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Review

Wind Parks in Poland—New Challenges and Perspectives

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Abstract: The wind farm market in Poland evolved very dynamically in the years 2000–2015. Unfortunately, the high public resistance caused the government in 2016 to freeze the development of this industry by introducing a restrictive act, which practically stopped the wind farm industry overnight. The climate aspects, such as reduction of the carbon footprint, which have been considered and widely discussed for several years at the European Union forums, were a chance to change this situation. The new regulations gave hope that the wind energy industry in Poland would soon be unblocked, unfortunately the commitment to coal was still an effective barrier, which is clearly visible in the presented study. The Russian aggression against Ukraine, which resulted in a blockade of hydrocarbon imports, has completely changed the center of gravity of the Polish energy and heating economy. The article focuses on the accelerated changes in the renewable energy sources (RESs) and the related legislation, especially emphasizing the prospect of building offshore wind farms. The huge European energy crisis means that new solutions, both legislative and technological, which will allow to quickly switch to green energy, must appear in Poland immediately. The direct conversion of green energy from RES farms into thermal energy in the planned investment in heat energy plants is discussed. This article also presents a broad view of new opportunities as well as the challenges and prospects that have recently arisen in the wind energy industry in Poland.

Keywords: wind parks; renewable energy sources; Poland energy policy; energy security; energy independence

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1. Introduction

Wind energy is a form of solar energy. It is assumed that approx. 2% of the energy radiated by the Sun is converted into kinetic energy from the wind, of which 30% is the energy of air masses directly adjacent to the Earth's surface. Wind is used to generate electricity by means of the kinetic energy generated by air in motion. It is transformed into electricity by means of wind turbines or wind energy conversion systems. The wind first strikes the turbine blades, causing them to spin and the turbine connected thereto begins to rotate. This converts kinetic energy into rotational energy by moving the shaft connected to the generator, thereby generating electricity using electromagnetism.

The history of the use of wind energy dates back to ancient times, including vertical axis windmills found on the Persian-Afghan border that are dated to around 200 BCE, the first horizontal axis windmills were used in the Netherlands and in the Mediterranean basin, between 1300 and 1875 AD [1–3]. Further evolution and improvement of windmills took place in the USA in the 19th century [4], when in the years 1850–1970 they were used to pump water. Wind turbines first appeared over a hundred years ago. Following the invention of the electric generator in the 1830s, engineers began trying to use wind energy to produce electricity. Wind power generation took place in the United Kingdom and the United States between 1887 and 1888, but modern wind power is believed to have first developed in Denmark [5], where horizontal axis wind turbines were built in 1891 and the operation of the 22.8 m wind turbine began in 1897.

The amount of power that can be extracted from the wind depends on the size of the turbine and the length of its blades. The capacity is proportional to the dimensions of the rotor and to the cube of the wind speed. Theoretically, when the wind speed doubles, the wind power potential rises eightfold. Over time, the efficiency of wind turbines has significantly increased. In 1985, typical turbines had a rated power of 0.05 megawatt (MW) and a rotor diameter of 15 m [6–10]. Today's new wind farm projects have a turbine capacity of around 2 MW onshore and 3–5 MW offshore. The wind turbines available on the market reached the power of 8 MW, with a rotor diameter of up to 164 m. The average capacity of wind turbines increased from 1.6 MW in 2009 to 2 MW in 2014. In 2020, there was a rapid growth for turbines installed in the 2.75–3.5 MW range [11].

Renewable energy sources (RESs), including wind energy, are classified as pro-ecological "green" energy sources (no waste in the form of ashes or radioactive waste, requiring further disposal). It is estimated that 1 TWh of electricity produced by a wind power plant prevents the emission to the atmosphere of 5500 Mg of sulfur dioxide, 4222 Mg of nitrogen oxides, 700,000 Mg of carbon dioxide, and 49,000 Mg of various types of dust and slags [12]. From an economic point of view, wind energy has many advantages. For example, it is characterized by a much lower cumulative energy consumption of energy production (3.5 MJ/kWh) compared to coal-based energy (13.0 MJ/kWh) [13]. An additional advantage is undoubtedly the possibility of the "immediate" conversion of wind mechanical energy into electricity (the obtained energy can be used immediately) as well as the low operating costs, their simple operation, and short assembly period.

The results of the survey conducted among the Polish Wind Energy Association (PSEW) members indicate that the average amount of total investment expenditure per 1 MW is approximately EUR 1.3–1.4 million [14]. They have analyzed the capital expenditure of wind farm projects that are currently under development or construction, with a planned capacity of several to several dozen MW per project. According to their estimates, the expected total investment expenditure per 1 MW of installed capacity amounts to approx. EUR 1.5 million. Wind turbines constitute the largest component of this amount. An important item is also the purchase of project rights (preparation) and the expenditure related to cabling and connections to the grid. The value of the connection fee for the distribution system operator alone amounts to approximately 3% of the project value. The average structure of expenses is as follows: turbines 60%, preparation/purchase of project rights 14%, GPZ and cabling 13%, construction works 7%, connection fee 3%, and others 3%. [15]

The durability of currently built wind farms is estimated at approx. 20–30 years. According to the International Renewable Energy Agency (IRENA), the data for 2020 [16], onshore energy is the technology with the lowest cost level while taking into account the levelized cost of electricity (LCOE) compared to other RESs and fossil fuels. The global average LCOE value reported by IRENA is approx. 39 USD/MWh, i.e., approx. 153 PLN/MWh. The second and third cheapest RES technologies are hydropower and PV (with LCOE at the level of approx. 44 USD/MWh and approx. 57 USD/MWh, respectively), while the LCOE range for fossil fuels reported by IRENA is 55–148 USD/MWh [17]. From 2020, the costs have increased significantly, while the proportion for individual investments is low.

According to the research presented in [18], old wind farms from before 2015 in Poland were not profitable. Only the introduction of the auction system in 2015 allowed some of them to leave the system of green certificates and obtain price guarantees for the next 15 years, but 2/3 of them still remain in the system of green certificates. This has contributed to the profitability of the farms. However, the problem of the old farms remains.

The energy potential of the winds is estimated at approx. 40 TW [19]. According to the World Wind Energy Association (WWEA) [20], the installed capacity in wind energy in the world is currently 744 GW, which accounts for 7% of the global demand for electricity. In 2020, 93 GW of new capacity was added. The world leaders are: 290 GW China; 122 GW US; 63 GW Germany; 39 GW India; 27 GW Spain; 24 GW Great Britain. The Global Wind Energy Council [21] estimates that 470 GW of new onshore and offshore capacities may arrive in the world by 2025.

In 2012, the total capacity in Europe was 109 GW, including 104 GW onshore and 5 GW offshore. Last year, in Europe, 17 GW of wind capacity was installed (including 11 GW in the EU), reaching the level of the installed 236 GW of wind capacity—207 GW onshore and 28 GW at sea (in the EU it is 189 GW of installed capacity, including 173 GW on land and 16 GW offshore). Wind energy covered an average of 16% of the continent's electricity needs, although in some countries, much more: 48% in Denmark; 28% in Italy; 27% in Germany; 27% in Great Britain; 25% in Portugal; 22% in Spain; 20% in Norway [22]. The largest number of all wind installations in Europe was achieved by Great Britain due to the large number of new offshore wind capacities (328 MW onshore and 2.3 MW offshore).

2021 was a favorable period for onshore wind energy—investments in this area amounted to 81% new installations. Most of them were built in Sweden (2.1 MW), Germany (1.9 MW), Turkey (1.4 MW), and the Netherlands (952 MW). Last year, only three European countries invested in offshore wind farms—the Netherlands (392 MW), Denmark (605 MW), and Norway (4 MW). In 2021, 660 MW of new onshore wind farm capacity was installed in Poland. In 2021, the total installed capacity was 6347 MW (these are only onshore farms) [23]. The energy produced in onshore wind farms filled 9% of the total electricity demand in Poland. New onshore capacities and the development of offshore wind energy in the coming years may lead to at least double these figures.

The energy transformation and the shift towards renewable sources is an extremely topical and continuously discussed topic. An extensive perspective on wind energy, considering the many various factors that impact the onshore wind farms development and growth was discussed in [24], whereas the development of wind energy in the Baltic Sea was presented in [25]. A case study of five small hydropower plants located on the Gwda river in Poland has been extensively covered in [26]. The research results on ecologically distributed energy generation systems in Poland, show that photovoltaic systems would be the fastest-growing energy sector one can find in [27], while the pathways leading to a carbon neutral future, including the closing of nuclear power plants, for the German energy system, are indicated in [28]. A multidimensional comparative analysis was utilized and presented by the authors in [29] for the analysis of data from the years 2017 and 2019 for 28 EU countries, concerning the use of energy sources such as combustible fuels, coal and manufactured gases, natural gas, oil and petroleum products, hydro/hydropower, wind power, solar photovoltaic, nuclear fuels, and other fuels not elsewhere classified. Following the research, it has been shown that in most EU countries the changes introduced in the structure of the use of various energy sources, in agreement with EU climate policy, have a positive impact on developing specific "green" energy sectors.

2. Renewable Energy Sources in Poland

2.1. Renewable Energy Sources in Numbers

The total installed capacity of all electricity sources in Poland amounted to 56.4 GW (conventional and renewable energy) [30], of which 17.4 GW is renewable energy (which constitutes 30.8%). The most important and largest sources of green energy currently used in Poland are the sun and wind. At the beginning of 2022, the installed capacity of renewable energy sources in Poland, compared to the beginning of 2021, increased by 37%. In January of this year alone, almost 36.6 thousand new installations were built using renewable energy sources [31]. Currently, photovoltaics (PV) dominate the structure of the installed RES capacity. The current installed capacity of solar installations amounted to over 8 GW, which is 47% of all of the capacity of renewable energy sources. Wind energy came second, the currently installed wind power in Poland amounts to 7.1 GW, i.e., 41% of the total RES capacity in Poland (see Table 1).

Table 1. The capacity of RESs in Poland.

RES Power Plants	Installed Capacity (MW)
hydroelectric power stations	976.6
wind farms	7118.4
biogas power plants	260.8
biomass power plants	915.0
photovoltaics	8146.5
TOTAL	**17,417.41**

As mentioned above, it was only in January of this year, in Poland, that a total of 36,626 new installations were created using renewable energy sources with a total capacity of 331.7 MW. Almost all were related to photovoltaics—36,621 units with a total capacity of 330.66 MW. The others were: (a) hydroelectric power plants—2 units (0.03 MW); (b) biogas power plants—2 units (0.01 MW); (c) wind farms—1 unit (1.01 MW); (d) no biomass power plant has been built.

The current total installed photovoltaic capacity in Poland is 8146.52 MW. This means an increase of 97.5% compared to the end of 2020. The average power of the new photovoltaic installation built last year was slightly above 9 kW. According to the Polish power grid (PSE) [30], in only one day (March 21) and during peak hours, the photovoltaic installations produced 4726 MWh, and 34,532 MWh during a 24 h period. For comparison, last year's record was set on May 11. On that day, between 12:00 a.m. and 1:00 p.m., the solar panels produced 3411 MWh. While, throughout the day, the photovoltaic sources produced 30,226 MWh of electricity. The weather conditions, especially the high insolation and relatively low temperature, contributed to such a large production. As a result, the PV panels could work in favorable conditions. In the summer months, despite the high insolation, the efficiency of the cells decreases due to the very high temperature.

According to the data of the Energy Market Agency (ARE) [31], from the end of January 2022, the installed capacity of wind farms was 7118.4 MW (see Figure 1). Compared to January of the previous year, it increased by 10.7%. According to the data of the Polish power grid [30], this year's wind generation record still belongs to January 29, 2022, 6.15 p.m., when wind farms operated with a capacity of 6682.8 MW, and between 5–6 p.m. produced 6646 MWh of electricity. The generation of electricity depends on the strength of the wind and is variable in nature—the amount of energy supplied by it often fluctuates from hour to hour. For example, at night they can work with a capacity of over 5 GW, and in the afternoon it will be below 1 GW.

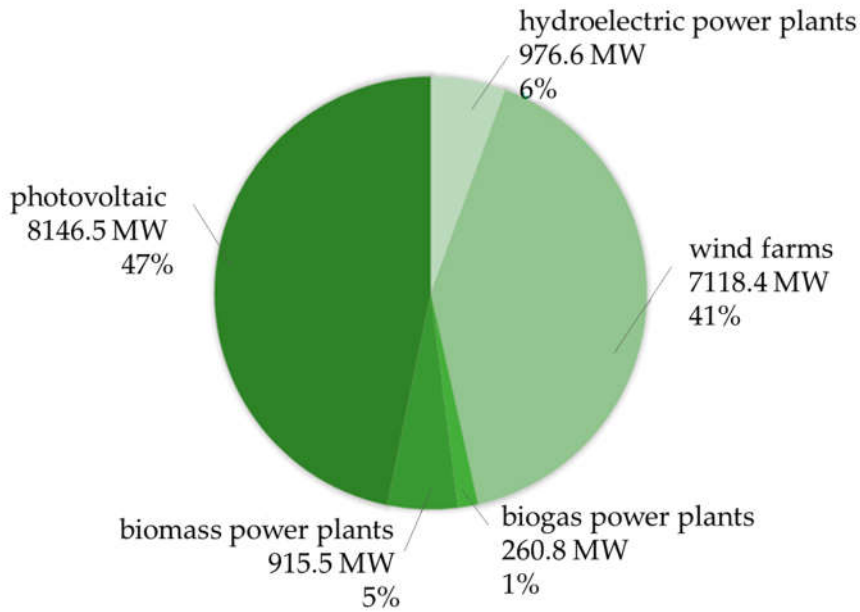

Figure 1. Installed capacity of RES power plants in Poland in 2022.

In conformity with the data of the Energy Regulatory Office (URE) [32], 1239 wind farms were operating in Poland at the end of 2020. Most of them (1111) are farms with a capacity of less than 10 MW (89.7%). The remaining 128 farms have a capacity greater than or equal to 10 MW.

2.2. Electricity Production in Poland

In Poland, the greatest amount of electricity comes from hard coal. Wind farms are the third force in energy production. According to the data of the Polish power grid [30], the electricity production in July this year amounted to 13,802 GWh, i.e., 4.23% less then in July last year. The domestic consumption was slightly lower than a year earlier (by 3.56%) and amounted to 13,931 GWh.

Among the commercial power plants, hydropower plants showed the smallest decline in dynamics—2.25% year-on-year. The production in hard coal-based power plants decreased (–15.61% y/y). Gas power plants also had negative dynamics (–4.87% y/y). Renewable energy sources show the highest production dynamics among all sources. Compared to July last year, wind farms produced more than twice as much electricity (1285 GWh). Other renewable sources increased production by 89.73% y/y, and produced the greatest amount of energy from all available sources—1323 GWh (see Table 2).

Table 2. Electricity production by source type in July, 2022.

Specification	**July**			**Cumulatively from January to July**		
	2021	**2022**	**Dynamics [(b – a)/a*100]**	**2021**	**2022**	**Dynamics [(e – d)/d*100]**
	(GWh)	**(GWh)**	**[%]**	**(GWh)**	**(GWh)**	**[%]**
	[a]	**[b]**	**[c]**	**[d]**	**[e]**	**[f]**
Total production	14,412	13,802	–4.23	97,504	102,919	5.55
Commercial power plants	13,102	11,192	–14.56	87,042	85,256	–2.05
Hydro power plants	177	173	–2.25	1775	1770	–0.24
Thermal power plants	12,925	11,021	–14.73	85,267	83,486	–2.09

hard coal-fired	7831	6608	–15.61	52,526	49,784	–5.22
lignite-fired	3972	3778	–4.87	25,182	27,445	8.99
gas-fired	1123	635	–43.48	7559	6256	–17.24
Other renewable power plants	697	1323	89.73	3088	5929	92.03
Wind farms	612	1285	109.95	7374	11,734	59.12
Foreign exchange balance	34	129	283.94	3306	–1579	—
National consumption of electricity	14,445	13,931	–3.56	100,810	101,340	0.53

In Poland, commercial power plants had the largest share in electricity production. For example, hard coal dominated—47.88% and was followed by lignite—27.37%. When it comes to green energy, other renewable energy power plants contributed almost 10% to energy production and wind installations contributed to over 9% (see Figure 2).

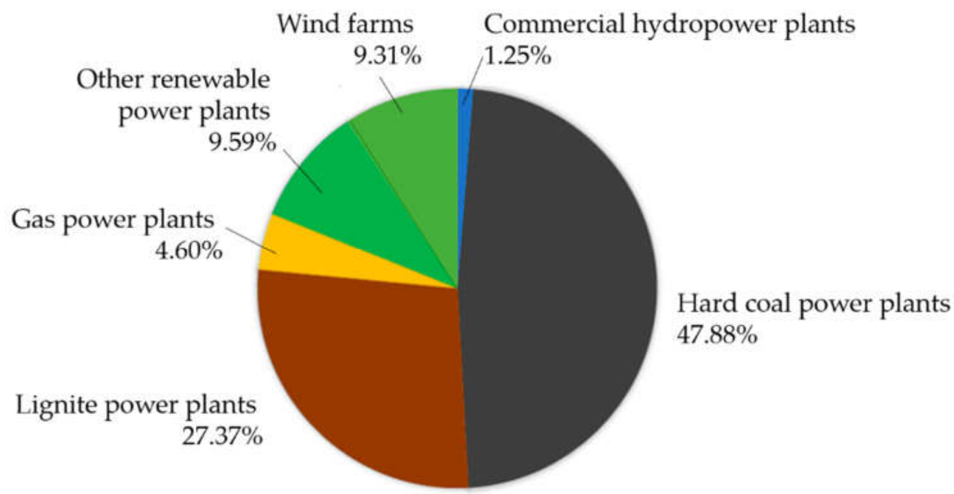

Figure 2. The structure of the electricity production in Poland in July, 2022.

The electricity production in Poland decreased until 2020, while in 2021 there was a significant increase in production and consumption. The share of renewable energy sources is still growing. According to the data of the Energy Regulatory Office [33], the electricity production in Poland in 2021 amounted to 173,583 GWh, i.e., 13.97% more than in the previous year. The domestic consumption was also higher: 174,402 GWh (see Table 3).

Table 3. Electricity production and consumption in 2019–2021.

	2019	**2020**	**2021**
Electricity production (GWh)	158,767	152,308	173,583
Domestic electricity consumption (GWh)	169,391	165,532	174,402
Electricity production from RESs (GWh)	14,344	16,372	18,984

In Poland, electricity is mainly produced in utility power plants. For example, in 2021, the production volume in these facilities amounted to 154,599 GWh, which accounted for almost 90% of the total production [34]. The most important fuel for electricity generation in Poland in 2021, was hard coal with a 53% share and lignite with a 26% share. Renewable energy sources produced 18,984 GWh, and their share increased to 11% (see Figure 3).

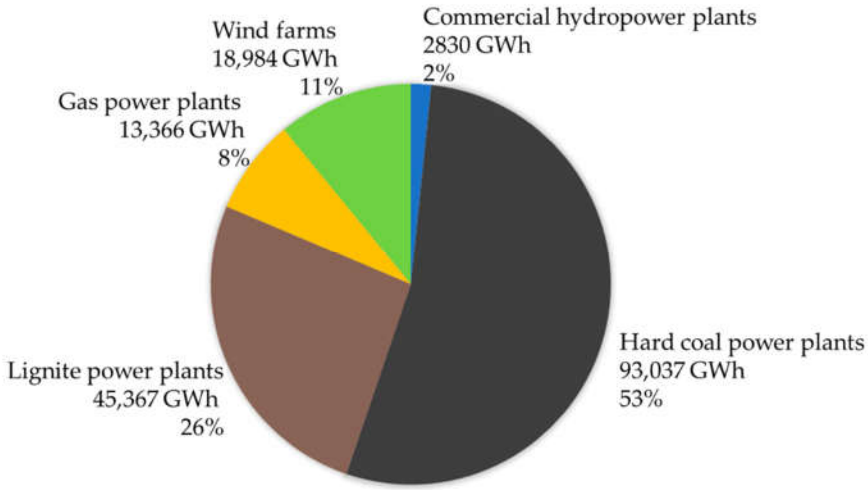

Figure 3. Sources for electricity generation in 2021, in Poland.

In June 2022, Polish power plants produced 13,785.2 GWh of electricity, of which 2927.1 GWh (22.1%) came from RESs. According to the ARE, the number of prosumer installations increased to 1,105,961 (from which 1,105,681 concerned photovoltaic installations). In June 2022, photovoltaic power plants had the largest share in the production of energy from renewable sources—1190.81 GWh and the wind power comes second—944.69 GWh (see Table 4) [34]. Compared to January 2021, all RESs, except water, showed a positive dynamic of electricity production growth, however, the largest photovoltaics were almost twofold (see Figure 4). It should be emphasized that photovoltaics has the largest share in terms of energy production in comparison to other RESs in June, because it is usually a hot summer month with intensely shining sun and a long day.

Table 4. Energy production by source in June 2022, compared to June 2021.

Source of Energy	2021	2022
Water (GWh)	149.96	120.79
Wind (GWh)	703.18	944.69
Biogas (GWh)	107.74	112.74
Biomass (GWh)	370.98	401.09
Co-combustion of biomass/biogas (GWh)	125.55	157.02
Photovoltaic (GWh)	652.99	1190.81

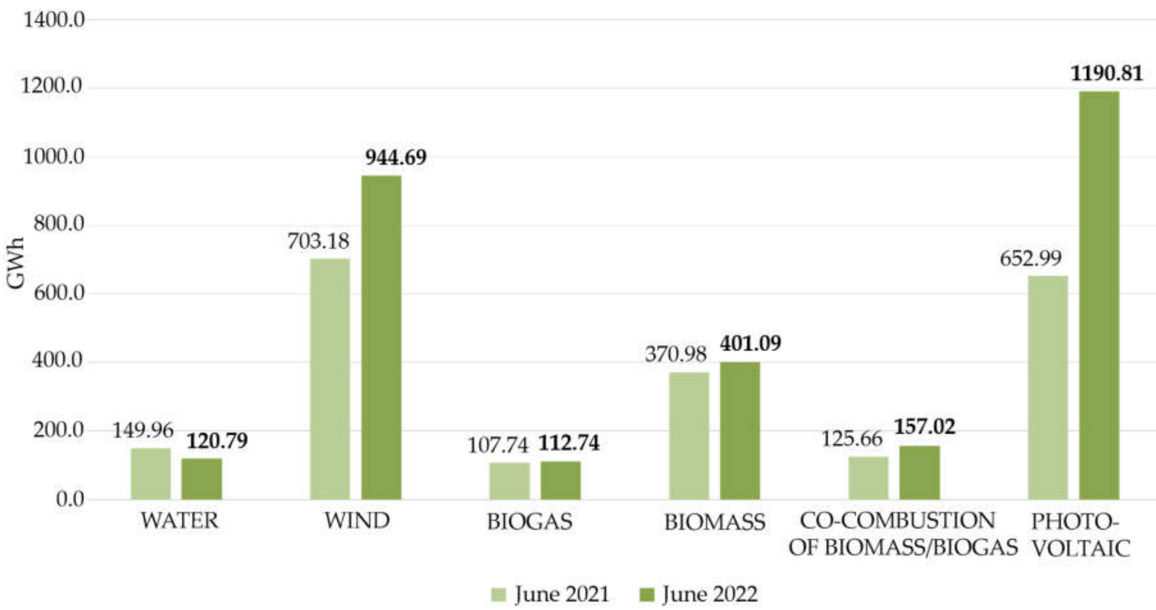

Figure 4. Juxtaposition of the electricity production from RESs in GWh in June 2021 and 2022.

The constant increase in the installed RES capacity on the domestic market may lead to the production exceeding the demand. Such a situation is most likely for PV systems, which has the highest share in productivity in summer at noon, when electricity consumption in households is at its lowest. Therefore, with renewable energy installations that are dependent on the weather, energy storage becomes crucial. According to the Polish Hydrogen Strategy, until 2030 and with a perspective until 2040 [35], increasing the share of electricity generated with the use of renewable energy sources is a challenge not only in Poland, but also in most developed economies of the world. Due to the lack of properly developed methods of large-scale energy storage and services for balancing power systems, the unlimited development of RESs is not possible, taking into account the need to ensure the security of the electricity supply. Hydrogen, as an energy store, can play an important role in the process of achieving climate neutrality, which is now at the heart of global and European energy efforts to achieve the goals set out by the Paris Agreement [36].

2.3. Structure of Electricity Production in Poland in 2020 and 2021

In 2020, electricity consumption in Poland decreased for another year in a row. It produced less electricity from coal (in total, its share in the energy mix fell to a record low level—70%). Generation from gas, wind, and photovoltaics increased, as well as imports.

In 2020, the trends of changes in the Polish power sector were almost identical to those in 2019. For a second year in a row, it recorded a decrease in electricity consumption by 2% (or 3.5 TWh) to 171 TWh. Contrastingly, net import increased (by 2.6 TWh, to a record 13.3 TWh), according to the recently published data of the Energy Market Agency [30]. As a result, in 2019, the domestic electricity production decreased (by 3.8%, or 6.2 TWh, to 157.7 TWh). Interestingly, despite the country's lockdown caused by the epidemic, last year's decline in domestic energy production was slightly smaller than in 2019 (when production in Poland shrank by as much as 3.9%). The largest decrease, in 2019, was recorded by coal-fired power plants and CHP plants (by 9%, i.e., 7.2 TWh, to 71.6 TWh) and lignite-fired (by 8%, i.e., 3.4 TWh, to 38.3 TWh). As a result, the share of hard coal in electricity production decreased to 46% in 2020, while the share of lignite decreased to 24% (see Figure 5). In total, the most emissive coal sources accounted for 70% of the national electricity generation, which was the lowest in the over 100-year history of the

Polish power industry. The change in power production of power plants in Poland in the years 2013–2020 can be observed in Figure 6.

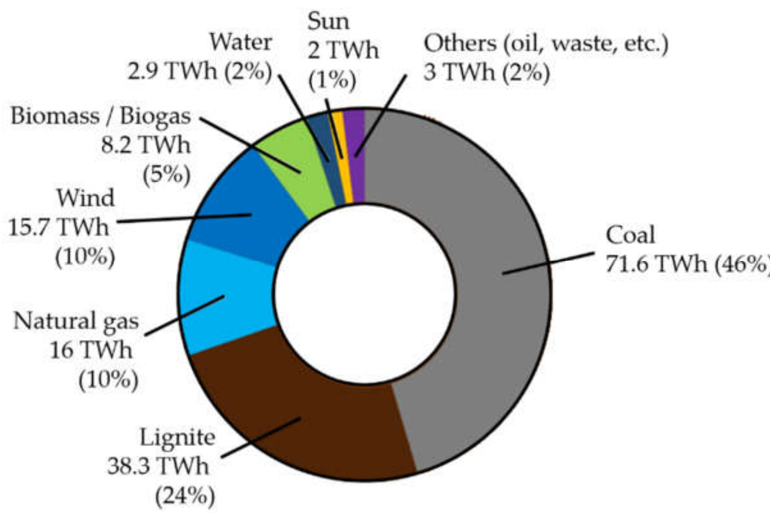

Figure 5. Electricity sources in Poland in 2020.

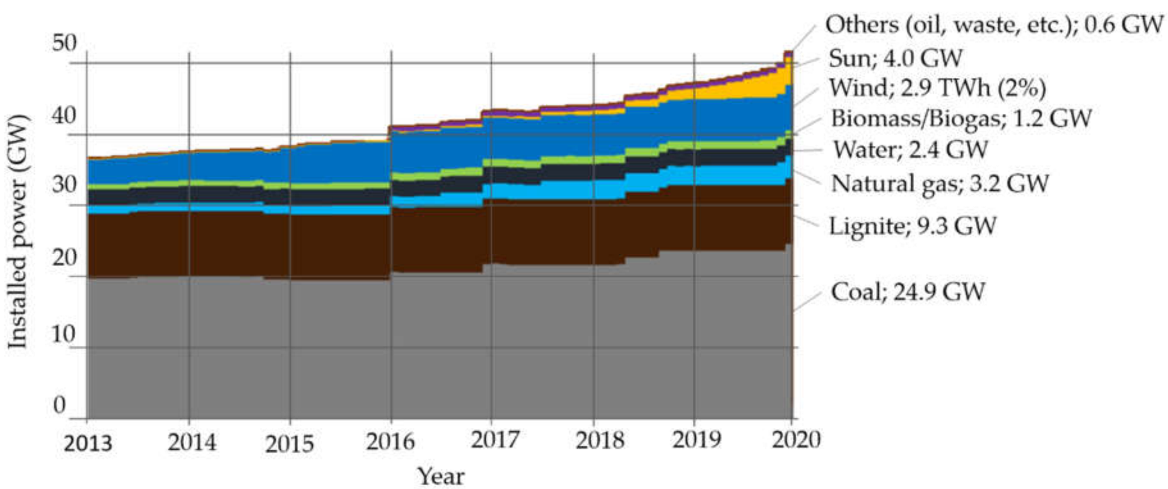

Figure 6. Power plant capacity in Poland through the years 2013–2020.

For a second year in a row, the production from renewable energy sources increased. A spectacular growth was recorded, above all, by photovoltaics—especially prosumer ones. Solar power plants supplied the system with 176% more energy year on year (2 TWh). Co-combustion of biomass with coal increased by 20% (to 2.2 TWh), which was supported by the high price of CO_2 emission rights. The third and fourth place in terms of growth dynamics among "green" power plants, were biogas plants (an increase by 10% to 1.2 TWh) and hydropower plants (by 8% to 2.1 TWh). Pumped storage hydropower plants, i.e., the largest energy storage facilities in Poland, were also used more often by 16% (0.8 TWh). This was mainly due to the increased share of variable energy sources (wind and photovoltaics), which the transmission system operator had to balance more often with the stored energy.

The two largest sources of renewable energy—wind farms and blocks fired exclusively with biomass—could boast of much smaller increases (wind by 4% to 15.7 TWh, and biomass by 3% to 4.8 TWh). Contrastingly, the production of electricity and heat from natural gas is still growing. In 2020, blocks fired with this fuel (mainly PKN Orlen CHP plants) supplied the power system by 1.7 TWh (i.e., 12%) more electricity (a total of 16 TWh). Due to further increases in CO_2 prices, which are very likely to remain above EUR 89. 15 per ton, the production in coal-fired power plants will shrink in subsequent years, while renewable energy generation and imports will increase [37].

In Poland in 2021, the structure of electricity production itself did not change significantly compared to the previous year. The decrease in the share of hard coal was only 0.2 pp. while the share of lignite increased by 1.2 pp. There was also a slight decrease in the case of natural gas by 1.2 pp.

Following the 2020 photovoltaic boom, there was another a good year in terms of increasing the installed capacity. At the end of October 2021, the installed capacity in PV was 6687.5 MW, while in 2020 it was 3936 MW, i.e., 2751.5 MW was added. The share of PV energy in energy production increased from 1.5% up to 2.9% (see Table 5) At the end of November 2021, the installed capacity in wind farms was 7185 MW compared to 6350 MW at the end of 2020. Despite an increase of almost 1 GW of capacity, the energy production remained at a similar level, and the share of wind energy in the overall generation structure decreased from 10.8% up to 9.4%

The reason for the regress in RESs was not due to the fact that 2021 was worse in terms of wind conditions, but most of all the increase in demand for electricity was caused by the reaction to the recovery from the third wave of the pandemic—an increase in energy demand (denominator).

Table 5. Structure of electricity production in Poland (%).

Type of Power Plant Depending on the Carrier	2019	2020	2021
coal	52.3	49.9	49.7
lignite	25.9	24.5	25.7
natural gas	7.3	8.8	7.6
natural gas from mine methane drainage	0.4	0.2	0.3
oil	1.1	1.1	1.3
biomass	1.4	1.6	1.2
pump-storage power plants	0.6	0.8	0.6
hydroelectric power stations	1.0	1.2	1.1
wind power plants	10	10.8	9.5
photovoltaic power plants	0.5	1.5	2.9

Looking at the perspective of the last three years 2019–2021, it can be argued that the structure of the energy sector has been preserved, and the sector efficiently transfers costs to consumers and the taxpayer. Seen from this perspective, the changes are not significant. In the structure of the energy mix, there was a slight decrease in the share of brown coal by 0.2 pp. and hard coal by 2.6 pp. Natural gas accounted for 7.6% share compared to 7.3% in 2019. The biggest change is the increase in the share of energy from photovoltaics from 0.5% to almost 3% (increase in new capacity by over 5.2 GW). Within three years, the share of electricity from RESs increased by 0.8% per year and reached the level of 13.6% [34].

Such a pace of transformation towards "net zero" emissions, as in the last three years, means that Poland will achieve the goal of climate neutrality by 2130. For example China, India, and even Kazakhstan and Venezuela will reach net-zero around 2060–2070. However, India announced at the COP-26 in Glasgow that they will reach the net-zero by 2070, but in 2030 it will already have 50% of the share of renewable energy. According to current trends, in 2030, Poland will reach only 20.8% of the share of energy from renewable sources [38].

In 2021, the production of electricity from coal in Poland increased by as much as 16 pp. compared to the previous year. Energy from natural gas remained at a similar level, as did green energy from wind farms, which produced more than 15.2 TWh in a year and is the main source of green energy. Trying from low levels, photovoltaics showed a significant increase in 2021, as in 2020, by as much as 125% producing 4.6 TWh (last year it was over 50% less—2.05 TWh). The amount of electricity produced in 2021 by generation sources is presented in Figure 7 [34].

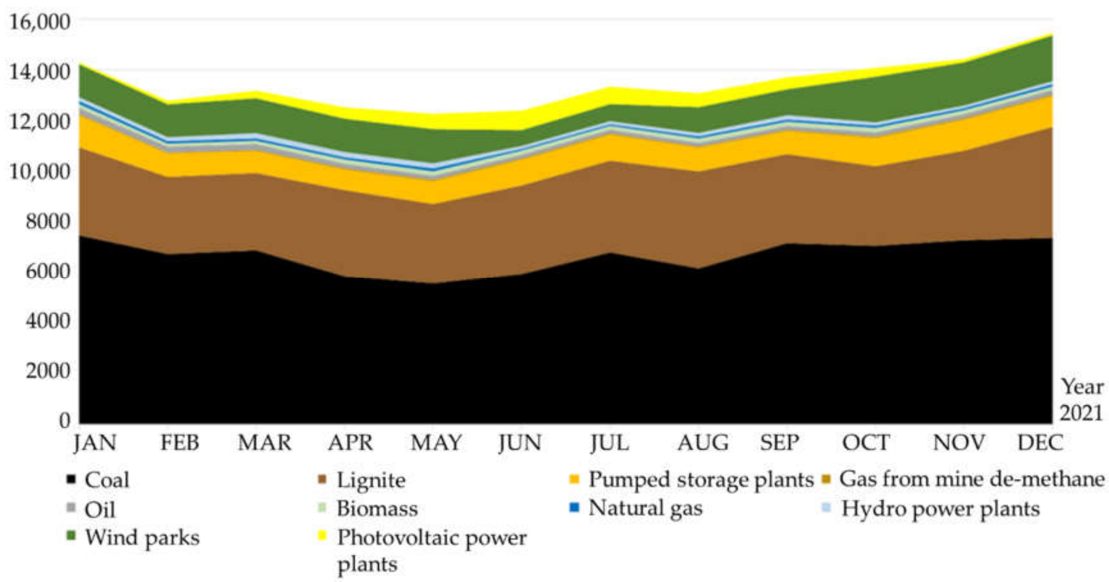

Figure 7. Electricity production in Poland in 2021 (GWh).

In the production structure, in the context of the shares of individual sources, it should be indicated that there is an approx. 4% increase in the volume of electricity generated by lignite-fired power plants—from 24.47% in November to 28.29% in December. Approximately 3% of hard coal power plants recorded a decline. Other sources, with slight fluctuations not exceeding 1% kept their November levels.

2.4. System Heating

The war in Ukraine has triggered a sharp increase in coal prices in all world markets. According to the ARA (Antwerp–Rotterdam–Amsterdam), which is the most important hub for maritime activities in Northern Europe, the introduced embargo on coal imported from Russia, in response to the aggression, increased to USD 351 per ton. Prior to February 24, the ARA coal price was USD 200/ton. March brought a maximum increase to USD 400/ton [39]

The high price, the difficulties with the availability of coal, and the use of technologies from the 1950s and 1960s [40] to a large extent in Poland, affect the heating sector hard. The society bears enormous costs of air pollution—Poland pays PLN 120 billion annually. According to [41], Poland's dependence on coal fuels is still much higher than that of other EU member states, which is why a fair transformation is so important for us, which means taking into account the starting point, the social context of the transformation, and counteracting the uneven distribution of costs between countries and the more burdensome economies with a high use of coal fuels.

According to the data published by the Energy Regulatory Office [42], coal fuel as a heating source has the largest share in heat generation. However, we notice its decrease by 12.8 pp. compared to 2020 with a simultaneous increase in the share of gaseous fuels—by 6.9 pp. and renewable energy sources, by 7.2 pp. and the cogeneration at the level of 7% in 2020. The consumption of fuels to generate heat varies depending on the voivodeship. As stated in [43,44], the greatest differentiation can be observed in the Mazowieckie voivodeship. The leaders in the share of renewable sources are three voivodeships: Kujawsko-Pomorskie, Podlaskie, and Pomorskie, while in the Lubuskie voivodeship, over 95% of heat is produced from natural gas. Hard coal definitely dominates in nine voivodeships: Dolnośląskie, Świętokrzyskie, Łódzkie, Opolska, Małopolskie, Lubelskie, Warmińsko-Mazurskie, Wielkopolskie, and Zachodniopomor-skie, and the share of consumption is over 80%, including the highest share in Dolnośląskie—nearly 90.4%.

According to the 2020 report of the consumption of fuels and energy carriers of the Central Statistical Office (GUS) [45], the maximum consumption of coal in Poland was 62.4 million tons. The individual branches into which the coal consumption was distributed are shown in Figure 8.

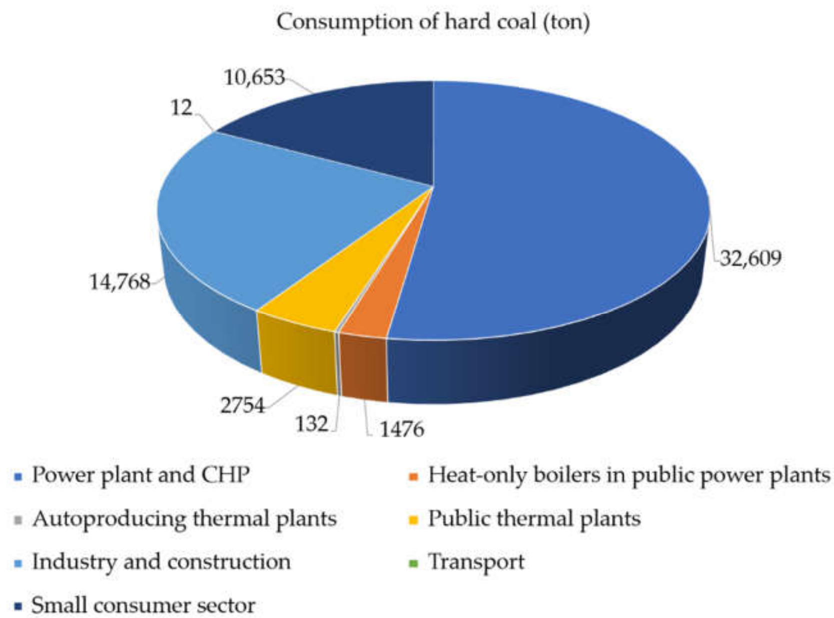

Figure 8. Distribution of coal consumption in Poland in 2020.

The first survey of the heating sector was carried out by the URE in 2002 [42]. Since then, the structure of the surveyed enterprises has changed significantly. When we started monitoring, just over 80% of companies operated in the form of capital companies. Licensed companies, in 2020, had already 95.5% of them.

In 2020, the surveyed heating companies had networks with a total length of over 22 thousand kilometers. In recent years, a gradual increase in the length of the heating network has been observed. In the period of nineteen years, the length of the network per enterprise has more than doubled. In 2020, there were over 60 km of networks per one network enterprise (in 2002 it was less than 24 km, and in 2019—less than 59 km) [43].

In 2020, the value of the installed thermal capacity was 53,271.1 MW, and the achievable value was 52,593 MW (in 2019, these values were respectively: 53,560.9 MW and 52,555 MW). The enterprises generated heat from sources, the majority of which were small, i.e., up to 50 MW of installed capacity (44.6% of generation companies in 2020). Only ten licensed enterprises had the achievable capacity of their sources in excess of 1000 MW each, and their total available capacity was over 1/3 of the available capacity of all licensed sources [43]

The diversification of fuels used for heat production is progressing very slowly. Coal fuels still dominate, the share of which in 2020 accounted for almost 69% of fuels used in heat sources (in 2019 it was 71%, in 2018—72.5%, and in 2017—74%). Since 2002, the share of coal fuels has decreased by 12.8 pp. At the same time, the share of gaseous fuels is increasing—by 6.9 percentage points and renewable energy sources—by 7.2 percentage points since 2002. In 2020, the total debt decreased and the financial liquidity of enterprises in the sector increased. In the years 2002–2020, a significant increase in the replacement of fixed assets ratio was recorded. This value increased by 37.5%, which indicates a high degree of investment, exceeding the level of depreciation of fixed assets [43].

In 2020, more than 90% of the heat was generated by all surveyed heating companies. They generated—including heat recovered in technological processes—almost 394,000 TJ of heat, which means a decrease in production by 1.6% compared to the previous year. In 2020, the share of heat from the cogeneration was 65.2% of the total heat production. Altogether, 370 companies producing heat participated in the study, while 128 of them also generated heat in the cogeneration (34.6%). The data was presented in the most recent report published by the URE [42].

3. Wind Energy

3.1. Legislation

The key legal act for wind energy in Poland is the Act of February 20, 2015 on renewable energy sources (RESs) [46]. This act implements the Directive of the European Parliament and Council 2009/28/EC of 23 April 2009 [47] on the promotion of the use of energy from renewable sources into the Polish legal order, amending and subsequently repealing Directives 2001/77/EC [48] and 2003/30/EC [49].

The RES Act regulates, inter alia, the rules and conditions for carrying out activities in the field of generating electricity from renewable energy sources, including wind energy; mechanisms and instruments supporting the production of electricity in RES installations, including the auction support system and the support system in the form of certificates of origin and the rules for issuing guarantees of origin for electricity generated in RES installations. Importantly, within the meaning of the Act on RES, a RES installation is, e.g., a wind farm (because it is a separate set of devices used to generate energy from RES). Moreover, the issue of connecting RES installations to the power grid is regulated by the Act of April 10, 1997, the Energy Law [50]. Thus, it can be said that the RES Act, supplemented with the provisions of the Energy Law, shapes the legal framework for the operation of onshore wind energy in Poland.

The first windmills were placed in Poland in 2001, but the years 2008–2016 were the period of constant growth of wind power. Until July 16, 2016, i.e., the entry into force of the act on investments in wind farms [51] (the so-called distance act), establishing the 10H rule, according to which wind farms cannot be located at a shorter distance than 10 times the total height of the turbine from residential buildings (or mixed-use buildings that include a residential function). In addition, the location of wind farms with a capacity greater than the capacity of micro-installations has become possible only on the basis of the Local Spatial Development Plan (MPZP). The legislator argued that it was based on proven Bavarian solutions [52], but did not take into account the basic issue, namely that the distance rule in Germany applies to compact buildings, while in Poland, scattered buildings dominate. The Polish legislator did not provide for another issue: the distance act deprived the communes of planning powers and resulted in the loss of investment areas.

The crowning argument for the introduction of this regulation were social protests and the claim that wind farms were built without any supervision. While it is possible to agree with the fact that in the case of the construction of the first wind farms, no clear regulations existed yet, it should be emphasized that it was a temporary state. The regulations specifying the conditions for the foundation of wind farms have been successively detailed. As a result, the foundation of a wind farm is subject to a number of requirements, resulting from, inter alia, construction law. Investors in the initial phase of the so-called development are required to obtain the appropriate legal title to the land, which will enable construction work and then the exploitation of all elements of the wind farm. Thus, also the transmission infrastructure, power stations, access roads, maneuvering and assembly yards, etc.

Environmental protection requirements are a separate issue. Obtaining a decision on the environmental conditions of an investment in wind farms is often associated with the need to conduct an environmental impact assessment of a given enterprise (the so-called EIA). The EIA [53] is a procedure assessing the impact of a planned project on the environment, which includes the verification of the environmental impact report, obtaining the required opinions and approvals and ensuring the possibility of public participation in the procedure. Ultimately, the 10H rule, in practice, has inhibited the development of onshore wind energy in the last five years.

Unlike onshore wind energy, the separation of offshore wind energy is only just beginning. The regulatory framework for the development of offshore wind energy in the Baltic Sea is contained in the Act on the Promotion of Electricity Generation in Offshore Wind Farms. The act was processed for over two years and although its adoption was considered a historical fact, in April, offshore entrepreneurs reported the need to amend the act adopted in February 2021 [54] to the need to correlate the investment support time with the duration of the permits, limiting the costs of extending the permit after the support period, clarifying the mechanism preventing over-support, shortening the procedures resulting from geological and mining law, as well as making the level of protection specified by the legislator more flexible for investment.

The regulation of the Minister of Climate and Environment of March 30, 2021 [55] determined the maximum price for electricity generated in an offshore wind farm and fed into the grid in PLN per 1 MWh, which is the basis for the settlement of the right to negative coverage, has already been issued, but a number of other offshore implementing regulations are still pending. The regulation in question was adopted with limited optimism, as the proposed price (less than PLN 320/MWh) is not satisfactory for investors.

The EU's objective is to accomplish climate neutrality ultimately by 2050 throughout the EU. An intermediate step to achieving this goal is the introduction of the Fit for 55 package which consists of thirteen legislative proposals. Subsequently, they became part of the new European legal order with the adoption by the EU of the Climate Law, which officially entered into force on 29 July 2021 [56]. The intention is to reduce the carbon footprint of the European economy by at least 55% by 2030. The reference is the emission level in 1990. The Fit for 55 legislative process will last until 2023. The changes included in the Fit for 55 have yet to be approved by the individual EU countries and the European Parliament. Therefore, the new guidelines may not become applicable until 2024. The actions taken by the EU as part of the Fit for 55 package are to contribute to sustainable economic growth, reduce the use of fossil fuels, and popularize renewable energy sources that will enable the introduction of new technologies and infrastructure development. The most important assumptions of the Fit for 55 are: (a) the establishment of the Social Climate Fund, financed ,inter alia, from the budget, which is to counteract energy poverty and increase the Modernization Fund for the energy transformation, excluding investments related to fossil fuels, including gas; (b) the revision of the Energy Tax Directive [57] by taxing all fossil fuels—now reduced rates or exemptions apply; (c) reducing energy use in Europe through, among others, the idea of the thermal modernization of public sector buildings—each year, 3% of these buildings are to be modernized in terms of energy efficiency; (d) accelerating the transition to a greener energy system with an increased target, whereby 40% of energy should be produced from renewable sources by 2030; (e) changes in Emissions Trading (EU ETS)—a proposal to tighten the emission reduction targets under the so-called Effort Sharing Regulation [58], (d) stricter CO_2 emission standards for passenger cars and vans by requiring a 55% reduction in average emissions from new cars from 2030 and 100% from 2035 compared to 2021 levels—all new cars registered from 2035 will be emission-free; (e) by 2035, achieving climate neutrality in the sectors of land use, forestry, and agriculture, by 2030, 3 billion trees are to be planted in the EU.

Unfortunately, the latest ideas and regulations of the Polish government, as a consequence of the current deep energy crisis, resulting in an act which regulates coal prices [59] and the act that subsidizes the purchase of coal [60], to discourage the replacement of non-ecological solid fuel stoves and the transition to green energy for households, are strongly at odds with the fit assumptions.

According to the recent legal regulations of 5 July 2022 [61] on the amendment to the act [51], a new wind farm may be located only on the basis of the MPZP. The aim and assumptions of the draft act making the distance act more flexible are very good, but in the proposed form, they may not fulfill their function. The multitude of procedures that will have to be met by both municipalities and investors is disappointing. However, there will be even more bureaucracy and competence disputes. The assessment of the effects of the regulation of this project indicates that in just two years, the increase in the installed capacity for new wind farms is 500 MW, which, in the opinion of the market, is an unrealistic assumption. In view of the fact that Poland, despite its undisputed potential, is a country with the lowest share of renewable energy sources in the energy mix in Europe, the project requires significant correction. Nevertheless, solutions such as making the 10H principle more flexible and introducing certified units servicing wind farms should be appreciated.

When analyzing the structure of sources from which renewable energy is produced in Poland, presented in [62], together with the development prospects, it can be concluded that it has a high growth potential. The production of energy from the sun and wind, as well as liquid biofuels, biogas, and geothermal sources is of particular importance. The authors of the study indicate that it is favored by geographic and atmospheric conditions. Therefore, it seems indisputable to create favorable legal conditions for investing in RESs.

A very large number of organizations declared that they submitted comments in the public consultation process. One can get the impression that the Ministry of Development, Labor, and Technology wants to introduce solutions liberalizing the current regulations, but without solutions that will actually allow to achieve the assumed goal.

3.2. Wind Conditions in Poland

Most renewable energy sources come from the sun as the primary energy source: solar radiation, wind energy, biomass, and water. The rest of the energy comes from the Earth—geothermal energy, and from the Moon—wave and tidal energy. The forms of solar radiation conversion are: photothermal (direct heat production), photovoltaic (direct electricity production), and photobiochemical (chemical bond energy) conversion. They require special devices and lead to more unstable forms of energy.

Wind energy is one of the energies that come from the sun. It is formed due to the uneven heating of the Earth's surface by the Sun. As a result, constantly moving systems of highs and baric lows, atmospheric fronts appear in the atmosphere. These constant movements of the air around the globe cause the wind. The speed and direction of the wind usually have a clearly defined diurnal and annual character and are strictly dependent on the climatic zones. The wind reaches its maximum speed in the midday hours, then it begins to fall to its minimum value at night near the ground. In most parts of Europe, wind speeds reach their maximum values from January to February, and their minimum in summer. In winter, wind speeds in Poland reach an average of about 150–170% of the average annual speed, while in summer it is about 50–70% [63].

The wind speed increases with altitude and is proportional to the second power of relative altitude. The speed increase depends on the roughness of the substrate and the vertical air temperature distribution. A flat area covered with grassy vegetation is an example of a terrain with a zero roughness class (see Table 6). It can then be said that the wind speed at the selected height is almost the same throughout the area. Numerous terrain obstacles, in the form of buildings or trees, in the path of air masses, cause a rapid reduction in wind speed and an increase in turbulence. The change of the wind speed above the ground occurs only up to a certain relative height, referred to as the gradient wind height. It means that above this height, the wind speed does not depend on the degree of roughness. The energy of the wind depends on its speed in the third power.

Table 6. Assessment of the roughness class of the terrain with regard to the possibility of using wind energy.

Roughness Class	Terrain Description
0—highly favorable	A flat open terrain with an average height of objects lower than 0.5 m
1—favorable	An open terrain with few low obstacles, may be slightly undulating with low, loose buildings or single trees far apart
2—quite favorable	A terrain with large open spaces, flat or undulating, with trees or groups of trees far apart. There may also be loose low buildings
3—unfavorable	A terrain with obstacles—forested areas, suburbs of large cities, small towns and suburban areas, industrial areas, loosely built-up
4—highly unfavorable	A terrain with numerous obstacles placed close to each other, clusters of trees or buildings, but at a distance of at least 300 m from the observation site
5—areas excluded from the possibility of location	A terrain with numerous, large obstacles located close to each other, forest areas, city centers, urbanized areas, peak areas

The total potential of wind on Earth cannot be fully utilized, if only because of the variability of wind power and direction. The sum of wind energy per 1 m^2 in Poland annually amounts to 1000–1500 kWh/year, depending on the location (mountains, coast). This value is analogous to that in Germany, the Netherlands, France, England, Denmark, and Sweden. According to the expertise of the EC BREC Institute for Renewable Energy [64], the size of the technical potential of RESs in Poland is approximately 2.5 thousand PJ/year, including 36 PJ/year coming from wind energy.

There are favorable conditions for the development of wind energy in Poland. According to the Global Wind Atlas [65], compiled by the International Renewable Energy Agency (IRENA) [16], the country's wind speed in most areas is adequate for the installation of wind turbines. As shown in Figure 9, at a height of 100 m (usually at this height there are nacelles of wind turbines), the wind speed in almost all of Poland oscillates around 7–8 m/s. The atlas makes it possible to estimate the wind speed in a given area and at a selected altitude from 10 to 200 m with an accuracy of 1 km. However, according to previous similar maps, such an estimate could be made with an accuracy of 10 km.

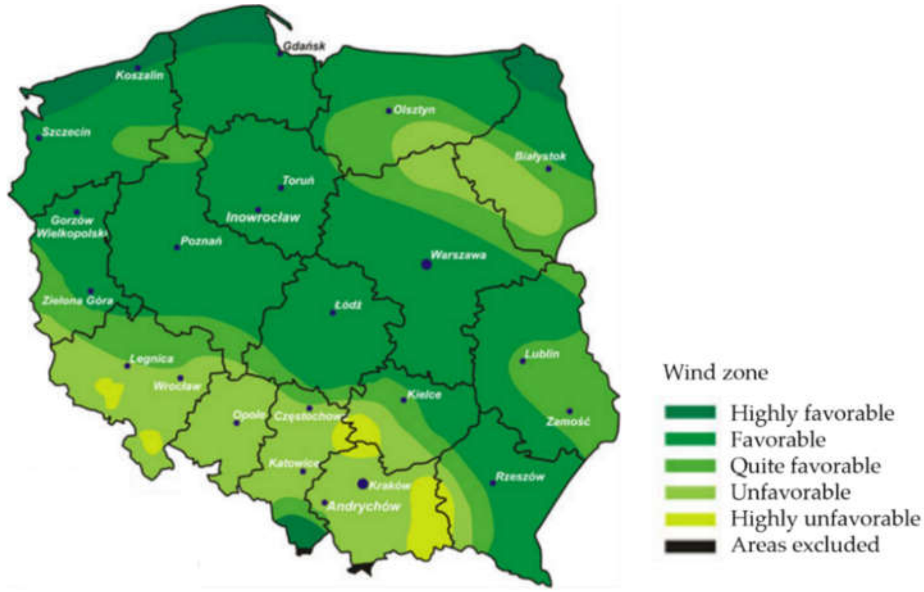

Figure 9. Wind map in Poland [66].

Wind parks are usually built in rural areas due to the best ground roughness class, i.e., in open areas with as few obstacles as possible, which creates good wind conditions. When locating a wind farm, it is necessary to take into account, in addition to wind conditions, other conditions, such as: flight and migration routes for birds, ornithological analyses, analyses of the occurrence and existence of bats, the criteria taking into account residential buildings, forest land, water reservoirs, areas related to nature protection and landscape, areas attractive for tourists, spa areas, the presence of other wind turbines in the vicinity, cultural and landscape conditions, as well as the presence of infrastructure related to roads, airports, railways, and power networks.

Many studies or even scientific publications in Poland still refer to the outdated wind map (see Figure 9). Wind speed measurements and tests were made by the Institute of Meteorology and Water Management (IMiGW) on the basis of measurement data from 1971–2001 [63] by prof. Halina Lorenc. However, they are not quite correct results due to the fact that: the measurement methodology, assuming measuring the wind speed eight times a day, is insufficient and can only be an approximation of this value; anemometers were placed too low, at a height of 10–20 m, with the use of weak equipment (gradient masts with a height of 40–120 m are recommended [67]); meteorological stations are usually located in the vicinity of cities and housing estates, while wind farms are not built in such places due to the high roughness class of the terrain and in mountainous regions, measuring stations were placed in valleys near human settlements, which lowered the results for higher, more windy areas [68].

One of the numerous facts concerning the irregularities in the IMiGW map are the results of the wind tests in Lower Silesia in the Sudetes. The area of the Sudety Foothills on the map of the IMiGW has been classified as an area with unfavorable wind conditions. Meanwhile, winds in Lower Silesia blow at a height of 100 m at a speed of 5 to over 7 m/s, and even 9 m/s (the area around Wałbrzych and Jelenia Góra). Favorable wind conditions also prevail in the vicinity of Lubawka. The entire range of the Sudety Fault is very well suited for this type of investment. This is evidenced by the preserved map from 1931, according to which there were about 600 windmills in Lower Silesia. The energy potential of wind in mountain areas is similar to that of the coast.

Due to inaccurate measurements, investors should conduct their own wind speed tests (unfortunately at their own expense, which is one of the factors discouraging investment) before starting the construction of the wind park. Failure to conduct such research and to follow the IMiGW map may result in overestimation of the expected energy production, and if in reality the wind conditions are much weaker—investment will not be profitable. Reliable assessment of wind resources is possible only thanks to many years of observation. When measurements are carried out over a period of up to one year, they can cause an error of 20% calculated in relation to the annual efficiency determined on the basis of several years of measurements, e.g., the average wind speed in Łeba was 3.9 m/s in 1966, and in 1989—6.2 m/s.

3.3. Perspectives—Wind Energy

Unlike onshore wind farms, the possibilities for offshore wind power in Poland are just beginning. The legal framework for the development of offshore wind energy in the Baltic Sea is contained in the Act on the Promotion of Electricity Generation in Offshore Wind Farms [54].

There are two strategic national Polish documents, the aim of which is to outline the desired directions of the electricity transformation and to define the goals to be achieved in the perspective of the next one or two decades. The first one is the National Energy and Climate Plan [38] (KPEiK) for the years 2021–2030, developed by the Polish government, in accordance with the requirements of the EU climate policy. Work on the KPEiK was led alongside with the work on the draft of the second strategic document, namely the Polish Energy Policy until 2040 (PEP2040) [41], which was finally adopted by the Polish government in February 2021. The KPEiK does not distinguish between onshore and offshore wind energy, nevertheless careful analysis of this document allows to estimate the government's plans for the development of onshore wind energy. General plans for the development of wind energy have been juxtaposed in Figure 10. There is a clear intention visible to gradually replace onshore generation capacity with offshore wind power. It is expected that the first offshore wind farm will be included in the electricity balance around the year 2025. The Polish coastline makes it possible to implement further installations at sea, but the possibility of balancing them in the national energy system will be of key importance for investors. These sources are planned to be responsible for the largest amount of electricity produced from RESs by 2040. According to the projections for the National Energy and Climate Plan, the achievable capacity of offshore wind installations is expected to increase to approx. 3.8 GW in 2030 and approx. 8 GW in 2040. Moreover, it is predicted that in the medium term, the increase in the share of onshore wind energy in the energy balance will be less dynamic than in previous years. A significant obstacle in the use of onshore wind energy is the lack of dependence between their work and energy demand, therefore the pace of their development should depend on the costs and balancing possibilities According to the projections, the KPEiK envisages an increase of capacity available in onshore wind installations to around 9 .6 GW by 2030 and a maintenance of this volume until 2040.

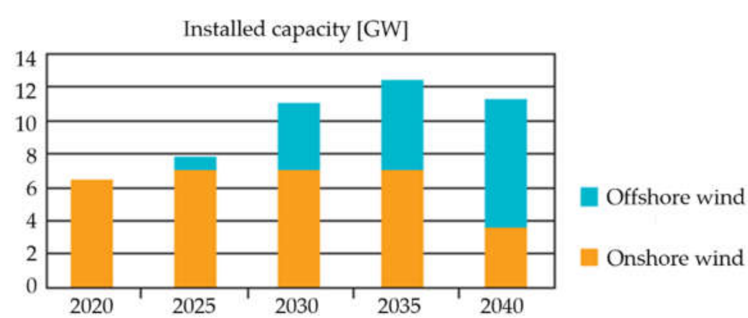

Figure 10. Wind Energy according to the KPEiK.

The enforcement of offshore wind energy in the Polish area of the Baltic Sea is the second strategic project defined under the specific objective No. 6: "Development of renewable energy sources" of the Polish Energy Policy until 2040 (PEP2040) [41]. The quantitative goals of PEP2040 assume an increase in the share of renewable energy sources in all sectors and technologies. In 2030, the share of renewable energy in the gross final energy consumption is to be min. 23%, including no less than 32% in the electricity sector, and approx. 40% in 2040, which is to be achieved mainly through the development of wind and photovoltaic energy. Offshore wind energy is expected to play a particularly important role in accomplishing the Polish RES goal. The energy policy assumes the potential of offshore wind energy at the level of 5.9 GW of the installed capacity by 2030 and at the level of approx. 11 GW by 2040 (see Figure 11).

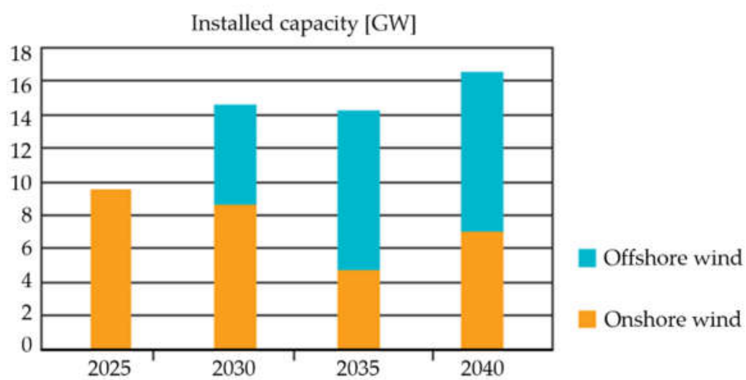

Figure 11. Wind Energy according to the PEP2040.

Achieving the indicated objectives within the scope of offshore wind farms will allow them to produce electricity at the level of approx. 24 TWh by 2030 and approx. 39.4 TWh by 2040.

According to the plan, the evaluation and revision of the KPEiK will take place in 2023. Considering that the KPEiK and PEP2040 should form a coherent whole, it should be assumed that, in particular, the PEP2040 will be subject to significant modifications in the near future. Undoubtedly, the intention is to gradually replace the land-based generation capacities with offshore wind power [15], with planned funds for investments in offshore wind farms amounting to PLN 130 billion [69].

The Polish power system definitely requires a thorough transformation. The country's energy mix, approximately 70% based on coal [69], does not meet the requirements of modern times and the ambitious plans declared by all political forces to build a modern welfare state. A necessary measure to achieve this goal is competitively priced energy, especially as domestic consumption is systematically growing year by year. The import of energy is also growing. Another factor accelerating the pace of the inevitable transformation is the European Union's climate policy, which is increasingly focused on reducing CO_2 emissions and building a zero-emission circular economy.

The current price of energy is approx. PLN 300/MWh, while wind investors have proposed approx. PLN 200/MWh in previous auctions. With the use of the current technological potential, it is possible to go down to 150 PLN/MWh. While in 2016, one could have doubts as to the profitability of investing in wind energy (at the energy prices at that time), today we cannot afford to limit its development. Its dynamic development is of a key interest—1 GW of installed capacity in the wind is currently over PLN 20/MWh in savings for the end-user, the consumer [69]. Cheap energy is of core importance for the competitiveness of the Polish economy, where 80% of exports go to the EU market.

The authors of the PEP2040 assumed the price of CO_2 emission allowances at EUR 30/ton in 2030 [41], which was already exceeded in December 2020. Moreover, the price forecast for 2040 (EUR 40) was reached at the beginning of the second quarter of 2021. Therefore, it is clear that the assumptions of the PEP2040 have become outdated. In addition, the upward trend will continue to increase, the latest forecasts say EUR 70/ton of CO_2 by 2030 [69]. Assuming this rate, with the emission ratio of 0.76 tons of CO_2/MWh and the exchange rate of 4.7 PLN/EUR, the allowances themselves will cost over PLN 250/MWh.

The assumptions for offshore wind farms by 2030 (5.9 GW) are very realistic, however, 11 GW in 2040 is an underestimation—due to the dynamics of the development and technological progress. In other countries, a significant acceleration of such investments and an increase in plans is observed comparing to previous estimates. Think tanks indicate the potential of the Polish part of the Baltic Sea at the level of 28–45 GW by 2050. Assuming conservative estimates, it could be at least 14–15 GW of installed capacity by 2040 [69]. Think tanks also emphasize that it is possible to move away from coal more quickly, drawing the prospect of a two times faster departure from coal in the power sector than assumed in the PEP2040. In fact, the potential seems to be much greater in both onshore and offshore wind farms—needless to say that, based on the existing and planned auctions, 10.5–11 GW of onshore capacity will be contracted. Therefore, the PEP2040 created in 2018–2019 does not sufficiently take into account the current realities in the field of energy prices, and thus the growing competitiveness of wind energy. The McKinsey & Company report [70] also indicates that the share of wind energy in Poland's energy mix in 2050 could be as high as 73%, with a 2.5-fold increase in energy demand.

The war in Ukraine has undermined the energy security of the whole of Europe which, in turn, disrupted the sense of independence and stability. In response to the threats, the European Commission presented the proposed solutions contained in the RePowerUE document [71]. Set out on 47 pages and in a series of accompanying documents, the plan has a dual purpose: to make Europe independent of Russian fossil fuels as soon as possible, ideally by 2027, while at the same time accelerating its green transition. The EU wants to go even further and faster, requiring the "mobilization at the level of the war economy". For the plan to work, significant additional investments of EUR 210 billion will be needed between now and 2027.

As a consequence of the Russian aggression against Ukraine, the goal of the Polish government has also become to achieve independence from fuel supplies from Russia, which requires updating Poland's energy policy. Due to the enormous potential of offshore wind energy, it can be assumed that the goals set for this technology will be increased.

3.4. Perspectives–Energy to Heat

What has been happening, among others, in Scandinavia since the 1950s, may begin in Poland in the coming years, and that concerns transforming green energy into green heat. This may occur due to the fact that many modern companies, which have their roots in developed countries in Western Europe, are opening branches in Poland. The experience of companies such as Eurowind Energy Ltd gained in recent years, on the implementation of modern energy systems in various European countries, allowed them to initiate a very innovative project in Poland. The idea of transforming electricity into heat arose as a result of bureaucratic problems related to the connection of the newly built wind farm to the municipal grid. The local administration quickly became interested in the idea of generating green heat and finally agreed to implement it. Thus, as has happened, a pioneering project was born out of a limitation and may turn out to be one of the most important paths of development in Poland in the current legal and infrastructural regulations.

The planned investment in Heat Energy Plant Ltd (ZEC) in Wałcz, is based on the cooperation with the Danish investor Eurowind Energy Ltd, which will build a wind farm and photovoltaic farm within a radius of 30 km from Wałcz, supplying the KR2 boiler houses in Wałcz with a direct power line. Green energy from RES farms will be sent directly to the boiler house in Wałcz with a private off-grid network, where 100% of it will be converted into thermal energy while using an electrode boiler.

The electrode boiler is made of a cylindrical high-pressure tank to which electricity is supplied. The supply voltage of the 10 MW boiler in question is 10–11 kV. The temperature in the boiler circuit is 130 ° C/95 ° C. The heart of the electrode boiler is an open vessel in which high voltage electrodes are immersed. As the electrodes are lowered into the reservoir and the water flow is adjusted, the heat output of the source increases. Importantly, unlike fossil fuel fired boilers, in these boilers the production efficiency is practically independent of the load on the device. At half power and full power load, it is at a similar level and amounts to 99.8%. This means that 99.8 MWh of heat will be sent from 100 MWh of electricity transmitted from the wind farm to the Wałcz district heating network. for comparison, the efficiency of coal boilers is 84% and gas boilers 95%.

In electrode boilers, the quality requirements of water in circulation are very high, e.g., the water must be fully demineralized, the electrical conductivity must be < 1 µs/cm (continuously monitored) and for efficiency improvement, there is nitrogen in the boiler instead of air. The high water quality regime makes the individual boiler short circuits the most effective (see Figure 12). Thanks to this, a dedicated water treatment plant does not have to be large and the costs of water preparation are lower. The basis of the station is the reverse osmosis process, thanks to which the almost complete demineralization takes place. If the programmed value of the electrical conductivity of the water in the boiler circuit is exceeded, the discharge process is automatically started by means of the water drain and the treated water is injected from the station. The water that enters the upper vessel is heated by the flow of the current between the electrodes. The throttle valve regulates the flow of water from the upper vessel to the lower part of the tank, from where it is pumped out to the heat exchanger. Once the heat is collected by the network water circuit, the boiler water goes back to the vessel with electrodes. Due to its relatively small volume, the boiler also functions as an expansion vessel.

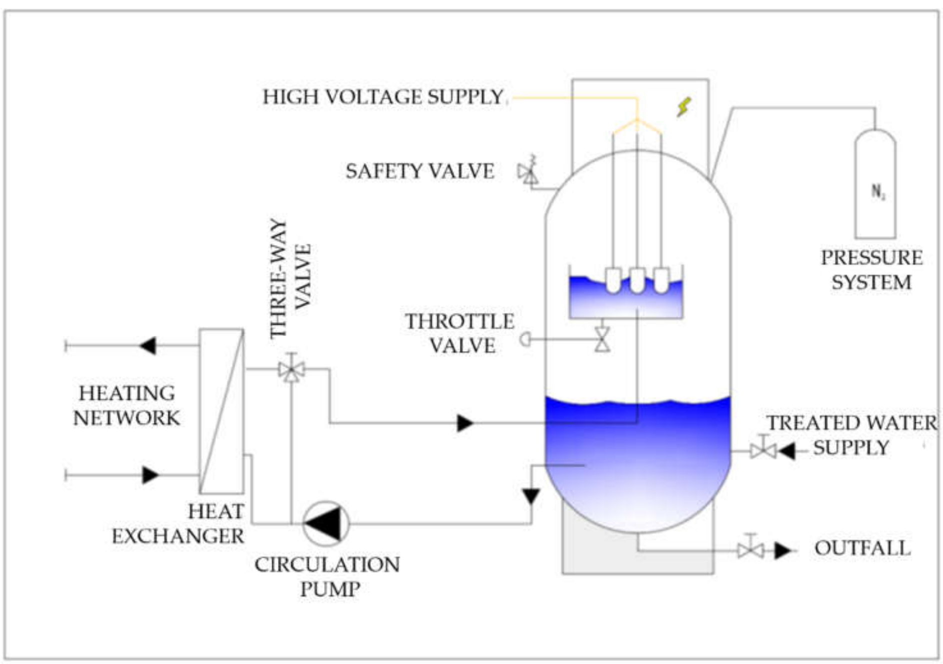

Figure 12. Scheme of the electrode boiler.

Example of an installed 10 MW electrode boiler from Parat in Denmark is presented in Figure 13.

Figure 13. Example of an installed 10 MW electrode boiler from Parat in Denmark.

4. Conclusions

The latest research commissioned by the Polish Wind Energy Association PSEW [72] showed that 81% of Poles support the development of on-shore wind farms, and as many as 75% believe that wind farms will contribute to an increase in energy security, which will also reduce the consumption of fossil fuels. Research has shown that as many as 85% of respondents believe that the law should support the development of renewable energy sources. Despite the generally growing approval of wind farms, in countries such as Iceland, one of the problems [73] is to reconcile the resulting conflict between the wind sector and nature-based tourism. Energy companies are making efforts to locate wind turbines in areas where they would have a less negative impact on the tourism industry compared to other areas.

The development of wind energy is an important direction for the energy industry to progress in the country. In accordance with the announced energy policy of the state until 2040 [41], Poland declares it will achieve a 23% share of RESs in its gross final energy consumption by 2030. This increase applies mainly to: offshore wind energy, solar energy, onshore wind energy, energy from biomass and biogas, and hydropower.

The development of renewable energy investments, including onshore wind, will not take place without the implementation of priority access to the grid, extension of the auction system, feed-in tariff system, subsidies, guarantees of origin and the aid mechanism aimed at technology development, and in particular the adjustment of the law.

More and more often, one can read the headlines in the press "Free the Windmills". The truth is, that in order to be able to implement investments, it is necessary to amend the so-called windmill act [51]. Assuming that such an act appears and despite the fact that the electricity grid in Poland is not prepared for the planned rapid expansion and development of wind farms, the conversion of green electricity into green heat is an example which proves that Poland's zero-emission approach in the coming decades is not only possible but also real.

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Abbreviations

ARE	Energy Market Agency
CHP	combined heat and power (plants)
EIA	Environmental Impact Assessment
GUS	Central Statistical Office
GWEC	Global Wind Energy Council
IEO	Institute of Renewable Energy
IMiGW	Institute of Meteorology and Water Management
IRENA	International Renewable Energy Agency
KPEiK	National Energy and Climate Plan
LCOE	levelized cost of energy
MPZP	Local Spatial Development Plan
PEP2040	Polish Energy Policy up to 2040
PSE	Polish Power Grids
PSEW	Polish Wind Energy Association
PV	photovoltaics
RES	renewable energy sources
URE	Energy Regulatory Office
WWEA	World Wind Energy Association
ZEC	Heat Energy Plant in Wałcz

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