development history of solar photovoltaics. *Energy Policy* **2017**, *101*, 386–402. [CrossRef]
5. Poulek, V.; Khudysh, A.; Libra, M. Innovative low concentration PV systems with bifacial solar panels. *Solar Energy* **2015**, *120*, 113–116. [CrossRef]
6. Boamah, F.; Rothfuß, E. From technical innovations towards social practices and socio-technical transition? Re-thinking the transition to decentralised solar PV electrification in Africa. *Energy Res. Soc. Sci.* **2018**, *42*, 1–10. [CrossRef]
7. Ceran, B.; Szczerbowski, R. Analiza techniczno-ekonomiczna instalacji fotowoltaicznej. In *Zeszyty Naukowe Instytutu Gospodarki Surowcami Mineralnymi i Energią PAN*; PAN: Warsaw, Poland, 2017.
8. Dalkey, N.; Helmer, O. An experimental application of the Delphi method to the use of experts. *Manag. Sci.* **1963**, *9*, 458–467. [CrossRef]
9. Skulmoski, G.J.; Hartman, F.T.; Krahn, J. The Delphi method for graduate research. *J. Inf. Technol. Educ. Res.* **2007**, *6*, 1–21. [CrossRef]
10. Rowe, G.; Wright, G. The Delphi technique as a forecasting tool: Issues and analysis. *Int. J. Forecast.* **1999**, *15*, 353–375. [CrossRef]
11. Dalkey, N.C. *The Delphi Method: An Experimental Study of Group Opinion*; Rand Corp.: Santa Monica, CA, USA, 1969.
12. Kurttila, M.; Pesonen, M.; Kangas, J.; Kajanus, M. Utilizing the analytic hierarchy process (AHP) in SWOT analysis—A hybrid method and its application to a forest-certification case. *For. Policy Econ.* **2000**, *1*, 41–52. [CrossRef]
13. Hill, T.; Westbrook, R. SWOT analysis: It's time for a product recall. *Long Range Plan.* **1997**, *30*, 46–52. [CrossRef]
14. Alptekin, N. Integration of SWOT analysis and TOPSIS method in strategic decision making process. *Macrotheme Rev.* **2013**, *2*, 1–8.
15. Engel, A. *Practical Creativity, and Innovation in Systems Engineering*; John Wiley & Sons: Hoboken, NJ, USA, 2018.
16. Timilsina, G.R. Are renewable energy technologies cost competitive for electricity generation? *Renew. Energy* **2021**, *180*, 658–672. [CrossRef]
17. Lovins, A. A 40 Year Plan for Energy. Available online: https://www.ted.com/talks/amory_lovins_a_40_year_plan_for_energy/transcript (accessed on 31 July 2021).
18. Global Change Data Lab. Our World in Data. Available online: https://ourworldindata.org/ (accessed on 31 July 2021).
19. Ignacy, Ł. Available online: https://EncyklopediaPWN (accessed on 31 July 2021).
20. UN. Iceland's Sustainable Energy Story: A Model for the World? UN Chronicle. 2020. Available online: https://www.un.org/en/chronicle/article/icelands-sustainable-energy-story-model-world (accessed on 31 July 2021).
21. Ministry of Industries and Innovation, Government of Iceland, Energy. Available online: https://www.government.is/topics/business-and-industry/energy/ (accessed on 31 July 2021).
22. LED. *Lighting Market Size, Share & Trends Analysis Report by End-Use (Residential, Commercial), by Product (Lamps, Luminaires), by Application (Indoor, Outdoor), by Region, and Segment Forecasts, 2021–2028*; Fortune Business Insights: Maharashtra, India, 2021.
23. Fischer, C. EU Ecodesign Regulation. In *More as Only a Light Bulb Ban*; EU-Oekodesign-Richtlinie. Mehr als ein Gluehbirnenverbot; Umweltmagazin, VDI Fachmedien GmbH & Co.: Düsseldorf, Germany, 2011.
24. Fukasawa, T. Consumer Preference for Durability and Energy Efficiency: Welfare Analysis of Light Bulb Market. Available online: https://ssrn.com/abstract=3839998 (accessed on 9 September 2021).
25. LED Light Bulb to Last More than 20 Years. Available online: https://www.bbc.com/news/technology-17992927 (accessed on 31 July 2021).
26. Senkus, P. *Zarządzanie i Dowodzenie z Wykorzystaniem Orientacji Procesowej*; Wydawnictwo Difin: Warszawa, Poland, 2013.
27. Economist. *Fuel Cells Meet Big Business*; Economist 07/24/99; The Economist Group: London, UK, 1999; pp. 59–60.
28. Govinda, R. *Demystifying the Costs of Electricity Generation Technologies*; Policy Research Working Paper, No. 9303; World Bank: Washington, DC, USA, 2020.
29. Ray, D. *Lazard's Levelized Cost of Energy Analysis—Version 13.0*; Lazard: New York, NY, USA, 2019; p. 20.
30. Smil, V. *Energy Transitions: Global and National Perspectives*; ABC-CLIO: Santa Barbara, CA, USA, 2016.
31. Ritchie, H.; Roser, M. Energy, OurWorldInData.org. Available online: https://ourworldindata.org/energy (accessed on 31 July 2021).
32. EU. *Quarterly Report on European Electricity Markets with Focus on the Impact of High Carbon Prices in the Electricity Sector Market Observatory for Energy DG Energy*; European Commission: Brussels, Belgium, 2021; Volume 14.
33. McDonough, W.; Braungart, M. *Cradle to Cradle: Remaking the Way We Make Things*; North Point Press: New York, NY, USA, 2010.
34. Boerema, N.; Morrison, G.; Taylor, R.; Rosengarten, G. High temperature solar thermal central-receiver billboard design. *Sol. Energy* **2013**, *97*, 356–368. [CrossRef]

35. Law, E.W.; Prasad, A.A.; Kay, M.; Taylor, R.A. Direct normal irradiance forecasting and its application to concentrated solar thermal output forecasting—A review. *Sol. Energy* **2014**, *108*, 287–307. [CrossRef]
36. Law, E.W.; Kay, M.; Taylor, R.A. Calculating the financial value of a concentrated solar thermal plant operated using direct normal irradiance forecasts. *Sol. Energy* **2016**, *125*, 267–281. [CrossRef]
37. Fraunhofer Institute for Solar Energy Systems, ISE. *Photovoltaics Report (PDF)*; Fraunhofer ISE: Freiburg, Germany, 2014.
38. Sabillon, C.; Franco, J.F.; Rider, M.J.; Romero, R. Joint optimal operation of photovoltaic units and electric vehicles in residential networks with storage systems: A dynamic scheduling method. *Int. J. Electr. Power Energy Syst.* **2018**, *103*, 136–145. [CrossRef]
39. Chung, J.; Shin, S.S.; Hwang, K.; Kim, G.; Kim, K.W.; Kim, W.; Ma, B.S.; Kim, Y.K.; Kim, T.S.; Seo, J. Record-efficiency flexible perovskite solar cell and module enabled by a porous-planar structure as an electron transport layer. *Energy Environ. Sci.* **2020**, *13*, 4854–4861. [CrossRef]
40. Feldman, D.; Ramasamy, V.; Fu, R.; Ramdas, A.; Desai, J.; Margolis, R. *US Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2020*; No. NREL/TP-6A20-77324; National Renewable Energy Lab. (NREL): Golden, CO, USA, 2021.
41. Shah, S.A.A.; Valasai, G.D.; Memon, A.A.; Laghari, A.N.; Jalbani, N.B.; Strait, J.L. Techno-economic analysis of solar pv electricity supply to rural areas of Balochistan, Pakistan. *Energies* **2018**, *11*, 1777. [CrossRef]
42. Xu, L.; Wang, Y.; Solangi, Y.A.; Zameer, H.; Shah, S.A.A. Off-grid solar PV power generation system in Sindh, Pakistan: A techno-economic feasibility analysis. *Processes* **2019**, *7*, 308. [CrossRef]
43. Chen, P.Y.; Qi, J.; Klug, M.T.; Dang, X.; Hammond, P.T.; Belcher, A.M. Environmentally responsible fabrication of efficient perovskite solar cells from recycled car batteries. *Energy Environ. Sci.* **2014**, *7*, 3659–3665. [CrossRef]
44. Malinkiewicz, O. Building on trust and vision. *Nat. Mater.* **2021**, *20*, 904. [CrossRef]
45. Wojciechowski, K.; Forgács, D.; Rivera, T. Industrial opportunities and challenges for perovskite photovoltaic technology. *Sol. RRL* **2019**, *3*, 1900144. [CrossRef]
46. The National Renewable Energy Laboratory. Concentrating Solar Power Projects. Available online: https://solarpaces.nrel.gov/ (accessed on 31 July 2021).
47. Irena, I. *Future of Wind: Deployment, Investment, Technology, Grid Integration and Socio-Economic Aspects*; IRENA Innovation and Technology Center: Bonn, Germany, 2019.
48. Doerffer, P.; Doerffer, K.; Ochrymiuk, T.; Telega, J. Variable Size Twin-Rotor Wind Turbine. *Energies* **2019**, *12*, 2543. [CrossRef]
49. The National Renewable Energy Laboratory. Land Use by System Technology. Available online: https://www.nrel.gov/analysis/tech-size.html (accessed on 31 July 2021).
50. BP, Great Britain. Statistical Review of World Energy. Available online: https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html (accessed on 31 July 2021).
51. Maghanki, M.M.; Ghobadian, B.; Najafi, G.; Galogah, R.J. Micro combined heat and power (MCHP) technologies and applications. *Renew. Sustain. Energy Rev.* **2013**, *28*, 510–524. [CrossRef]
52. Dye, S.T. Geoneutrinos and the radioactive power of the Earth. *Rev. Geophys.* **2012**, *50*. [CrossRef]
53. REN21. *Renewables 2020: Global Status Report*; Chapter 01; Global Overview: Paris, France, 2020.
54. Geothermal Energy Association. Geothermal Energy: International Market Update May. 2010. Available online: https://geothermal.org/sites/default/files/2021-02/GEA_International_Market_Report_2010.pdf (accessed on 31 July 2021).
55. El Bassam, N.; Maegaard, P.; Schlichting, M. *Distributed Renewable Energies for Off-Grid Communities: Strategies and Technologies toward Achieving Sustainability in Energy Generation and Supply*; Elsevier: London, UK, 2013.
56. Morrone, P.; Algieri, A. Integrated Geothermal Energy Systems for Small-Scale Geothermal atlas of Europe. Combined Heat and Power Production: Energy and Economic Investigation. *Appl. Sci.* **2020**, *10*, 6639. [CrossRef]
57. Hurtig, E.; Cermak, V.; Haenel, R.; Zui, V. *Geothermal Atlas of Europe*; IAEA: Vienna, Austria, 1992.
58. REN21 Renewable Now. Available online: https://www.ren21.net/ (accessed on 31 July 2021).
59. Abdelshafy, A.M.; Jurasz, J.; Hassan, H.; Mohamed, A.M. Optimized energy management strategy for grid connected double storage (pumped storage-battery) system powered by renewable energy resources. *Energy* **2020**, *192*, 116615. [CrossRef]
60. Witt, A.; Chalise, D.R.; Hadjerioua, B.; Manwaring, M.; Bishop, N. *Development and Implications of a Predictive Cost Methodology for Modular Pumped Storage Hydropower (m-PSH) Projects in the United States*; ORNL/TM-2016/590; Oak Ridge National Laboratory: Oak Ridge, TN, USA, 2016.
61. Gençsü, I.; Whitley, S.; Roberts, L.; Beaton, C.; Chen, H.; Doukas, A.; Geddes, A.; Gerasimchuk, I.; Sanchez, L.; Suharsono, A. *G20 Coal Subsidies (PDF)*; ODI: London, UK, 2019.
62. Chang, S.; Zhuo, J.; Meng, S.; Qin, S.; Yao, Q. Clean coal technologies in China: Current status and future perspectives. *Engineering* **2016**, *2*, 447–459. [CrossRef]
63. Guan, G. Clean coal technologies in Japan: A review. *Chin. J. Chem. Eng.* **2017**, *25*, 689–697. [CrossRef]
64. Burton, E.A.; Upadhye, R.; Friedmann, S.J. *Best Practices in Underground Coal Gasification*; (No. LLNL-TR-225331); Lawrence Livermore National Lab. (LLNL): Livermore, CA, USA, 2017.
65. Perkins, G. Underground coal gasification–Part II: Fundamental phenomena and modeling. *Prog. Energy Combust. Sci.* **2018**, *67*, 234–274. [CrossRef]
66. Berlinguette, C.P.; Chiang, Y.M.; Munday, J.N.; Schenkel, T.; Fork, D.K.; Koningstein, R.; Trevithick, M.D. Revisiting the cold case of cold fusion. *Nature* **2019**, *570*, 45–51. [CrossRef]
67. Pitkänen, M. Cold Fusion Again. *Prespacetime J.* **2016**, *379-396*, 379–396.

68. Petrescu, F.I.; Calautit, J.K. About nano fusion and dynamic fusion. *Am. J. Appl. Sci.* **2016**, *13*, 261–266. [CrossRef]
69. El Naschie, M.S. From fusion algebra to cold fusion or from pure reason to pragmatism. *Open J. Philos.* **2015**, *5*, 319. [CrossRef]
70. Biofuels Explained Ethanol and Biomass-Based Diesel. Available online: https://www.eia.gov/energyexplained/index.php?page=biofuel_home (accessed on 31 July 2021).
71. Paska, J. *Wytwarzanie Rozproszone Energii Elektrycznej i Ciepła*; Oficyna Wydawnicza Politechniki Warszawskiej: Warsaw, Poland, 2010.
72. Szczerbowski, R.; Kornobis, D. The proposal of an energy mix in the context of changes in Poland's energy policy. *Polityka Energetyczna* **2019**, *22*, 5–18. [CrossRef]
73. Jurdziak, L. Czy grozi nam ubóstwo? Analiza potencjalnych skutków unijnej polityki walki z globalnym ociepleniem dla gospodarstw domowych w Polsce. *Polityka Energetyczna* **2012**, *15*, 23–50.
74. Energii, F. Energy Transition in Poland Edition. 2020. Available online: http//www.forum-energii.eu (accessed on 31 July 2021).
75. Pietrzak, M.B.; Igliński, B.; Kujawski, W.; Iwański, P. Energy transition in Poland—Assessment of the renewable energy sector. *Energies* **2021**, *14*, 2046. [CrossRef]
76. Igliński, B. Badanie Sektora Energii Odnawialnej w Polsce–Potencjał Techniczny, Badania Ankietowe, Analiza SWOT, Analiza PEST. Available online: https://www.researchgate.net/publication/338740614_Badanie_sektora_energii_odnawialnej_w_Polsce_-potencjal_techniczny_badania_ankietowe_analiza_SWOT_analiza_PEST (accessed on 30 July 2021).
77. Szczerbowski, R. Wyzwania Polskiego Sektora Wytwórczego do 2030 Roku. Available online: http://yadda.icm.edu.pl/yadda/element/bwmeta1.element.baztech-942bfb08-5d91-496a-a9ac-cccc305832ae (accessed on 31 July 2021).
78. Szczerbowski, R. The forecast of Polish power production sector development by 2050–coal scenario. *Polityka Energetyczna–Energy Policy J.* **2019**, *19*, 5–18. [CrossRef]
79. Szczerbowski, R. Strategia Zrównoważonego Rozwoju a Sektor Wytwarzania Energii w Polsce. Energetyka. Available online: https://cire.pl/filemanager/Zalczniki%20stron%20tekstowych/1f238adcf76fdc992b70b76917205c41e9b00e97ba4d041b6008c06f3ef940e2.pdf (accessed on 11 July 2021).
80. Ceran, B.; Szczerbowski, R. Energy cost analysis by hybrid power generation system. In *IOP Conference Series: Earth and Environmental Science*; IOP Publishing: Poznan, Poland, 2019; Volume 214, p. 012001.
81. Dyląg, A.; Kassenberg, A.; Szymalski, W. *Energetyka Obywatelska w Polsce–Analiza Stanu i Rekomendacje do Rozwoju*; Instytut na Rzecz Ekorozwoju: Warszawa, Poland, 2019.
82. Woszczyński, M.; Stankiewicz, K. Analiza efektywności energetycznej i założenia techniczne rozbudowy instalacji fotowoltaicznych na dachach obiektów przemysłowych. In *Innowacyjne I Przyjazne Dla Środowiska Techniki I Technologie Przeróbki Surowców Mineralnych*; KOMEKO: Gliwice, Poland, 2021; p. 67.
83. Dach, J. *Biogaz w Polsce—Raport 2020*; Biomass Media Group Sp. z o.o.S: Warsaw, Poland, 2020.
84. Small Nuclear Power Reactors. Available online: https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx (accessed on 31 July 2021).
85. Kapusta, K.; Stańczyk, K.; Wiatowski, M.; Chećko, J. Environmental aspects of a field-scale underground coal gasification trial in a shallow coal seam at the Experimental Mine Barbara in Poland. *Fuel* **2013**, *113*, 196–208. [CrossRef]
86. Zhang, Y.; Jia, W.; Wang, R.; Guo, Y.; Guo, F.; Wu, J.; Dai, B. Investigation of the Characteristics of Catalysis Synergy during Co-Combustion for Coal Gasification Fine Slag with Bituminous Coal and Bamboo Residue. *Catalysts* **2021**, *11*, 1152. [CrossRef]
87. Schilling, H.D.; Bonn, B.; Krauss, U. *Coal Gasification*; Graham & Trotman: London, UK, 1976.