Achieving the goal

Coal phase-out in the Polish power sector

instrat

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Complementary publications:
- *What's next after coal? RES potential in Poland.*
- *The missing element. Energy security considerations.*

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Abbreviations and definitions

ARE	Agencja Rynku Energii S.A.
CHP	Combined heat-and-power plants
EDM	Early Decommissioning Mechanism
PSPP	Pumped storage power plant
GHG	Greenhouse gases
IND	Industrial generating units
JWCD	Centrally dispatched generating units
EC	European Commission
NECP	National Energy and Climate Plan for the years 2021-2030
NPS	National Power System (pl. KSE)
NABE	National Energy Security Agency
nJWCD	Non-centrally dispatched generating units
RES	Renewable energy sources
PEP2040	Polish Energy Policy until 2040
PGE	PGE Polska Grupa Energetyczna S.A.
PPEJ	Polish Nuclear Power Program
PSE	Polskie Sieci Elektroenergetyczne
SRMC	Short-run marginal cost
UE	European Union

Summary and key recommendations

1. The share of coal in electricity generation in Poland may decrease from the current 70 percent to 13 percent in 2030, while maintaining energy security. This means a reduction of CO_2 emissions in the power sector by 59% in the period of 2015-2030 – two times faster than in the official Polish Energy Policy until 2040 (PEP2040).

2. Poland can meet the EU climate objectives in the power sector, which the restructuring plan for power and mining sectors and the PEP2040 are not compliant with.

3. The phase-out date for coal combustion in power plants is 2035. In order to maintain the energy security of the country, we suggest that 5 coal-fired power units with the lowest emissions and a total capacity of 4.2 GW remain in cold reserve until 2040. Their generation would be limited to 300-500 hours per year, which would allow the use of existing capacity auctions in compliance with EU law.

4. Already in 2020, approx. 45 percent of Polish coal-fired power units had problems with generating a positive operating margin. After the expiry of the capacity market contracts, they will become unprofitable and require public aid for survival.

5. The cost of the proposed solution is assessed at PLN 14 billion (€ 3 bn) — i.e. four times less than the estimated total costs of the power sector restructuring plan prepared by the utilities and the government.

6. The plans to maintain hard coal mining at the current level or at the level assumed in PEP2040 by 2049 are not feasible. Thermal coal consumption is likely to drop from the current 32 to 10 million tonnes in 2030 which can be met by the Bogdanka mine itself.

7. Investments in new gas-fired power plants are not profitable, as in the 2030s they will be pushed out of the energy mix by cheaper renewable energy sources.

8. The share of RES in electricity generation will increase to 76 percent in 2030, which leads to a decrease in electricity imports.

In order to enable investment project planning and just transition activities, it is necessary to declare the phase-out dates of individual coal-fired power plants and coal mines, in line with the EU climate objectives, as well as to create a cold capacity reserve with strict limitations of annual CO_2 emissions. The phase-out date of the coal-fired power plants is 2035 (5 power units remain in reserve until 2040), and of the coal mines — 2030 (except for the Bogdanka mine).

It is necessary to immediately unlock investments in onshore wind farms — to amend the “anti-windfarms act”, increase the RES auction volume, introduce subsequent versions of the “My Electricity” program, timely implement offshore wind projects, and modernize the network infrastructure.

Investment projects involving CCGT power plants should be abandoned, except for the Dolna Odra and Ostrołęka units, and it should be assumed that the Turów complex will be shut down in 2026 and transformed into a pumped storage power plant.

It is absolutely necessary to make the energy debate transparent. Until now, it has been held behind closed doors and navigated through leakages in social media. Together with the report, we will publish a detailed database of Polish power plants. Furthermore, we also declare to make the entire energy model used in the analysis public.

The publication is the first in a series on the Polish energy transition:

- *Achieving the goal. Coal phase-out in the Polish power sector.*
- *What’s next after coal? RES potential in Poland.*
- *The missing element. Energy security considerations.*

1. Introduction

There has been a stormy debate about the transition of the Polish power sector for many months. At the moment, there is no solution that would ensure energy security for Poland at the same time being in line with the climate objectives of the European Union (EU) for 2030. Contrary to expectations, such a scenario is definitely not included in the Polish Energy Policy until 2040 (PEP2040) adopted in February 2021, assuming an unrealistically high share of coal in the energy mix. Plans to maintain hard coal mining until 2049, recommended by the mining sector in the context of negotiations of the "social agreement", seem to be even less probable. It is difficult to imagine that such solutions would be approved by the European Commission as it would make it impossible for the entire European Union to achieve the reduction targets for 2030.

This publication shows that another route is possible — one that allows Poland to actively participate in the Community's decarbonization effort, but without jeopardizing the Polish energy security, while taking into account social and economically advantageous perspectives.

The proposed scenario also responds to the basic malady of the Polish power sector — abrupt decrease in profitability. In 2020, mining companies suffered colossal losses and face the prospect of not having enough funds to pay salaries. On the other hand, energy producers have to get used to negative margins from electricity generation, which means that they are protected against bankruptcy only by the capacity market.

The answer was supposed to be the restructuring of the power sector, but in November, the Instrat team estimated that the plan proposed by the power companies would expose the State Treasury to billions of zlotys in financial burdens. In turn, ClientEarth analysts identified many legal barriers to its implementation. The analysis presents an alternative solution that is not only more affordable but also compliant with the EU law.

In the first of a series of three publications, we provide a diagnosis of the current power sector restructuring plans, propose a scenario for shutting down coal-fired power plants and combined heat and power plants, assess the possibility of replacing them with renewable energy sources, and compare our findings with the proposals of the government. In the subsequent two publications we analyze in detail the renewable energy sources (RES) development potential in Poland, as well as aspects of the transition related to energy security and network infrastructure.

2. Currently considered energy transition plans

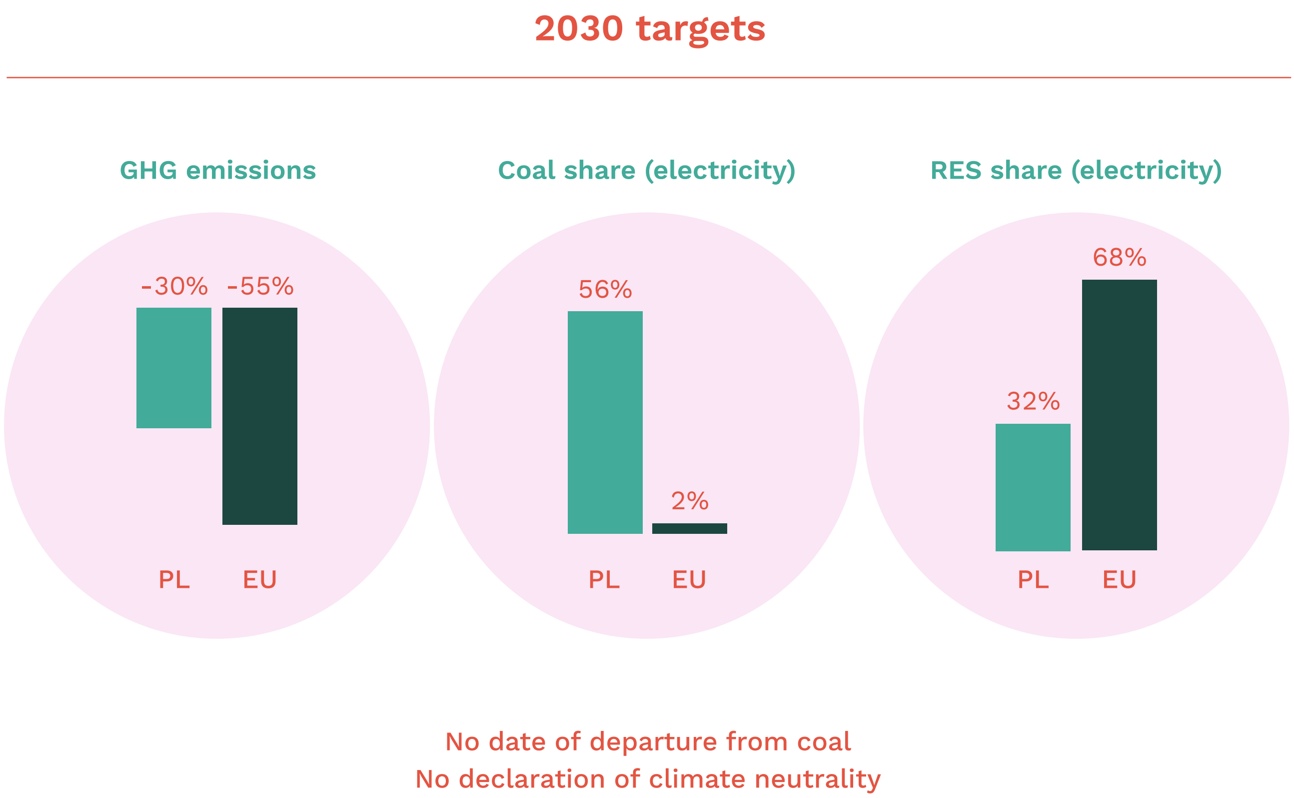
The energy transition plans considered in Poland are inconsistent with the climate objectives of the European Union for 2030 and economically unfavorable. The most "progressive" power sector restructuring plan from autumn 2020 currently under discussion assumes a high level of public aid for the coal-fired power sector, which is unlikely to be approved by the European Commission. It is, therefore, necessary to develop a solution with an ambition to meet the objectives of the EU and at a lower cost.

2.1. Poland's climate ambitions in relation to EU objectives

The currently proposed energy transition targets and plans in Poland are at least modestly ambitious from the point of view of the EU climate policy. The Polish Energy Policy until 2040 adopted in February 2021 assumes a reduction of greenhouse gases (GHGs) emissions only by approx. 30% by 2030 compared to 1990, and as much as 56% of coal share in electricity generation in the baseline scenario — in an alternative scenario this is an equally unambitious level of 37%. By contrast, the European Union targets a reduction of at least 55% in GHGs and only a 2% share of coal in electricity generation for 2030 (Ecologic & CLIMACT, 2020). The PEP2040 assumes only a 32% share of RES in electricity generation in 2030, while the EU average is expected to be 68%. The European Commission estimates that the average reduction of CO_2 emissions in the power sector should amount to approx. 70% in 2015-2030, whereas in the PEP2040 it is 25%. Across the EU, coal is expected to account for 50 TWh of net electricity in 2030. In a more ambitious PEP2040 scenario, electricity generation from coal in 2030 is to be 68 TWh net. Therefore, the Polish proposal prevents the entire Community from reaching the 2030 climate targets.

Such a high coal share in electricity generation is also inconsistent with the obligations of Poland under the Paris Agreement. Their fulfillment requires almost complete elimination of coal from the power mix in 2030 (Czyżak & Hetmański, 2020). Taking decisive actions towards decarbonization of the power sector is therefore not only necessary from the point of view of climate, but also in order to meet the international obligations of Poland. In addition to the 2030 targets, the tardiness of Poland also threatens the achievement of the EU climate neutrality target by 2050 (which Poland, as the only EU country, has not yet declared). It is therefore unavoidable to declare the coal phase-out date and the date of achieving climate neutrality, along with the preparation of a plan for replacing coal power with RES.

Figure 1. The comparison of PEP2040 scenarios with EU climate targets



Source: internal analysis of Instrat based on the PEP2040, (EC, 2020), (Ecologic, 2020)

Discussions on the energy transition have been in progress since 2020. However, the restructuring plan of the Polish power sector, disclosed in autumn 2020, suggests that in 2030 coal-fired power plants alone would generate 50 TWh of electricity (Czyżak & Kukuła, 2020). Assuming that Poland will increase its share in European electricity generation from coal from 22% in 2018 to 40.07% in 2030 (Moore, 2020), the Polish coal-fired power units will be able to deliver 22 TWh of gross electricity[1]. In the restructuring plan and the PEP2040, this value is exceeded several times. The restructuring plan proposes a faster pace of shutting down coal-fired power plants than the PEP2040 or the National Energy and Climate Plan (NECP), but it should not be expected to be approved by the European Commission in the light of such huge deviations from the climate objectives.

1 Assuming own consumption (i.e. the difference between net and gross consumption) at the level of approx. 10%

2.2. Economic aspects of the power sector restructuring

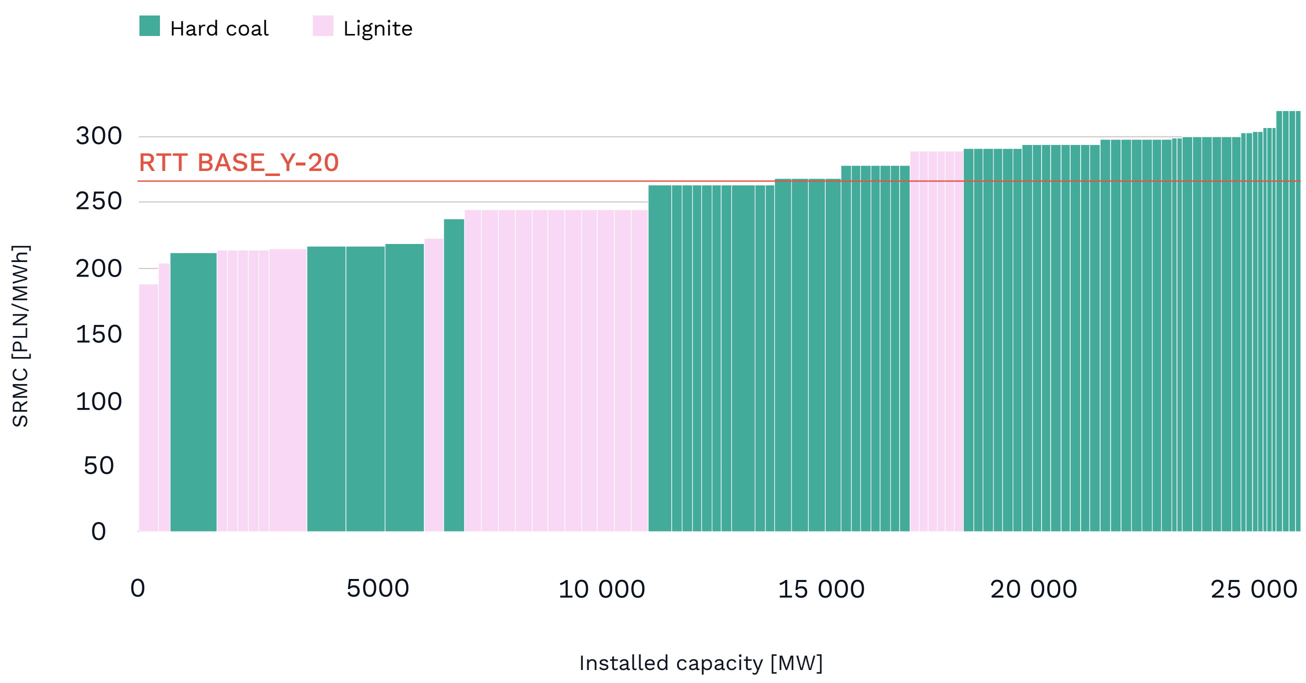
The need to take immediate actions to shut down Polish coal-fired power plants results not only from the updated climate objectives of the European Union but also from economic reasons. Power companies have been signaling their unfavorable financial situation for many months and even a vision of bankruptcy in the near future (Oksińska, 2020). The generation costs of one megawatt-hour of electricity are higher in many coal-fired power units than revenues from its sale.

We estimate that by the end of 2020, for approx. 45% of Polish coal-fired power units, the short-run marginal cost (SRMC) exceeded the volume-weighted average price of annual futures contracts (RTT BASE_Y-20[2] – PLN 266.47/MWh). The power units with the lowest efficiency — in Dolna Odra, Połaniec, Siersza, Skawina, Łaziska, Łagisza power plants, recorded a loss on the variable margin of PLN 30/MWh and more (Fig. 2). The structure of costs and revenues of a power plant includes additional components — i.a. revenues from the operating capacity reserve (by the end of 2020), day-ahead market, balancing market, fixed costs, overhaul costs — therefore, the net profit/loss is difficult to estimate. However, the variable margin can be considered as a reliable indicator of the profitability of energy production. In 2021, the percentage of unprofitable power units in terms of operation will increase: the main costs component – the average prices of CO_2 emissions allowances – increased from 26.5 EUR/t in 2020 to 36.7 EUR/t in 2021 (energy.instrat.pl, 2021a). According to the estimates of PGE, the losses on the variable margin can currently amount to as much as PLN 60-80/MWh for 200 MW-class power units (Strączyński, 2021). Therefore, the operation of Polish coal-fired power plants depends on revenues from the capacity market. After the expiry of the capacity contracts in 2025 and 2028, most of the Polish coal-fired power units will lose their profitability. Their sudden shutdown would lead to a decrease in increments in generation capacity and a threat to energy security.

In order to avoid this situation, the above-mentioned power sector restructuring plan (Czyżak & Kukuła, 2020) proposed the transfer of the coal assets of the PGE, Tauron, and Enea Groups to the newly created National Energy Security Agency (pl. NABE), as well as the introduction of an early decommissioning mechanism (EDM). Detailed assumptions of the plan were discussed in the report of November 2020 (Czyżak & Kukuła, 2020). From an economic point of view, this plan has a number of defects — in particular, it shifts the maintenance of declining coal assets onto the burdens of taxpayers. Based on the assumptions included in the restructuring plan, we

2 Większość energii w Polsce sprzedawana jest w kontraktach terminowych, spośród nich, kontrakt BASE_Y charakteryzuje się typowo największym wolumenem obrotu

Figure 2. SRMC of coal-fired power plants



Source: internal analysis of Instrat Assumptions for the SRMC calculations are included in Appendix 1.

assessed that during the operation period, NABE would generate losses of PLN 31 billion (€ 6.75 bn). The EDM would additionally cost PLN 32 billion (€ 6.97 bn), out of which PLN 18.3 billion (€ 3.98 bn) would cover the fixed operating costs of coal-fired power plants. In total, the State Treasury would therefore spend almost PLN 50 billion (€ 10.88 bn) to maintain coal-fired power plants, not counting the costs of reinstatement of areas left after power plants and mines or voluntary leave plans for the personnel.

Despite its defects, the restructuring plan proposes a faster pace of shutting down coal-fired power plants than the PEP2040. At the same time, the Polish Economic Institute estimates that increasing the decarbonization rate leads to the reduction of costs for the Polish economy in relation to the status quo scenario with a high coal share (Gniazdowski et al., 2021). Therefore, the restructuring plan is the “cheapest” solution currently discussed for the Polish power sector. Our publication suggests a scenario with a few times lower costs.

It should not be forgotten that the implementation of the restructuring plan for the power sector involves granting public aid to the power plant owners, which will certainly raise an objection from the European Commission. An investigation explaining the public aid to lignite in Germany is currently ongoing, as the European Commission has several concerns regarding compensation for the early closure of power plants and mines (EC, 2021a). The German government has concluded an agreement with the biggest producers of electricity from lignite, RWE and LEAG, under which these operators are to receive financial compensation of € 4,35 billion in total. These funds are intended to cover the (future) profits of electricity producers lost due to their early closure. According to the EC, the amount of support is both highly disproportionate to the potential losses incurred and assumes an excessively long time horizon. While the EC has doubts as to the amount of future profits of German electricity producers, it is known that the Polish power units will not generate such profits.

On the other hand, the auction organized in autumn 2020 in Germany to reward hard coal-fired power plants that declare the fastest shutdown date (Wehrmann, 2020) is considered a success. The 2020 auction was popular and ended with relatively low compensation for hard coal-fired power units, but as many as half of the power units that won in it were only less than seven years old. This means that the new, less emissive power units are shut down before high-emissive power units, which is completely in conflict with the climate objectives.

The solutions applied in Germany are therefore not flawless. First of all, however, their preparation took several years. During this time, the prices of CO_2 increased sharply and the EU adopted new emission reduction targets. The situation of owners of coal-fired power plants has therefore deteriorated significantly and their negotiating position is now much weaker. Poland will therefore pay dearly for the delays in the implementation of the energy transition and it will now be extremely difficult to obtain consent to grant public aid to the coal sector. Even if such consent was possible, designing a new financing mechanism and negotiations with Brussels would take too much time for Poland to allow timely replacement of coal-fired power by 2030. Therefore, the following analysis proposes a solution based on the existing legislative mechanisms which are not in conflict with the EU climate policy.

3. The optimum scenario of shifting away from coal

Below we present a scenario of decommissioning coal-fired generating units to ensure energy security and imply the reduction of CO_2 emissions to the extent required by the updated EU climate objectives.

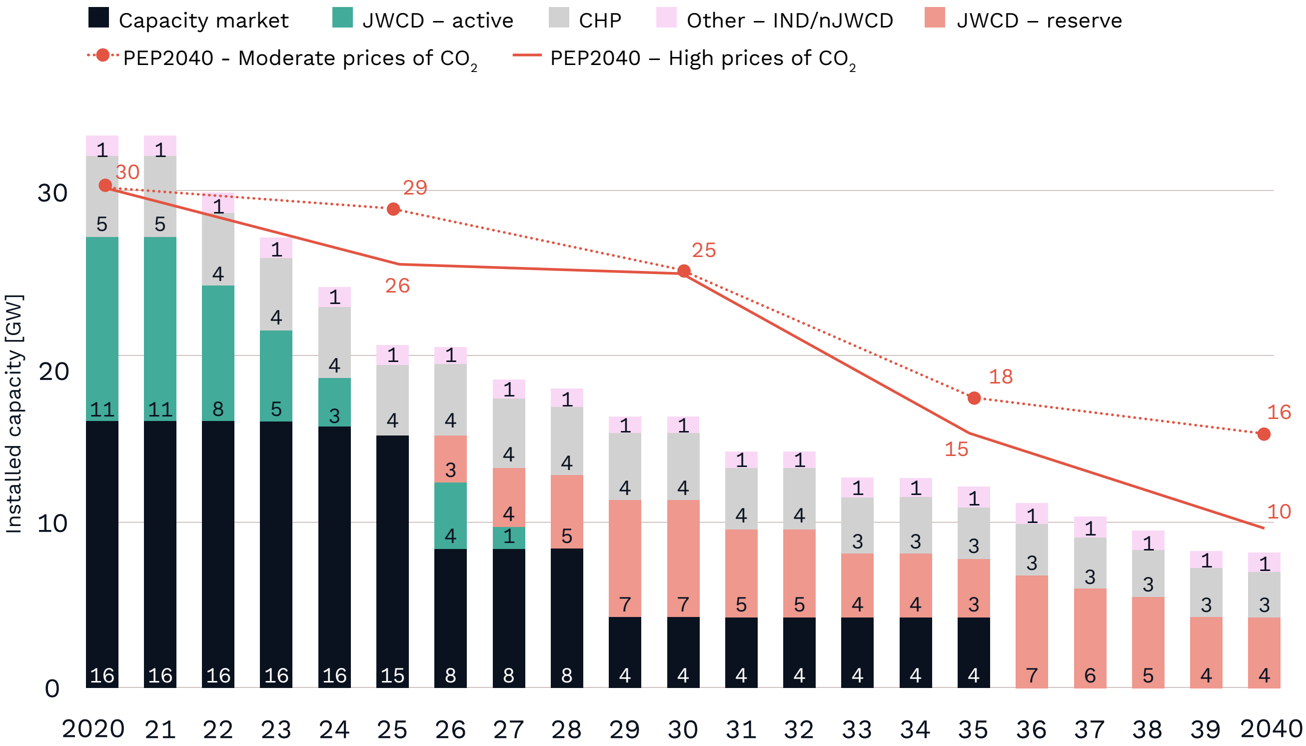
3.1. Decommissioning coal-fired power plants

While the decommissioning of coal-fired power plants is being discussed, citations often refer to an example of the German reverse auction mechanism of rewarding coal-fired power plants that declare the closest date of the shutdown. However, as mentioned above, this mechanism does not include many factors, such as the efficiency of individual power units, which leads to an increased emissivity of the entire power system. Since the German solution is imperfect, an original scenario was prepared, taking into account:

- emissivity,
- SRMC – the marginal cost of energy generation,
- expiry dates of power contracts,
- power units' commissioning dates and last general retrofit dates,
- already announced shutdown dates (or resulting from e.g. the EU Industrial Emissions Directive – IED (Flisowska, 2020)).

In accordance with point 2.2., to ensure that after the expiry of power contracts, sufficient operating capacity will remain in the national Power System (NPS) to meet the peak demand, we propose an additional mechanism of the cold capacity reserve. The extended operation of coal-fired power units allows the expansion of gas capacity to be lower than in alternative scenarios. Already in the 2030s, gas-fired power plants would have difficulties in competing with RES, which means a reduction in their capacity utilization factor and the inability to obtain a return on investment.

Figure 3. The path of shutting down coal-fired power units



JWCD – Centrally Dispatched Generating Units
nJWCD – non-Centrally Dispatched Generating Units
CHP – combined-heat-and-power plants
IND – industrial generating units

Source: internal analysis of Instrat

Coal-fired power units in reserve will have to limit their generation to 350 kg CO_2/kW per year, resulting from the Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity (EC, 2019a).

To determine the date of a given coal-fired power unit going into reserve, the time of operation in reserve and the date of complete shutdown, the following algorithm was used:

1. The power units were ordered by the expiry dates of power contracts, SRMC and the date of the last general retrofit;
2. In each year between 2021 and 2030, the power units were moved to the reserve in the order complying with point 1, so as to obtain a linear decrease in installed power;
3. The power unit could not be transferred to the reserve before the expiry of the power contract;

4. After 2030, only the power units with power contracts until 2035 remain active, and they are completely shut down in 2040;

5. The operating time in reserve was determined from emissivity. The least emissive power units could remain in reserve for up to 10 years (up to the 40th percentile), the most emissive power units were immediately targeted for shutdown;

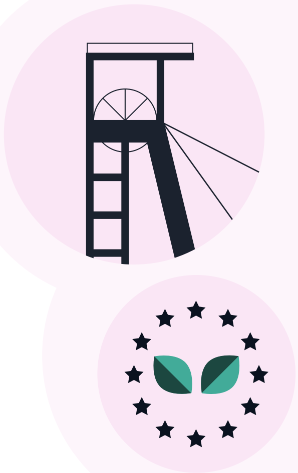
6. No power unit could be operated longer than the limit date (e.g. IED or the date already announced by the owner).

The above procedure was used to find the path of the shutdown of individual coal-fired power units as shown in Fig. 3. The cold reserve mechanism was applied to smooth out the abrupt drops in generating capacities resulting from the expiry of power contracts. The installed capacity of the units in reserve ranges from 3 to 7 GW. A scenario was also proposed for shutdowns of coal-fired combined heat and power plants (CHP) based on the dates of their start-up and location[3]. The power output of coal-fired combined heat and power plants is reduced from the existing 4.9 GW to 2.8 GW in accordance with PEP2040. The power output of industrial units and non-centrally dispatched generating units (nJWCD) remains constant at 1.1 GW (ARE, 2020). The precise dates of the transition to reserve and the shutdown of individual units are included in Appendix No. 2 and in the Excel sheet attached to the report.

As part of the project, it was not possible to fully analyze scenarios for the decarbonization of heating and industry in Poland. Therefore, the modeling used the assumptions from PEP2040 and took into account the conversions of coal-fired combined heat and power plants into gas-fired ones as planned by 2030. However, we recommend the complete elimination of coal in heating systems by 2035 through limiting the demand and increasing energy efficiency, together with increasing the share of RES in heat production, and replacing all coal-fired power units with natural gas units which would also combust green hydrogen from 2035.

3 these were the only possible criteria due to no access to detailed data on emission or efficiency

In the proposed schedule, the total capacity of coal-fired units is reduced much faster than in both scenarios of the new PEP2040. In 2030, the difference between the Instrat scenario and PEP2040 is as great as 9 GW. In subsequent years, in the PEP2040 scenario of high prices of CO_2, the rate of coal capacity reduction increases, which results in reaching a value close to that of the Instrat scenario in 2040.



An exception to the algorithm presented above is the Turów Power Plant owned by PGE. PGE has obtained an extended mining permission until 2026. However, the decision was opposed not only by environmental organizations, but also the Czech Republic and Germany, as the Turów complex is located in their close vicinity. Both countries lodged complaints with the European Commission, which considered the Czech Republic's arguments to be justified (EC, 2020a). Subsequently, the Czech Republic lodged a complaint with the Court of Justice of the EU. With such widespread resistance not only from the society but also from the governments of neighboring countries, it should be recognized that the extension of lignite mining in Turów beyond 2026 is very unlikely. Therefore, it was assumed that all power units of the Turów Power Plant will stop operating in 2026. It was also assumed that power contracts expiring after 2025 will be sold to other producers. Two contracts until 2028 would be awarded to the Ostrołęka B Power Plant (extending the current contracts by 3 years), and the 15-year contract would be performed by Unit No. 10 at the Łagisza Power Plant (currently it has a contract until 2025).

As will be shown later in the report, the presented scenario allows the safe balancing of the power system and, at the same time, rapid reduction of the share of coal in the energy mix, reducing CO_2 emissions from the electrical power sector to the level compliant with the EU objectives of – 55% GHG.

3.2. Replacement of generation capacity

In order to assess the possibilities of replacing coal-fired power plants, the RES potential in Poland was analyzed in detail to an unprecedented extent.

Methodological assumptions concerning the calculation of the RES potential and detailed results are presented in a dedicated publication "What's next after coal? RES potential in Poland".

Using spatial data and the GLAES framework (Ryberg, Robinius & Stolten, 2018), the paper proposed a layout of individual onshore wind farms with an accuracy down to a single turbine and identified the areas available for photovoltaic farms. The selection criteria included e.g. (Czyżak, 2020):

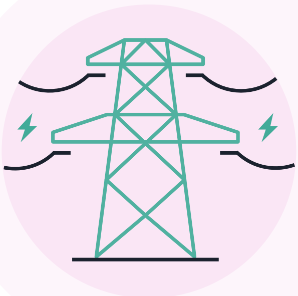
- **social aspects – distance from residential buildings;**
- **economic and technical aspects – wind force, distance from transformer stations, surface inclination;**
- **environmental aspects – distance from protected areas, reserves;**
- **infrastructural aspects – distance from roads, airports, industrial facilities.**

The wind and solar energy potentials obtained are much more conservative than the European Commission's popular estimates from the ENSPRESO project (EC, 2019b). The rate of development of photovoltaic and onshore wind energy does not exceed the historical values obtained in Poland. Gradual repowering of the existing turbines was taken into account, which not only increases the installed capacity but also increases the capacity utilization factor. Assumptions concerning offshore wind farms are based on the map of offshore areas created by Instrat (energy.instrat.pl, 2021b), as well as the dates of delivery of projects under the already concluded connection agreements. The installed capacity of biomass increases slightly (as per the expected volumes of RES auctions in 2021), together with an increase of capacity factors for existing plants. A relatively strong increase in the capacity of biogas plants was assumed in accordance with the investment plans of i.a. PGNiG (Kajmowicz, 2020).

RES systems were supplemented with energy storage facilities. Due to the probable shutdown of the Turów mine and power plant, a new 2300 MW pumped storage power plant has been proposed in the area of the open-pit mine (Węgrzyn et al., 2020). It would be commissioned in 2037, after 11 years of filling the reservoir with water from the surrounding rivers. Additionally, the model includes the development of battery energy storage facilities, which by 2030 would reach a power output of more than 1 GW (PGE itself plans 800 MW (PGE, 2020), up to 5 GW by 2040 (Biznesalert.pl, 2019)).

The investment in new gas-fired power plants was minimized – the analysis showed that these power plants, with an increasing share of RES in the energy mix, are used only occasionally, which would make it impossible for their owners to achieve a positive return on investment. From among the planned CCGT projects, it was assumed to construct two Dolna Odra units and one unit in Ostrołęka, with both already having capacity contracts[4]. From 2035, these units will be burning hydrogen produced from a surplus of RES electricity to reduce CO_2 emissions. The analysis did not include nuclear energy as the delays of the Polish Nuclear Power Program (PPEJ) and comparable projects implemented in the EU indicate that it will be very unlikely that a nuclear power plant will be launched by 2040 (Czyżak, Hetmański & Szpor, 2019).

Conservative assumptions have been made with respect to energy imports – only the cross-border link expansion projects planned by PSE until 2030 have been implemented, which translates into an increase in the capacity available for import from the current 4.6 GW to 7.3 GW. Additional assumptions are included in Appendix No. 1. The installed capacity based on this scenario is shown in Fig. 4.



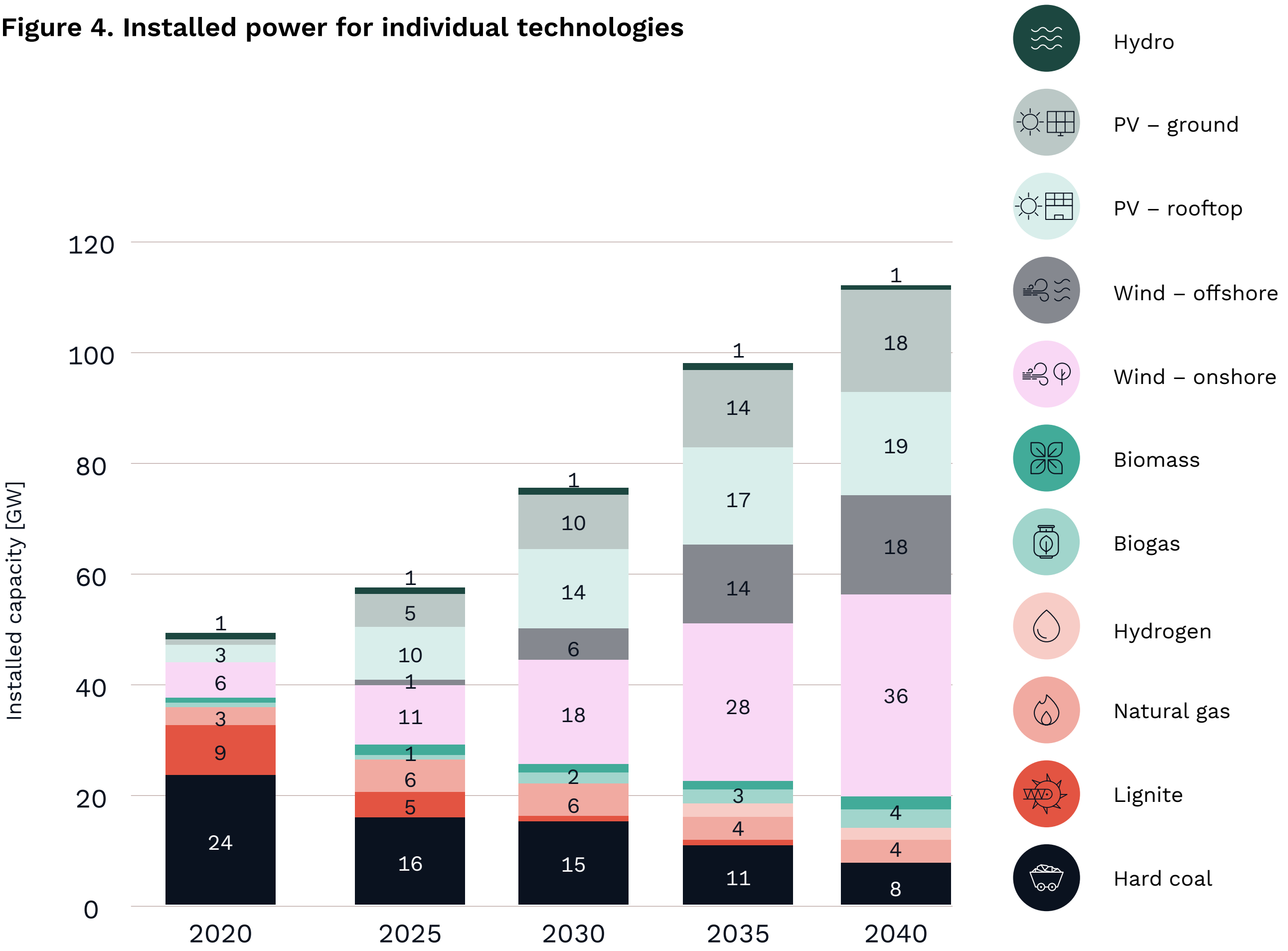
Restrictions on the volume of energy imports have a significant impact on the results of modeling. At the same time, the development of RES requires extensive transmission network projects. Therefore, a separate publication addresses the issues related to the balancing of power system, import of energy and fuels, as well as the costs of projects for network infrastructure: "The missing element. Energy security considerations."

In 2030, RES capacity exceeds the capacity of conventional sources. In 2030, the capacity of wind farms reaches 18.4 GW onshore and 5.5 GW offshore. The capacity of photovoltaic micro-systems increases from the existing 3 GW to 14.4 GW. For large PV farms, an increase from 1 GW to 9.9 GW is observed. In 2040, RES capacity increases further but still does not reach 100% potential of the onshore solar and wind power. Further expansion of the offshore wind capacity would require setting out new investment land not yet included in the offshore law. Increasing the capacity of biogas plants above the values for 2040 would pose a threat to sustainable fuel generation.

4 In the case of Ostrołęka C, the contract was awarded for the planned coal-fired power unit, however, it is planned to replace it with a gas-fired power unit that could meet the capacity obligation.

In order to assess the structure of electricity generation on the basis of the above assumptions, a multi-node PyPSA-PL optimization model was used, created by Instrat using the PyPSA framework (Brown, Hörsch & Schlacht-berger, 2018). The model maps the shape of the PSE 400/220 kV trans-mission network (approx. 100 nodes); a detailed generator database was also built that contains approx. 90 coal-fired units, approx. 100 CHP units, planned gas/hydrogen units, existing and planned energy storage facilities, planned offshore wind farms, as well as RES plants and industrial power plants broken down by voivodeships. Energy generation was optimized in each hour of the year to cover demand, based on variable costs for indivi-dual generators, which is done similarly in reality[5]. Assumptions concerning the increase in the energy demand in subsequent years came from PEP2040.

Figure 4. Installed power for individual technologies

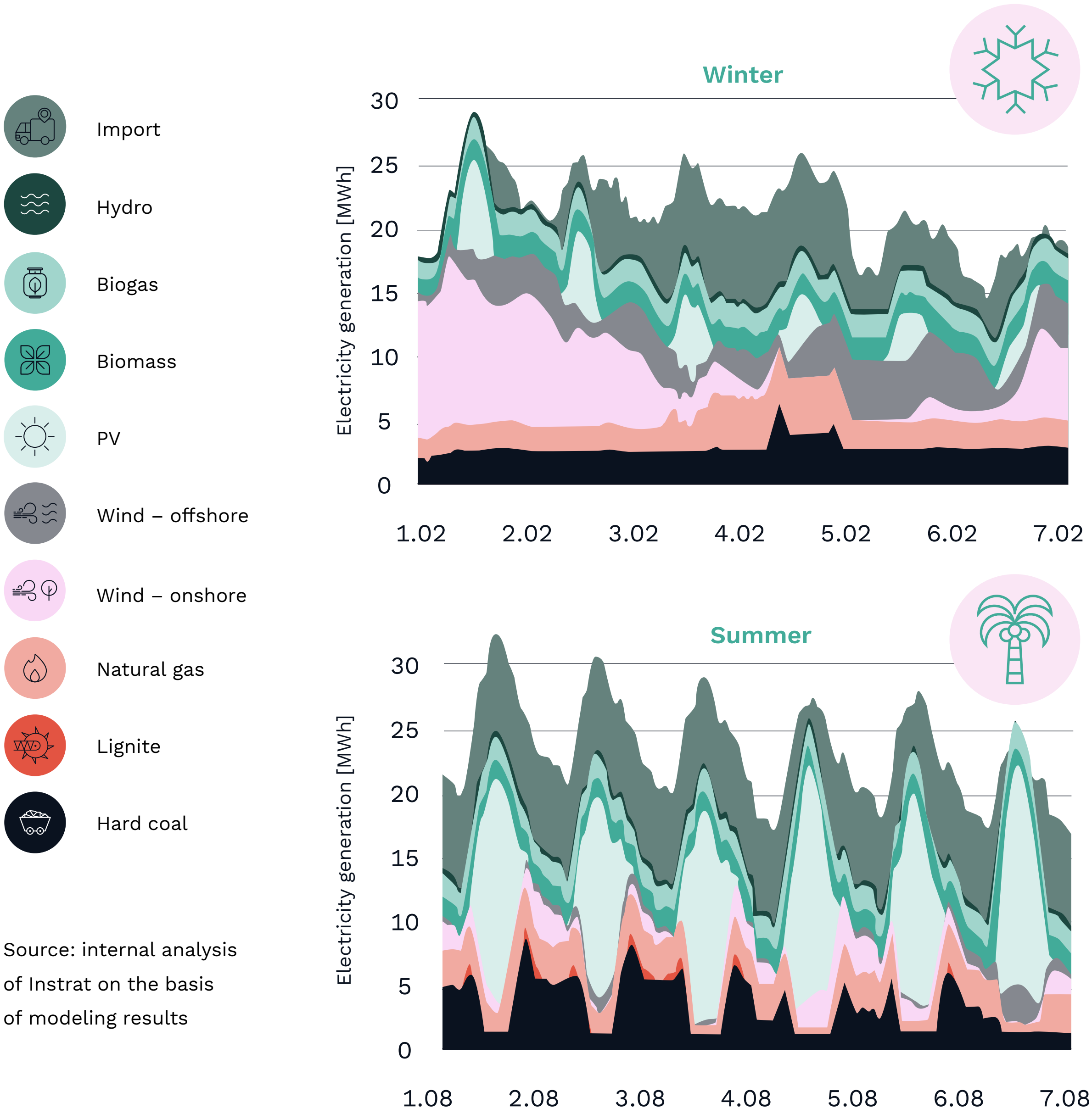


Source: internal analysis of Instrat, ARE data for 2020 from:energy.instrat.pl

5 Scientific studies often use capacity expansion models (CEMs) that optimize the combined variable and investment costs. In this case, such a solution was not chosen as in fact the generation profile results only from variable costs. Moreover, the CEM approach often leads to unrealistic results, e.g. the rate of expansion of new capacities significantly exceeding historical trends, or not taking into account social, legal, political factors by focusing solely on the economics.

An example of the production profile in selected weeks of 2030 is presented in Fig. 5. In the winter week, a large share of wind energy can be seen in the structure of electricity generation; in less windy moments, there is an increase in imports of energy cheaper than that from domestic conventional sources[6]. Only after the import possibilities have been exhausted, gas-fired and, if necessary, coal-fired power plants are started up. In summer, the generation structure is dominated by solar energy, which is made up with fossil fuels in a week with a smaller windiness. In 2030, the capacity of energy storage facilities is relatively small because, over the coming years, they assume the role of a buffer, covering demand in the afternoon-evening peak, limiting the need for import.

Figure 5. Example of an hourly profile of electricity generation in the winter and summer weeks in 2030

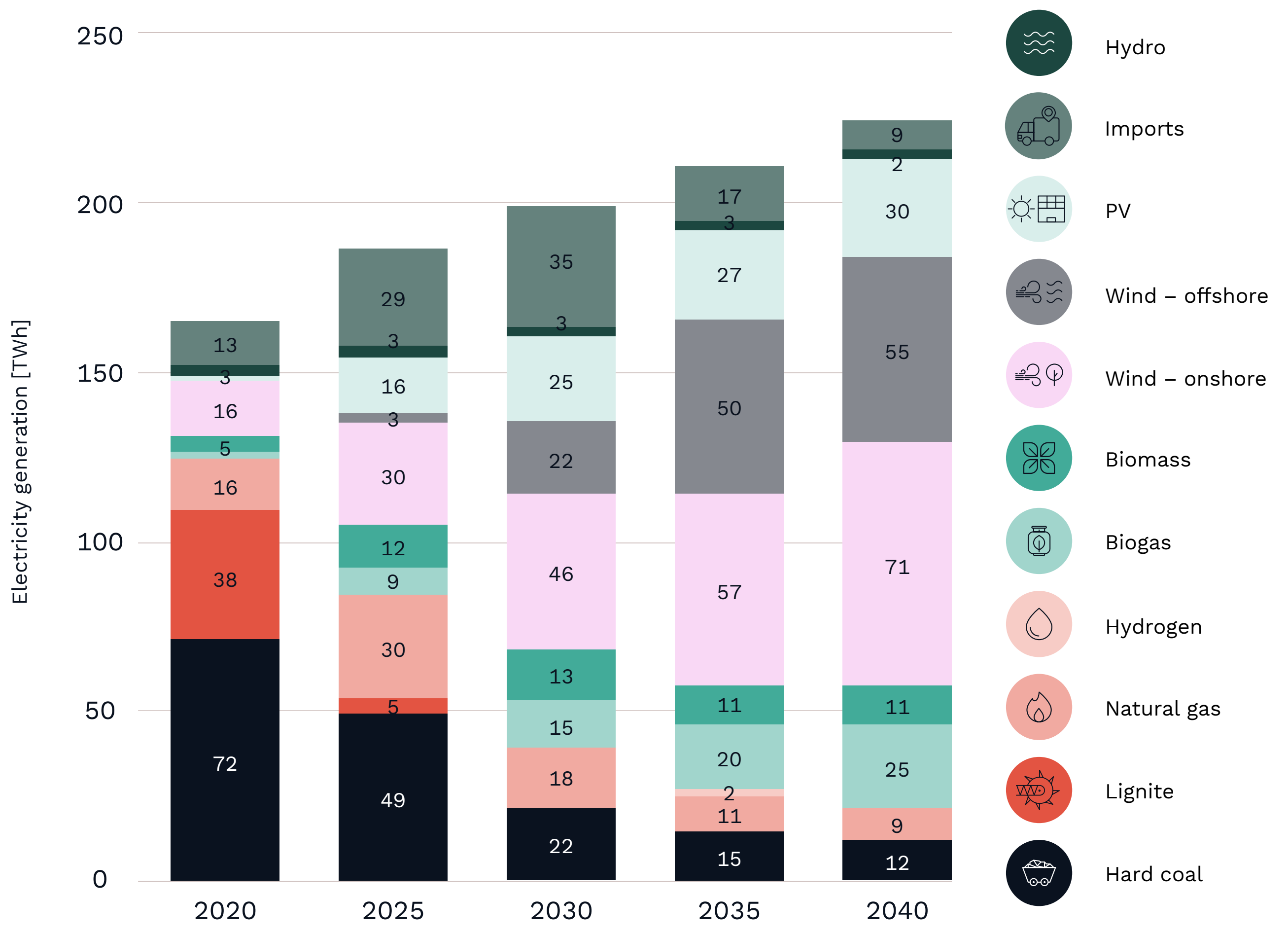


Source: internal analysis of Instrat on the basis of modeling results

6 An additional scenario for minimum import was also prepared, in which imports are used only when national generation capacities are exhausted.

Fig. 6 shows the annual energy generation broken down by generation technologies. Energy import increases significantly until 2030 (from 13.3 TWh at present to 35 TWh), which is caused by increasing costs of coal-generated energy. In the long run, RES are able to meet most of the demand, while imports decrease. The generation of energy from coal decreases to 22 TWh in 2030. Unlike in other studies, no significant increase in energy production from natural gas is expected.

Figure 6. Annual energy generation between 2020 and 2040 broken down by technologies

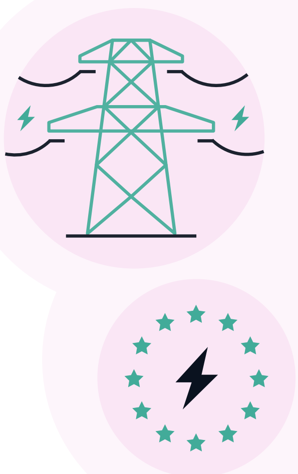


Source: internal analysis of Instrat based on modeling results, 2020 ARE data from:energy.instrat.pl

The change in the generating structure translates into a sharp drop in the share of coal in the domestic electricity generation (Fig. 7) – from 70% in 2020 to 13% in 2030. In 2040, electricity from coal is generated almost exclusively in combined heat and power plants and industrial power plants. RES share increases to 76% in 2030 and 90% in 2040.

Figure 7. Share of fossil fuels and RES in domestic electricity generation

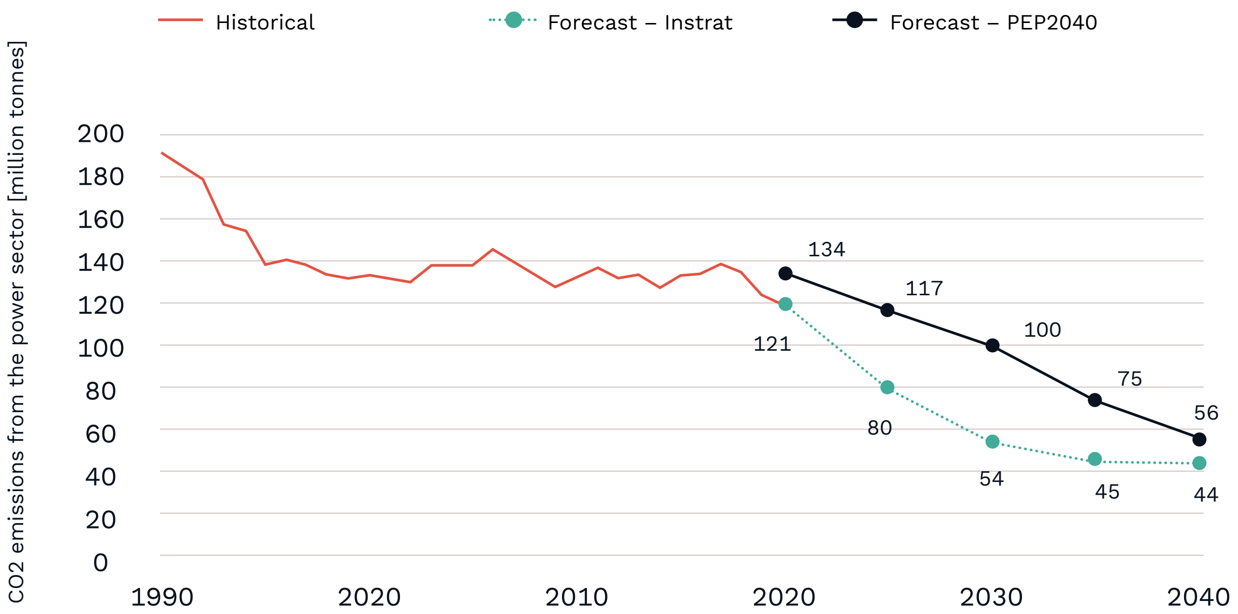
Source: internal analysis of Instrat based on modeling results, 2020 ARE data from:energy.instrat.pl



The analysis also included a scenario that limits the import to the minimum that is necessary to cover the demand. In such a variant, in 2030, the import is reduced from the expected 35 TWh to as low as 0.09 TWh. This makes the share of coal in the energy mix increase to 25%. However, despite balancing almost all demand from domestic sources, the share of RES is as great as 63%, which is still twice as much as planned in PEP2040. Of course, such a scenario would require artificially halting the electricity imports contrary to EU requirements to make 70% of cross-border link capacity available for trade purposes. Therefore, this scenario is unlikely to take place but shows that a high RES share in the power system does not have to involve an increase in imports, in fact, it leads to the opposite result.

The decrease in coal electricity generation translates into a sharp reduction of CO_2 emissions by 2030, required by the updated EU climate targets (Fig. 8). Compared to the values of 2020[7], emissions from the power sector will fall by 54.9% by 2030. In comparison, in the scenario with high CO_2 prices in PEP2040, it is a 25.6% reduction – more than twice lower and does not allow for significant contribution to the EU targets of GHG–55%. After 2030, the rate of emission reduction is decreasing, which results from several factors that should be addressed in future studies: the largest share of CO_2 emissions in 2040 is achieved by CHP plants and industrial power plants. As mentioned in point 3.1., heating and industry decarbonization scenarios could not be analyzed in detail in this study, therefore the assumptions from PEP2040 were adopted. However, the elimination of coal in both sectors and its replacement with RES and natural gas and also with green hydrogen from 2035 would allow an almost complete decarbonization of the power sector around 2040. A significant share of biogas and biomass plants in CO_2 emissions may also raise doubts. Several studies suggest that life-cycle emissions for both technologies are close to zero or even negative and use those assumptions in modelling. The analysis conservatively took into account all emissions from the combustion of biomass and biogas[8].

Figure 8. CO_2 emissions from the power sector

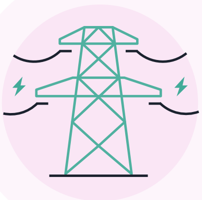


Source: internal analysis of Instrat on the basis of modeling results, as well as energy generation according to Eurostat, ARE, EEA, KOBiZE, energy.instrat.pl, PEP2040

7 120 million tonnes, based on the EEA and KOBiZE emission database, and the production of electricity by Eurostat and ARE for energy.instrat.pl. In PEP2040 for 2020, the value of 134 million tons is assumed, therefore it was a reference for the calculation of the percentage reduction for PEP2040.

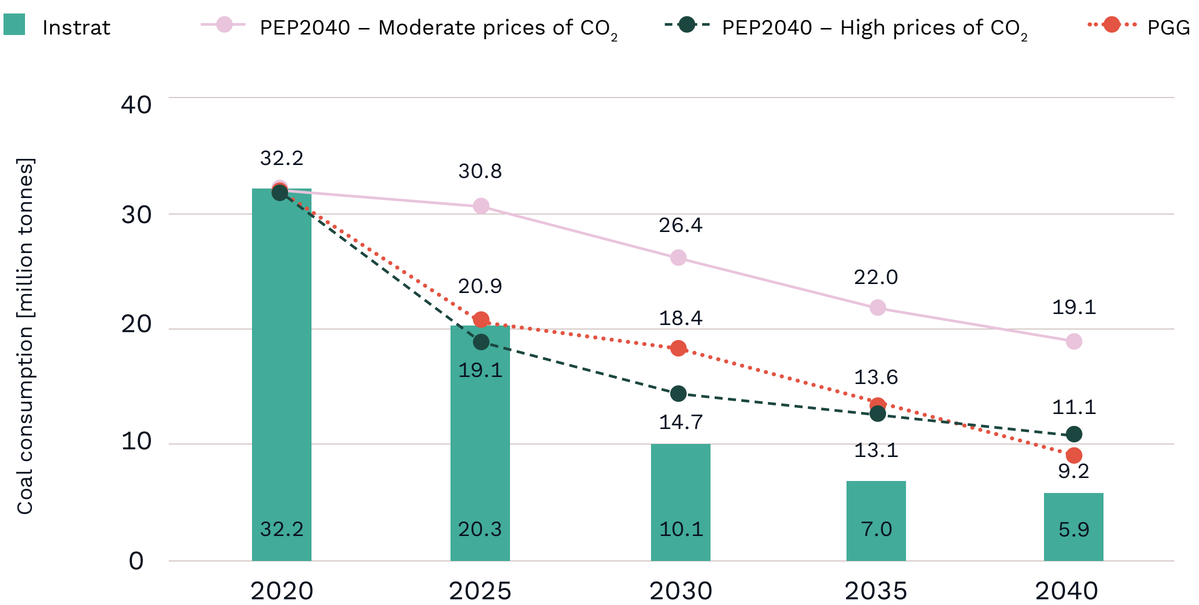
8 Assuming 0.403 tCO_2/MWth for biomass and 0.178 tCO_2/MWth for biogas, source: (EPA, 2014)

Finally, the reduced coal energy production translates into a decrease in the consumption of thermal coal. Already between 2019 and 2020, this consumption decreased from 36 to 32 million tonnes (ARE, 2020). The modeling results indicate that this consumption will decrease to 10.1 million tonnes in 2030 and 5.9 million tonnes in 2040. A similar trend is presented in PEP2040 as well as in the strategy of the Polish Mining Group, however, the latter plans to extract nearly double the amount of coal in 2030 than in modeling results. PEP2040 also assumes higher coal consumption than in Instrat forecasts, however, in the scenario of high CO_2 prices, there is a decrease by more than 50% between 2020 and 2030. The modeling results mean that after 2030, the demand for steam coal will be lower than the planned generation in the Bogdanka mine alone (Soboń, 2020)[9]. The strategy of the Polish Mining Group and the government's declarations on maintaining high hard coal mining until 2049 should be considered unrealistic due to the lack of demand.



Detailed results on fuel consumption and import are discussed in the third publication of the series: "The missing element. Energy security considerations."

Figure 9. Consumption of hard coal in electricity generation



Source: internal analysis of Instrat based on modeling results, PEP2040, PGG strategy presented at the Europower 2020 conference. 2020 data from ARE.

9 9.4 million tonnes in 2019 and planned 8.8 million tonnes per year by 2040 (Soboń, 2020)

3.3. Comparison of scenarios for shifting from coal

The presented scenario of shifting away from coal enables Poland to meet the EU climate objectives and thus potential to apply for additional financing for the restructuring of the power sector. As indicated in Chapter 2, both scenarios included in PEP2040 of February 2021 are not consistent with the objective of reducing greenhouse gas emissions by 55% by 2030. In the power sector, the reduction of CO_2 emissions in 2030 compared to 2015 is only 25%. The European Commission estimates that this should be around 70% on average in the EU. The Instrat scenario indicates a reduction by 59%, almost corresponding to the target for the entire EU, despite historically higher than the average share of coal in the economy.

Table 1. Selected parameters of the Instrat, PEP2040 and UE IA scenarios for −55% GHG

2030

	GHG-55% – target	GHG-55% – consequence for Poland	PEP2040 – Moderate prices of CO_2	PEP2040 – High prices of CO_2	Instrat
Reduction of CO2 emissions compared to 2015	-70%			-25%	-59%
CO2 emissions [million tonnes]		40		100	54
Share of coal in electricity generation	2%		56%	37%	13%
Gross electricity generation from coal [TWh]		22	113	75	22
Share of RES in electricity generation	68%		32%	32%	76%
Hard coal consumption [million tonnes]			26	15	10

Source: internal analysis of Instrat based on modeling results, PEP2040, (Ecologic, 2020)

According to Chapter 2, electricity generation from coal across the EU is expected to decrease to 55 TWh gross in 2030, of which 22 TWh gross would be Poland's share[10]. Such a value can be achieved in the Instrat scenario, which strongly contrasts in this respect with the PEP2040. In PEP2040, coal still dominates the energy mix in 2030. This also translates into an inability to achieve the RES targets, more specifically, in PEP2040, the RES share in electricity generation is only 32% in 2030, while in the EU, it is envisaged to be 68% on average, and in the Instrat scenario it is as much as 76%. To the best of our knowledge, the proposed scenario is the only document allowing to meet the updated GHG emission reduction targets in the EU, containing specific shutdown dates for individual units of coal-fired power plants and combined heat and power plants, and based on RES potential taking into account the specificities of the Polish social and legal environment.

10 Assuming own consumption (i.e. the difference between net and gross consumption) at the level of approx. 10%

4. Implementation of a mechanism for decommissioning coal-fired power units

One of the advantages of the scenario proposed in the report is its relatively easy implementation. It should be remembered that designing and agreeing with all stakeholders on the shape of the Polish capacity market took more than five years. In order to be able to meet the 2030 climate targets, Poland needs to use solutions that will not require long-term negotiations and complex legislative changes. Below we discuss the method of implementing a mechanism for shutting down coal-fired power plants, which takes into account the above requirements.

4.1. Legislative structure

As explained, in order to ensure continuity of electricity supplies by 2040, it is recommended to introduce a cold reserve mechanism based on the lowest emission coal-fired power units. However, it is commonly believed that a new public aid for coal-fired power plants after 2025 is impossible in the European Union.

The EU Regulation on the internal electricity market (EC, 2019a) provides protection against the use of uncontrolled public aid for high-emission methods of energy production by EU Member States. Article 22 (3b) excludes units *emitting more than 550 g CO_2 from fossil fuels per kWh of electricity and more than 350 kg CO_2 from fossil fuels on an annual average per kWe of installed capacity* from receiving payments under the capacity market after 2025.[11] With the average emissions of the olish power system above 700 gCO_2/MWh and the emission of many coal-fired power units exceeding 1,000 gCO_2/MWh, this excludes the coal-fired power sector from the capacity market. However, the joint structure of the conditions contained in the quoted Article is crucial. This means that if the generating unit reduces emissions of CO_2 to 350 kg/kWe, it is not subject to exclusion from payments under the capacity market.

11 For some of the Polish high-efficiency power units, an exception was agreed in the form of admission of 15-year contracts.

The newer hard coal-fired power units – e.g. Jaworzno 2 B7 – could operate for up to 500 hours per year, and for older lignite-fired power units this would be approx. 300 hours. The modeling results for the years 2030-2040 indicate that the load of coal-fired units not only does not exceed these values but with the forecasted moderate volume of imports, it is significantly lower. In 2035, the coal-fired power unit with the highest utilization of installed capacity – Kozienice B11 – produces energy only for 407 hours per year. In 2040, this is only 71 hours. It is worth noting that this results not from the top-down restrictions imposed, but from the optimization based on the variable cost of energy generation. In other words, in the 2030s, the volume of energy from renewable sources in the Polish power system is so large that coal-fired power plants are used only to secure the power balance at times of low windiness. On the one hand, this makes it impossible to obtain revenues from the sale of energy, but on the other hand, opens the door to conclude additional capacity market contracts which would not contribute to an excessive CO_2 emission.

Therefore, such a solution does not require radical legislative changes and thus may be used in the short term of 2030. The units that would remain in the power system as a cold reserve after the expiry of the current capacity contracts could participate in new auctions on the capacity market. Of course, it might be necessary to reassess the maximum prices and to agree (potentially with the European Commission) on additional conditions for granting aid to coal-fired power plants – e.g. the need to prepare plans for personnel, to invest in renewable energy sources, land reclamation, possible exemptions from IED BAT (Best-Available-Technology) etc. Nevertheless, the use of the existing legislative mechanisms created for the capacity market allows for a significant reduction of administrative procedures. First of all, it is the only solution that is not in conflict with the EU Regulation on the internal electricity market and, therefore, the only one that the European Commission may agree to, in particular after the controversy regarding the support provided to the German coal-fired power plants.

In the above considerations, we disregard the ownership structure of coal assets. A detailed discussion of the positive and negative aspects of the creation of the National Energy Security Agency or the consolidation of energy companies is included in the Instrat and ClientEarth report of November 2020 (Czyżak & Kukuła, 2020).

4.2. Costs and financing

An important role in the selection of the target solution is played by its cost. This cost will be borne by the State Treasury – i.e. by taxpayers. It is worth noting that once the costs of a given mechanism are estimated, it is also necessary to identify various financing options – from public, private, national, foreign funds, etc.

Among the examined solutions, the NABE/EDM scenario seems to be the most expensive. According to its preliminary version, the EDM mechanism itself would cost a total of PLN 32 billion (€ 6.97 bn) and would be divided into the following components:

1. Fixed costs of coal-fired power plants – PLN 18.3 billion (€ 3.98 bn),
2. Voluntary leave plans for power plant employees – PLN 3.7 billion (€ 0.81 bn),
3. Reclamation of former power plant areas – PLN 2.4 billion (€ 0.52 bn),
4. Reclamation of former mining areas of the Turów and Bełchatów mines – PLN 7.8 billion (€ 1.7 bn).

Some controversy may be caused by the last two points. The process of decommissioning the mine is regulated by a number of legal acts, including (as in: Mróz, 2015):

1. Act of April 27, 2001 Environment Protection Law,
2. Act of March 27, 2003 on spatial planning and development,
3. Act of June 9, 2011 Geological and Mining Law,
4. Act of February 3, 1995 on the protection of agricultural and forest lands.

In particular, the funds for land reclamation of the former open pit mine should be taken into account at the project planning stage and secured under the "mine decommissioning fund". The PGE's reserve value for the reclamation of mine excavations amounted to PLN 6.1 billion (€ 1.33 bn) in 2019 (PGE, 2019), and it will even increase by the end of their operation period. Moreover, in the former mining and power plant areas, investment projects will be carried out, e.g. wind and solar farms or energy storage facilities. In both cases, the funds for land preparation will be secured as part of financing new investment projects. In the case of pumped storage power plants, the existing level difference in the open pit mine will even be beneficial for the profitability of the investment project. Therefore, it is difficult to explain the appropriateness of granting additional public aid for reclamation, since the financing of these activities should be secured under the statutory obligations of the owner of the mine or power plant.

The labor cost component is already the subject of a number of studies on the just transition of coal regions, e.g. (WWF, 2021) and the means to finance it will come from, inter alia, the EU Just Transition Fund, in accordance with investment projects described e.g. in Territorial Just Transition Plans. Therefore, it does not seem necessary to create an additional aid mechanism for the restructuring of the power sector.

Therefore, the further analysis focused on fixed and variable costs of operation of power plants after the expiry of the capacity market contracts.

According to Instrat's estimations of 2020 (Czyżak & Kukuła, 2020), the NABE in the proposed shape would generate PLN 31.1 billion (€ 6.75 bn) of operating losses by 2040, despite a very optimistic assumption concerning the sale of the entire energy at peak prices (PEAK). In order to cover fixed costs in the EDM mechanism (only two years), power plants would receive PLN 18.3 billion (€ 3.98 bn).

In the recommended proposal of Instrat, covering the fixed costs of operation of the coal-fired power units for the period of their operation in the cold reserve (even up to 10 years) will reach the amount of PLN 14.3 billion[12] (€ 3.11 bn). Additional compensation to cover variable costs should not be required due to the extremely limited volume of production. Using the approximate production volume from the year of the expiry of the capacity market contract, even assuming a loss on the variable margin of 100/ PLN/MWh[13] (€ 3.11 bn). Additional compensation to cover variable costs should not be required due to the extremely limited volume of production. Using the approximate production volume from the year of the expiry of the capacity market contract, even assuming a loss on the variable margin of 100/ PLN/MWh,[14], the amount of potential compensation would amount to PLN 0.6 billion (€ 0.13 bn). If all back-up power units operated at the maximum permissible load (contrary to the modeling results), this amount would increase to PLN 3.15 billion (€ 0.69 bn). However, as indicated, both these amounts are not realistic and only fixed costs estimated at PLN 14.3 billion (€ 3.11 bn) should be considered as the costs of the proposed solution. In the NABE/EDM scenario, all costs of the EDM program should be taken into account, as well as operational losses of NABE – in total, this is as much as PLN 63.3 billion (€ 13.78 bn), i.e. four times more than in the Instrat proposal.

The last alternative worth considering is the introduction of reverse auctions for shutting down hard coal-fired power plants and a separate compensation mechanism for lignite-fired power plants, as in Germany. As shown in Chapter 2, this mechanism has many drawbacks. In particular, it is unlikely that it will be prepared in a sufficiently short term and it raises the European Commission's doubts. However, for comparison, the costs of applying the German solution in Poland were estimated. Similar auction prices were assumed for hard coal – 66 thousand EUR/MW (Wehrmann, 2020). By subtracting the units that have already declared the closing date from the pool, 15.5 GW of hard coal units could participate in the Polish auctions. The cost of conducting the auction would then amount to PLN 4.53 billion (€ 0.99 bn). However, such amount would not allow to cover the fixed costs of operation

12 The fixed unit costs for hard coal and lignite were derived from PEP2040, for details – see Appendix 1.

13 The fixed unit costs for hard coal and lignite were derived from PEP2040, for details – see Appendix 1.

14 Which is not realistic, as these power units will operate only at times of the highest demand for electricity, so at excessively high prices on the market

of back-up units, which could lead to their premature closure, to the detriment of the energy security of the country. In the case of lignite, the RWE company was awarded EUR 2.6 billion to close the power plant with a capacity of approx. 10 GW. In Poland, the installed capacity of the lignite-fired units is 8.8 GW, whereas some of them (owned by ZEPAK) already have the dates of shutting down determined. The value of the compensation could therefore be lower than in the case of Germany, in particular because of the reservations of the European Commission. However, assuming a similar scale of state aid, the cost of applying German solutions in Poland would amount to PLN 16.1 billion (€ 3.50 bn).

Table 2. Comparison of costs of optimum and NABE/EDM scenarios

	NABE/EDM	Instrat	German solution
Total costs [billion PLN]	63.3	14.3	16.1
Total costs [billion EUR]	13.78	3.11	3.50

Source: internal analysis of Instrat

A summary of the costs of individual solutions is included in Tab. 2. According to the above analysis, the Instrat's proposal is not only the only option in terms of regulations, but also the least burdensome for the State Treasury.

A separate issue is the method of obtaining funds for the implementation of the aid mechanism, but this problem applies to all analyzed solutions. Since the proposed mechanism would be based on the auctions of the capacity market, the capacity fee would be a natural source of financing. However, it already raises doubts, as it affects not only households, but it primarily contributes to the loss of competitiveness of the Polish industry. Therefore, it would be necessary to diversify the sources of financing and include, for example, the National Rehabilitation Program or the Just Transition Mechanism among them. However, in the case of the use of EU funds, the financing of the coal reserve would have to be directly linked to investments in renewable energy sources, as most of the EU schemes exclude the financing of investments in fossil fuels. Admission of such a form of financing could therefore only be possible if it would lead to a guaranteed reduction of CO_2 emissions.

However, as indicated, the proposal presented in the report is the only one consistent with the climate objectives of the EU, so the EC's approval to finance it should be considered as much more probable than in the case of the NABE/EDM solution or the scenarios resulting from PEP2040.

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Appendix 1. – Assumptions

The following is a description of the assumptions made in the analysis. This description is in a simplified form, as the assumptions concerning RES, network infrastructure and fuel consumption are subjects of dedicated publications. Moreover, all data used in the model together with the source code shall be made available by Instrat[15].

The basic assumptions concerning electricity demand, raw material prices and other variable costs came from PEP2040 (Tab. Z.1). The demand was converted to gross values, increasing the net value by 10%. The current forecasts of CO_2 emissions allowance prices for the years 2021–2030 prepared by the National Center for Emissions Management (KOBiZE, 2021a) were used. It was conservatively assumed that those prices would not increase further beyond 2030.

We propose that starting from 2035 gas-fired power plants in Dolna Odra and Ostrołęka burn hydrogen produced from RES surplus. According to the estimates of the consortium involved in the European HyDeal Ambition project, after 2030 the costs of production, storage and transport of hydrogen will amount to approx. 1.5 EUR/kg (Renew Economy, 2021). The assumed average net calorific value of hydrogen is 130 MJ/kg, and 21.6 MJ/kg for hard coal (ARE, 2020).

The costs of lignite extraction are not public information. Many studies use data prepared by Booz & Co in 2012, but it is aggregated to the country level and not really up-to-date (Booz & Company, 2012). Therefore, the estimates included in a scientific publication (Czopek & Trzaskuś, 2009) were used, calibrated on the basis of the report on the activities of KWB Konin (KWB Konin, 2019), showing that the extraction costs for KWB Konin amounted to PLN 92.1/t in 2019.

The costs of transport of hard coal were calculated on the basis of the distance from the nearest hard coal mine and PKP Cargo tariffs for 2020 (PKP Cargo, 2019), assuming a 50% discount (Stala-Szlugaj, 2012) and an increase in the future resulting from linear trend extrapolation (Tab. Z.1).

The EUR/PLN rate was 4.43, and the USD/PLN rate was 3.74.

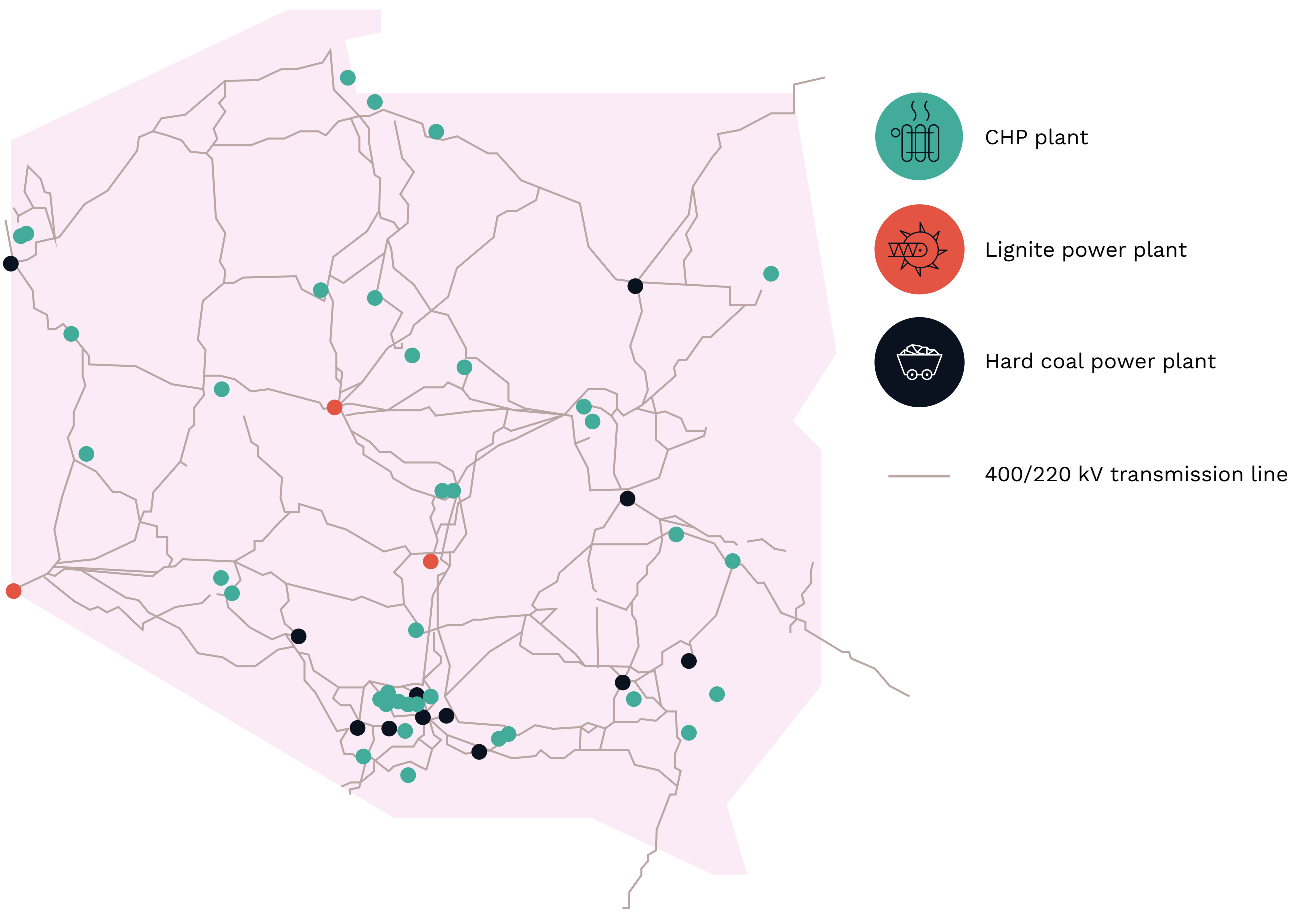
The energy modeling is based on the proprietary implementation of the PyPSA tool – an open modeling environment written in the Python language

15 At the time of publication of the first report, we provide a database of power plants and combined heat and power plants at: http://instrat.pl/en/coal-phase-out. The data can also be found at http://energy.instrat.pl/.

and developed at the German Karlsruher Institut für Technologie (Brown, Hörsch & Schlachtberger, 2018). PyPSA is widely used in European power system analyses, including those carried out by the German government or the European Commission. Instrat operates its own implementation of PyPSA – the PyPSA-PL model which enables to optimize the energy mix with an hourly resolution and with a number of network constraints, and, among others, to estimate marginal costs of energy generation, total system costs, loads on individual transmission lines, necessary investments in infrastructure, CO_2 emissions, and fuel consumption.

The model maps the shape of the PSE 400/220 kV transmission network (Fig. Z.1.). Using the data of energy.instrat.pl, Agencja Rynku Energii S.A., Polskie Sieci Energetyczne S.A., Europe Beyond Coal, EC Joint Research Center, strategies of power companies and a number of other sources, a detailed list of generators was prepared – approx. 90 coal-fired power units, approx. 100 combined heat and power plant units, a dozen or so planned gas/hydrogen units, existing and planned energy storages and planned offshore wind farms.

Figure Z.1 Map of transmission network and generating units



Source: in-house study based on, i.a., data of energy.instrat.pl, ARE, PSE, open stream map

Table Z.1 Main cost parameters used in modeling

Parameter	Unit	2020	2025	2030	2035	2040	Source
Net electricity demand	TWh	159.9	170.1	181.1	191.9	204.2	(PEP2040, 2021)
Price of CO2 emissions allowances	EUR/t	26.5	40.8	72.3	72.3	72.3	(KOZiZE, 2021)
Hard coal price	PLN/GJ	13.2	11.4	11.9	11.9	11.9	(PEP2040, 2021)
Natural gas price	PLN/GJ	28.3	29.2	29.2	30.6	32.4	(PEP2040, 2021)
Green hydrogen price	EUR/kg				1.5	1.5	(Renew Economy, 2021)
Costs of lignite extraction – Turów	PLN/t	85.6	85.6	85.6	85.6	85.6	(Czopek & Trzaskuś, 2009), (KWB Konin, 2019)
Costs of lignite extraction – Bełchatów	PLN/t	75.2	75.2	75.2	75.2	75.2	(Czopek & Trzaskuś, 2009), (KWB Konin, 2019)
Costs of lignite extraction – ZEPAK	PLN/t	92.1	92.1	92.1	92.1	92.1	(KWB Konin, 2019
Other variable costs – hard coal	PLN/MWh	15.14	15.14	15.14	15.14	15.14	(PEP2040, 2021)
Other variable costs – lignite	PLN/MWh	14.22	14.22	14.22	14.22	14.22	(PEP2040, 2021)
Other variable costs – natural gas and hydrogen	PLN/MWh	8.38	8.38	8.38	8.38	8.38	(PEP2040, 2021)
Increase in transport costs	%	100.00%	113.95%	127.90%	141.85%	155.80%	In-house calculations

Source: internal analysis

Onshore solar and wind farms were distributed with the accuracy to a single turbine/power plant, however, for modeling purposes, they were aggregated to the voivodship level, similarly to biogas plants and biomass plants as well as industrial fossil fuel power plants. In the scenario presented in this study, the potentials of onshore wind farms and PV systems were not fully utilized due to the limitations in the pace of their development, which does not exceed the values achieved historically. For PV, the rate of increase goes down from 2.4 GW achieved in 2020 to 970 MW in 2040. For onshore wind, the limiting value was 1.2 GW achieved in 2016, while the repowering of the existing turbines after 20 years of operation was also taken into account. Details concerning the arrangement of RES, the potential of installed capacity and the pace of their development are included in the dedicated publication: *What's next after coal? RES potential in Poland.*

The generation profile for the combined heat and power plants was limited by the historical profile – in summer, in particular, combined heat and power plants do not operate at full capacity, which was mapped in the model. Hourly generation profiles for wind and photovoltaics in individual voivodships came from the EMHIRES project of the European Commission (energy.instrat.pl, 2021c). Similarly to RES, domestic demand was divided into voivodship values on the basis of Statistics Poland (GUS) data.

Assumed was only the implementation of projects to expand cross-border links as planned by PSE until 2030 and entered into the ten-year ENTSO-E Plan (ENTSO-E, 2021):

- GerPol Improvements
- LitPol Link Stage II
- Baltics synchro with CE
- GerPol Power Bridge I

The implementation of those projects translates into an increase in the capacity available for imports from the current 4.6 GW to 7.3 GW in 2030. Projects planned after 2030 have not been taken into account. Import costs were estimated in a way to achieve a profile and volume consistent with the historical values for 2020.

Appendix 2. – Generating units

Along with the publication, a spreadsheet containing a complete database of centrally dispatched coal-fired generating units and combined heat and power plants, including the parameters used in the algorithm for determining the shutdown date, was also made available at http://instrat.pl/en/coal-phase-out.

Table Z.2. Coal-fired centrally dispatched generating units including shutdown dates

Owner	Name	Fuel	Installed capacity [MW]	Last year before including in reserve	Decommissioning date
PGE	Belchatow B10	Lignite	390	2024	2024
PGE	Belchatow B11	Lignite	390	2024	2024
PGE	Belchatow B12	Lignite	390	2024	2024
PGE	Belchatow B2	Lignite	370	2027	2027
PGE	Belchatow B3	Lignite	380	2023	2023
PGE	Belchatow B4	Lignite	380	2024	2024
PGE	Belchatow B5	Lignite	380	2028	2028
PGE	Belchatow B6	Lignite	394	2028	2028
PGE	Belchatow B7	Lignite	390	2028	2028

PGE	Belchatow B8	Lignite	390	2028	2028
PGE	Belchatow B9	Lignite	390	2024	2024
PGE	Belchatow II B14	Lignite	858	2028	2036
PGE	Dolna Odra B1	Hard coal	222	2021	2021
PGE	Dolna Odra B2	Hard coal	232	2021	2021
PGE	Dolna Odra B5	Hard coal	222	2021	2021
PGE	Dolna Odra B6	Hard coal	222	2021	2021
PGE	Dolna Odra B7	Hard coal	227	2021	2021
PGE	Dolna Odra B8	Hard coal	232	2022	2022
Tauron	Jaworzno 2 B7	Hard coal	900	2035	2040
Tauron	Jaworzno 3 B1	Hard coal	225	2025	2030
Tauron	Jaworzno 3 B2	Hard coal	225	2023	2023
Tauron	Jaworzno 3 B3	Hard coal	225	2025	2030
Tauron	Jaworzno 3 B4	Hard coal	225	2023	2023
Tauron	Jaworzno 3 B5	Hard coal	225	2025	2030
Tauron	Jaworzno 3 B6	Hard coal	225	2023	2023
Enea	Kozienice B1	Hard coal	228	2023	2023
Enea	Kozienice B10	Hard coal	560	2027	2037
Enea	Kozienice B11	Hard coal	1075	2035	2040

Enea	Kozienice B2	Hard coal	228	2023	2023
Enea	Kozienice B3	Hard coal	225	2025	2032
Enea	Kozienice B4	Hard coal	228	2026	2032
Enea	Kozienice B5	Hard coal	228	2026	2032
Enea	Kozienice B6	Hard coal	228	2027	2032
Enea	Kozienice B7	Hard coal	228	2026	2032
Enea	Kozienice B8	Hard coal	228	2027	2032
Enea	Kozienice B9	Hard coal	560	2025	2035
Tauron	Lagisza B10	Hard coal	460	2035	2040
Tauron	Lagisza B6	Hard coal	120	2021	2021
Tauron	Lagisza B7	Hard coal	120	2021	2021
Tauron	Laziska B1	Hard coal	125	2021	2021
Tauron	Laziska B10	Hard coal	225	2028	2030
Tauron	Laziska B11	Hard coal	225	2028	2030
Tauron	Laziska B12	Hard coal	225	2023	2023
Tauron	Laziska B2	Hard coal	125	2021	2021
Tauron	Laziska B9	Hard coal	230	2025	2030
PGE	Opole B1	Hard coal	386	2023	2023
PGE	Opole B2	Hard coal	383	2023	2023

PGE	Opole B3	Hard coal	383	2028	2038
PGE	Opole B4	Hard coal	380	2028	2038
PGE	Opole B5	Hard coal	900	2035	2040
PGE	Opole B6	Hard coal	900	2035	2040
Energa	Ostroleka B B1	Hard coal	221	2025	2035
Energa	Ostroleka B B2	Hard coal	230	2028	2038
Energa	Ostroleka B B3	Hard coal	230	2028	2038
ZEPAK	Patnow I B1	Hard coal	222	2024	2024
ZEPAK	Patnow I B2	Hard coal	222	2024	2024
ZEPAK	Patnow I B3	Hard coal	200	2021	2021
ZEPAK	Patnow I B4	Hard coal	200	2021	2021
ZEPAK	Patnow I B5	Hard coal	200	2023	2023
ZEPAK	Patnow I B6	Hard coal	200	2021	2021
ZEPAK	Patnow II	Hard coal	474	2024	2024
ENEA	Polaniec B1	Hard coal	225	2022	2022
ENEA	Polaniec B2	Hard coal	242	2022	2022
ENEA	Polaniec B3	Hard coal	242	2022	2022
ENEA	Polaniec B4	Hard coal	242	2022	2022
ENEA	Polaniec B5	Hard coal	225	2022	2022

ENEA	Polaniec B6	Hard coal	242	2025	2034
ENEA	Polaniec B7	Hard coal	239	2025	2034
PGE	Rybnik B1	Hard coal	225	2022	2022
PGE	Rybnik B2	Hard coal	225	2022	2022
PGE	Rybnik B3	Hard coal	225	2022	2022
PGE	Rybnik B4	Hard coal	225	2022	2022
PGE	Rybnik B5	Hard coal	225	2025	2030
PGE	Rybnik B6	Hard coal	225	2022	2022
PGE	Rybnik B7	Hard coal	225	2022	2022
PGE	Rybnik B8	Hard coal	225	2023	2023
Tauron	Siersza B1	Hard coal	153	2025	2030
Tauron	Siersza B2	Hard coal	153	2025	2030
Tauron	Siersza B3	Hard coal	123	2021	2021
Tauron	Siersza B6	Hard coal	128	2021	2021
CEZ	Skawina B3	Hard coal	110	2021	2021
CEZ	Skawina B5	Hard coal	110	2021	2021
CEZ	Skawina B6	Hard coal	110	2021	2021
Tauron	Stalowa Wola B7	Hard coal	125	2021	2021
Tauron	Stalowa Wola B8	Hard coal	125	2021	2021

PGE	Turow B1	Lignite	235	2026	2026
PGE	Turow B11	Lignite	460	2026	2026
PGE	Turow B2	Lignite	235	2026	2026
PGE	Turow B3	Lignite	235	2026	2026
PGE	Turow B4	Lignite	261	2026	2026
PGE	Turow B5	Lignite	261	2026	2026
PGE	Turow B6	Lignite	261	2026	2026