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Changes in the Structure of Electricity Generation in Poland in View of the EU Climate Package

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Abstract: The fuel mix of electricity generation in Poland is currently based predominantly on solid fuels. In addition, the generation power base is outdated. Many of the generating units are inefficient, uneconomic, and do not comply ecological standards, so they should be withdrawn from use in the near future. Poland, which consumes approximately 170 TWh of electricity, needs to determine the direction of the further development of the energy sector. The concepts of covering domestic demand for electricity were outlined by the government in the draft Energy Policy of Poland until 2040, where it was pointed out that the most important pillars of the Energy Policy should be the following: The energy security of the country, competitiveness, and the improvement of the energy efficiency of the economy, as well as limiting the impact on the environment. The article presents the current state of the Polish power sector and the directional changes planned by the government in the area of new capacities for the power industry. The authors present a critical evaluation of this document indicating the opportunities and threats in the area of its implementation. In contrast to many European countries, the Polish government is not considering coal phase-out.

Keywords: energy mix; energy policy; energy security

1. Introduction

The global forecasts for the consumption of primary fuels and the production of electricity are carried out by many specialized centers and scientific units. The forecasts developed by the IEA (International Energy Agency) [1] and the EIA (U.S. Energy Information Administration) [2], which include scenarios for the economic development of the world and regions until 2040 are particularly noteworthy. Three development scenarios regarding the structure of primary energy development, electricity generation, and CO₂ emissions by 2060 have also been developed by the WEC (World Energy Council) [3].

The energy and climate policy of the European Union is reflected in the decisions of many governments of member states to withdraw from the production of electricity in coal-fired power plants. In line with the Paris Climate Agreement the governments of EU countries have declared coal phase-out by 2030. Poland is one of the few countries in which such a scheme is not considered [4]. This does not mean that there are no works related to energy transformation.

One of the most important documents resulting from the regulations and directives of the European Parliament and the Council, the National Energy and Climate Plan for 2021–2030, is currently in the discussion phase [5]. The final version of this plan, in line with obligations imposed on Poland, should be presented to the European Commission by the end of 2019 [6]. Its content and the adopted directions of actions should be consistent with the energy policy of the country. Meanwhile, there is no strategy regarding Poland's long-term energy policy. The last such document was published in 2009 [7]. Almost 10 years have passed since its adoption, during which changes both in the economy and politics of Poland, as well as in the EU's approach to issues related to the Energy Union, energy market, and

above all, to issues related to climate change, have taken place. Therefore, it should be considered that this document is no longer relevant. Meanwhile, the draft Energy Policy of Poland until 2050 [8] was presented in 2015, although, for many reasons (including the change of the government), it was not adopted.

The main directions of the current Polish energy policy are only outlined by the government framework document adopted in 2017, the Responsible Development Strategy until 2020—with prospects until 2030 [9].

The Strategy for Responsible Development until 2020 is a broad strategy according to which the goal of the energy sector is to provide the country's economy with stable and sufficient energy supplies through the effective use of available resources and increasing cooperation between energy generation, the supply sectors, and the recipients. At the operational level, developing energy storage, smart grids, electro-mobility, and introducing energy-saving and highly-efficient technologies are proposed.

The necessity to update and adopt a strategic document for the energy sector has been postulated for many years. In addition to the document created for the needs of the European Union (the National Energy and Climate Plan for 2021–2030), the draft Energy Policy of Poland until 2040 (PEP2040) [10] was also prepared by the government at the end of 2018. The document was subject to public consultation and, according to the government declaration, it was supposed to be adopted by mid-2019 (unfortunately, its launch was delayed, most probably due to elections).

The provisions in these documents are consistent with the energy policy of the European Union and are complementary to the Strategy for Responsible Development until 2020—with prospects until 2030. These include the following: Strengthening the energy security, reducing emissions of the economy, increasing energy efficiency, building a stable and efficient internal energy market, and developing innovation in the energy sector. The prioritization of goals and selected implementation paths are a consequence of the specific conditions of Poland.

The main objective of Poland's the energy policy is the energy security of the country while ensuring the competitiveness of the economy, energy efficiency, reducing the impact on the environment, and the optimal use of its own energy sources. The PEP2040 policy provides for actions in the following eight strategic directions:

- The optimal use of own energy resources;
- The expansion of the infrastructure and electricity network;
- The diversification of oil and natural gas supplies and the development of electricity network infrastructure;
- The development of energy markets;
- The implementation of nuclear energy;
- The development of renewable energy sources;
- The development of district heating and cogeneration;
- The improvement of energy efficiency.

In this article, the authors analyze the planned directions of development of the Polish power system, taking the European Union's climate and energy policy and national conditions, aimed at ensuring the security of energy supplies is taken into account.

2. Materials and Methods

The article presents the current state of the power sector and the directions of changes planned by the government in the area of new generating capacities for the power industry. The available data (with references) on this subject is analyzed. Attention is paid to the specific structure of electricity generation in Poland, due to the availability of primary fuels. The next section (Results) presents the domestic energy resources and the current state of the domestic power industry while indicating the elements determining future development. It also points out the problems and challenges of the Polish power industry the affect the fuel structure of power generation, which are related to the environmental

requirements of the EU. The discussion section presents original and own opinions of the authors on the proposed development directions of the energy sector in Poland.

3. Results

The main energy sources are primary energy sources, including hard coal, brown coal, crude oil, natural gas, and uranium, as well as renewable energy sources including water, wind, solar energy, energy from the heat inside the earth, and gravity.

It is well known that the Polish energy sector has, for many years, been based on domestic energy sources, i.e., hard coal and brown coal, and, to a much lesser extent, on crude oil and natural gas.

3.1. The Domestic Energy Resources and Their Production

Poland, compared to other European countries, has significant reserves of hard coal and brown coal. The reserves of other energy sources (crude oil, natural gas) are limited. Table 1 presents the geological resources (anticipated economic resources) of domestic energy sources and their production in 2017, as well as the number of deposits. The resources available in already developed deposits (those in which the operation has already been undertaken) are specified.

Table 1. The geological balance resources (anticipated economic resources) and production of domestic energy sources in Poland in 2017¹.

Fuel	Number of Deposits		Units	Resources		Output in 2017
	Total	in which: Developed		Total	in which: in Developed Deposits	
Hard coal	158	50	million Mg	60,496	22,497	56.82
Brown coal	91	8	million Mg	23,385	1276	63.06
Crude oil	86	64	million Mg	23.6	23.16	0.94
Natural gas	295	207	billion m ³	117	94	5.01
Coal-bed methane	62	30	billion m ³	97	42	0.33

¹ Own work, based on Reference [11].

Due to historical reasons, as well as taking the existing energy infrastructure into account, hard coal remains the most important fuel for the Polish energy sector.

3.1.1. Hard Coal

The geological resources (anticipated economic resources) of hard coal (158 deposits), as of 31 December 2017, are around 60,495 million tons. Nevertheless this does not mean that all those resources can be exploited. The part of them—proved reserves—might be economically feasible to exploit. The estimation of reserves is possible only after the development of the deposit, based on the deposit development project. The amount of the reserves of hard coal varies from year to year, not only as a result of exploitation, but also as a consequence of changes in the assessment of resources of the currently exploited mines resulting from the implementation of market economy rules and subsequent restructuring measures [12]. By the end of 2016, the proven reserves in the currently exploited deposits with mining licenses amounted to 1560 million tons [13]. This amount is not very high. However, at the current level of production, the reserves should last for over 20 years. There is also a large number of documented deposits that are not yet developed. Their possible development and the use of coal for energy purposes would be of key importance for the country's energy security.

Hard coal mining in Poland has the potential for development, but a number of weaknesses limit the ability to effectively achieve goals and success [14]. The declaration of government support and the government's favorable policy based on the conviction that the energy security of Poland can be

strengthened by the use of indigenous resources is essential for achieving this objective [15]. Such support was granted to the industry thanks to the government's approval of a program for the hard coal mining sector, which assumes that, by 2030, 40% of electricity production in Poland will be based on coal [13] (p. 56).

3.1.2. Brown Coal

The geological resources (anticipated economic resources) of brown coal in 91 deposits are estimated to be around 23.4 billion tons, including approximately 1.27 billion tons in the developed deposits.

Brown coal mining is currently carried out in the five following mines: Bełchatów, Turów, Adamów, Konin, and Sieniawa. Brown coal mining in 2017 amounted to 63,060 thousand tons. Due to the depletion of the available resources, a decline in the production and use of brown coal in the energy sector is to be expected after 2020 [16]. The electricity production from brown coal after 2020 will be possible basically in two power plants, Bełchatów and Turów, assuming that mining licenses will be granted and that the deposits will be made available.

It should be noted that brown coal mining, as well as the use of brown coal in the power industry, despite many upgrades, are now seen as obsolete technologies that negatively affect the natural environment. Therefore, the discussed energy carrier has no prospects for further development in the coming years due to increasingly stringent environmental requirements and the lack of social acceptance.

3.1.3. Crude Oil

In Poland, the exploitable oil resources, documented in 86 deposits, are estimated to be around 23.6 million tons, of which approximately 23.16 million tons are in 64 developed fields, while approximately 14.48 million tons are proven reserves.

In 2017, the production of crude oil and condensate amounted to 939.24 thousand tons from all deposits. There are no prospects in Poland for a significant increase in production. It is expected to remain stable at a level not exceeding 1 million tons per year. The growing demand for this energy source will be met by imports.

Thus, the oil economy of the country is based on imports. In recent years, a significant change in the sources of supply for domestic refineries can be observed. The share of oil imported from Russia has decreased, while supplies from the Persian Gulf countries, mainly Saudi Arabia, Iraq, and Iran, have increased [17].

3.1.4. Natural Gas

The geological resources (anticipated economic resources) of natural gas in Poland are estimated at 117 billion m³. Proven reserves in developed deposits are estimated at 42.5 billion m³. In 2017, indigenous natural gas production amounted to 5.01 million m³.

Natural gas, from all fossil fuels, is currently the most ecological fuel for all stationary energy devices, such as boilers, turbines, industrial dryers, heating boilers, and stoves. Natural gas turned out to be an economically desirable and environmentally-friendly substitute for solid fuels. Under Polish conditions, more than 2/3 of natural gas used in the Polish economy comes from imports and, therefore, the development of gas-based energy is considered to be a transitional solution.

The resources of coal-bed methane (CBM) are documented in 62 fields in the area of the Upper Silesian Coal Basin and amount to 96.95 billion m³. Meanwhile, proven reserves, determined for 29 deposits, amount to approximately 5.7 billion m³.

The methane production amounted to over 332 million m³ (the amount of methane captured by the methane drainage systems of individual hard coal mines and methane exploited independently based on outbursts from boreholes reaching to the abandoned workings of closed hard coal mines).

The use of coal bed methane, on the one hand, is dictated by the safety of mining operations and, on the other hand, is perceived as unconventional gas recovery due to the form of its occurrence, which requires the use of special desorption recovery technologies. The coal-bed methane share in the

primary energy balance of Poland is low, despite the growing interest, associated with environmental protection, in methane vented from coal mines.

3.2. The Current State of the Polish Energy Sector

The national power system is based mainly on commercial power plants. Some industrial power plants that produce electricity mainly for own needs are also in the system, but are connected to the national grid (Table 2). The installed capacity in 2018 amounted to almost 46 GW. The thermal power plants are the majority of entire commercial energy sector, of which coal-fired and brown coal-fired power plants accounted for 23 and 8 GW, respectively. The capacity of gas-fired plants is low—some above 2.3 GW. In addition to thermal power plants, the national commercial power sector is complemented by hydropower plants (2.3 GW) and plants based on renewable energy sources (6.6 GW).

The total installed capacity in coal-fired power plants (both hard and brown coal) is 31,967 MW, which is 69.58% of the installed capacity of the entire system, while the energy production in these units is 131,447 GWh, which is 79.56% of the total energy generated.

Most of the existing hard coal-fired power plants are obsolete units characterized by low efficiency. The age structure of boilers and turbo-sets used in power plants is highly variable [18–20]. New generating units—in operation for less than 10 years—constitute only 10% in the power structure. A total of 57% of generating units are over 30 years old, of which as many as 9% are over 40 years old [21]. Obsolete units must be gradually withdrawn from the power system.

Table 2. The national power system in 2018 ¹.

Item	Installed Capacity (MW)	The Share in the Total Installed Capacity (%)	Maximum Capacity (MW)	The Share in the Total Installed Capacity (%)	Electricity Production (GWh)	The Share in the Production (%)
Commercial power plants	36,638	79.75	36,582	80.13	143,234	86.69
- Commercial hydropower plants	2341	5.10	2391	5.24	2197	1.33
- Commercial thermal power plants, including:	34,296	74.65	34,191	74.89	141,037	85.36
o Hard coal power plants	23,215	50.53	23,069	50.53	82,375	49.86
o Brown coal power plants	8752	19.05	8806	19.29	49,072	29.70
o Gas power plants	2330	5.07	2316	5.07	9590	5.80
- Wind farms and other renewable energy sources	6621	14.41	6452	14.43	11,958	7.24
Industrial power plants	2680	5.83	2,615	5.73	10,022	6.07
TOTAL	45,939	100.00	45,650	100.00	165,214	100.00

¹ Based on Reference [22].

In addition, it should be borne in mind that if the planned implementation of the new emission standards, BAT (best available techniques) [23], is taken into account, even more generating units would have to be decommissioned. According to Szczerbowski [19], over 20 GW of generating units will have to be decommissioned by 2035. Meanwhile, according to Duda et al. [24], the construction of around 26 GW of installed capacity by 2030 is required.

Current investments in the power sector include the construction of several new coal-fired units, as follows: Koziernice (1075 MW), Opole (2×900 MW), and Jaworzno III (910 MW). This means that the use of domestic coal will continue to meet the country's energy needs. The investment decisions are, however, not related to any long-term action plan.

Table 3 presents the structure of electricity production in Poland in the years 2010, 2015, 2016, 2017, and 2018. The table shows that electricity production from hard coal in this period decreased by almost 9.3 TWh; in 2010 it amounted to 89.2 TWh and in to 79.99 TWh in 2017, while a slight increase to 82.4 TWh was observed in the year 2018. In the case of brown coal, the volume of electricity production in 2018 was almost at the same level as in 2010, over 49 TWh. A significant increase in energy production from wind energy, by almost 10.4 TWh in 2018 compared to the 2010 level, can be observed.

Table 3. The structure of electricity production in domestic power plants, the volume of electricity exchange with foreign countries, and the energy consumption in Poland in 2015, 2016, 2017, and 2018 (GWh)¹.

Item	Year				
	2010	2015	2016	2017	2018
Commercial power plants	146,106	141,901	140,727	141,790	143,234
- Commercial hydropower plants	3268	2261	2399	2767	2197
- Commercial thermal power plants in which:	142,838	139,640	138,328	139,023	141,037
o Hard coal power plants	89,212	81,883	81,348	79,868	82,375
o Brown coal power plants	49,456	53,564	51,204	51,983	49,072
o Gas power plants	4166	4193	5776	7172	9590
- Other renewable power plants	11	73	146	150	280
- Wind power plants	1300	10,041	11,623	13,855	11,678
Industrial power plants	8923	9757	10,130	10,057	10,022
Total production	156,342	161,772	162,626	165,852	165,214
The foreign exchange balance	-1354	-334	1999	2287	5718
The domestic electricity consumption	154,988	161,438	164,625	168,139	170,932

¹ Based on Reference [22].

In the analyzed period, 2010–2018, an increase in the energy consumption in Poland (almost by 10.3%) accompanied by a small (5.7%) increase in the total production can be observed. Poland relies heavily on imports to meet the demand for electricity. In 2018, electricity imports amounted to 5.7 TWh.

3.3. Problems and Challenges of the Polish Power Sector

Like all branches of industry, the energy sector is transforming and modernizing along with technology advances and changing economic (business) trends. Environmental conditions play an important role in shaping the energy industry's future, while technological breakthroughs change the competitiveness of individual industries. Solutions based on information and communication technologies enable the use of tools in the production and optimization of energy consumption. Trends affecting the development of the energy sector in recent years include the following [25]:

- A breakthrough in hydrocarbon exploration and production technologies;
- The emergence of global infrastructure and the liquid natural gas LNG trading market;
- Increasing popularity and cost efficiency of alternative fuels;
- The development of technologies for the production of energy from renewable sources;
- The constant improvement of energy storage technologies;
- The increased importance of energy in the structuring of international relations and geopolitics;
- Growing social awareness of the environment and pressure to limit the impact of the energy sector on the environment;
- The emphasis on reducing greenhouse gas emissions and moving away from carbon-based energy sources;
- The growing potential of the digital economy and the expanding field of applications of information and communication technologies (ICT).

In the coming years, the influence of these factors may contribute to a structural breakthrough in the functioning of both energy companies and end-users of energy, as well as to fundamental changes in their relations.

The lack of appropriate forecasts and assumptions for energy and economic policies of the government constitutes a significant obstacle to the development of the domestic energy sector. At present, the binding documents that address, to a varying degree, issues related to the strategic problems of the energy sector development are the following:

- The Energy Policy of Poland until 2030 [7]: A document from 2009, considered to be outdated.
- Strategy for Energy Security and the Environment—2020 perspective [26]: A document adopted in 2014, focused on sustainable management of environmental resources and providing the national economy with a safe and competitive energy supply and improvement of the environment; however, the problem of the energy mix in the future is not discussed in detail.
- Strategy for Responsible Development until 2020—with prospects until 2030 [9]: A government document from 2017, comprehensively covering a number of economic issues in Poland, outlining (unfortunately vaguely) a long-term predictable energy policy and sectoral strategies and legal and institutional regulations implemented on its basis.

Elements of actions and strategic assumptions were presented in two drafts by the Ministry of Economy, which, in 2015, were subject to public consultations. However, these efforts have not yielded any official governmental strategies. They included the following:

- Project. National Program of a Low-Emission Economy [27];
- The draft Energy Policy of Poland until 2050 [8].

The change of the government in the autumn of 2015 stopped the work on these strategic documents. It was only after three years (at the end of 2018) that the new government documents were subject to public consultations. These are the following:

- The Energy Policy of Poland until 2040 (PEP2040) [10],
- National Energy and Climate Plan for 2021–2030. Assumptions, goals and policies [5].

In the entire period from the approval of the previous strategic document, including the prospect until 2030, a number of forecasts of the future energy mix were made by various institutes, the purpose of which was to define the framework for the next government document. The future demand for electricity was the basis for the analyses [28]. The possible solutions for the future energy mix, with their economic consequences aimed on fulfilling the EU targets for 2050, were analyzed in the 16 different scenarios in the Mineral and Energy Economy Research Institute [29–33]. Further works from different scientists and different research groups have developed a wide range of possible directions of development in specific political, economic, and geopolitical conditions in Poland [34–38].

It should be noted that PEP2040 [10] is a document prepared by the new government, and the proposed directions of actions, although supposed to serve similar purposes, did not always take the previous works into account. However, it should be mentioned that, with the exception of several minor adjustments, the forecasted main directions of development in the 2040 forecast remain similar as in previous national energy policy projects. The delay in the governmental decision caused instability that did not serve the development of the energy sector in Poland [39]. Ten years have passed, during which potential investors abstained from the decision, considering the mentioned actions to be too risky.

As a result of many years of neglect, the coming years are a time of enormous challenges for the Polish energy sector. This is related to the conditions resulting from the following: More stringent climate regulations, limited energy resources, not fully clarified mechanisms supporting renewable energy, instability of fossil fuel prices, or difficulty in forecasting the demand for electricity. Therefore, the sector looks forward to strategic decisions at the national level and their consistent implementation in the coming years.

The provisions of the IED (Industrial Emissions Directive) [40] on industrial emissions regulating emissions of pollutants are currently the greatest challenge for generating units when it comes to meeting environmental standards. The European Commission has also adopted BAT conclusions (best available techniques) containing BAT-AEL (associated emissions levels) [23]. These conclusions were prepared on the basis of documents for each of the BREF sectors (BAT Reference documents) [41]. These conclusions are to apply from 2020.

3.4. The Energy Policy of Poland Until 2040

PEP2040 defines 8 policy directions, along with activities that are subject to dynamic changes due to the changing environment. These directions, as well as the mentioned activities, are related to following three elements of the PEP2040 goal: Energy security, competitiveness, and improvement of the energy efficiency of the economy and the reduction of environmental impact.

The PEP2040 assumes:

1. The optimal use of domestic energy resources (hard coal, brown coal, natural gas, crude oil, biomass, and non-agricultural waste); The goal: Rational use of energy resources; Actions: Profitability of the hard coal mining sector, rational exploitation, innovations in extraction and use, prospecting of new gas and crude oil fields (including unconventional fields), and supplementation of the domestic gas and oil supply with diversified supplies.
2. Meeting the demand for electricity (generation capacity, transmission infrastructure); The goal: Covering the demand for electricity; Actions: The ability to meet the demand with domestic production, meeting the increased demand with energy sources other than conventional coal, a 60% share of coal in the production by 2030, 6–9 GW of nuclear power by 2043, natural gas mainly serving as a balancing (regulatory) capacity, the development of transmission and distribution networks, security of transmission and distribution networks, secure cross-border energy supplies, an increase in the quality of energy distribution, the development of energy storage, and the development of smart grids.
3. Diversification of gas and oil supplies and the development of network infrastructure (natural gas, oil, and liquid fuels); The goal: Fully competitive electricity, natural gas, and liquid fuel markets; Actions: In the case of gas—the ability to receive supplies, efficient cross-border connections, the development of gas transmission, distribution, and storage networks; while in the case of oil and liquid fuels—further expansion of the transmission network and storage sites.
4. Development of energy markets (electricity, natural gas, petroleum products); The goal: A fully competitive market for electricity, natural gas, and liquid fuels; Actions: In the case of electricity—strengthening the consumer’s position, protecting the competitiveness of energy-intensive transmission, implementing electro-mobility, marketing of system services, reform of electricity trade; while in the case of natural gas—market liberalization, strengthening Poland’s position in the European gas market, new gas use segments; and in the case of petroleum products—the alignment of roles and increasing the role of non-traditional fuels (bio-components, alternative fuels, or electro-mobility).
5. The implementation of nuclear energy; The goal: Lowering the emission level of the energy sector and increasing the system safety; Actions: Commissioning of the first nuclear power plant with a capacity of 1–1.5 GW by 2033 and the next five until 2043 (in total about 6–9 GW), ensuring formal, legal, and financial conditions for the development of nuclear energy sector, staff training, nuclear supervision, and providing a landfill site for low- and intermediate-level wastes.
6. The development of renewable energy sources; The goal: Lowering the emission intensity of the energy sector and the diversification of energy generation; Actions: A 21% renewable energy sources (RES) in gross final energy consumption in 2030, 1–1.3% of annual consumption increase in heating and cooling, maintaining the increase in the electricity sector, the implementation of offshore wind energy, 10% and 14% RES in transport in 2020 and 2030, respectively, conditional development of uncontrolled renewable energy sources, the possibility of RES balancing (storage sites, energy clusters, regulatory sources), and support for the development of renewable energy sources (with the assurance of network security).
7. The development of district heating and cogeneration; The goal: General access to heat and low-emission heat generation throughout the country; Actions: In district heating—competitiveness to individual sources, increase in the use of high-efficiency CHP, the use of renewable energy and waste, the development of heat and cold supply systems, the use of heat storage sites, obligation to

connect customers to the district heating network; in the case of individual heating—increasing the use of non-solid fuels (gas, non-combustible RES, or electricity), effective monitoring of pollutant emissions, and limiting the use of solid fuels.

8. The improvement of energy efficiency of the economy; The goal: To increase the competitiveness of the economy; Actions: A total of 23% primary energy savings compared to the primary energy forecasts from 2007, legal and financial incentives for pro-efficiency measures, exemplary role of public sector, the improvement of environmental awareness, intensive energy renovation of housing, and the reduction of energy poverty.

Table 4 presents the actual (2010 and 2015) and forecasted (years: 2020, 2025, 2030, 2035, and 2040) production of individual fuels and energy carriers (ktoe). In the analyzed period, 2010–2040, hard coal production is to be reduced by almost 13.5 Mtoe; the forecasted production for 2010 and 2040 is 35.3 and in 21.8 Mtoe, respectively. In the case of brown coal, the production volume in 2040 will decrease significantly, almost by 8.7 Mtoe, and by 2040 this volume will amount to only 2.8 Mtoe.

Table 4. Domestic production of individual fuels and energy carriers in the perspective up to 2040, ktoe ¹.

Item	Year						
	2010	2015	2020	2025	2030	2035	2040
Hard coal	35,302	32,136	31,868	31,082	30,605	25,000	21,768
Coking coal	8216	9155	10,089	10,183	10,261	10,336	10,410
Coke	6701	6666	7198	7358	7491	7610	7722
Brown coal	11,559	12,299	10,336	10,915	10,906	8106	2829
Crude oil	681	914	1000	1000	1000	1000	1000
Natural gas	3693	3683	3595	3627	3653	3675	3694
Nuclear fuel	0	0	0	0	0	0	0
Biofuel	446	936	1100	1171	1212	1195	1167
Solid biomass	5866	6268	7022	7078	7535	7951	8400

¹ Source: [42].

An increase in the production of solid biomass for energy purposes is clearly visible. In 2040, the planned increase is to exceed 2.5 Mtoe compared to the 2010 level and reach 8.4 Mtoe.

Table 5 presents the electricity generation forecast for 2020, 2025, 2030, 2035, and 2040. The decline in electricity production from brown coal by 42.6 TWh can be seen; the forecasted amount for the year 2020 is 54.3 TWh, while for 2040 it is 11.7 TWh.

The forecasted electricity production from hard coal will decrease by 10.8 TWh; the forecasted production in 2020 and 2040 is 51.3 TWh in 2020 (33.1 TWh for the existing power plants and 18.2 TWh for the power plants that are planned and under construction) and 40.5 TWh in 2040 (15.5 TWh for the existing power plants and 25.0 TWh for the power plants that are planned and under construction). By 2035 and 2040, the production of electricity from nuclear power will increase to 20.8 and 41.5 TWh, respectively. The role of gas power plants will also increase; electricity production in 2040 will reach 38.0 TWh (26.8 TWh in power plants and 11.2 TWh—CHP plants), an increase of 28.5 TWh compared to 2020. It is worth noting that the amount of electricity produced from gas in cogeneration with heat will nearly double.

A decrease in the production of electricity, from onshore wind farms, of 12.9 TWh is expected. The production in 2020 and 2040 is 14.7 and 1.8 TWh, respectively. On the other hand, a significant increase in the production of electricity from offshore wind farms, by 24 TWh, is foreseen. The forecasted production in 2030 and 2040 is 17.1 and 41.1 TWh, respectively. A significant increase, by 19.1 TWh, is forecasted for electricity production from photovoltaic power plants, where the amount produced in 2020 and 2040 is 0.8 TWh and 19.9 TWh, respectively. The forecasted total electricity production in the analyzed period 2020–2040 will increase by almost 40.5% (66 TWh), where the forecasted production in 2020 and 2040 is 165 and 231.8 TWh, respectively.

Table 5. Electricity production forecast for the year 2040 broken down by technology, TWh¹.

Item	Year				
	2020	2025	2030	2035	2040
Brown coal power plants	54.3	58.4	56.9	30.3	11.7
Hard coal power plants (the existing ones)	33.1	30.2	24.5	21.5	15.5
Hard coal power plants—planned and under construction	18.2	21.3	20.6	25.6	25.0
Hard coal CHP plants (the existing and new)	23.2	22.3	22.3	21.9	22.4
Nuclear power plants	0.0	0.0	0.0	20.8	41.5
Natural gas power plants	3.7	9.3	9.14	24.5	26.8
Natural gas CHP plants	5.8	6.5	9.6	10.2	11.2
Photovoltaic power plants	0.8	4.8	9.6	14.7	19.9
Onshore wind power plants	14.7	16.0	13.7	4.9	1.8
Offshore wind power plants	0.0	0.0	17.1	23.3	41.1
Other RES power plants (biomass, biogas, and water power)	9.5	11.0	14.1	15.9	13.0
Other power plants	1.7	2.0	2.0	2.0	1.9
Reserve power plants (OCGT * / diesel)	0.0	0.0	0.0	0.0	0.0
TOTAL	165.0	181.8	199.8	215.6	231.8

* OCGT (Open Cycle Gas Turbines); ¹ Source: Reference [43].

Table 6 presents the forecast of the installed capacity, broken down by the technology used, in the years 2020, 2025, 2030, 2035, and 2040. The numbers representing installed capacities and their increments are not proportional to the production volumes presented in Table 5 due to the differences occurring in the efficiency of electricity production in individual technologies. In the forecasted period, from 2020–2040, the installed capacity is to increase by 30.6 GW. The forecasted installed capacity for 2020 and 2040 is 42.0 and 72.6 GW, respectively.

Table 6. The forecast of the net installed capacity, broken down by the technology used, until 2040, MW¹.

Item	Year				
	2020	2025	2030	2035	2040
Brown coal power plants	7400	7600	7600	3800	1500
Hard coal power plants (the existing ones)	12,700	11,100	9300	5400	3100
Hard coal power plants—planned and under construction	2500	3400	3400	3400	3400
Hard coal CHP plants (the existing and new)	5450	5210	5130	5010	5485
Nuclear power plants	0	0	0	2800	5600
Natural gas power plants	1500	2000	4700	7900	9700
Natural gas CHP plants	1350	1520	2200	2330	2745
Photovoltaic power plants	90	5200	10,200	15,200	20,200
Onshore wind power plants	6400	7000	6000	2100	800
Offshore wind power plants	0	0	4600	6100	10300
Other RES power plants (biomass, biogas, and water power)	3400	3800	4100	4300	4300
Other CHP plants	400	470	470	460	470
Reserve power plants (OCGT * / diesel)	0	0	0	3600	5000
TOTAL	42,000	47,300	57,700	62,400	72,600

* OCGT (Open Cycle Gas Turbines); ¹ Source: Reference [43].

The largest increase in the installed capacity (by 19.3 GW) is forecasted for photovoltaic power plants, where the forecasted installed capacity for 2020 and 2040 is 0.9 and 20.2 GW, respectively. The second-largest increase in the installed capacity (by 5.7 GW) is forecasted for offshore wind farms, in 2030, where the forecasted installed capacity for 2030 and 2040 is 4.6 and 10.3 GW, respectively. The third largest increase in the installed capacity is forecasted for nuclear power plants, where the forecasted installed capacity for 2035 and 2040 is 2.8 and 5.6 GW, respectively. In addition, a large (by 5.9 GW) decrease in the installed capacity is forecasted for brown coal-fired power plants, where the forecasted installed capacity for 2020 and 2040 is 7.4 and 1.5 GW, respectively. This also applies to

hard coal-fired power plants, where the installed capacity is forecasted to decrease by 8.7 GW. In 2020 and 2040 the forecasted capacity is 15.2 GW (12.7 GW for the existing power plants and 2.5 GW for the power plants that are planned and under construction) and 6.5 GW (3.1 GW for the existing plants and 3.4 GW for power plants that are planned and under construction), respectively. The installed capacity of onshore wind power plants in the analyzed period is expected to decrease by 5.6 GW, where the forecasted installed capacity for 2020 and 2040 is 6.4 and 0.8 GW, respectively.

4. Discussion

Hard coal, the current leader in electricity generation according to the data presented in the draft Energy Policy of Poland, will gradually lose its dominant role in meeting the demand for electricity. The planned electricity generation from this fuel in 2020 will account for approximately 45% of the total electricity production and will decrease to about 27% in 2040. The reduction in the use of brown coal will be even more significant. The share of this fuel in electricity production will decrease from 32.9% in 2020 to 5% in 2040. This means that the need to reduce the emissions associated with energy generation has been noticed. Despite the available resources and their exploitation, it is noted that the government is not planning to build new energy generation capacities based on this fuel in the future. The existing and planned power plants will operate until their technical wear and other sources of production are available. There is no other way to ensure the necessary electricity supply in the conditions of the currently available investment funds.

Meanwhile, the exploitation of hard coal deposits will face serious challenges. The main obstacle for the development of mining industry is the EU climate and energy policy, which gradually eliminates coal from electricity generation. In order to improve the competitive position of domestic coal in relation to imported coal, decisive corrective and restructuring measures in the sector, aimed at reducing the costs of coal production, are necessary. At the same time, it should be noted that large investment expenditures of PLN 32 billion, necessary to ensure the production capacity of Polish mines and for the modernization of the sector, should be financed from enterprises' own funds. According to the principles of the European Union, state support for investment activities is not possible.

It is also necessary to continue the activities in the field of the development of coal gasification technology and the use of methane captured in hard coal mines. Currently, the mining sector is faced with the lack of profitability, a shrinking consumer market, declining competitiveness of coal against other fuels (including RES) and imported coal, delays in opening new reserves and limited and insufficient financial resources. In this situation, focusing on coal is largely declarative, which is associated with the belief that the use of domestic energy sources contributes to improving the country's energy security. Paradoxically, the lack of sufficient progress in the modernization of the hard coal mining sector may result in the need to import coal to cover the demand of the existing coal-fired power plants.

Sticking to coal means the need to look for solutions improving the efficiency and flexibility of coal-based capacities in energy sector. The ongoing construction of new coal-based capacities is associated with the improvement of their efficiency. The new generating units will have an efficiency of up to 45% and will replace the old ones, with an efficiency of less than 38%.

There are also problems with determining the share of brown coal in the energy mix. The currently exploited deposits are slowly being depleted. The development of new brown coal deposits is associated with large investment outlays and increased costs of obtaining this coal. The opening of new deposits is opposed by local communities, while the profitability of these projects raises serious doubts and requires further studies. In addition, one of the obstacles to the further use of brown coal are stringent regulations related to the reduction of pollutant emissions [23,40].

The main barrier to the wide use of gas in the power industry, which would reduce emissions from this sector, is the price of this gas compared to other energy carriers. One should be aware that the factor determining the role of gas in the production structure is the price of CO₂ emission allowances, depending on the European Commission. However, the share of gas in electricity generation will

increase to 16.4% in 2040, compared to 8.7% in 2020. Furthermore, gas consumption in the domestic economy will grow significantly due to its use as a less emission intensive alternative for coal-fired boilers, as a chemical raw material, and for heating purposes in households. Therefore, a strategic activity, extremely important for ensuring the energy security of Poland, is the diversification of gas supplies, already partially implemented thanks to the LNG terminal in Świnoujście. One should also mention the intention to build the Baltic Pipe, a gas pipeline linking Poland with Norway's deposits, as an alternative to the supplies from Russian Gazprom.

Currently, a move away or significant reduction in the use of fossil fuels in the energy sector can be observed, in favor of a wider use of renewable energy sources. Renewable energy sources are local and enable the diversification of energy supplies while strengthening energy independence [44]. The development of renewable energy sources will take place along with demonstrating the economic efficiency and financial capabilities of investors. The development of wind power has recently been slowed down by wind farm location constraints [45] and a reduction of subsidies for energy production from renewable sources [46]. As a result of this policy, a gradual decrease in electricity production, from 16 TWh in 2025 to 1.8 TWh in 2040, is expected.

As an alternative, the government indicates the development of offshore wind farms. An increase in the share of wind energy in the electricity generation to 18.5% in 2040 is forecasted. This means the construction of offshore wind farms with a capacity of 10.3 GW. One should pay attention to two elements, as follows:

1. A reduction in the capacity of onshore wind farms from 7 GW in 2025 to just 0.8 GW in 2040 will take place.
2. It is unclear how the investments in offshore wind power will be financed, although some large energy production companies have already achieved licenses, and whether the transmission infrastructure will be able to properly distribute the generated energy.

Due to the ever-lower investment costs, photovoltaic installations are being developed by both prosumers and large energy entities. The document envisages a significant development of photovoltaics to over 20 GW of installed capacity in 2040, which gives an 8.6% share in the structure of electricity generation.

At present, Poland does not have nuclear power plants. There are several factors behind the introduction of nuclear energy to the country's energy mix, as follows: The stability of electricity generation with zero emission of air pollutants, diversification of the energy generation structure at a reasonable cost, the lifespan of nuclear power plants exceeding 60 years (20 years more than in the case of coal-fired units), and the stringent nuclear safety standards, which ensure the safety of nuclear plant operation and waste storage. Poland plans to commission the first nuclear power generating unit (with a capacity of around 1–1.5 GW) in 2033. In the next years, another five units are planned for commissioning (by 2043).

It should be noted, however, that the construction of nuclear energy was already heralded in the previous document on the energy policy of Poland until 2030. Although the first unit should already be operating, no binding decisions on the construction have yet been made. There is no social approval for such an investment, but it is also not clear how to fund the construction of nuclear power plants. In order to balance the demand for electricity, it is forecasted that nuclear power shall account for almost 18% of the total power in 2040. In the case of delays in the implementation, the deficit of stable generation sources, e.g., nuclear generating units, will cause major problems in balancing the demand for electricity.

The option of constructing small modular reactors (SMRs) is also considered in the discussions, which would have several advantages over large nuclear units. Firstly, they could be constructed gradually along with the decommissioning of outdated coal-fired units in order to spread costs over time. In addition, smaller reactors could be deployed in different parts of the country, creating a more distributed power network. In the long run, it is also possible to use small HTR reactors (high temperature reactor), which can be used primarily in the industry.

Figure 1 presents the forecasted structure of electricity production in the years 2020–2040.

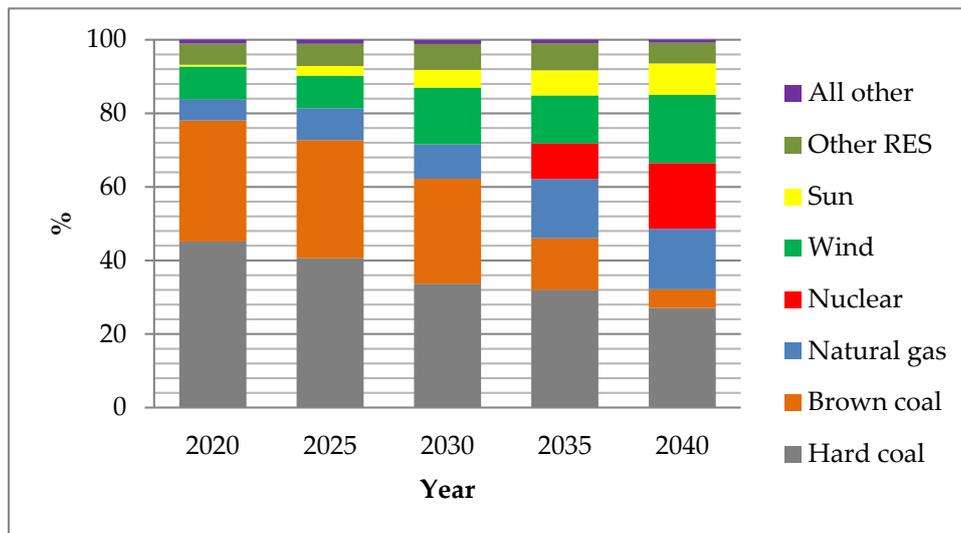


Figure 1. The forecasted structure of electricity production broken by energy carriers (own work, based on Reference [43]).

Moving away from hard coal and brown coal in favor of other less emission intensive or emission-free energy sources is a step towards reducing emissions from the electricity generation sector.

Figure 2 presents historical (since 2005) and forecasted greenhouse gas emissions in the energy sector up to 2040 as part of the planned policies and measures.

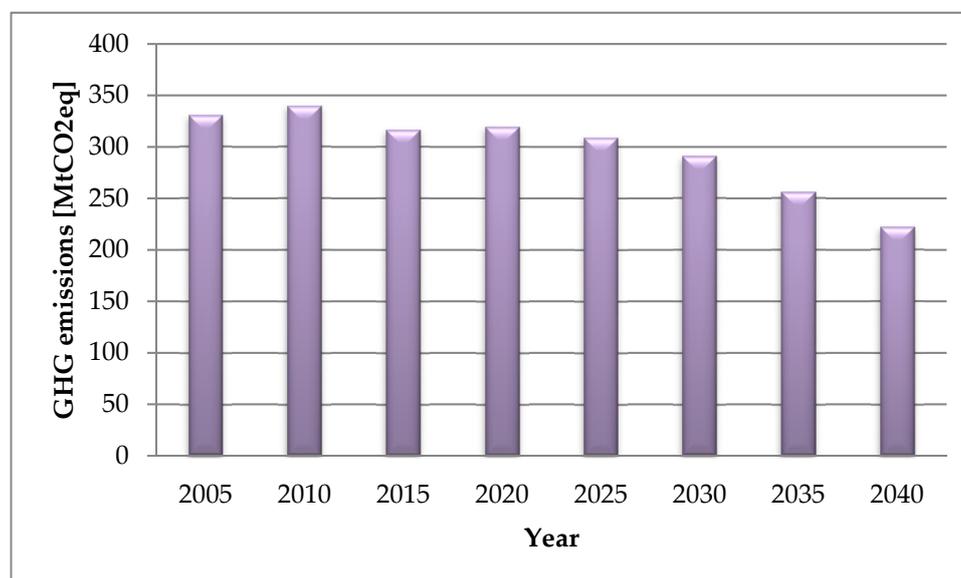


Figure 2. Greenhouse gas emissions from the energy sector, Mt CO_{2eq} (own work based on Reference [42]).

It should be noted that an increase in emissions, compared to 2015 levels, is expected in 2020. The immediate cause is the suppression of wind power production from onshore wind power plants. According to the forecast for 2040, the reduction in emissions to the level of about 222 Mt CO₂, which means a decrease of 33% in relation to the emissions from 2005 and over 30% in relation to 2020, is expected. The increase in the emission reduction is visible especially from 2035, which is associated with the launch of the nuclear power.

In addition to the development of the energy system, the state policy is also focused on local activities. Local energy clusters, aimed at offering services in the area of generation, distribution, storage, and the supply of energy and fuel to the local population may be of significant importance for local communities.

Numerous studies and analyses indicate that, in the long term, hydrogen will play an important role in solving technological and ecological problems of the energy and transport sectors [47,48]. The use of hydrogen for energy purposes requires its separation from other substances commonly found in nature. The dominant technology is the electrolysis of water. The process requires energy and, therefore, the further development of hydrogen energy, related to the current trend of energy decarbonization, should be based on the use of renewable energy for hydrogen production. The following paths of hydrogen use are considered: Electricity–electricity (power to power), electricity–gas (a mixture of H₂ and CH₄), electricity–gas (methane), and electricity–gas (hydrogen fuel) [49].

The Act on Electro-Mobility and Alternative Fuels [50] is a development of the ideas presented in the Strategy for Responsible Development regarding the country's development directions, which, according to the assumptions, is aimed at creating conditions for popularizing electric transport in the country. The adoption of the solutions proposed in the Act will contribute to increasing the energy security of the country, while the development of the alternative fuels market in transport can significantly improve the quality of air in cities. It should be emphasized that without intelligent energy, the development of electro-mobility is impossible.

In the long run, the development of transport powered by electricity will have an impact on increasing the demand for electricity. This direction of development will necessitate the expansion of generating capacities of the national energy sector.

Many organizations and institutions present scenarios regarding the future fuel and technological structure of the Polish energy sector. These scenarios were developed for various assumptions regarding the pace of economic development, population growth, the development of the political situation, and the situation on the fuel market. Therefore, their credibility is difficult to assess. However, those analyses may be helpful for indicating the necessary technological development for achieving economic and ecological goals. They can also indicate developmental constraints resulting from the adopted assumptions and emerging political uncertainties. It should be emphasized that Polish documents strongly stress the use of domestic resources in the energy system and the need to take different starting points into account. Poland's starting point suggests a relatively high share of coal in the production of electricity in the next two decades. Energy technologies using fossil fuels have reached a very high level of technical development, especially in terms of the efficiency, reliability and, above all, minimization of the environmental impact. They still have the potential to increase their efficiency and reduce their emissions.

However, the key decisions that will shape the evolution of the Polish fuel mix regard nuclear energy and the role of gas technologies in power generation. Without consensus on these two fundamental issues, it is difficult to forecast the technological development of energy sector in Poland until 2040 (2050). Without a dynamic increase in gas production (or imports) it will be difficult to increase the share of renewable energy in the power sector and significantly reduce the emission intensity of the power industry and the entire economy.

The Polish energy mix is characterized by a low share of gas, both as a primary source and, especially, as a fuel for electricity generation. This state of affairs hinders and will continue to hinder the introduction of RES to the grid. Gas power is a flexible source of production and can quickly replace unstable renewable sources in the event of adverse weather conditions (lack of wind and/or sun). Poland's obligations under the Climate Agreement (Paris) and the European Council decision of October 2014 pose a serious challenge for the Polish power industry when it comes to the fuel and technological transformation of generation sources in the Polish Power System. This transformation should lead to a change in the structure of the primary energy used for electricity production, allowing a 40% reduction of CO₂ emissions to be achieved by 2030 [51], compared to 1990 emissions.

5. Conclusions

The energy policy of Poland is a long awaited document, the final adoption of which is expected by all entities associated with the energy sector. Outlining the preferred directions of development and their consistent implementation creates possibilities for new energy investments.

The presented project does not explain how external investors will be encouraged to invest in such projects, but it establishes the guidelines to state entities in the sector and largely reduces the investment risk. Nevertheless, finding investors will be difficult as it is obvious that the necessary investment expenditures are enormous. In the 2013 estimates, investment needs for the construction of new capacities in the sector were evaluated at 80–127 billion euros until 2050 [29]. The lower value is a scenario in which changes in the fuel structure of energy production are minimized, maintaining coal-based power plants regardless of environmental protection requirements.

It is also not shown to what extent the direction taken by the government will ultimately translate into electricity prices.

It should also be noted that the adopted solutions, although they are going in the right direction, do not fully comply with the guidelines of the European Commission's so-called "Winter Package". Their implementation will require negotiations at the European level. It seems, however, that under Polish conditions, abandoning coal completely in the next twenty years is not possible.

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