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Savings driven by fast deployment of renewables by 2030

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Instrat Policy Paper 03/2023

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Key findings and figures

68% **of RES in 2030**	the share of renewables in Poland's electricity mix in the RES high ambition scenario, according to modelling by the Instrat Foundation. This is 15 percentage points higher than in the medium ambition scenario.
31 billion PLN	the amount of savings on purchasing natural gas and CO_2 emission allowances in the RES high ambition scenario compared to the medium ambition scenario (total for 2026-2030). That's about 1% of Poland's GDP in 2022.
12 TWh	net imports of electricity in 2030 in the medium ambition scenario for RES development. In the high ambition scenario, the balance approaches net zero thanks to higher production from solar PV and wind farms.
15% **higher CO_2 emissions**	in 2030, emissions from the power industry in the medium ambition scenario would amount to 40 million tons of CO_2 versus 35 million tons of CO_2 in the high ambition scenario. In total, the higher level of ambition for RES development allows Poland to avoid as much as 20 million tons of CO_2 emissions between 2026 and 2030.

- Using the updated PyPSA-PL model, we analyse two paths of RES development in Poland – **the high ambition scenario** and **the medium ambition** scenario. Both options significantly reduce the use of fossil fuels in power generation. However, only the RES high ambition scenario aligns with the EU's climate goals.

- Without unlocking onshore wind power, removing administrative barriers, and an unprecedented programme to modernise power grids, we will at best follow a path of medium ambition. This would result in a greater reliance on fossil fuels, especially imported natural gas.

- Instrat's power system model takes into account the need to provide power at every hour of the year with adequate reserve to guarantee short-term energy security. Using this tool, we will analyse other aspects of Poland's energy transition in further publications.

1. Introduction

Solar and wind farms are the cheapest new sources of electricity. Technological developments have led to a reduction in the cost of power generation in such installations by 88% and 68%, respectively, compared to 2010 (IRENA, 2022, pp. 30-31). Unlike coal and gas-fired power plants, the cost of renewable energy is not dependent on volatile fuel prices and the rising cost of carbon emission allowances. Their obvious limitation, however, is the weather-dependent energy production.

Poland has irrevocably embarked on the path of the energy transition. Since 2019, solar PV capacity has been growing rapidly (energy.instrat.pl, 2023). Wind turbines located off the Baltic coast are expected to join Polish power system within a few years (PSE, 2023a). With these trends, Polish power system in 2030 will be based on renewable sources to a much greater extent than in 2020. It will also exceed the assumptions in the 2030 decarbonisation scenarios stemming from the existing government strategic documents (MKiŚ, 2021). However, it is the level of government ambition that will largely determine whether Poland will take full advantage of the opportunities for transformation or will remain, for the longer term, the last major EU economy to rely so heavily on expensive energy produced from coal and gas.

How fast should further transformation take place? Can the energy system be based mostly on renewable sources? What consequences will this have, and what challenges do we have to prepare for? The answers to these questions require an appropriate analysis. In a series of publications from 2021, Instrat Foundation experts presented transformation scenarios up to 2040, considering issues such as:

- the pace of the shift away from coal (Czyżak, Wrona, 2021),
- the potential of RES development (Czyżak, Sikorski et al., 2021),
- energy security (Czyżak, Wrona et al., 2021).

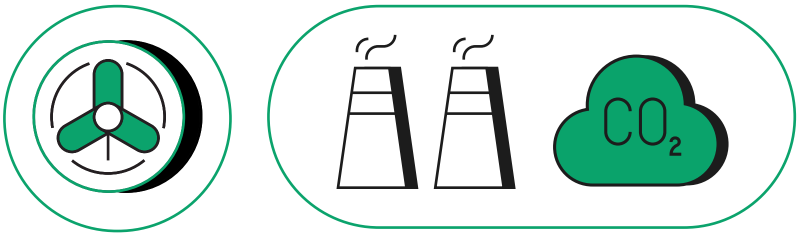
This report presents preliminary findings from the new edition of our research project. In this report, we show the results concerning the structure and cost of electricity production in 2025-2030 and indicate the savings for the Polish economy in the scenario of ambitious RES development.

PyPSA-PL modelling

Our analysis is based on our in-house power system model built using the PyPSA library (Brown et al., 2018). The new version of our model, PyPSA-PL v2, allows us to identify and analyse cost-optimal scenarios for the development and operation of Polish generating capacity. These scenarios consider the need to provide power at every hour of the year with adequate reserve to guarantee short-term energy security.

We rely on a set of carefully compiled assumptions about electricity demand, weather, investment, and operating costs (including fuel and emission allowance prices), as well as opportunities for cross-border electricity exchange. The starting point is the year 2025. We assume that the situation for this year is already determined by current trends and investment processes.

For 2030, our model indicates an optimal (from the investment and operating costs point of view) structure for new generation capacity in solar PV, onshore wind and gas-fired power. Then, the model simulates year-by-year operation of the entire power system from 2026 to 2029, assuming a path to target capacity consistent with the optimisation results for 2030. A key assumption for the end-of-decade scenarios is the limited rate of development of new RES capacity – installing all the wind turbines or solar panels needed in just a few years is not possible due to grid, infrastructure and administrative constraints.



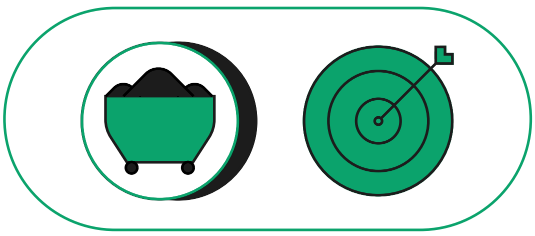
2. Poland's power mix by 2030

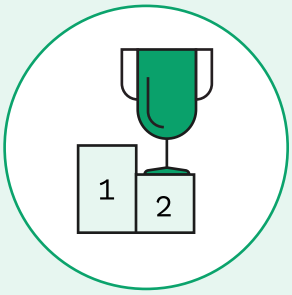
The ongoing energy crisis has confirmed that dependence on imported fossil fuels, particularly natural gas, is a key threat to Poland's and Europe's energy security. The development of low-carbon generation sources is the key to reduce the use of fossil fuels in the power industry. It is also a prerequisite for electrification to lead to a reduction in fossil fuel consumption for the transportation, building and industrial sectors. This is another argument, in addition to climate goals and the interests of the Polish economy, for accelerating the transition already in the current decade.

In this analysis, we considered two scenarios – high and medium RES ambitions. We want to see how an increase in the pace of RES integration translates into the structure of electricity generation. We are also interested in the consequences for: the cost of consumed fuels and emission allowances, and the country's electricity trade balance.

2.1. Assumptions for scenarios

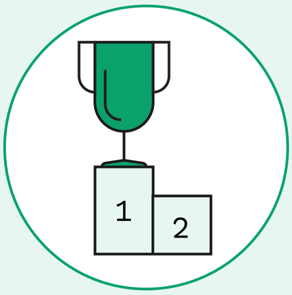
The compared scenarios have a common starting point in 2025. Both use analogous assumptions about, among other things, the investment costs of the various technologies, fuel and emission allowance prices, electricity demand, the rate at which coal-fired power plants are being phased-out, the development of offshore wind power, and the growth of pumped storage and battery storage capacity. The differences in assumptions are related only to the maximum rate of development of onshore wind power and solar PV (Figure 1).





Medium ambition scenario

In this scenario, 12.7 GW of onshore wind capacity is achieved by 2025, as projected by PSE (Polish TSO) (PSE, 2023b). However, this capacity does not increase further thereafter due to only partial liberalisation of the 10 H rule (it even decreases as the oldest plants close due to exceeding their service life)[1]. Solar power reaches 22.2 GW in 2025 and continues to grow, but power grid constraints are slowing this pace to a maximum of 1.5 GW of new capacity per year, much lower than today.



High ambition scenario

In this scenario, onshore wind power develops after 2025 at a maximum rate of 2 GW per year (much faster than in Poland so far). This is made possible by amending the current law (in addition to further liberalisation of distance requirements, it would be necessary to significantly streamline and shorten administrative procedures as envisioned by the REPowerEU program). Extensive investment in upgrading power grids is another necessary condition for such expansion. These measures also allow to maintain the pace of solar power development, which is only slightly reduced compared to recent years and amounts to a maximum of 3 GW of new capacity per year, encompassing both photovoltaic farms (1 GW per year increment) and prosumer installations (2 GW per year increment).

Both of the options presented deviate significantly from the now completely outdated decarbonisation scenarios from previous government documents, which projected only 5-7 GW of solar capacity for 2030 (MKiŚ, 2021). In contrast, the scenarios prepared by the Instrat Foundation reflect current market trends and the high willingness of investors to build new RES capacity. On the other hand, it depends on the government's actions whether medium or high ambitions for RES development become more likely to be realised.

1 In this scenario we assume that the partial liberalisation of the 10 H rule, by allowing the construction of turbines at 700 metres from residential buildings, with other requirements, will not allow the connection of new capacity before 2030, due to, among other things, the duration of the investment process. However, turbines could enter Polish power system in the early 2030s.

FIGURE 1. Installed capacity in onshore wind power and photovoltaics – historical trends and forecasts, and scenarios for maximum capacity growth after 2025.

Source: Instrat's own analysis. For onshore wind, we present a three-year moving average based on URE (Energy Regulatory Office) data – data up to 2018 (URE, 2022a), ENTSO-E – data for 2019-2020 (ENTSO-E, 2023c) and PSE – data for 2021-2025 (PSE, 2023b). For photovoltaics, we present ARE (Energy Market Agency) data – up to 2022 (ARE, 2023) and a forecast up to 2025 based on the results of RES auctions (URE, 2022c) and current trends in prosumer photovoltaics (PTPiREE, 2023).

2.2. By 2030, it is profitable to develop RES as fast as possible

In both scenarios, cheap renewable energy gradually displaces fossil fuels. The cost-optimal level of RES development in 2030 (without restrictions on maximum annual capacity additions) would be even higher than in the high ambition scenario. For this reason, the model considers it optimal to incorporate new wind and solar capacity at the maximum possible rate. Each year installed capacity scenarios increasingly diverge. In the high ambition scenario, we will reach 21.6 GW of wind power capacity in 2030, compared to 11.6 GW in the medium ambition scenario. The corresponding figure for solar power is 37.2 GW versus 29.7 GW (Figure 2).

The difference in RES capacity translates into the calculated level of investment needed in new gas capacity. In the high ambition scenario, we do not go beyond the 7.6 GW of capacity that, according to announced investment projects, could be available as early as 2027 (Charkowska et al., 2022). In the medium ambition scenario, the natural gas power plant capacity is developed to 9.6 GW (the difference is 2 GW, which is the capacity of the new gas units planned for 2027 at Kozienice Power Plant).

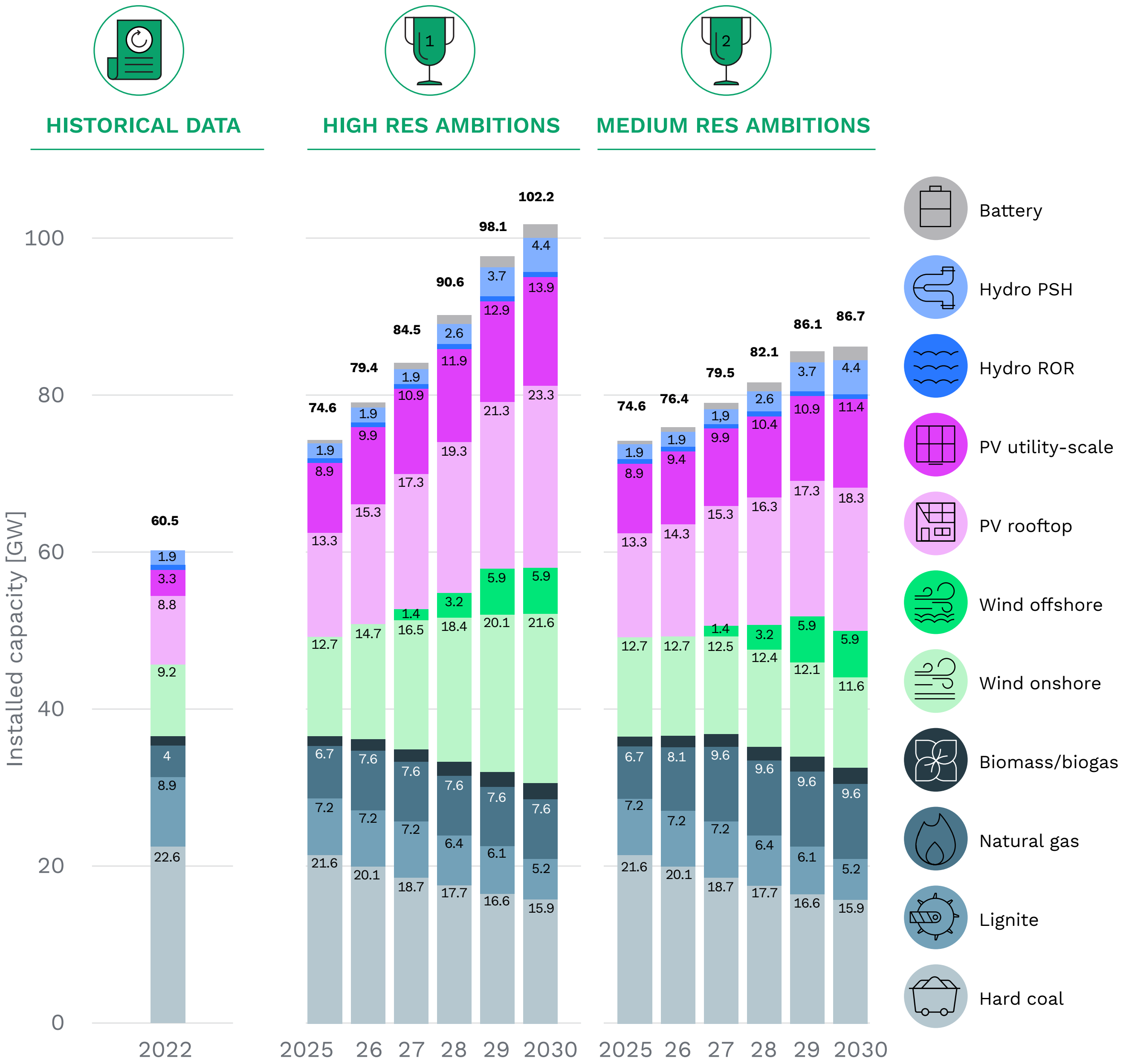
In both scenarios, we assume the same phase-out schedule for coal-fired power plants. This rate is lower than pure cost optimisation would suggest, although higher than official government plans. Coal-fired power plants can still act as backups in extreme situations beyond our modelling scenarios (e.g., during unusually severe frosts or in case of long-term in case of long-term power plant outages).

2.3. Less RES means higher gas and electricity imports

Looking ahead to 2030, the development of renewable sources does not allow for the full phase-out of coal and gas-fired power plants. This is due to the need to ensure an uninterrupted power supply during periods of low RES production. District heating needs, which will still largely force the operation of conventional thermal power plants, will also be a barrier[2]. Fossil fuel-powered units, however, will be able to operate for fewer and fewer hours per year. Thus, the ambitions of renewable energy development translate primarily into the structure of electricity generation, and that is crucial from the emissions and fuel purchase costs point of view.

2 The developments in the heat pump market can greatly improve this situation. Integration of the power and heating sectors will be the subject of further analysis by the Instrat Foundation.

FIGURE 2. Installed capacity in high and medium RES ambition scenarios

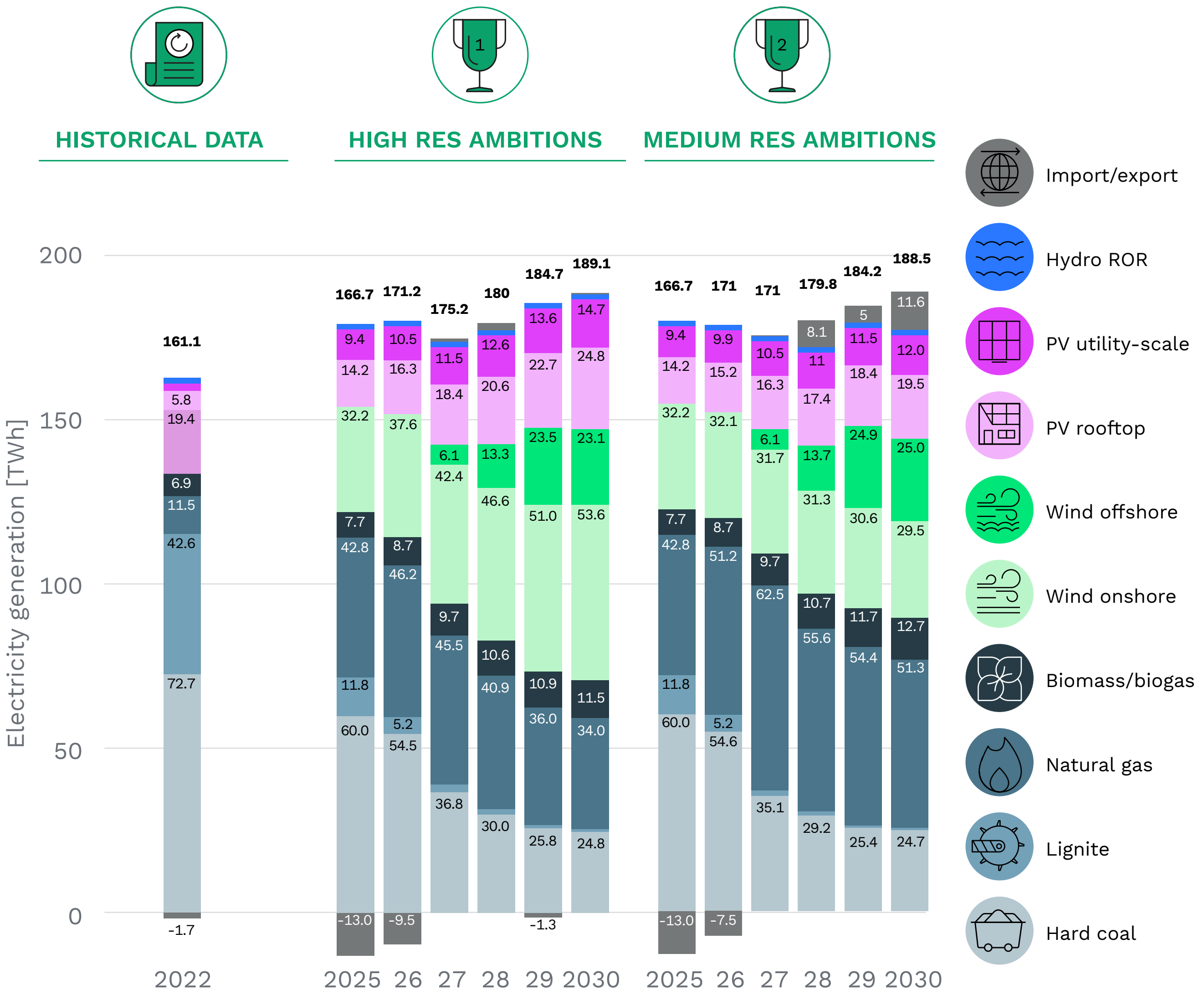


Source: Instrat's own analysis based on historical data (2022) and assumptions about the rate of development of specific technologies and PyPSA-PL simulations (2025-2030).

In the high ambition scenario, we are already approaching a 68% share of RES in meeting the country's electricity demand in 2030. For about 60% of hours in the year, more than half of the instantaneous power consumption (including exports) is guaranteed by domestic RES sources. By comparison, in the medium ambition scenario, this situation occurs for about 45% of the hours, and in 2025 for about 20%. The rest of the supply is supplemented mainly by coal-fired power plants still in operation, flexible gas capacity and imports.

Whether it will be cheaper to obtain energy from gas or coal depends on the market situation. In our model, we assume long-term contract prices for TTF gas for 2025 (ICE, 2023) at around EUR 50/MWh. For 2030, we assume values according to the International Energy Agency's (IEA, 2022) intermediate scenario – about EUR 30/MWh. As these values suggest, natural gas can be a cheaper fuel for electricity generation than coal[3] and it will be the daily supplement to RES. Coal, on the other hand, would be used in thermal power plants and during extended periods of bad weather.

FIGURE 3. Electricity production mix in high and medium ambition RES scenarios



Source: Instrat's own analysis based on Energy Market Agency's historical data for 2022 (ARE, 2023) and PyPSA-PL simulations (2025–2030).

3 Due to the high price of emission allowances and high carbon Emissions intensity of coal-fired power generation, coal combustion in the European Union will be particularly uncompetitive, which will affect global flows of fuels.

An important role in balancing the system is played by cross-border electricity trade, which we analyse taking into account, weather conditions in neighbouring countries (e.g., windy days in Poland are often windy in Germany as well). We conservatively assume the availability of only half of the cross-border transmission capacity relative to projections based on the announced European grid development projects (ENTSO-E, 2023b).

In the high ambition scenario, Poland has a virtually zero trade balance at the end of the decade. Thanks in part to the ability to export electricity, forced curtailment of renewable capacity remains a relatively small problem. In the high ambition scenario, about 7% of the wind energy is curtailed[4], which does not significantly affect the profitability of investment in wind turbines.

The medium ambition scenario in 2030 equals the electricity production gap of 32 TWh resulting from a halt in onshore wind power development (24 TWh) and a slowdown in solar power development (8 TWh), totalling nearly 17% of projected annual demand (Figure 3). Poland would fill the gap primarily by more gas combustion, which is more cost-effective than using coal under our 2030 cost assumptions.

Of course, in practice, the share of coal may be higher due to political considerations, but this would translate into even higher costs for the Polish economy. In the medium ambition scenario, the trade balance also becomes negative: net imports amounts to almost 12 TWh of electricity (some of which originates from German wind farms). Again, Poland can artificially limit this, e.g., by not developing transmission infrastructure, but at the expense of even higher costs for the economy.

Interestingly, in the medium ambition scenario, our offshore wind power plants produce slightly more electricity due to less curtailment, but this only fills 6% of the gap attributed to other renewable energy sources[5].

Offshore wind turbines play an important role in both scenarios due to their scale and production profile. Any delays in the implementation of these projects would pose a significant problem for Polish electric power sector. These are projects of strategic importance to the country's energy security.

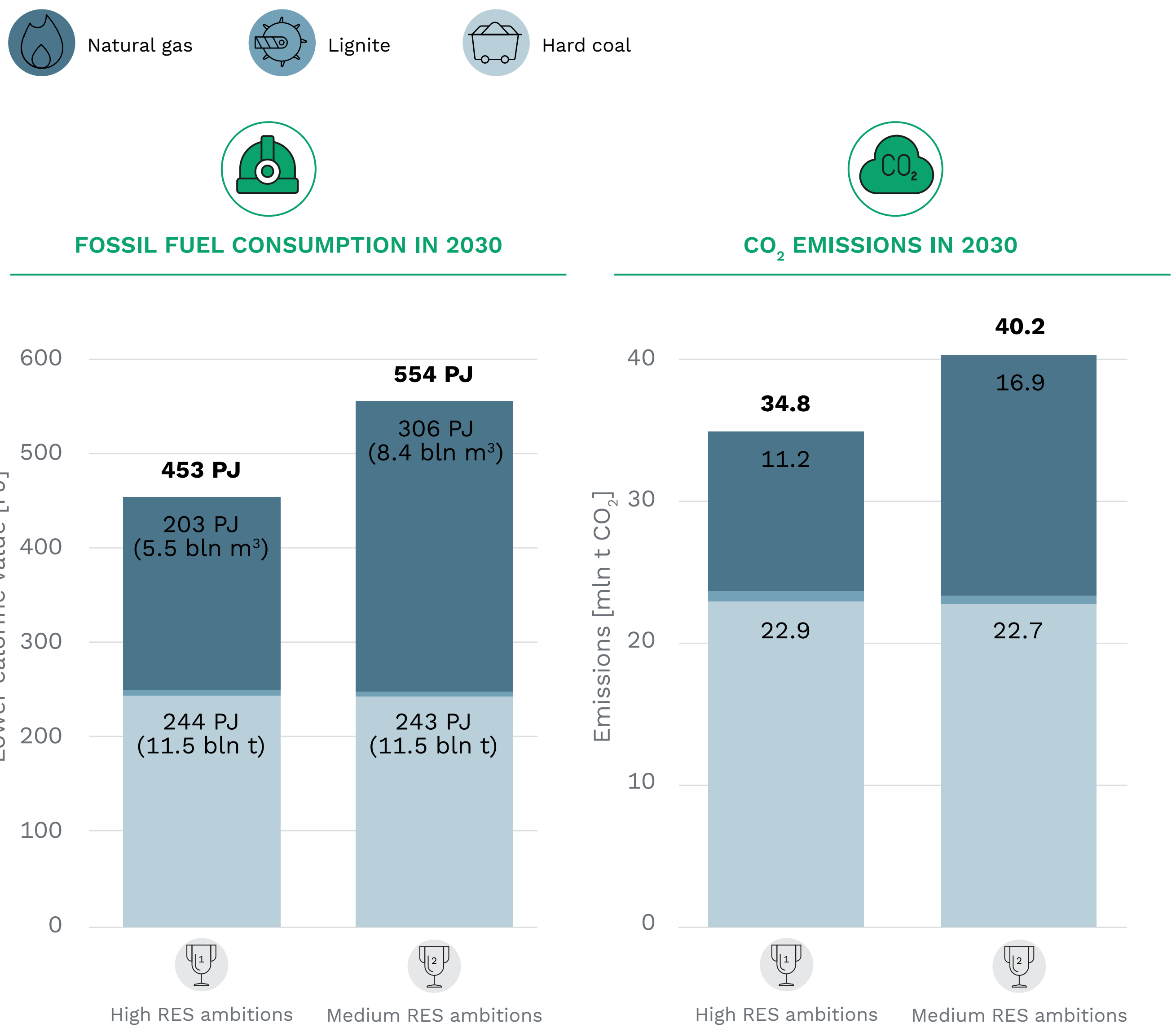
4 In fact, this value will be raised by local power grid constraints and lowered by an increase in the flexibility of demand (use of excess energy, for example, for charging electric cars).

5 Thus, in this scenario, Poland's RES capacity is much more geographically concentrated and distant from major consumption areas, which raises problems from the point of view of power grids and the country's energy security.

3. Let’s not burn money

The medium ambition scenario leads to Polish electric power sector burning 50% more gas for electricity production in 2030, compared to the high ambition scenario. This translates into 15% higher carbon dioxide emissions from this sector (Figure 4). Medium ambitions also mean greater dependence on electricity imports. If we were to fill the RES gap with coal, we would probably pay even more in fuel and emission allowance costs.

FIGURE 4. Fossil fuel consumption and CO_2 emissions in the power sector in 2030 in high and medium RES ambition scenarios



Source: Instrat’s own analysis based on PyPSA-PL simulations.

At the same time, it should be emphasised that the medium ambition scenario does not mean that the country's energy transition would be fully blocked. Thanks to the development of offshore wind and solar power generation, Poland would source up to 53% of its electricity from RES in 2030[6]. This is a level of ambition slightly higher than presented in PSE's grid development strategy (PSE, 2022), which, however, does not include the development of prosumer solar panels after 2021.

The high ambition scenario offers savings on fossil fuel costs, emission allowance fees and an improved electricity trade balance.

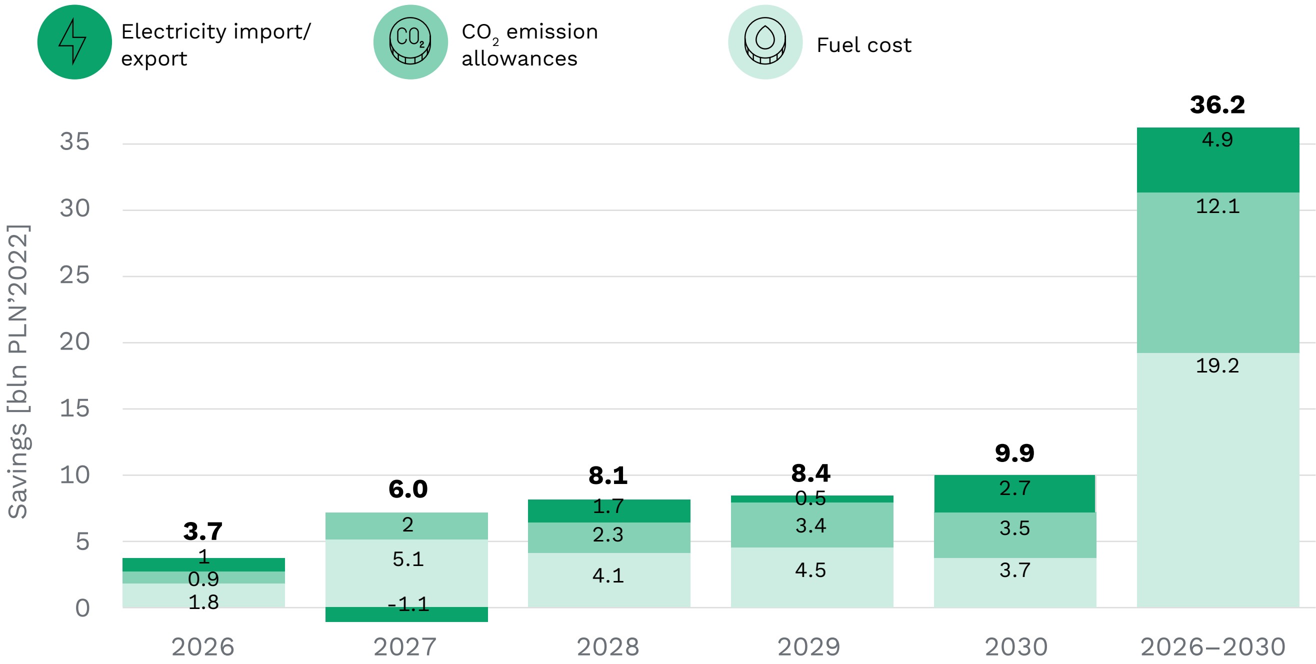
In total, they could amount to more than 36 billion PLN between 2026 and 2030 (Figure 5).

However, the high ambitions also mean high investments. The estimated difference in investment costs between the scenarios is about 90 billion PLN. Under the assumptions of a constant annual level of savings after 2030 (i.e., about 10 billion PLN per year), the investment in additional RES capacity could be recovered as early as 2036. That is long before the end of their service life. The costs of expanding the power grids need to be added, which will have to be incurred anyway in the perspective of extensive electrification.

Cheap energy from RES will also be needed to fuel the electrification of transportation and heating, which will reduce dependence on imported oil or thermal coal. In both scenarios, the average annual wholesale price of electricity falls sharply thanks to the RES development. In the high ambition scenario, the price could even be as low as PLN 408/MWh in 2030. This is PLN 75/MWh less than in the medium ambition scenario (Figure 6). However, it should be noted that the price of electricity for final customers may not necessarily exhibit such a spectacular decrease. One important reason for that will be an unavoidable increase in transmission and distribution fees used to finance the grid development.

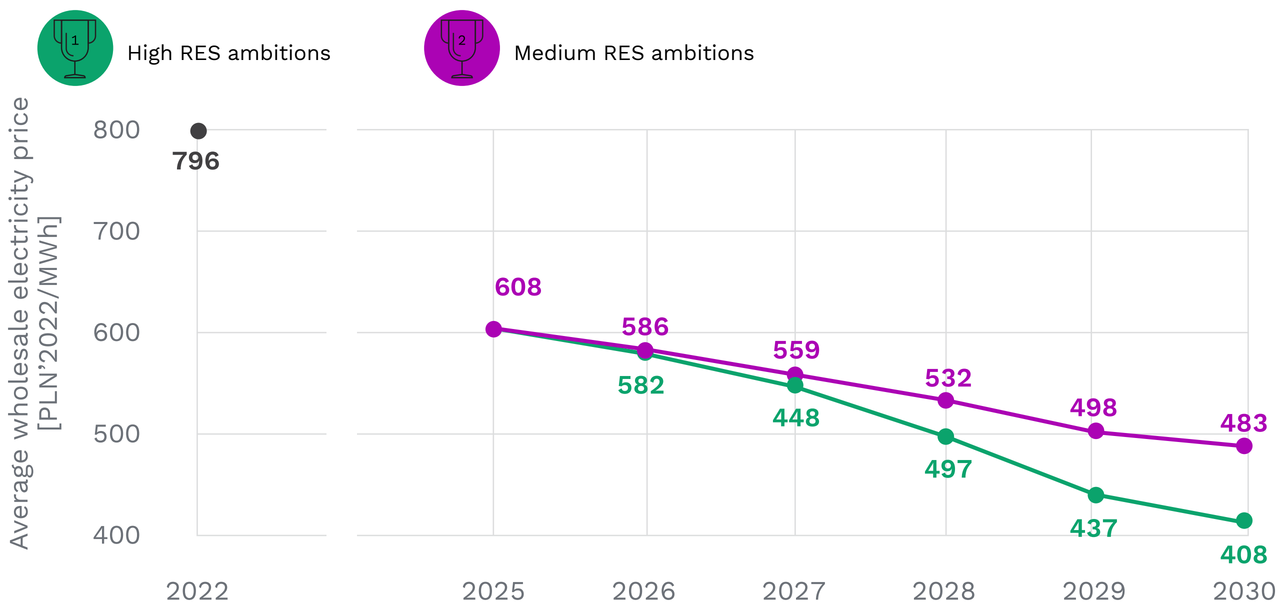
6 The actual share of RES in satisfying the country's electricity demand, with the rate of RES development assumed in both scenarios, may be lower than the modelling results due to additional technical constraints (related to grid and generating units). Higher demand for electricity resulting from faster development of electromobility, electrification of heating, or green hydrogen production may also have an impact.

FIGURE 5. Difference in fuel costs, emission allowance fees, and electricity trade balance between medium and high ambition RES scenarios



Source: Instrat's own analysis based on PyPSA-PL simulations and price assumptions.

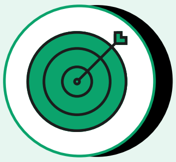
FIGURE 6. Scenarios for the average annual wholesale price of electricity



Source: Instrat's own analysis based on PyPSA-PL simulations and price assumptions (from 2025 to 2030) and historical data from TGE (Power Exchange in Poland) for 2022 (TGE, 2023). Prices for the period 2025-2030 reflect the resulting structure of electricity production in both scenarios and price assumptions, provided that the pricing mechanism is a merit order based on short-term marginal costs. The results are not a full simulation of the energy market and do not constitute a price forecast.

4. Conclusions

Poland needs a transition that includes all three pillars of weather-dependent renewable energy – solar, offshore wind and onshore wind power. The Polish government should first remove artificial legal barriers, and streamline the entire bureaucratic process associated with new investment in renewable energy. This would respond to the expectations of Polish industry, municipalities, and civil society. Such actions would also be in line with the direction indicated by the REPowerEU package. Despite the financial and technical challenges, it is essential to accelerate the modernisation of power grids, going even beyond the plans expressed in the recent agreement of the distribution system operators in Poland (URE, 2022b).

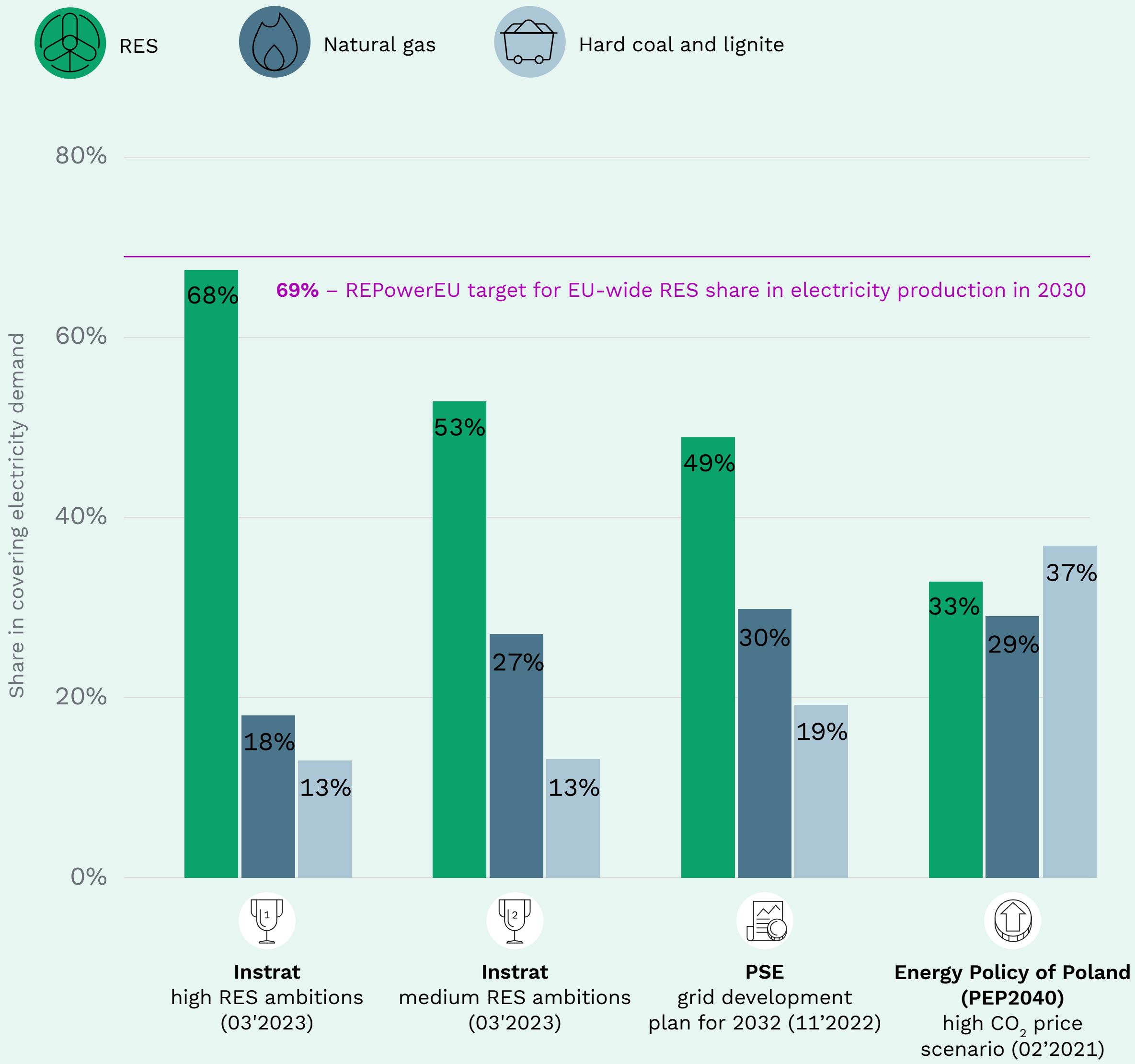


Targets for RES share in the power sector in 2030

The two scenarios analysed in this report go beyond the plan included in Energy Policy of Poland until 2040 by the Polish Ministry of Climate and Environment (MKiŚ, 2021), which assumed only a 33% share of RES in the power sector by 2030. PSE's transmission grid development plans indicate a possible 49% share by 2030–2032 (PSE, 2022).

According to an earlier analysis by Instrat, meeting the EU's target of a 40% share of RES in final energy consumption would require achieving more than a 60% share of RES in Polish power sector (Wrona, 2021). In the high ambition scenario presented in this analysis, Poland would meet this target. The share of RES in Polish power sector would be close to 69%, which is the overall EU target under the REPowerEU program (European Commission, 2022).

FIGURE 7. Share of individual energy sources in meeting the domestic electricity demand in 2030*



Source: Instrat's own analysis based on PyPSA-PL simulations and official documents from PSE (PSE, 2022) and the Ministry of Climate and Environment (MKiŚ, 2021).

*The Figure shows the production of energy sources as a percentage of demand (rather than total production) to offset the impact of electricity import on the result.

5. Selected methodological remarks

The process of scenario-building and modelling the power system requires:

- making a number of methodological assumptions,
- establishing a uniform interpretation of physical and monetary quantities,
- appropriate selection of data sources.

In this part of the report, we present selected methodological details to help interpret our results.

- **Our scenarios are not forecasts – we do not assess the likelihood of their realisation in the face of complex social and political conditions.** The model indicates the cost-optimal production structure, taking into account, among other things, assumed emission allowance prices (they are the main factor reflecting the level of climate ambitions). Under current assumptions, the high ambition scenario presented here would allow the Polish power sector to contribute to the current EU reduction targets for 2030. However, it is not sufficient to limit global warming to 1.5°C compared to the pre-industrial era (Wilson et al., 2021).
- We express all monetary values in 2022 real prices. Conversions between currencies are made based on average annual exchange rates (for 2022: EUR 1 – PLN 4.69, USD 1 – PLN 4.46).
- We express electricity production in net values, ignoring the electricity needed for the operations of conventional power plants. We assume net annual demand for electricity according to PSE's forecast in the high demand growth variant (PSE, 2022). Installed capacity is the nominal capacity at the end of the year corresponding to the gross value – for the purposes of the simulation, the net capacity is estimated through multiplication by a technology-specific factor.
- In our modelling, we do not assume the need for so-called base load of conventional units beyond the must-run operation profile of coal and gas-fired combined heat and power plants (estimated based on analysis of historical correlations of their utilisation with air temperature and domestic power load) and industrial power plants (continuous production at a constant level). This deviates fundamentally from the current assumptions of transmission grid operator PSE, which involve 7–9 GW of system technical minimum resulting from the need to maintain grid

operating parameters, such as frequency and voltage (wnp.pl, 2023). However, based on observations of the grid development plans in other countries and on the expert literature, we believe that the technical minimum for necessarily functioning conventional units can be significantly reduced (Denholm et al., 2020). For the purposes of the simulation, we assume that solutions in this direction will be implemented as early as 2025–2030. However, specific technical requirements (other than an hourly reserve power of 9% of consumption) are not explicitly represented. Any requirement for a non-zero base load provided by conventional sources will reduce the share of RES in the electricity generation mix.

- For 2030, for all generating units we optimize the annual operating costs, and for onshore wind turbines, photovoltaics and CCGTs, in addition, we optimize the fixed costs and total investment costs converted to an annuity (at a discount rate of 3%), with capacity growth constraints specific to the scenario. For 2025–2029, we only optimise operating costs, and installed capacity is based on our assumptions about the rate at which we will reach the 2030 capacity targets. The operating profile of combined heat and power plants, industrial power plants and run-of-river hydropower plants is forced and not subject to optimisation. In addition, as a result of the public support scheme for biogas and biomass-fired units, we assume that there will be a significant increase in their capacity (by an additional 1.5 GW in total between 2026 and 2030). We also assume that their average annual capacity utilisation will reach no less than 80% of technical capacity.

- Our assumptions of long-term (2030) prices for energy carriers and ETS allowance fees are based on the Announced Pledges scenario from the World Energy Outlook 2022 publication (IEA, 2022). The natural gas price for 2025 corresponds to the current price of TTF contracts for that year (ICE, 2023). The remaining prices result from a linear interpolation of 2022 prices and 2030 assumptions (Table 1). Assumptions regarding generation technology characteristics and associated costs are based on data from the Danish Energy Agency (DAE, 2023), as shown in Table 2.

TABLE 1. Price assumptions for key variable costs of electricity generation

Price	2022	2025	2026	2027	2028	2029	2030
Hard coal (PLN/GJ)	20	17	16	14.9	13.9	12.9	11.9
Lignite (PLN/GJ)	17.4	15.2	14.5	13.1	13.1	12.3	11.6
Natural gas (PLN/GJ)	170.5	65.1	59.3	53.5	47.7	41.9	36
CO_2 emission allowances (EUR/t CO_2)	81	102.6	109.8	117	124.2	131.4	138.6

Source: Instrat's own analysis based on historical data, market data (ICE, 2023) and World Energy Outlook 2022 forecasts (IEA, 2022).

TABLE 2. Assumptions for investment optimisation

Technology	Investment cost (PLN million/MW)	Fixed cost (annual % of investment cost)	Variable cost (PLN/MWh)	Service life (in years)
Natural gas (CCGT)	4.2	1.9	23.6	25
PV utility-scale	2.5	2.2	0	37.5
PV rooftop	4.6	1.2	0	37.5
Wind onshore	5.9	1.2	7.8	28.5

Source: Instrat's own analysis based on data from the Danish Energy Agency (DAE, 2023).

- We assume that the pricing mechanism is a price stack based on short-term marginal variable costs, the so-called merit order – the wholesale price of electricity is determined by the instantaneous marginal cost of its production. The instantaneous unit cost of electricity import/export is equated with the instantaneous price of electricity in the domestic market.

- For the purposes of the simulation, we assume 50% availability of cross-border transmission capacity compared to the projected maximum values (ENTSO-E, 2023b). Hourly data on availability of weather-dependent RES and power load (as a percentage of annual demand) refer to 2012, which was a typical year in terms of weather. Differences in the optimal level of installed CCGT capacity and natural gas consumption between the analysed scenarios do not depend significantly on these assumptions.

- Hourly profiles of wind and solar power availability in neighbouring countries (and indirectly also in Poland) are based on the Pan-European Climatic Database (PECD) used for simulations by ENTSO-E (De Felice, 2022). The voivodeship-level profiles for Poland used in our model are based on the more granular data of the EMHIRES project (Gonzalez-Aparicio et al., 2021), which have been nonlinearly scaled so that the data agree with PECD data at the national scale. In addition, we assume that wind turbines built between 2021 and 2030 have, on average, a 20% higher capacity utilisation than those built until 2020.

- Installed capacity, hourly demand profiles and annual electricity demand in neighbouring countries are based on the National Trends scenario in the TYNDP 2022 Scenario Report (ENTSO-E & ENTSO-G, 2022). The hourly demand profile (as a percentage of total annual demand) for Poland corresponds to the 2012 historical profile (ENTSO-E, 2023a).

- Data on the current state of the Polish power system, as well as trends in its changes, are an original compilation by the Instrat Foundation based on data from institutions such as the Energy Market Agency (ARE, 2023), Polskie Sieci Elektroenergetyczne (Polish transmission system operator) (PSE, 2023b, 2023a), Energy Regulatory Office (URE, 2022a), Polish Society for Transmission and Distribution of Electricity (PTPiREE, 2023) and industry knowledge. The data reported by these institutions often diverge from one another, making it difficult to indicate a single most important source of information, and it becomes necessary to do our own analysis. For conventional units, we base our scenarios on energy.instrat.pl (Charkowska et al., 2022), and the assumed shutdown dates for coal-fired units are based on an algorithm similar to the one in our earlier publication (Czyżak, Wrona, 2021).

The source code of the PyPSA-PL v2 model and all input data used for the analysis presented here have been published in the repository https://github.com/instrat-pl/pypsa-pl/.

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