Development perspectives of the Polish power generation sector according to the climate preservation conference COP21 policies

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Abstract. Power generation policy equals the safety policy of a certain country. It should be reasonable and it should consider the access to available energy sources. The crucial issue revolves around minimizing the negative influence of power generation sector on the environment. At the same time, recent years have proven the united stand of world policies toward power generation. Poland has also attempted to determine a new model of power generation strategy. This strategy ought to consider the needs of both the recipients and climate challenges. But there is a crucial question of the shape of the new strategy for development of power system within the next years in the light of requirements of convention on climate change. During the Climate Conference in Paris in December 2015 – 195 countries accepted the first world agreement related to climate preservation. The agreement determines a world action plan, which is to prevent climate change as the result of climate warming. One of the goals is a quick reduction of emissions including power generation sector. This overview presents a current state of National Power System, availability of primary energy sources and various power technologies of future strategy for power system development. The technologies are described in view of their possible use for power generation and their applicability for the reduction of emissions of harmful substances to the atmosphere.

1 Introduction

The arrangements of 21 Conference of the Parties of UN Framework Convention on Climate Change COP21 which was held in 2015 in Paris, include several important goals which aim at the reduction of greenhouse gases and lowering global climate changes. The key points of the agreement, which was entered into by nearly 200 countries, include mainly:

- possibly quickest reduction of greenhouse gases emissions,
- sustaining the world temperature rise at the level of much less than 2°C and making attempts to limit the temperature to 1.5°C,
- the assessment of progress in terms of these goals shall be performed every five years.

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As the consequence, it is assumed that, beginning with the year 2050, world industry may become nearly of zero emissions. Moreover, the agreement made at climate summit in Paris does not impose any defined commitments on its signees. In fact, it means the necessity to prepare new strategies for low emissions economic development in all the countries which have been sceptical toward the issue of gas emissions. The agreement will come into force when at least 55 parties of Climate Convention, responsible for 55% of world emission, decide to ratify it. It is expected that the Agreement will become effective at last at the end of 2020. Poland and other European countries, besides the new climate agreement concluded during the summit COP21 in Paris, must also abide by European climate regulations. Now, it is a climate and power generation package which expires in 2020. In the near future EU is going to discuss climate regulations for the years 2020 – 2030.

In the context of these changes, it is quite difficult and risky to predict the future of the power generation sector, especially for a longer perspective. Such forecasts are generally made on the basis of previous trends and future changes. Decisions are influenced by many factors, such as economic matters or difficult to predict – political agendas. Economic development of a country is determined by security of energy supply which, on the other hand, should be generated from easily available sources and at satisfactory prices. These indicators are the conditions of the choice of the sources which are going to shape the future composition of National Power System.

2 Current state of National Power System

National Power System is mainly based on power plants heated with coal; the system is one of the biggest in Europe; current installed capacity has exceeded 40 GW. Comparing to the year 2014, there has been an increase of installed capacity of more than 2.3 GW and it has been mostly caused by new investments into renewable energy sources (1.8 GW), mainly wind power plants [1]. Table 1 presents basic data concerning the current situation of National Power System. As it may be observed, the total installed capacity in coal power plants equals 28 638 MW, which constitutes more than 70% of installed capacity, however, the production of energy in these sources exceeds 83%.

Table 1. The present state of the National Power System (data on 31.12.2015).

List	Installed capacity	Share of installed capacity	Maximal capacity	Share of maximal capacity	Production	Share in production
	MW	%	MW	%	GWh	%
Power plants	31 927	78.9	32 069	80.6	141 901	87.7
Water power plants	2 290	5.7	2 330	5.9	2 261	1.4
Thermal power plants (hard coal, brown coal, gas)	29 637	73.3	29 739	74.8	139 640	86.3
Wind and RES	5 687	14.1	5 258	13.2	10 114	6.3
Industrial	2 831	7.0	2 451	6.2	9 757	6.0
Total	40 445	100	39 777	100	161 772	100.0

Source: Own elaboration on the basis of data [1]

The age structure of boilers and turbine sets working in Polish power plants indicates that more than 60% of them have operated for over 30 years. Thus, in the nearest 20 – 30 years they will be gradually removed from the energy system [2]. Despite such production structure, Poland has managed to reduce emissions of CO_2 to the atmosphere. Table 2 presents the data related to CO_2 emissions to the atmosphere for these recent years.

Table 2. Emissions of CO_2 from combustion of fuels in Poland in the years 1990-2013.

Years	1990	1995	2000	2005	2010	2012	2013	%change 90-13
CO_2 emissions from fuel combustion [million tonnes of CO_2]	344.8	333.4	289.7	296.3	310.4	296.8	292.4*	15.2%
CO_2 emissions from fuel combustion – coal [million tonnes of CO_2]	291.2	273.6	221.5	215.6	217.5	206.5	206.4	29.1%

Source: Own elaboration on the basis of data [3,4]
* Electricity and heat production 157.6 million t CO_2

Presently in Poland there are several ongoing investments related to the construction of new power capacity fuelled with hard coal, brown coal and gas. In the subsequent years there will be new power units started which will belong to JWCD [1]: unit 473 MW, gas and steam, in thermal plant Włocławek; unit 467 MW, gas and steam, in thermal plant Stalowa Wola (2016); unit 596 MW, gas and steam, in thermal plant Płock (2017 r.); unit 1075 MW, fuelled with hard coal in power plant Kozienice (2018); unit 496 MW, fuelled with brown coal, in power plant Turów (2018); 2 units each of 900 MW, fuelled with hard coal in power plant Opole (2019); unit 910 MW, fuelled with coal in power plant Jaworzno III (2019). In total the capacity joined to the system equals 5817 MW, which means that the lacking capacity, caused by removing old units, should be complemented by the year 2020.

3 Power generation with coal

The publication "Balance of mineral resources deposits in Poland" [5], published this year, presents the state of fossil fuels at the end of the year 2015. It also informs that Poland has presently got 91 deposits of brown coal, including 9 which are already in use, and 156 deposits of hard coal, including 51 which are already in use (table 3). Deposits of brown coal equal more than 23 516 million tons, and deposits of hard coal equal more than 56 220 million tons, including 71.6% of fossils which are energy-generating coals. (type 31–33).

Active mines of brown coal supply directly power plants in Bełchatów, Adamów, Konin and Turów. Coal mining for particular power plants is presented in Table 4. Additionally, there is the estimation of depletion of industrial and balance resources which are presently in use, assuming that the level of mining in a certain mine is not going to change. There is a presentation of balance resources which are not used and are stored in the vicinity of power plants; and there is also a calculation of time for depletion of recognised reserves, assuming that the demand of Polish power plants is not going to change and deposits are going to be used up completely.

On the basis of the data from the Table 4, it is reasonable to assume that none of the presently operating power plants is going to be cut off from brown coal supplies within life period of present energy units.

Now, there are no accepted plans for the construction of new open pits of brown coal in Poland. Thus, it is difficult to predict which deposits will be in use in the future. Table 5 presents theoretical reserves which may be used in the future for power generation. These reserves have been divided according to the extent of their recognition.

On the basis of data from Table 5, it may be observed that significant reserves of brown coal are located near Legnica, Gubin and Ścinawa. However, the construction of an open pit mine for brown coal in each of these locations may be difficult because of possible strong protests of local societies.

Resources of hard coal in Poland are located in: Górny Śląsk Mining Region, Lublin Mining Region and Dolny Śląsk Mining Region, which production was finished in the year 2000. Balance resources of active coalfields have been presented in Table 6. Additionally, the table shows the time of depletion of energy-generating coal resources at the present rate of production and also a recognised resources of energy-generating coal. Notice that average percentage of energy-generating coal in total production of hard coal has been recently at the level of around 85%, including around 60% which is consumed by power plants and heating plants. It can be also noted that the resources of coal deposits ,which have been already mined, are still of significant amounts, thus, in the future we may consider contribution of this fuel into the production of electricity. One of the fundamental obstacles to overcome for further production of hard coal, may be economic issues related mainly to the present and prospective coal prices at international markets and the price of production of domestic coal.

Table 3. Geological reserves of brown and hard coal in Poland in million tons (data on 31.12.2015).

Deposits	Number of deposits	Geological reserves		Industrial reserves
		balance	off-balance	
Brown coal				
Total	91	23 516.2	3 522.4	1 129.1
Active plants	9	1 418.7	48.3	1 112.2
Detailed recognition	35	5 838.7	872.6	16.8
Initial recognition	39	16 242.5	2 574.98	-
Discontinued operation	8	16.30	26.51	-
Hard coal				
Total	156	40 234.8	12 404.1	2 109.3
Active plants	49	12 071.2	4 789.0	2 097.1
Mines under construction	2	6.2	3.77	-
Detailed recognition	40	11 267.8	1 157.8	-
Initial recognition	19	13 828.1	6 194.5	-
Discontinued operation	47	3 061.5	259.0	12.22

Source: Own elaboration on the basis of [5]

Table 4. Brown coal mining, possible resources of brown coal in mining regions and the time of depletion of resources at the current rate mining (data on 31.12.2015).

Mine		Bełchatów	Adamów-Konin	Turów
Production [thousands of tons]		42 081	13 653	7 328
Resources [thousands of tons]	balance	946 566	105 949	364 815
	industrial	707 368	86 037	317 689
Time of depletion of balance resources [years]		22.5	7.8	49.8
Time of depletion of industrial resources [years]		16.8	6.3	43.4
Balance resources recognised [thousands of tons]	detailed	744 393	287 276	-
	initial	594 032	19 044	349 087
Time of depletion of resources recognised in details [years]		17.7	21.0	-
Time of depletion of resources recognised initially [years]		14.1	1.4	47.6
Theoretical time of operation for active mines of brown coal [years]		54.3	30.2	97.4

Source: Own elaboration on the basis of [5]

Because of the latest assumptions of climate policy, domestic energy system faces a great challenge. The proposal of significant reductions of emissions in power generating sector may exclude coal from power generating industry.

In the context of EU requirements the key challenges for Polish power generation industry are related to:

- lack of technological adjustment of power and heating plants in terms of parameters of emissions,
- significant dependence of power and heating plants on coal,
- poor technical condition of production sources and power networks,
- small scope of use of RES and lack of nuclear power production,
- low power effectiveness within the range of production and use of energy.

Table 5. Possible development of brown coal deposits in Poland (data on 31.12.2015).

Location	Geological reserves recognised in details [thousands of tons]	Geological reserves recognised initially [thousands of tons]
Legnica	1 702 950	1 723 049
Ścinawa	1 766 983	-
Czempiń-Krzywiń	-	1 701 085
Gubin-Brody-Torzym	1 613 500	2 862 849
Gostyń-Oczkowice	996 298	1 988 830
Szamotuły-Trzcianka	300 077	746 326

Source: Own elaboration on the basis of [5]

Table 6. Hard coal mining, possible resources of coal in mining regions and the time of depletion of resources at the current rate mining (data on 31.12.2015).

Mining Region		Górny Śląsk	Lublin
Total production [thousands of tons]		58 255	6 815
Resources of energy-generating coal in developed deposits [million of tons]	balance	11 402.6	674.7
	industrial	1 926.7	170.4
Time of depletion of balance resources [years]		195.7	99.0
Time of depletion of industrial resources [years]		33.1	25.0
Recognised balance resources of energy-generating coal [million of tons]	detailed	7 776.2	3 462.6
	initial	8 135.0	5 693.1

Source: Own elaboration on the basis of [5]

4 Power generation based on renewable resources

The alternative for power industry based on coal, and more and more important source of future energy production in all its forms, is undoubtedly renewable sources of energy. In Poland the biggest hopes are related to biomass, wind power and solar power. Total world wind power production has exceeded 430 GW. Especially significant dynamics is visible in investments into sea wind farms. Wind may be used in energy production if its speed falls into the range between 4 and 25 m/s. Wind conditions in Poland are of great changeability and there is a lack of high annual average wind speed. Wind power production also considers the second important factor which is the distribution of annual wind speed. Strong winds in Poland are present in winter months, i.e. from November to March. Almost 1/3 of Polish territory has proper wind conditions for the installation of wind plants. Polish wind power plants have the capacity of above 5.6 GW which still rises quickly. It is estimated that in 2020 it should reach 7–9 GW. National potential of wind power production equals around 7 GW on sea and 10-12 GW in land. However, annual coefficient of installed power use is estimated at 22–28% (1900–2400 hours depending on the location) [6]. The main problem of wide wind power use is the lack of possibility to store the energy, which solution would balance the vague energy production. July 1, 2016 was published the law on investments in wind power plants, which introduced significant

restrictions on construction and location of wind turbines. According to many specialists in the wind energy industry, currently over 95% of new location projects of wind turbines were stopped [7].

Photovoltaic systems may also be expected to be more important in a long-term perspective. In 2015 world capacity of these systems reached 245 GW. In the next decades photovoltaic systems may become the important source of world power, with a domineering role in poor tropical countries, but also in countries of moderate climate, such as Poland. Presently in Poland photovoltaic systems have total installed capacity of over 90 MW, while in Germany their capacity exceeded 40 GW, which is the best illustration of prospective development of photovoltaic systems in Poland. Their further development mainly depends on unit costs of PV installation and possible supporting systems. According to the report of IRENA [6], installed capacity in 2030 in our country may reach 5 GW. The coefficient for installed capacity in use currently equals around 11–12%.

Poland has a small potential of water power plants which results from flat form of landscape and high soil permeability. Domestic production of energy from water is mainly focused on the Vistula river. Polish hydro-energetic reserves are estimated at 13.7 TWh a year, and the potential is used merely in around 12%, which relates to around 7% of installed capacity in a domestic power system. Water power production at the end of 2015 equalled installed capacity of around 1 GW. According to the report IRENA [6], the potential development of domestic water power generation is estimated at around 1.5 GW by the end of 2030.

The production of energy from wind power plants or photovoltaic power plants on a large scale in Poland will not be able to replace conventional sources of energy soon. It is caused by weather conditions, especially in terms of solar hours available and average wind speed a year. The development of wind power generation and photovoltaic systems will mainly depend on the possibility to store such energy. If the future allows for effective storage of energy for stabilization of network operation and better quality of energy, then these sources of energy will certainly thrive.

5 Nuclear power

Polish energy policy by the year 2030 includes the statement of development of nuclear power in our power generation system. A nuclear power plant of capacity of 3000 MW, which will possibly be joined to the system after the year 2030, is not going to improve energy crisis which is likely to be suffered earlier, i.e. in the years 2016–2019. Even after its introduction to the system, it will still not have a significant influence on Polish power generation system, which capacity in 2025 should exceed 40 GW. But there is a question of resigning from the construction of a nuclear unit and further development of this technology. Many countries, which base their system on nuclear power, schedule its further development and construction of new nuclear reactors. The examples are: Finland, Czech Republic or Great Britain. The construction of a nuclear power plant will definitely be an expensive investment for the period of 50-60 years as that is the time of new-generation power plants to operate. Moreover, a nuclear power plant operating at the base of load will improve the stability of the power system, which, in the perspective of significant development of unstable renewable energy sources, will be certainly of crucial importance.

6 Power generation based on gas fuels

Climate policy of zero emissions is integrated into plans of national energy groups which plan investments of new production capacities based on natural gas. Tauron works

toward the construction of gas unit of capacity equalling 400 MW in Stalowa Wola, Energa works toward the construction of a gas unit of capacity equalling 860 MW in Grudziądz, and Polska Grupa Energetyczna intends to construct two gas units of capacity around 400-450 MW in the complex of power plants Dolna Odra; they also conduct preparatory works for the needs of construction of gas units in their heating plants in Bydgoszcz and Gorzów and consider the construction of a power plant in Puławy, including a gas unit of capacity equalling 400 MW. The construction of a gas unit of capacity equalling 500 MW in Płock is announced by PKN Orlen. Similarly, KGHM Polska Miedź has elaborated the concept of construction of two gas units of the capacity of 45 MW. The construction of own gas sources is also considered by PGNiG Termika; EC Żerań is going to construct a gas-steam unit of capacity equalling 450 MW [1]. The plans of energy investments include also a LNG port in Świnoujście. However, the operation of gas power plants in Poland and many European countries is presently unprofitable. The price of this material makes energy units based on gas fuel too expensive for use. The advantage is a low cost of investment and short time of construction.

7 Development plans for power generation system

Upon analysing available documents and other papers dealing with the attempt to determine the strategy for the development of power generation system, i.e. among others: Energy policy in Poland by 2030 [8]; Energy mix 2050, Analysis of scenarios for Poland, Warsaw 2011 [9]; Energy mix for Poland by 2060, elaborated for Chancellery of the Prime Minister by the Department of Strategic Analyses, [10]; Coal for Polish energy industry in the perspective of 2050 – scenario analyses, the document elaborated for the Polish Mining Chamber of Industry and Commerce [11]; The Strategy for Sustainable Development, Ministry of Development, draft law on the date 29 July 2016 [12]; it may be noticed that each of these strategies highlights the role of coal in the near future. Considering average values of production capacity given in the scenarios above, Table 7 presents the required production capacity by the year 2050.

Table 7. The forecast of power demand and a lack of installed capacity by 2050

Year	Installed capacity [GW]	Withdrawals [GW]	New production capacity [GW]	Forecast for power demand [GW]	Lack of installed capacity [GW]
2016	40.44	-	-	-	-
2020	-	4.97	5.82	46.00	4.70
2030	-	4.78	-	51.00	14.43
2040	-	8.19	-	56.00	27.63
2050	-	3.90	-	67.00	43.27

Source: Own elaboration on the basis of [1,8-12]

It will certainly be difficult to execute the construction of new open mining pits of brown coal, or to make a decision on the construction and starting of a new brown coal mine. The prices of coal on international markets may also influence the situation when it is more profitable to buy it from abroad. This may cause abandonment of investments into domestic production resources. However, the data above, in comparison to the plans of construction of new and conventional power units, show that, in theory, we have the potential to secure future supplies of power for the following years. If we consider the scenario of a nuclear unit in 2030 in NPS and in the subsequent year – the second one; and if we also consider the development of heating sources of gas technology and gas-steam technology, then one may think that our system is able to secure necessary power supplies. Of course, there are also renewable energy sources which are becoming more and more

important. The development and contribution of renewable energy sources is determined not only by technological development, but mainly by all political decisions which impose a certain contribution of renewable resources into the total installed capacity. The political nature of changes in the recent months, mentioned above, has caused severe turbulence in the sector of renewable energy sources, mainly among the wind farms owners. Thus, it will be difficult to assess the right direction of the development of RES in our country. Following the opinions of different specialists, RES sector related to wind technology, as the result of necessity, will have to choose sea locations for their further investments. It is also worth-mentioning the potential of the development of small and dispersed production sources. The development of prosumer power generation in Denmark and Germany shows that also these sources may have a great share in national demand for energy supplies in the future. Dispersed sources which are supported by energy storage technologies will allow for joining them into virtual power plants of potential regulatory role in the whole system [13].

A very important aspect which is often omitted by various analyses is the flexibility of a power generating system. In the contemporary world flexibility gains special meaning as energy systems are more and more loaded as the result of rising demand for power supplies. Moreover, more significant contribution of renewable energy (wind power plants and photovoltaic systems) provides for the less stability of energy systems. The bigger share of renewable energy, the less predictable production of energy becomes. In order to take prompt actions in response to changeable situation of power generation, power plants must be flexible i.e. able to increase capacity in wide range in a short period of time required for the start-up of a power plant. Contrary to appearances, differences between technologies are sometimes enormous. Big steam power plants usually have a long period of start-up and are of low flexibility. It results from a slow process of steam production for the turbines to operate.

Modelling of energy system development has significant limitations. Altogether with the development of liberalisation processes of power sectors there are new factors which determine the choice of production technology. Because of the risk related to the competitive market the investors have preferred technologies with a short period of expense return and a short period of construction. A power sector is also more and more susceptible to the environmental policy, including the necessity to reduce CO_2 emissions. It requires a diametrical change into the directions of production sector development, especially for the benefit of clean coal technologies and nuclear plants, and also renewable energy sources (including decentralised systems). The selection of future technologies will depend on many factors. The comparison of the basic characteristics of production technologies are given in Tables 8a and 8b.

8 Conclusion

Energy policy constitutes a national security policy. It should be well-thought and consider the access to energy sources. Other important issue, is the necessity to be independent from imports of fuels. The identification of domestic power potential presented herein shows that in the perspective of 30 years, it is possible to base the power system on coal power plants. This time will certainly allow for the construction of a new energy mix, of greater and greater share of other power technologies. Decisions on the construction of new production sources must also consider their influence on the National Power System. Moreover, another aspect is also the access and price of the fuel, altogether with the costs of its future CO_2 emissions.

RES are clean energy sources and in the long-term perspective they will certainly be more important in the power industry [19]. However, having enormous amounts of coal we may expect that in the near future the energy system will be based on stable coal sources. It

is sure that future will also bring the necessity to change the energy composition, as the result of, among others, shrinking fuel resources and the influence of environmental issues. Nevertheless, till these changes are made, there is the possibility to base the system on highly efficient and infallible coal sources. Reduction of CO_2 emissions should not be executed through rejecting coal from Polish energy mix, but it should take place through investments into new technologies supporting CO_2 reduction and the construction of energy units of higher efficiency. Significant share of solid fuels, coming mainly from domestic sources, should be the guarantee of energy security for the country in the next decades. The selection of technology for new generation sources in a long-term perspective must be based only on economic criterion, which considers the knowledge of expected total costs of energy, altogether with environmental costs. However, it is necessary to determine if iplementation of proposed processes of energy changes is possible and what will be its future cost. The agreement which was signed in Paris assumes that the future energy mix will engage all technologies. It is important, though, that this mix considers a balanced development.

Table 8a. Main characteristics of energy technologies [14-18].

Technology	Units power	Construction time	Lifetime [years]	Investments cost/kW	Fuel costs	CO_2 emissions
OCGT	Medium	Short	25	Low	High	Medium
CCGT	Medium	Short	30	Low	High	Medium
Coal power plant	Large	Long	45	High	Medium	High
NPP	Very large	Long	60	High	Low	N/a
Water power plant	Small - large	Long	100	Very high	N/a	N/a
Wind power plant	Small	Short	25	High	N/a	N/a
PV	Small	Short	25	Very high	N/a	N/a

Table 8b. Main characteristics of energy technologies [14-18].

Technology	Efficiency	Min load [$\%P_{max}$]	Start up time [h]	Ramping speed [$\%P_{max}$/min]	Black start	Quick start (10 min)
OCGT	30–40	20–50	0.2–0.5	10–20	Yes	Yes
CCGT	45–58	30–50	2–4	4–10	No	No
Coal power plant	35–48	30–60	4–8	2–6	No	No
NPP	30–35	40–50	25–48	0.5–5	No	No
Water power plant	80–90	15–20	0.1	5–40	Yes	Yes
Wind power plant	25–35	2–4	-	0.5–1	-	-
PV	15–20	-	-	-	Yes	-

Future domestic energy mix must be highly flexible as the share in renewable energy sources will increase. Optimal schedule for the energy system will allow for stability and effectiveness of use of available sources of energy. Power plants, which operate in a power system as the base, should be characterised mainly as highly-efficient and they should generate low emissions of harmful gases. Moreover, the system also requires power plants of high flexibility in order to cover changeable peak demands and cooperate with renewable energy sources to compensate momentary variations related to changeable wind strength or sun radiation. Planning the future development of the energy system it is necessary also to take account of possible risks. For example the lack of development of nuclear power in Poland, the cost of implementing RES and other economic determinants of implementation of different scenarios diversification of energy sources in Poland

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