



# Modernising the European lignite triangle

Towards a safe, cost-effective and sustainable energy transition

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## Preface

Europe's top-three lignite countries are Germany, Poland and the Czech Republic, Europe's coal triangle. Over the last dozen or so months, national discussions on the gradual phasing out of lignite have accelerated in these countries. The German Coal Commission proposed to close all hard coal- and lignite-fired power plants by 2038 at the latest, and the German parliament adopted this plan. A Coal Commission was also set up in the Czech Republic. By the end of the year, it will determine when the Czech Republic will exit coal. In Poland, no official talks are yet underway, but many discussions are taking place in view of the country's dwindling lignite reserves.

But looking at national phase-out plans individually is not enough, since the interconnected EU energy systems are interdependent. On account of energy prices, flows and CO<sub>2</sub> emissions, energy sources and the specificity of their use are important for the whole region. The move away from coal in one country may not lead to a drop in emissions if neighbouring countries continue to produce energy from the coal. It is important, therefore, to coordinate energy policy between countries.

An important background to this discussion is the decision by the European Council in December 2019 to make the European Union climate-neutral by 2050, the key policy goal of its European Green Deal 2030 strategy. The COVID-19 pandemic has only reinforced the urgency of the strategy. EU Heads of States have agreed that the European Green Deal is one foundation of the post-COVID 19 economic recovery. Despite the recession, the European Commission under the leadership of Ursula von der Leyen will present a comprehensive plan to increase the EU's climate target to at least 50% and as much as 55% by 2030. This will inevitably require a faster lignite phase-out than previously planned because of all the fossil fuels lignite is the most CO<sub>2</sub>-intensive.

More than ever, discussion is now needed on how to transform Europe's lignite triangle and initiate a planned exit from coal.

We wish you a pleasant read.

**Dr. Joanna Maćkowiak-Pandera,**  
President of the Forum Energii

**Dr. Patrick Graichen,**  
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# 1. Introduction

## 1.1. Background of the study

Energy in Europe is changing. The last five years have brought more change than the past five decades. At the heart of this transformation is the drive to reduce CO<sub>2</sub> emissions and the need to replace generating units amid increasing demand for electricity.

The technological environment and beliefs about the energy sources of the future are also changing. Electricity has now become the future of many economic sectors – transport, heating, industry.

When investing in new infrastructure, we usually assume that it will be used for several dozen years, but the end of fossil fuels is already in the offing. National and EU regulations stipulate specific dates for eliminating coal and even natural gas. The reason for the departure from fossil fuels is not only climate action, however. There are many other pragmatic reasons why individual countries have decided to implement plans for a deep energy transformation:

- **The energy-market structure.** In Europe's power market, the technologies that have the lowest marginal costs occupy a privileged position. Renewable sources, mainly wind and sun, have a near-zero marginal cost, because they bear neither the cost of fuel nor of buying CO<sub>2</sub> certificates. From the investors' perspective, the focus on renewables, therefore, eliminates two important risk factors.
- **The need to reduce CO<sub>2</sub> emissions.** Coal, especially lignite, is the most carbon-intensive energy source. For this reason, there's increasing pressure to move away from its use. The programme to rebuild the EU economy after the COVID crisis aims at reducing emissions and will make this a condition for assistance. Without public support, mining will plunge into crisis and public funds will be spent even more judiciously than before. The EU offers aid for the fossil fuel sector such as the Just Transition Fund, provided that the transformation is planned and climate neutrality is achieved.
- **The high price volatility of energy resources.** The EU has limited fossil-fuel resources. The prices of hard coal, gas and oil are subject to global price fluctuations, destabilizing investment, ravaging fuel sectors in various countries and, in the long run, limiting supply. Since the beginning of 2020, oil prices have fallen by 67%, gas by 40% and coal by 14%. Lignite is less subject to these trends, but its production costs are highly dependent on changes in CO<sub>2</sub> prices. The volatility of all these prices means that the market is highly unpredictable.
- **The lack of social acceptance and economic justification for new lignite openings.** Current lignite deposits in Germany, Poland and the Czech Republic are likely to be exhausted in about 10–15 years. Theoretically, it is possible to open new deposits, but the costs would be high and the competitiveness of electricity produced from coal is falling. At the same time, there is increased public awareness of environmental effects such as record-low groundwater levels, competition with agriculture, permanent land transformation and the impairment of natural habitats. While some local communities may find employment in such investment, most people's living conditions will change significantly.
- **The costs of RES technology.** The existing alternatives put pressure on investment. 30 years ago, coal was the primary power source in all three countries. Now the costs of renewable sources are falling – photovoltaic costs are on average 90% less than five years ago, and the productivity of wind energy is increasing as well. The variability of these sources is a challenge for the power system, but every year knowledge of renewable technology increases, while regulations, grid codes and balancing models are moving towards greater market flexibility by adapting conventional sources to variable work.

As all these factors indicate, lignite is a declining industry, and its phase-out needs to be dealt with in a planned manner. Addressing the issue in the lignite triangle – Germany, Poland and the Czech Republic – will be important for the entire EU.

Currently, each of these countries is pursuing a different strategy:



The Germany has engaged in dialogue with its Coal Commission and has already decided to phase out coal by 2038. According to the plan, lignite plants will remain in the energy mix into the 2030s. Amid low gas prices and rising prices for CO<sub>2</sub>, lignite is coming under increasing pressure and might exit the energy system much sooner.



The Czech Republic has also established a Coal Commission; by the end of 2020, it plans to announce the date of its coal exit.



Poland is talking about opening new plants as it struggles with its own energy problems. But it has made no decisions about the fate of its lignite power plants, including the one in Bełchatów, the largest in the world and projected to close within 10 years.

Questions arise in each of the coal triangle countries: How will eliminating coal affect energy supply security? What will happen if Germany or the Czech Republic phases out coal and Poland does not? Conversely, what if Poland makes strategic decisions and the others delay theirs? How will energy prices develop? What energy sources can replace coal? These are questions this report will address.

## 1.2. Objective of the study

The aim of the study is to look at the effects of the withdrawal from lignite in Poland, the Czech Republic and Germany in parallel. We assess the consequences for power engineering and answer the following questions:

1. How will the security of supply be ensured after lignite power is shut down?
2. Who will be an importer and who will be an exporter of electricity in the region? How will electricity flows change?
3. How will CO<sub>2</sub> emissions change?
4. What will be the costs of eliminating coal from the energy mix and how will it affect wholesale energy prices?
5. Is it possible for the countries of the coal triangle to phase out lignite in parallel? Is it necessary?

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## 1.3. Organisation of the study

The study consists of the following parts:

- 1) EU energy and climate goals; analysis of Member States' regulations.
- 2) Development of the reference scenario for the EU electricity market with a special focus on the Czech Republic, Germany and Poland. In this scenario, we take into account the current objectives for the development of the electricity mix.
- 3) Preparation of two additional scenarios, one assuming a faster withdrawal (2035 or 2032) in the coal triangle and one a joint withdrawal.
- 4) Development of assumptions regarding technical and economic parameters of various technologies and prices (fuel and CO<sub>2</sub>).
- 5) Hourly simulations of interconnected power systems; cost optimization.
- 6) Results by country.
- 7) Summary and future action plan.

## 2. Executive Summary

The electricity systems of the European Union countries are interconnected by a common energy market. This means that changes in national energy mixes mutually affect security of supply, CO<sub>2</sub> emissions and electricity prices in the region.

One of the most urgent climate problems in the EU is the production of electricity from lignite, which emits more CO<sub>2</sub> than any other fossil fuel. Our report examines the three countries in Europe that burn the most lignite: Germany, Poland and the Czech Republic, known collectively as the coal triangle. We consider the regional impacts resulting from the replacement of lignite in these countries with other, low-emission energy sources.

In this report, we present the effects of the early withdrawal of lignite-based power generation in Germany, Poland and the Czech Republic, as suggested by current forecasts. We compare three scenarios:

- **Baseline scenario.** This scenario is based on the current policies of each of the three countries of the coal triangle, combined with the economic simulation of investments.



**Germany** - The benchmark is the German Coal Phase-Out Act, i.e. the phasing out of both lignite and hard coal by 2038, with the goal of achieving a 65% share of renewable energy in the energy mix by 2030.



**Poland** - The Poland part of the baseline scenario is based on the "Energy Policy of Poland until 2040" (PEP 2040, November 2018). However, the scenario deviates from PEP 2040 in two ways: We do not include nuclear power generation capacity in the forecast and we use economic principles to estimate capacity decisions for both conventional and renewable units.



**Czech Republic** - The assumptions for capacity development are based on the Czech National Energy and Climate Plan and the capacity planning published by CEZ. The scenario deviates from the national plan with regard to the development of renewables in two ways: we assume faster development following market realities and no new nuclear plants due to costs.

- **Lignite decommissioning scenario in 2035.** This scenario assumes that lignite power plants in the three countries will be shut down by 2035. The difference in electricity production compared with the reference scenario will be complemented by renewable energy.
- **Lignite decommissioning in 2032.** This is the most ambitious scenario. It takes into account the megatrends and responds to the challenge of raising the 2030 climate target in the European Union. The differences in electricity production relative to the two scenarios are covered by renewables.

Detailed modelling and scenario assumptions are presented in the report. Below we present the most important conclusions.

**The decline of lignite is inevitable. Key decisions and coordinated regional action are needed.**

The share of lignite is already falling. Power plants are becoming less and less profitable, because their costs related to emissions of CO<sub>2</sub> and air pollutants are increasing. There is also increasing competition from sources without marginal costs, and to some extent, from natural gas. The time of coal-fired power plants are coming to an end, and many units are no longer profitable. These market trends need to be reflected in national strategies and coordinated in the countries of the coal triangle. It is worth synchronising dates between neighbouring countries in view of the EU's plan to significantly reduce emissions by 2030.



- In the reference scenario, which only takes into account current decisions in the three coal countries, lignite electricity production decreases by 40–50% by 2030.<sup>1</sup> After 2030, the process of shutting down lignite-fired power plants will accelerate dramatically due to the depletion of currently exploited deposits. An action plan needs to be developed now because there are less than 10 years left to close the generation gap.
- It is crucial to coordinate neighbourhood plans for several reasons:
  - a. The EU has committed itself to a significant reduction in CO<sub>2</sub> emissions by 2030. Coordinated, feasible and effectively implemented actions are, therefore, essential.
  - b. While the shutdown of individual power plants is the responsibility of the owner and system operator of a given country, the shutdown of several GW of power in multiple countries, including Bełchatów, the largest lignite unit in Europe, has to be planned and organised gradually. How the gap left by coal is filled is important because switching off the emitting capacity in one country could cause an increase in emissions in another.
  - c. Exhaustion of lignite deposits in Poland may take place faster than indicated by government documents. The departure from lignite differs from hard coal in that when deposits are depleted, production drops sharply.

**Security of supply in the region can be ensured even if we speed up the phase-out of lignite, but such a transformation requires a plan.**

The analysis shows that the majority of lignite units will become permanently unprofitable sometime during the second half of the 2020s and will have to be closed. In Poland, old lignite units will still benefit from subsidies from the capacity market until 2028. This means that decision-makers, regardless of whether they intend to adopt a coal exit strategy or not, will not escape the question of how to ensure security of supply and power adequacy in the system. Moreover, our study finds that it will be possible to close lignite power plants as early as 2032 without jeopardising security of supply provided that the replacement of generation capacity is planned and implemented well in advance. The available capacity could exceed peak demand in each of the three countries at any point in time. Some important factors to keep in mind:

- A prerequisite for an effective and significant reduction of CO<sub>2</sub> emissions is the replacement of the high-emission energy sources with low- or zero-carbon energy sources in each country. To this end, the carbon transition must be included in national energy and climate plans. A strategy is needed for the development of new energy sources through planned auctions and changes in the national energy market.
- The construction of new generation capacity has to take into account the different options available to the system. The options include not only new generation sources such as RES but also demand-side flexibility, storage and interconnection capacity.
- New CHP capacity meeting energy and heating needs will be needed in Germany and the Czech Republic, both of which use lignite in cogeneration.

<sup>1</sup> In the Czech Republic, electricity production from lignite-fired power plants will decrease from 30 TWh in 2020 to 18 TWh by 2030. In Poland, lignite production will fall from 49 TWh in 2020 to 29 TWh by 2030 (a drop of 40%). The decrease in Poland is also caused by the exhaustion of lignite reserves, which can be exploited in an economically justified manner. In Germany, power generation from lignite power plants will decrease from 196 TWh in 2020 to 99 TWh by 2030 (down 50%). The decrease in the role of lignite in the German mix is also due to the legally adopted closure path for coal-fired power plants.

- For the success of the energy transition, it is essential that the necessary investment in the energy sectors in Germany, Poland and the Czech Republic. Although there are mechanisms to support generation capacity in Germany and Poland (the strategic reserve and the capacity market, respectively), they can at most minimise the risk of power shortages. In fact, the Polish capacity market needs an urgent reform towards clean-energy support. Planning, permitting and construction of new generation capacity are long-term processes that need careful monitoring. This is especially important now as the economic crisis threatens to disrupt supply chains and significantly delay investment.

**A move away from lignite can significantly reduce CO<sub>2</sub> emissions in the region and in the EU.**

As our analysis shows, abandoning lignite-based power generation will significantly reduce CO<sub>2</sub> emissions. In the baseline scenario, emissions from the power sector could fall by 32% in the coal triangle, from a total of 448 million tonnes in 2020 to 302 million tonnes in 2030. It is already clear, however, that the phase-out will have to be accelerated considerably. The EU's current target is a 40% reduction in greenhouse gas emissions (relative to 1990 levels), which means a 43% reduction in the sectors covered by the ETS (relative to 2005). But the EU will need to increase its ambitions for 2030 in order to comply with the Paris Agreement. An earlier withdrawal of lignite than planned would significantly reduce CO<sub>2</sub> emissions from power generation in Germany, Poland and the Czech Republic.

The impact of faster action on lignite is shown in the lignite phase-out scenario in 2032. If lignite phase-out is accelerated and occurs in 2032, total power sector emissions in 2030 in the three countries will fall to 226 million tonnes, or by 50% relative to today's (compared with -32% in the baseline scenario). By 2040, cumulative CO<sub>2</sub> emission savings will be around 660 million tonnes of CO<sub>2</sub> over the baseline scenario.

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**Leaving lignite faster will not cost more.**

In the coal triangle, reducing the share of lignite in favour of renewable sources will either reduce wholesale electricity prices (Poland, Czech Republic) or maintain them (Germany). An earlier withdrawal of lignite, provided it is replaced by renewable sources, will also decrease wholesale electricity prices, because the operating costs of wind and solar power plants are much lower than conventional power plants.

- In Germany and Poland, wholesale electricity prices in the 2035 or 2032 decommissioning scenario are 3 EUR/MWh lower in 2030 than in the reference scenario.
- In the Czech Republic, phasing-out lignite by 2035 or 2032 leads to wholesale electricity prices that are 8 €/MWh lower than in the reference scenario.

Due to the high share of energy from renewable sources, the overall price level in Germany is lower than in Poland and the Czech Republic.

Similar conclusions apply to the total system costs. Due to the relatively low share of RES in the Polish and Czech electricity markets, system costs in the coal phase-out scenarios are lower on average by 0.1–0.4% (Poland) and 1.3–1.7% (Czech Republic) over 20 years. In Germany, system costs do not rise due to decreasing RES support.

**Accelerated withdrawal from lignite reduces electricity imports.**

The structure of the energy mix in the coal triangle has a significant impact on the level of imports and exports. The analysis shows that a faster withdrawal from lignite and its replacement with renewable energy sources decrease electricity imports both in Poland and the Czech Republic:



**In Poland**, electricity imports in the decrease from 11 TWh in 2030 in the baseline scenario to 6 TWh in 2030 under the 2032 decommissioning scenario.



**In the Czech Republic**, electricity imports decrease from about 5 TWh in 2030 in the baseline scenario to almost zero in 2030 in the phase-out scenario.



**In Germany** the trade balance is similar in all three scenarios because its RES share is already significant in the reference scenario. In fact, Germany already exports much more electricity than it imports.

**Date of lignite exit: 2032 is realistic.**

Our study finds that eliminating lignite in the region by 2032 is realistic. Poland's lignite deposits are mostly depleted and market forces will push carbon-intensive units out of the market across the EU. Lignite-fired power plants in many countries are already unprofitable, so instead of constantly paying extra for them, decisions must be made that transform the power industry – creating the needed capacities and safeguarding energy security. This is why it is necessary to coordinate the policies of the coal triangle countries.

**To phase out lignite successfully, an alignment of strategy is necessary.  
This includes the future role of gas in the system.**

Our study finds that the amount of electricity produced from natural gas will need to increase somewhat. But the use of natural gas, though less emission-intensive than other fossil fuels, must still be reduced in order to achieve climate neutrality. Moreover, natural gas must still be imported, although the diversification of suppliers has increased in recent years due to significant improvements in the integration of the European gas market and due to access to the liquefied natural gas (LNG) market.

Despite the need to expand gas capacity, discussions are needed to prevent the energy system from becoming larger than needed. Investing in natural gas is only justified if it can be replaced by green gas in the future. At the same time, achieving the positive effects of a more rapid elimination of lignite (lower imports, lower wholesale prices and system costs) is possible only if RES is the primary alternative.




### 3. Scenario design, model, and assumptions

#### 3.1. Scenario design

In the present study, we analyse three scenarios for each country: a reference scenario, which is broadly based on current government policies, combined with an economic simulation of investment decisions; and two lignite phase-out scenarios, in which lignite leaves the system by 2035 and 2032, respectively. This section explains the scenario set-up in detail.

**Reference Scenario.** In the reference scenario, the development of the power system in each country is based on announced policies relating to either coal or renewables as well as market economics.

Table 1. National energy strategies

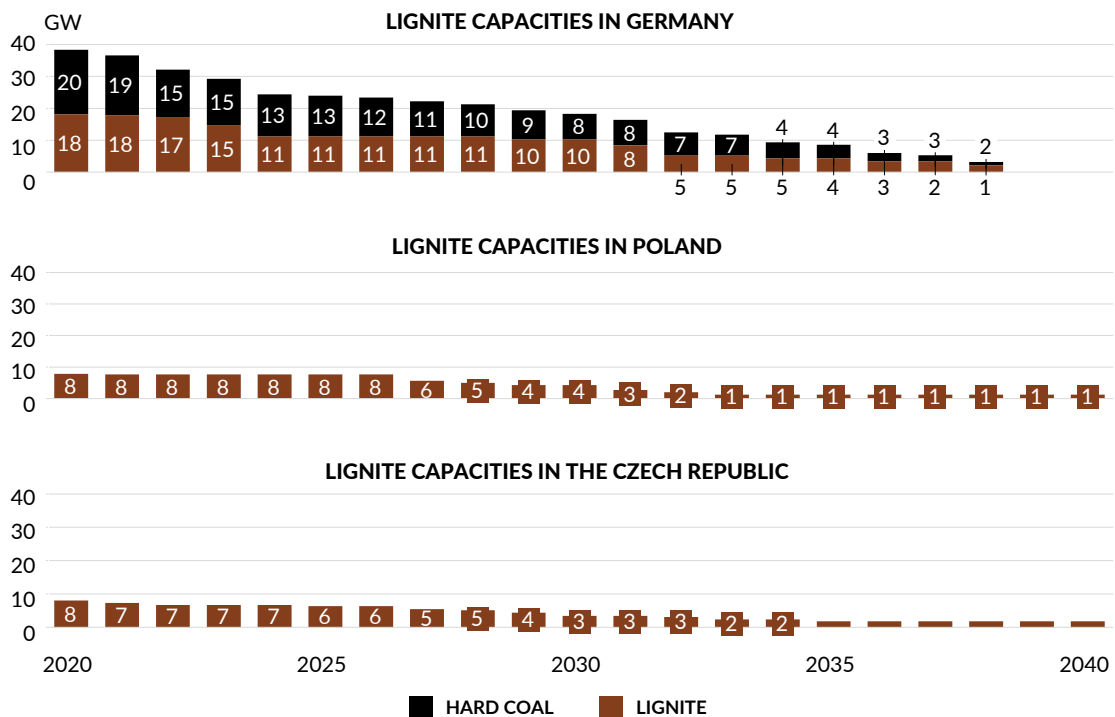
 Germany	 Poland	 Czech Republic
<p>In Germany, both lignite and hard coal plants are phased out in accordance with Germany’s coal phase-out plan, as proposed by the Coal Commission in early 2019. Additionally, we further incorporate the government’s 65% RES target by 2030, which has also been endorsed by the Coal Commission. In the following years, political support further increases the share of renewables in the power sector to 80% in 2040.</p>	<p>The reference case in Poland is defined partly by the “Energy Policy of Poland until 2040” (PEP 2040) draft released in late 2018, but it is more strongly guided by the likely economic evolution of the system. The PEP 2040 draft outlines the path that the Polish Ministry of Energy expects the Polish energy sector to head and lays out long-term capacity projections for the power sector. We deviate from the PEP draft in not including nuclear in our capacity forecast (for technological and economic reasons outlined below) and in allowing for capacity decisions on an economic basis for both conventional and renewable capacities. The updated PEP draft from November 2019 also plans to open two new mines. We deviate from this view as we do not believe that the economic and political environment is conducive for new mine openings.</p>	<p>In the Czech Republic, assumptions regarding capacity development rely on the country’s National Energy and Climate Plan (NECP) as well as on published capacity planning by ČEZ, the largest lignite plant operator. However, in our view, the NECP takes an unrealistically conservative view regarding the development of intermittent renewables. We therefore include more ambitious projections, which we confirmed in conversations with market participants.</p>

Source: Aurora Energy Research.

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The construction of subsidy-free renewables, thermal capacities, and flexible technologies across all countries are made on an NPV basis if discounted future market returns allow for it.

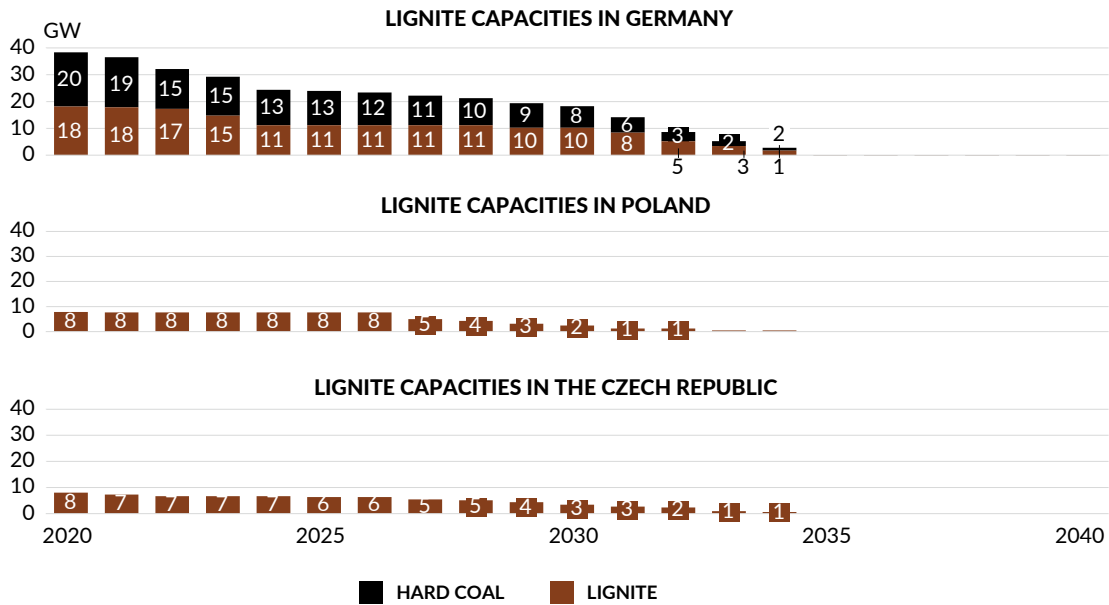
Exhibit 1: Development of lignite capacities in the reference scenario



Source: Aurora Energy Research.

**Lignite phase-out 2035 scenario.** In the Lignite phase-out 2035 scenario, the lignite fleet in each respective country is expected to go offline by 2035. The difference in power production compared to the reference scenario is replaced entirely by renewables assuming a 50-50 split between onshore wind and solar. In light of the existing plans to phase out coal in Germany, we assume that hard coal will be phased out at the earlier end of the 2035–2038 timeframe proposed by the Coal Commission. The phasing out of hard coal in Poland and the Czech Republic follows the same economically driven trajectory as in the reference scenario.

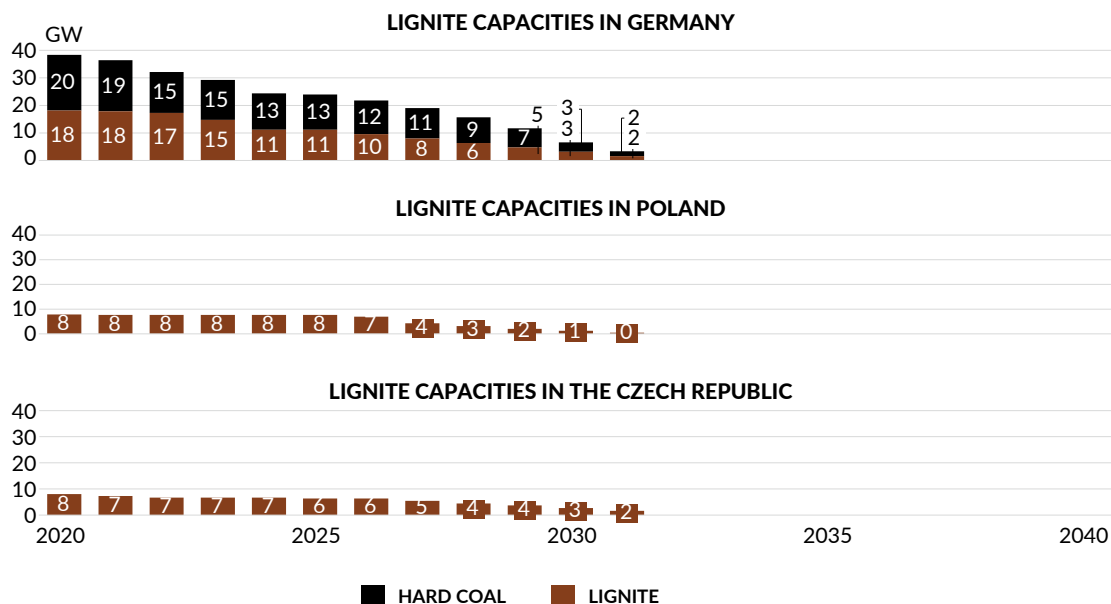
Exhibit 2: Development of lignite capacities in the 2035 lignite phase-out scenario



Source: Aurora Energy Research.

**Lignite phase-out 2032 scenario.** In the lignite phase-out 2032 scenario, the pace of phasing out lignite plants is further accelerated. By the end of 2032, all lignite-fired power plants in Germany, Poland, and the Czech Republic are decommissioned. Like the 2035 scenario, the difference in power production will be fully replaced by renewables assuming a 50-50 split between wind onshore wind and solar. In line with the accelerated decommissioning of lignite-fired capacities, hard-coal plants in Germany are also phased out by 2032. The decommissioning of hard-coal capacities in Poland and the Czech Republic once again follow the trajectory in the reference scenario.

Exhibit 3: Development of lignite capacities in the 2032 lignite phase-out scenario



Source: Aurora Energy Research.

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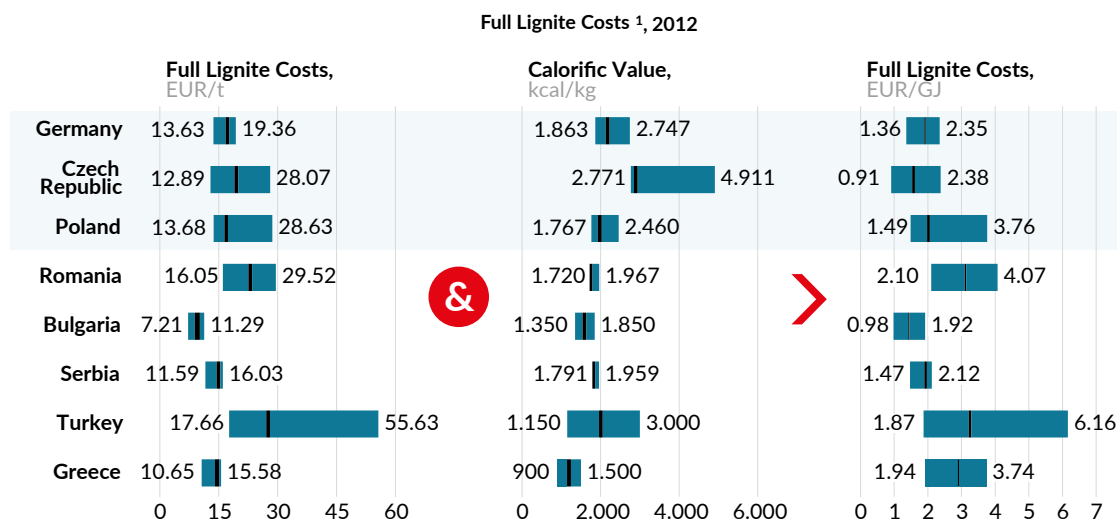
### 3.2. General assumptions

#### 3.2.1. Commodity prices

The price trajectories here represent long-term trends. Short-term disruptions following, say, environmental or political events are always possible.

**Lignite prices.** For the modelling, we assume constant variable lignite fuel costs of 1.76 EUR/MWh<sub>th</sub>. This simplification is an average value considering the abundance of lignite reserves and the limited influence of fuel costs in lignite power generation.

Exhibit 4. Components of lignite costs for the three countries.

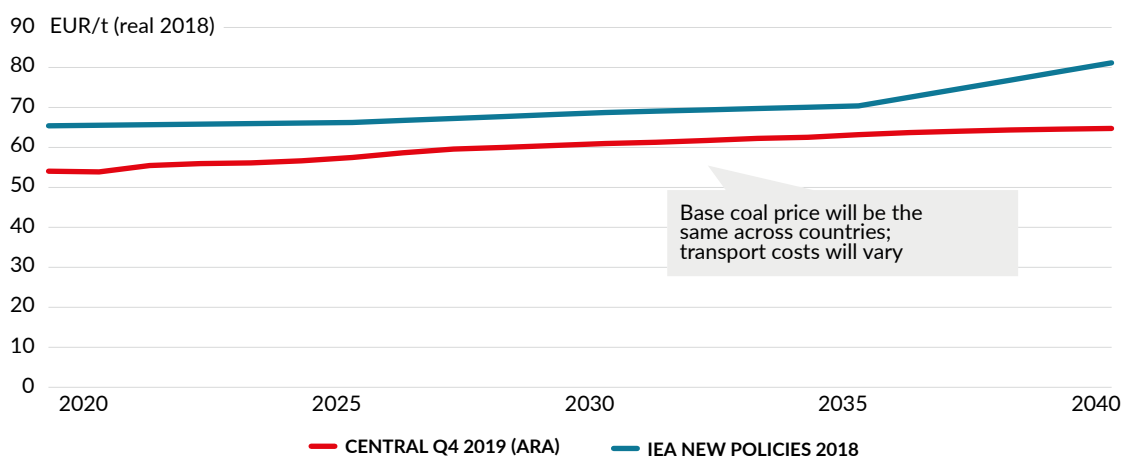


Source: Euracoal, IEA, Eurostat, Annual reports, Debriv, Statistical Office of Serbia, Turkish Statistical Institute, Niemann-Delius i inni, Achlada, M.E.T.E, PPC, Booz & Company.

Lignite prices differ between regions and even mines, due to the high variation in calorific value, both labour costs, and intensity. This is shown in Exhibit 4. In terms of the lignite price per tonne, all three countries score rather high in a European comparison.<sup>2</sup> However, since all of them also display an above-average calorific value, the full costs (i.e., including mining costs, depreciation and cost of capital) per GJ energy are between 0.91 EUR and 3.76 EUR (or 3.28 EUR/MWh<sub>th</sub> to 13.54 EUR/MWh<sub>th</sub>). Because the weighted average of total costs are comparable in the three countries, we model them with uniform lignite prices.

**Hard-coal prices.** Excluding transportation costs, ARA coal prices are expected to fall to 54 EUR/tonne in 2020, before increasing to 61 EUR/tonne in 2030 and 65 EUR/tonne in 2040. This is illustrated in Exhibit 5. We assume the ARA coal price plus transportation costs for each country to determine the price at which domestic producers can sell their coal.

Exhibit 5: Average annual coal prices at ARA without transportation costs through 2040



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Source: Aurora Energy Research, IEA World Energy Outlook, 2018.

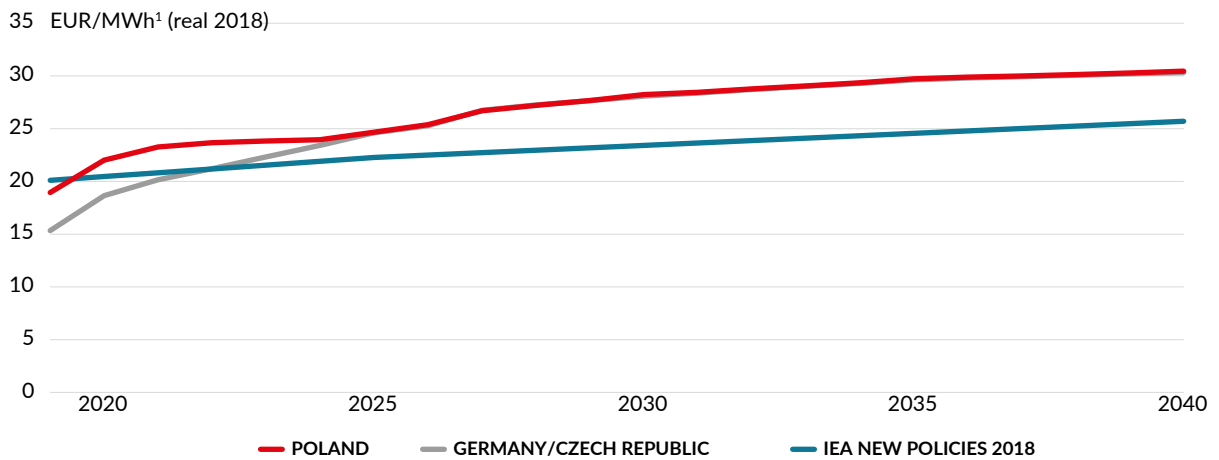
1) Hard coal price refers to the Amsterdam-Rotterdam-Antwerp coal price. For years 2018-2024, the prices shown with decreasing weight take into account current futures prices for the years in question.

The trajectory for coal prices reflects declining coal consumption in most regions of the world outside of Africa and Asia. In the global coal market, the growth in both production as well as consumption is driven primarily by India. African consumption is also projected to rise throughout the projected horizon. By contrast, many developed countries such as Australia, New Zealand, the UK, France, and Germany aim to phase out coal-fired power generation and reduce its role in manufacturing. This will result in a decline in the consumption of both thermal and coking coal, thereby partly mitigating the increase in prices. On the supply side, Chinese production is expected to decline due to cuts on the supply side. In parallel, the production of coal in the US and Russia are expected to decrease due to increasing extraction costs that reduce export competitiveness.

These underlying drivers are considered in other price projections such as those of the IEA. Compared with the IEA's New Policies Scenario, we expect a stronger coal-to-gas switch, leading to lower demand and thus lower prices than in the NPS.

**Natural gas prices.** In 2020, natural gas prices in the Czech Republic and Germany are expected to be 19 EUR/MWh, compared with the 22 EUR/MWh in Poland. This is illustrated in Exhibit 6.

### Exhibit 6: Natural gas price forecast



Source: Aurora Energy Research, TGE.

1) Given as High Heating Value MWh 2) GAS BASE futures for Polish TGE market average of October 2019 contracts.

Irrespective of this difference, the early 2020s see an oversupply of natural gas in the market, which dampens the price of natural gas. This is largely due to a wave of new LNG liquefaction plants coming online, spare production capacity in Russia, and a relatively warmer winter in Europe and Asia. By the mid-2020s, the price of natural gas in Germany, the Czech Republic, and Poland is expected to approach 25 EUR/MWh. We expect gas prices in Poland, the Czech Republic, and Germany to converge with the installation of the Baltic pipe and better integration of European gas markets.

Over the projected horizon, gas prices increase, reaching 30 EUR/MWh (the long-term delivery costs of LNG) in 2030. During this period, local production of natural gas in Europe is expected to decrease and be replaced with Russian and Norwegian pipeline imports and LNG production.

The price trajectory shown in Exhibit 6 reflects an increase in natural gas demand from Asia, which results in natural gas prices rising globally. Further exacerbating this trend is the global rise in oil prices, which will increase costs for suppliers in the oil and gas supply chain. This is expected to shift the underlying cost structure of the gas industry and increase the natural gas price in the medium-to-long term. Nearing the end of the projected horizon, the price of natural gas in Europe will increasingly be set by US LNG, resulting in Northwest European prices for natural gas to converge towards that of Asia's.

Compared with the IEA, we see a stronger coal-to-gas switch, resulting in more demand for gas. Our price projections are therefore higher than those in IEA's New Policies scenario.

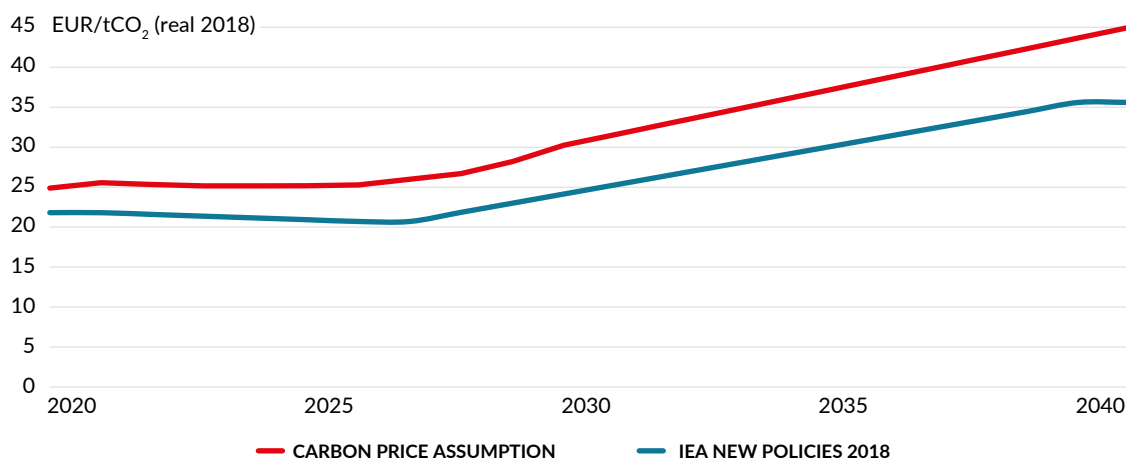
**Carbon prices.** Carbon prices are expected to increase from 26 EUR/tCO<sub>2</sub> in 2020 to 32 EUR/tCO<sub>2</sub> and 45 EUR/tCO<sub>2</sub> in 2040. The steeper price increase in the late 2020s is a market response to the anticipated tightening of the EU ETS in Phase V, which begins in 2031.

The price trajectory for allowances illustrated in Exhibit 7 takes into account the existing EU target to achieve a 40% reduction in overall emissions by 2030 (relative to 1990 levels) and a 43% reduction of emissions in sectors covered by the EU ETS (relative to 2005). The ramping-up of targets to either 50 or 55% as planned by the incoming European Commission is not yet reflected in this price trajectory and could lead to significantly higher carbon prices. Compared with the IEA New Policies scenario, we project higher prices for emission allowances. The IEA scenario starts at a lower point as its 2018 forecast does not take into account the most recent price increase.



To allow for a better comparison among the scenarios, we assume carbon prices across scenarios to remain identical, although the phasing out of coal across the three scenarios could result in the freeing up of emission allowances. This would involve the government calculating the emissions that are saved by the coal exit measure, including interactions with other thermal plants (e.g. gas plants running more) and other power markets (e.g. a country importing more during certain hours), and retiring this number of EUAs. Hence, we assume that the net amount of freed carbon certificates will be removed from the market, which keeps carbon prices identical between the scenarios.

Exhibit 7: Annual average price of EUAs



Source: Aurora Energy Research, IEA, World Energy Outlook 2018

We assume governments will cancel the European emission certificates as they phase out coal, thereby preventing a negative effect on EUA prices.<sup>3</sup> Without cancellation, the emission savings from the coal exit measure will fall. How much is difficult to quantify ex ante: some estimates indicate that most of the emission savings would still be effective, because the newly introduced Market Stability Reserve (MSR) will cancel all EUAs in the market that exceed the amount that was issued in the previous year.<sup>4</sup> Others expect that additional EUAs from a coal measure could be consumed before the MSR, which acts with a delay.<sup>5</sup>

### 3.2.2 Interconnection

The buildout of interconnection between EU states is a central EU energy policy topic to allow for better power market integration. For this study, we assume the future baseline maximum available interconnection capacity in each country to be equivalent to the average of its past monthly auctioned capacities. To reach the maximum monthly historical value, this baseline is linearly scaled up until the early 2020s. Additionally, new capacities corresponding to projects listed in ENTSO-E's Ten-Year Network Development Plan are de-rated so as to account for the probability of completion, and further added to the baseline.

The assumed available interconnection capacities between Germany, Poland, the Czech Republic, and each country's neighbouring countries are displayed in the following Exhibit.

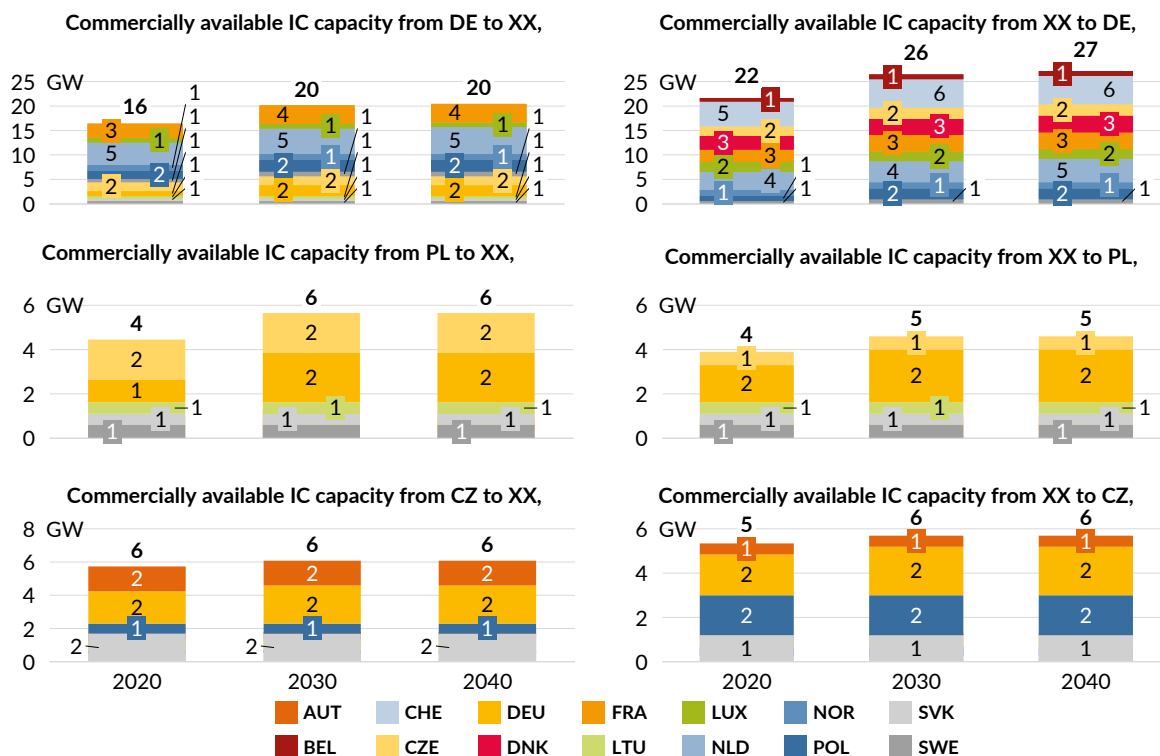
<sup>3</sup> To maximize the impact of the measure, the certificates that exit the market should be eliminated. In the context of phasing out lignite in all three countries, it would be sensible to agree on a unified approach for calculating and retiring excess EUAs. One approach for cancelling surplus certificates would be to reduce the ETS cap, which is currently being discussed as part of the European Commission's new EU 2030 climate target of 55%.

<sup>4</sup> Agora Energiewende & Öko-Institut, 2018.

<sup>5</sup> Pahle, Edenhofer et al., 2019

Due to uncertainty regarding national implementation, these projections do not yet include the 70% interconnector availability target introduced under the Clean Energy Package<sup>6</sup>. Furthermore, implementing this target will tend to facilitate the phase-out of lignite capacities and the system integration of renewables, making the present study a conservative estimate of the system impact of a lignite phase-out.

Exhibit 8: Interconnector capacities for Poland, Germany, and the Czech Republic

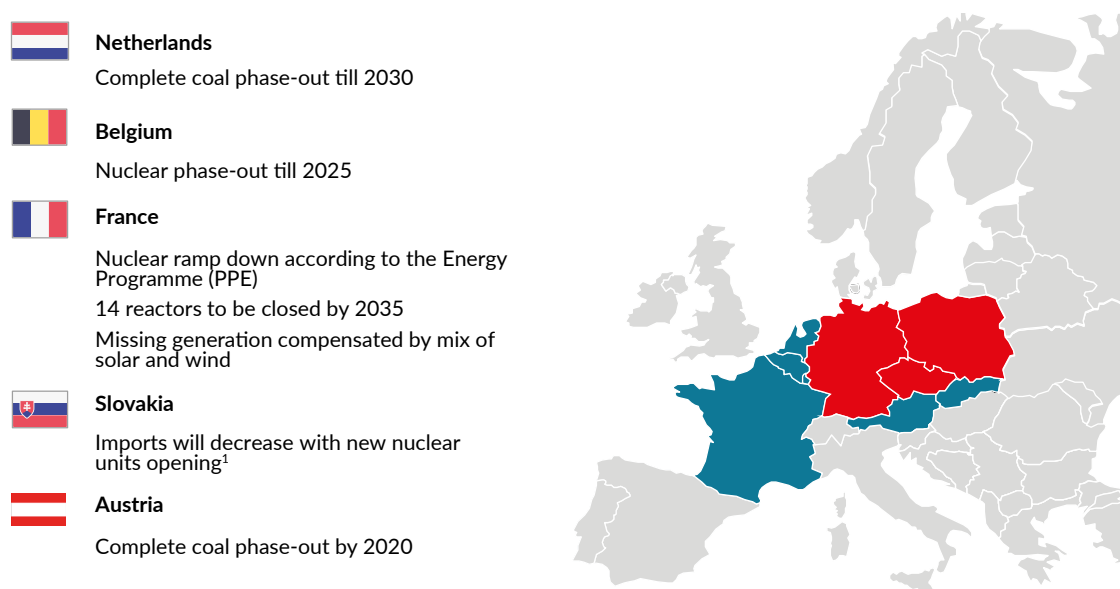


Sources: ENTSO-E, Aurora Energy Research.

### 3.2.3. European power market

Because policies in neighbouring European countries have an impact on the power markets in Germany, Poland, and the Czech Republic, we account for recent political developments in the Netherlands, Belgium, France, as well as Slovakia and Austria. This is displayed in Exhibit 9.

Exhibit 9: Further input assumptions in key neighbouring countries



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Source: Aurora Energy Research.

1) Assuming that Mochovce 3 & 4 (942 MW) units to be commissioned in 2021 and no further ones to be developed.

Under existing regulations, conventional capacities with low marginal costs are expected to leave the system in the Netherlands, Belgium, and France, while Slovakia has plans to increase those capacities with the addition of new nuclear units. As it stands, the commissioning of Mochovce 3 and 4 in 2021 is expected to add 942 MW of capacity to the Slovakian power system, thereby reducing the amount of imports to the country. By contrast, France and Belgium both have plans to ramp down nuclear generation. According to the Energy Programme (PPE), 14 reactors in France are expected to be shut down by 2035. The gap in generation is expected to be filled with a mix of wind and solar generation. Belgium is expected to phase-out nuclear by 2025. The Netherlands and Austria are expected to phase-out coal by 2030 and 2020, respectively.

### 3.2.4. System adequacy

In the modelled scenarios, there is no unserved load in any of the countries in the study, since sufficient capacity is built to meet peak residual load. This is a model result rather than an assumption. However, it relies on 2013 as an exemplary weather and demand year. Also, the model does not formulate minimum requirements for dispatchable generation other than that demand has to be met in every hour. This is because we expect that ancillary services can increasingly be fulfilled by non-conventional generation such as batteries or renewables.

A more sophisticated analysis on supply security would rely on estimating the Loss of Load Expectation (LOLE). Using probabilistic modelling, this would result in the number of hours in a given year for which the available generation capacity is expected to be insufficient to meet demand, and by how much. The analysis would be carried out across a large number of weather years combined with different demand years and stochastic plant outages. While this was beyond the scope for this particular study, such modelling could be conducted in the future.

### 3.3. Country-specific assumptions

#### 3.3.1. Germany

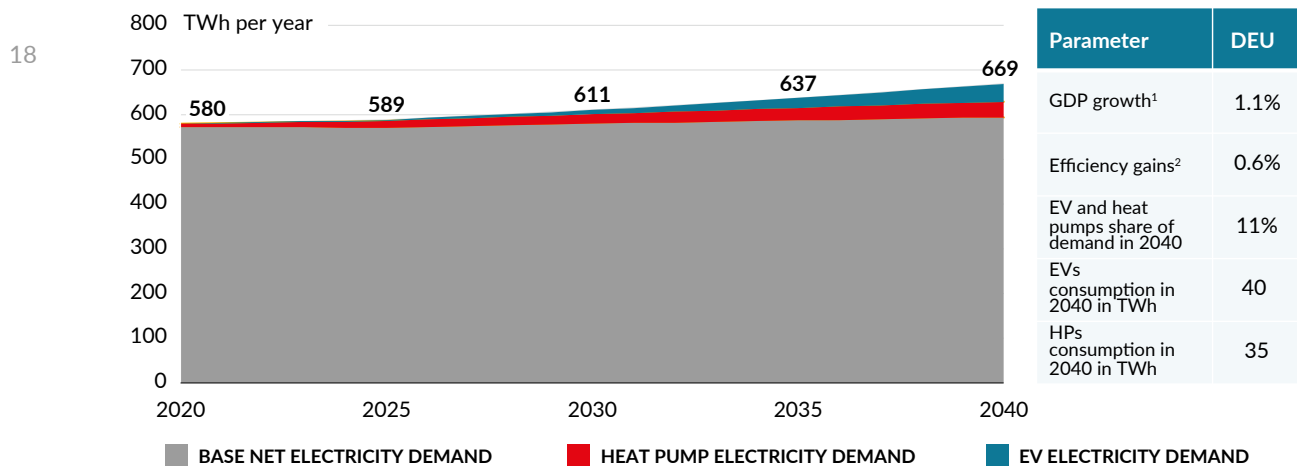
**General regulations.** In Germany, we assume the implementation of the coal phase-out as outlined in the draft proposal released by the “Coal Commission” in early 2018. Thus, all coal and lignite capacities are expected to exit the system by the end of 2038. Moreover, we assume in all scenarios that RES capacities develop such that Germany reaches its RES target of 65% by 2030 and 80% by 2040.

**Demand.** Aurora’s proprietary demand model considers the electricity needs stemming from households as well as from industrial and commercial sectors. The model accounts for GDP growth and improvements in energy efficiency, key underlying drivers of demand across all sectors.

The combination of demand from households, industry, and commerce constitute the “base demand” for electricity in Germany. Demand from heat pumps and EVs are added to make up total net electricity consumption.

As illustrated in Exhibit 10, total net electricity consumption in Germany is expected to be 580 TWh in 2020. With the electrification of heat and transport, demand stemming from heat pumps and EVs is expected to contribute 35 TWh and 40 TWh to total net demand by 2040, respectively, putting overall demand at 669 TWh. For this period, we also assume continuous efficiency gains. We assume that the energy needed to generate each unit of GDP decreases by 0.6% each year. These developments correspond to a peak demand of ca. 80 GW in 2020 and around 115 GW in 2040.

Exhibit 10: Assumed net electricity consumption in Germany up to 2040



Sources: Aurora Energy Research, IMF, Oxford Economics.

1) Annual average over 2019-2040 2) Understood as the yearly decrease in energy intensity; weighted across all sectors.

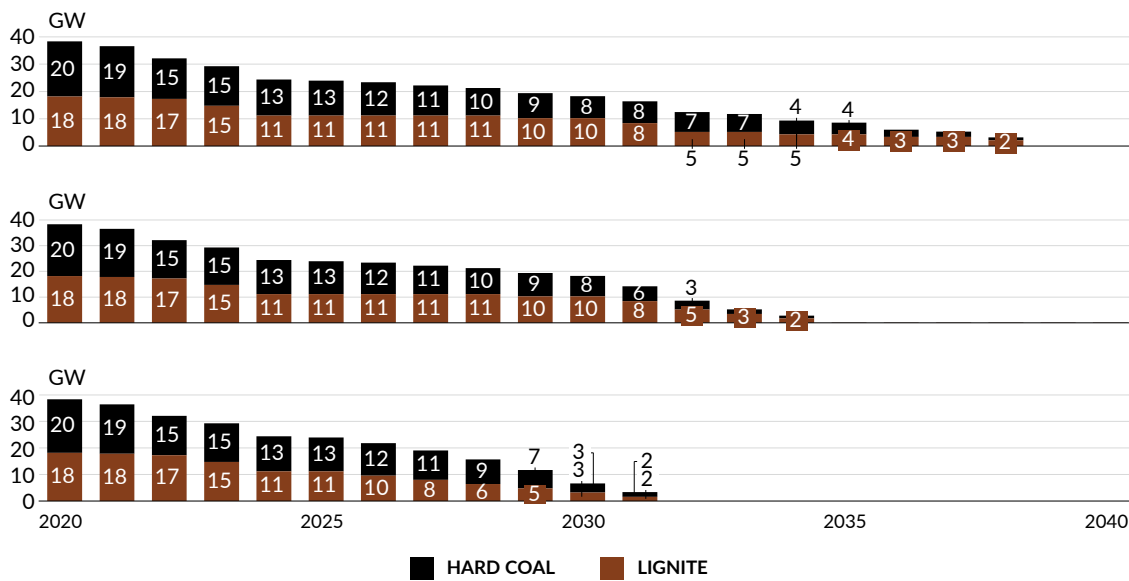
**Lignite and hard-coal capacity.** The trajectory for lignite and hard-coal capacities in Germany are assumed to follow the timeline outlined by the Coal Commission in early 2018. According to the proposal, all coal-fired power plants are expected to be phased out by the end of 2038 at the latest. Under this trajectory, installed coal capacities are expected to fall to 30 GW by the end of 2022 and to 17 GW by the end of 2030. Details on the coal phase-out are provided in an appendix to this report.

The proposed coal phase-out timeline is reflected in the reference scenario. As shown in Exhibit 11, coal capacities under the reference scenario are expected to decrease from 38 GW in 2020 to 30 GW by 2023. By 2031, the total coal capacity in the system amounts to 16 GW—8 GW of which stem from lignite. After 2038, coal is assumed to have completely left the system.

Alternatively, to reflect the proposed possibility of an early exit in the Coal Commission report, all hard-coal and lignite capacities in the lignite phase-out 2035 scenario exit the system by 2035. Up until 2030, coal plant closures in the accelerated timeline are identical to that of the reference scenario.

In the event that the coal phase-out is pulled forward by another three years, all lignite and hard-coal capacities leave the power system by 2032 in the lignite phase-out 2032 scenario. Before 2025, however, hard-coal and lignite capacities are assumed to follow an identical trajectory to the reference scenario.<sup>7</sup>

Exhibit 11: Lignite and hard-coal capacities in Germany up to 2040



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Source: Aurora Energy Research.

**Nuclear.** In accordance to the 13th amendment of the Atomic Energy Act, we assume nuclear power stations in Germany will be shut down either on or before the respective legal deadlines outlined in the legislation. The closure timeline is illustrated in the table below.

Table 2: Operational nuclear plants in Germany and expected closure dates

Plant	Commissioning Year	Reactor type	Operator	Installed capacity (GW)	Closure date
Grohnde	1985	PWR	RWE	1.36	31 Dec 2021
Gundremmingen C	1984	BWR	RWE	1.28	31 Dec 2021
Brokdorf	1986	PWR	RWE	1.41	31 Dec 2021
Isar 2	1988	PWR	RWE	1.41	31 Dec 2022
Emsland	1988	PWR	RWE	1.33	31 Dec 2022
Neckarwestheim 2	1989	PWR	EnBW	1.31	31 Dec 2022

Source: Aurora Energy Research.

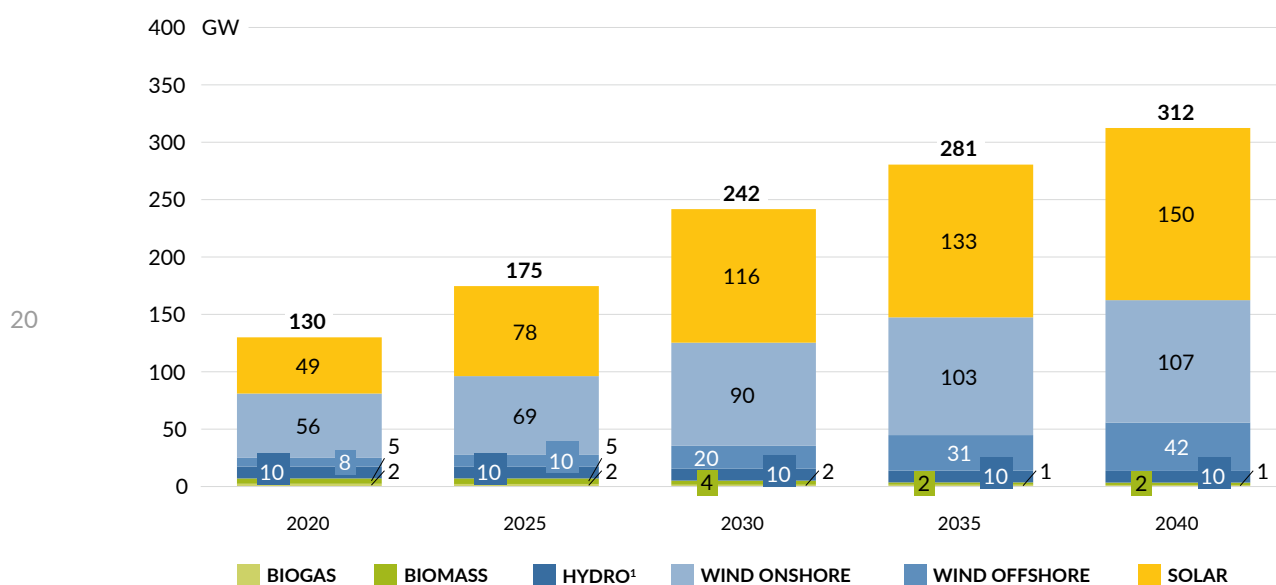
<sup>7</sup> The rationale for closure is detailed in section 2.1.1. It should be noted that blocks can only shut down completely; lignite blocks supplied by one mine shut down together. Thus, the distribution between hard coal and lignite can vary slightly between the scenarios.

**Renewables.** Renewables capacities in Germany are assumed to develop such that the government's renewables targets are met. This requires that renewables make up 65% of the gross electricity demand in 2030. By 2040, we assume that renewables reach a share of 80%.

To meet these targets, the following capacity development (illustrated in Exhibit 12) is assumed: wind onshore and offshore capacities increase from 56 GW and 8 GW in 2020 to 90 GW and 20 GW in 2030, respectively. By 2040, wind onshore and offshore capacities reach 107 GW and 42 GW, respectively. Solar capacities are expected to increase from 49 GW in 2020 to 116 GW in 2030. By 2040, 150 GW of solar capacity will be installed in Germany.

Given the current controversies about onshore wind, we expect most of the future renewables buildout to focus on offshore wind and solar, with capacities quintupling and tripling, respectively, rather than onshore wind, where capacities only double. The renewables buildout is assumed to be supported by financing schemes to ensure that targets are met despite increasing cannibalisation at high penetrations.

**Exhibit 12: Installed RES capacity in Germany up to 2040**



Source: Aurora Energy Research.

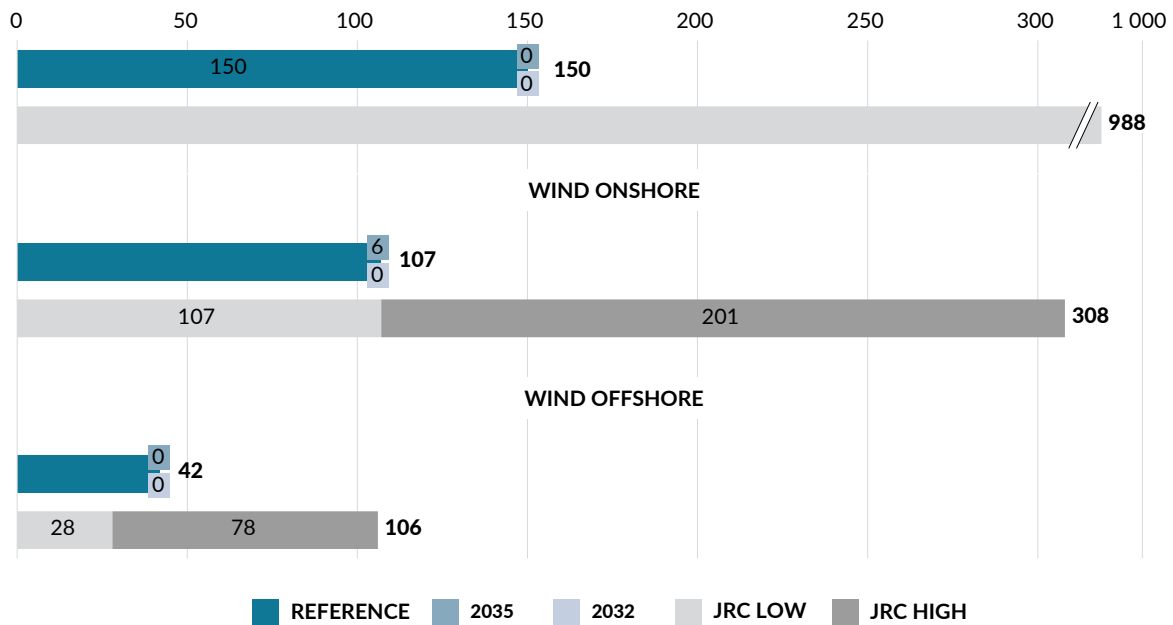
1) Hydro includes run-of-river, hydro storage and pump storage.

The wind capacities assumed are within the potentials identified in a report by the European Commission's Joint Research Centre in 2019<sup>8</sup>: for onshore wind, this report identifies a potential for 107 GW of onshore wind in high wind conditions (defined as having load factors above 20%) under reference conditions, i.e. if current distance regulations remain in place, and 308 GW if distance rules are lowered. Greater distance requirements, as currently discussed by the German government, could lower the available potential. For offshore wind, a potential of 106 GW is identified in the report with low space restrictions. For solar, the JRC report<sup>9</sup> identifies a potential for 988 GW of installed capacity, assuming 170 GW per m<sup>2</sup> on 3% of the available land. The capacities we see in our scenarios lie well below this number. A comparison between the RES buildout in the scenarios and the RES potential is shown in Exhibit 13.

<sup>8</sup> European Commission, Joint Research Centre, 2019a.

<sup>9</sup> European Commission & Joint Research Centre, 2019b.

Exhibit 13: RES capacities and potentials for Germany

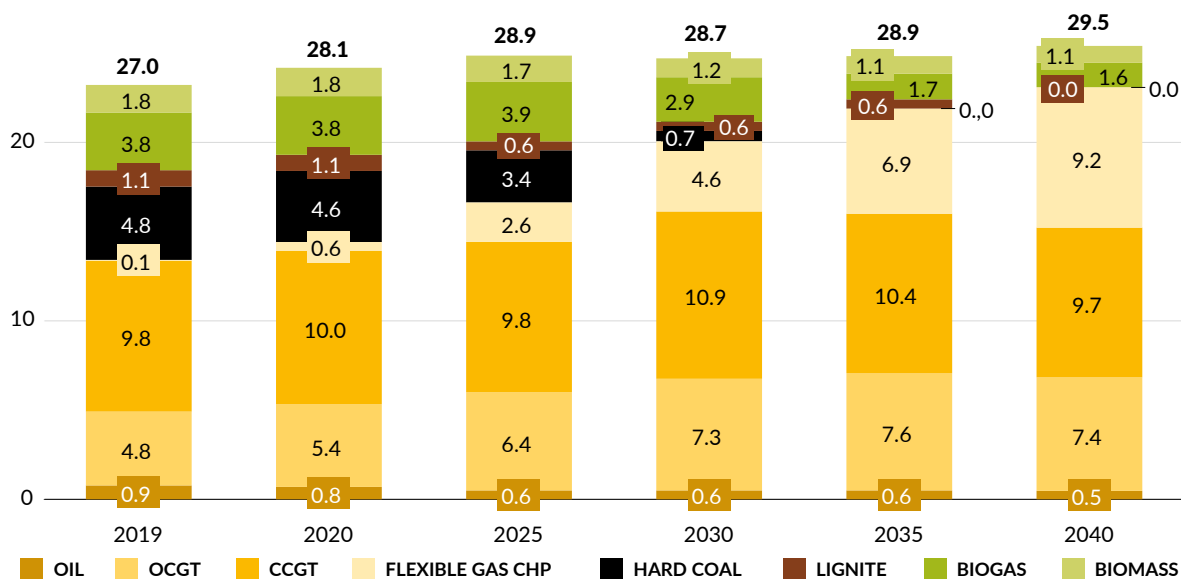


Source: Aurora Energy Research, European Commission & Joint Research Centre (2019). JRC for solar assumes 170W/m2 with 3% of available, non-artificial land used. Light grey refers to the reference scenario with current legal requirements in place. Dark grey depicts the low restrictions scenario. The data for onshore refers to locations with capacity factors > 20%.

**Heat generation.** We assume coal and lignite fired CHP plants that leave the system will be replaced by a mixture of CCGT, OCGT, and flexible CHP plants, consisting of a gas reciprocating engine, a power-to-heat (PtH) unit, and a heat storage, as in Aurora’s Central scenario. The heat load provided by retired plants is met by new capacity additions. This is a slightly simplified assumption, since the focus of the study is on the power sector. As illustrated in Exhibit 14, CCGT capacity in Germany is expected to grow from 9.8 GW in 2019 to 10.9 GW in 2030. Due to decommissioning, the CCGT capacities are expected to decrease to 9.7 GW by 2040. To make up for coal and lignite CHPs leaving the system, a total of 7.4 GW of OCGT and 9.1 GW of CCGT will be installed by 2040.

For the purposes of this study, we assume that CHP replacement plants will run solely on natural gas. It should be noted, however, that these plants could also run on green gases or biomass and biogas. While this would yield positive benefits in terms of emissions, costs would be higher.

Exhibit 14: Conventional CHP capacities in Germany up to 2040



Source: Aurora Energy Research.

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**Battery storage and other sources of flexibility.** The construction of battery storage is based on economics. In this sense, batteries are built if load shifting proves profitable in the model. Batteries for balancing services are not modelled due to the limited interactions these batteries have with the wholesale market. As will be seen in the results section, the construction of batteries for wholesale market load shifting does not become profitable in Germany in the modelling horizon due mostly to the significant amount of interconnection in the market.

We model electric vehicles and heat pumps as described in the demand assumptions. They have the possibility of charging in a ‘smart’ manner, meaning that they respond to power prices and thus add flexibility to the system.

In total, we see a capacity of 1.55 GW for a demand-side response in 2020, increasing to 2.1 GW in 2040. This is a conservative estimate; various studies have estimated a technical DSR potential exceeding 10 GW for the German market. Additionally, behind-the-meter batteries contribute to peak shaving. For Germany, we project 8 GW of household batteries and 2 GW of industrial batteries by 2040. These can, among other things, store electricity generated from behind-the-meter rooftop solar.

### 3.3.2. Poland

**General regulations.** As discussed above, the reference scenario for Poland is inspired by the Polish Energy Policy 2040, but deviates from it in a number of dimensions where we expect the system to be dominated by economics in the longer term. In particular, this affects the decision to enter nuclear power generation, which we do not include in our reference scenario, and the decline of coal capacities, which we expect to come sooner and be more pronounced than the PEP 2040.

We assume that the Polish capacity market will extend past 2025 due in part to the significant need for newbuild dispatchable capacities in Poland over the next two decades. Starting in 2025 (i.e. based on a 2020 auction), plants with an emissivity above 550 gCO<sub>2</sub>/kWh will no longer be eligible for new capacity contracts, while existing contracts made before 31 December 2019 will be honoured.

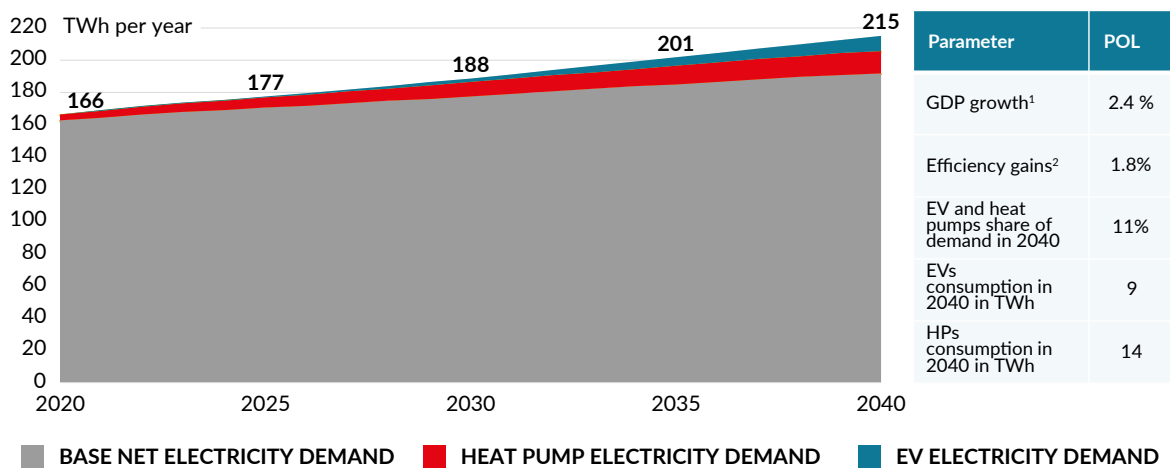


**Demand.** As with Germany, we take a sectoral approach when it comes to assessing the total demand for electricity in Poland, and account for increasing GDP and efficiency gains across the projected horizon. The base demand in Poland is an aggregation of residential, industrial, commercial, and agricultural demand. Combined with the electricity demand from heat pumps and EVs, this results in the total electricity demand in Poland.<sup>10</sup>

For future years, we project a constant and near-linear increase in demand in light of GDP increasing at an average annual rate of 2.4%. Due to efficiency gains averaging at 1.8% each year, demand is expected to increase at a more moderate rate relative to the increase in GDP.

As shown in Exhibit 15, total net electricity consumption is expected to increase from 166 TWh in 2020 to 215 TWh in 2040. Demand from heat pumps and EVs is expected to grow to 14 TWh and 9 TWh in 2040, respectively. The peak demand over this period is project to increase from 26 GW to 34 GW.

Exhibit 15: Assumed net electricity consumption in Poland up to 2040



23

Sources: Aurora Energy Research, IMF, Oxford Economics, Forum Energii.

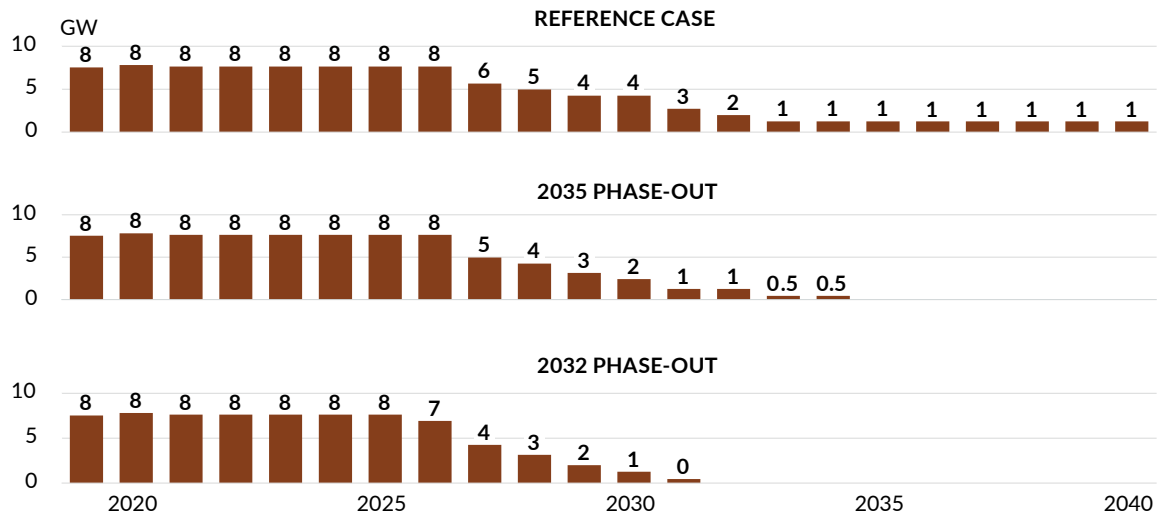
1) Annual average over 2019-2040 2) Understood as the yearly decrease in energy intensity; weighted across all sectors.

**Lignite and hard-coal capacity.** The development of lignite capacities in the reference scenario is economically driven but constrained by the availability of lignite resources. Consequently, we assume that current mines are exploited fully, and no new mines are opened. Older units at the Bełchatów power station are expected to begin closing in 2028, while newer units at the Bełchatów and Turów power stations are assumed to remain operational up to 2040.

Lignite capacities under the reference scenario are expected to decrease from 8 GW in 2020 to 4 GW by 2030, and to 1 GW by 2040 as lignite use loses its economic viability. This is illustrated in Exhibit 16.

By comparison, under the lignite phase-out 2035 scenario, capacities decrease to 2 GW by 2030, since older units at the Bełchatów power plant are required to close by 2030. New units at Bełchatów and Turów remain operational until 2035, by which time they are expected to close. In the lignite phase-out 2032 scenario, only the new units at the Bełchatów and Turów power plants remain operational. These are phased out entirely by the end of 2031.

Exhibit 16: Lignite capacities in Poland up to 2040



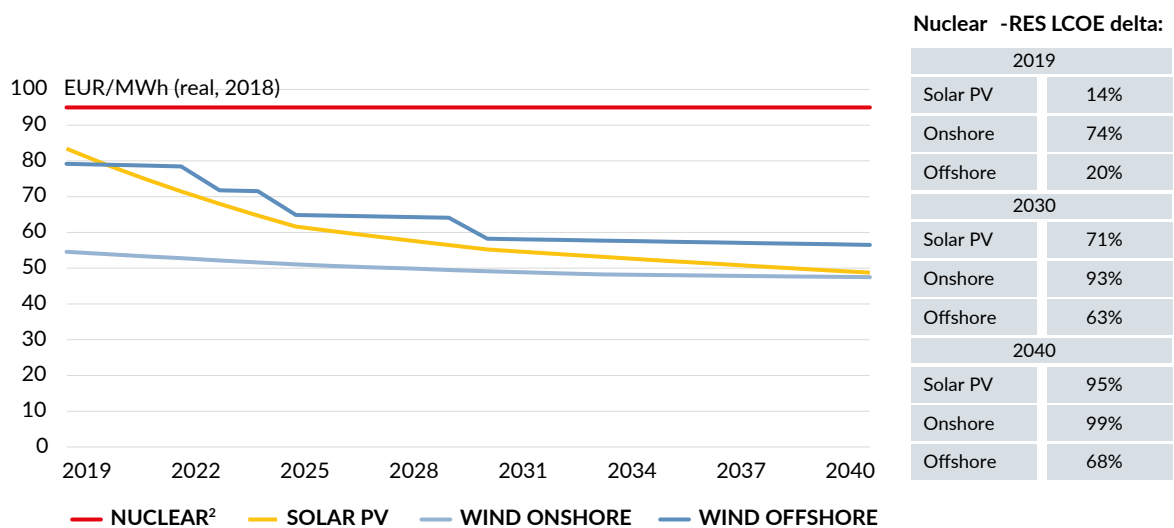
Source: Aurora Energy Research.

**Nuclear.** We do not foresee the construction of nuclear power plants to replace closed lignite capacity. As outlined in the PEP 2040, the Polish government plans to build several nuclear units starting in 2033; we consider it unlikely that these plans will be realised, however.

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The first reason has to do with economics. As illustrated in Exhibit 17, the LCOE for a new-build nuclear plant is significantly higher than that of new-build RES technologies. Specifically, in 2020 the LCOE for nuclear is expected to be 20% higher than both wind offshore and solar, and 76% higher than wind onshore. Over the projected horizon, this gap is expected to widen. By 2040, the LCOE for nuclear is 40%, 49%, and 50% greater than the LCOEs of wind offshore, solar, and wind onshore, respectively. While LCOE does not account for the intermittent nature of renewable power generation, we do not expect the intermittency of the RES fleet in Poland to be large enough to offset the cost advantage of renewables.<sup>11</sup>

Exhibit 17: LCOE for nuclear and RES technologies in Poland



Source: Aurora Energy Research.

1) WACC of 9% assumed for all technologies. 2) Nuclear assumptions: CAPEX of 6.3 mEUR/MW, FOM of 84 kEUR/MW, VOM of 10 EUR/MWh.

11 The observed differences are based on an assumed WACC of 9%. Under a more conservative WACC estimate for nuclear, which reflects the full technological risk of such projects, the divergences between WACCs are likely to increase. Conversely, government subsidy schemes such as CfDs could reduce LCOEs for all technologies by increasing leverage on the projects.

Second, there are technical risks to be considered: in the PEP, nuclear is intended to replace lignite in the Polish electricity mix when current mines run out. Delays in nuclear projects could introduce a considerable security of supply risk.<sup>12</sup>

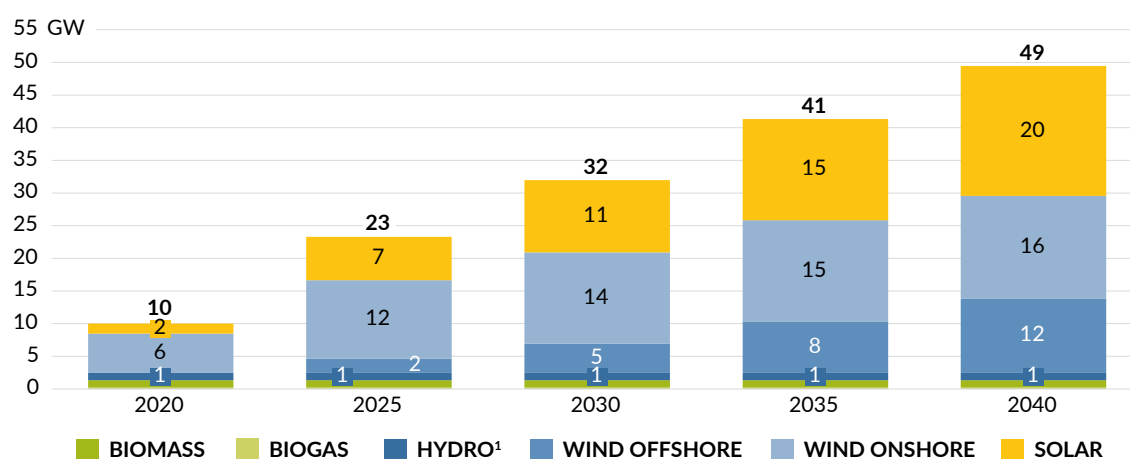
Third, our scenario leads to lower emission than the ones in the current Polish energy policy, even though they do not include nuclear. This shows that a non-nuclear system can contribute to a clean energy transition.

**Renewables.** As illustrated in Exhibit 18, renewable capacities are expected to increase from 10 GW in 2020 to 49 GW in 2040. By 2040, 20 GW of installed capacity is expected to stem from solar. Solar capacities in Poland are assumed to develop in accordance to the 2018 draft of the PEP 2040. If sufficient capacities are not delivered on a subsidy-free basis, we assume they will receive financial support via auctioned contracts for difference (CfD).

By comparison, we expect offshore wind capacities to slightly exceed government targets by 2040, reaching 12 GW in total. We reflect the measures foreseen in the draft offshore act to provide CfD for offshore projects. As currently discussed, they would first be awarded at levels set by the government and later determined through auctions. These capacities are assumed to be supported by CfD auctions.

The buildout of onshore wind is expected to be driven purely by economics as we do not assume further support for onshore wind via CfD auctions beyond the ones that have already been announced. As a result, we expect wind onshore to reach 16 GW by 2040. To support this, we assume the 10H rule will weaken in upcoming years.

Exhibit 18: Installed RES capacities in Poland up to 2040



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Source: Aurora Energy Research.

1) Hydro includes run-of-river, hydro storage and pump storage

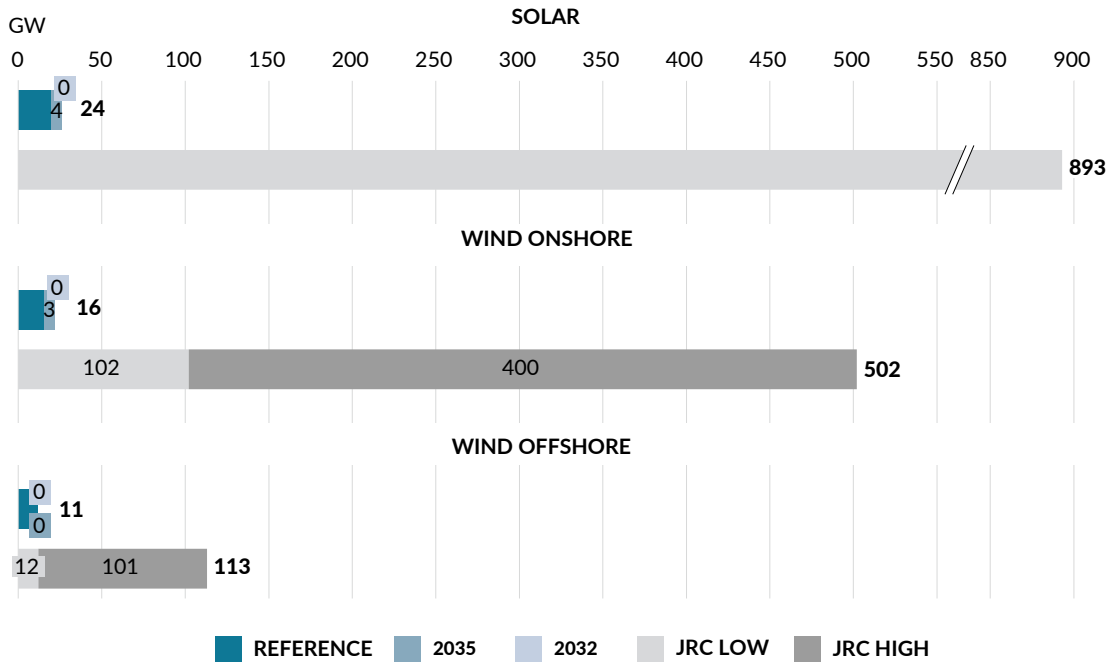
The wind capacities assumed are within the potentials identified in a 2019 report by the European Commission’s Joint Research.<sup>13</sup> For onshore wind, this report identifies a potential of 102 GW of onshore wind in high wind conditions (defined as having load factors above 20%) under reference conditions, i.e. if current distance regulations remain in place, and 502 GW if distance rules are removed. For offshore wind, a potential of 113 GW is identified with low space restrictions. For solar, the JRC report<sup>14</sup> identifies the potential for 893 GW of installed capacity, assuming 170W per m<sup>2</sup> on 3% of the available land. The capacities we see in our scenarios lie well below these potentials. A comparison of the RES buildout in the scenarios and the RES potential is shown in Exhibit 19.

<sup>12</sup> Haas, Thomas & Ajanovic, 2019.

<sup>13</sup> European Commission & Joint Research Centre, 2019a.

<sup>14</sup> European Commission & Joint Research Centre, 2019b.

Exhibit 19: RES capacities and potentials in Poland



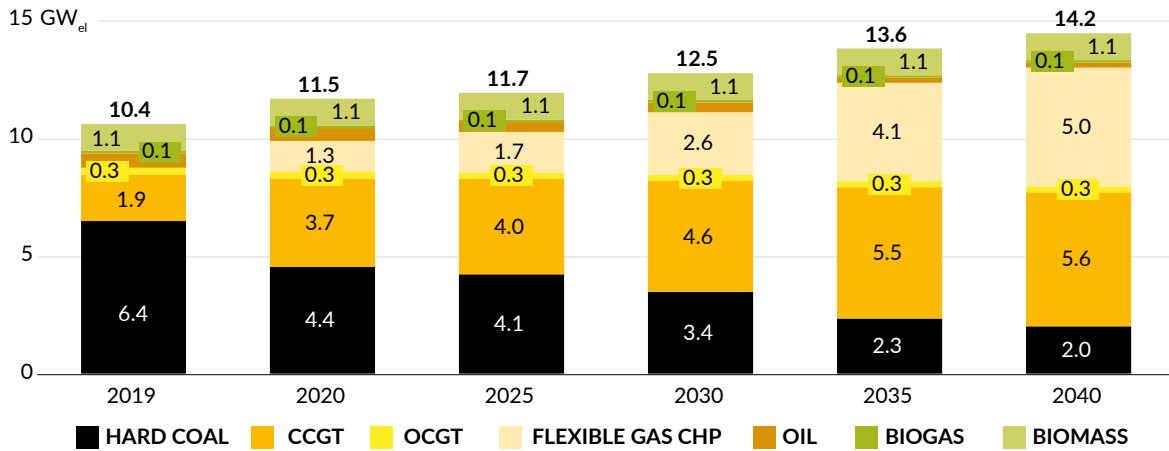
Source: Aurora Energy Research, European Commission & Joint Research Centre (2019).

JRC for solar assumes 170W/m<sup>2</sup> with 3% of available, non-artificial land used. Light grey refers to the reference scenario with current legal requirements in place. Dark grey depicts the low restrictions scenario. The data for onshore refers to locations with capacity factors > 20%.

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**Heat generation.** There are no lignite CHP plants in Poland. For hard-coal-fired CHP plants, we assume that they will be replaced by a mixture of CCGT and other flexible CHP plants, consisting of a gas reciprocating engine, a power-to-heat (PtH) unit, and a heat storage, such that the heat load of existing plants as well as additional heat load from linked district-heating projects can continue to be served.

Exhibit 20: Conventional CHP capacities in Poland up to 2040



Source: Aurora Energy Research.

As illustrated in Exhibit 20, installed coal CHP capacity is expected to decrease from 6.4 GW in 2019 to 2 GW by 2040. To replace the lost heat load, an addition of 5.6 GW of CCGT and 4.9 GW of flexible gas CHPs is expected to be added to the system by 2040. In addition to the replacement of old assets, we expect an overall increase of CHP units from 10.4 GW in 2019 to 14.1 GW in 2040.

**Battery storage and other sources of flexibility.** The construction of battery storage is based on economics. In this sense, batteries are built if load shifting proves profitable in the model. Batteries for balancing services are not modelled due to the limited interactions these batteries have with the wholesale market. As will be seen in the results section, the construction of batteries for wholesale market load shifting does not become profitable in Poland in the modelling horizon due mostly to the significant amount of interconnection in the market.

Furthermore, we model electric vehicles and heat pumps as described in the demand assumptions. They can charge in a ‘smart’ manner, meaning that they respond to power prices and thus add flexibility to the system.

For Poland, we conservatively estimate that 0.5 GW of demand-side response will be available to the wholesale market, and that it will increase to 2.4 GW by 2040.

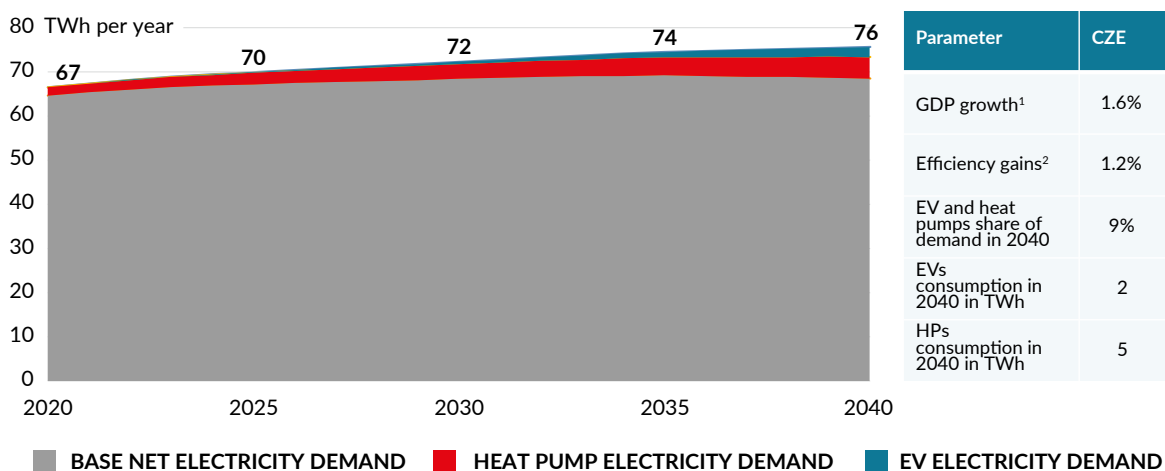
### 3.3.3 Czech Republic

**General regulation.** The Czech electricity market is mostly based on nuclear and lignite, with a very low share of intermittent renewables. The government foresees that lignite will be replaced by nuclear in the longer term, with only minor contributions from intermittent renewables.<sup>15</sup> For cost reasons outlined below, we expect intermittent renewables to play a larger role, with no construction of new nuclear plants taking place.

**Demand.** The base demand for electricity in the Czech Republic is determined by sector. The projected demand trajectory up to 2040 shown below accounts for expectations regarding GDP growth and improvements in energy efficiency as both are key underlying factors that shape demand within each sector. Total power demand also includes demand from heat pumps and electric vehicles.

As illustrated in Exhibit 21, the total net demand<sup>16</sup> for power in the Czech Republic is projected to be 67 TWh in 2020, of which 1.8 TWh is expected to stem from heat pumps. With the electrification of heat and transport over the course of the forecast period, the amount of electricity demand from heat pumps and EVs is expected to grow, reaching 5 TWh and 2 TWh by 2040, making up 9% of total demand in the aggregate. We see peak demand increasing from 11 GW in 2020 to 12 GW in 2040.

Exhibit 21: Assumed net electricity consumption in the Czech Republic up to 2040



Sources: Aurora Energy Research, IMF, Oxford Economics.

1) Annual average over 2019-2040 2) Understood as the yearly decrease in energy intensity; weighted across all sectors

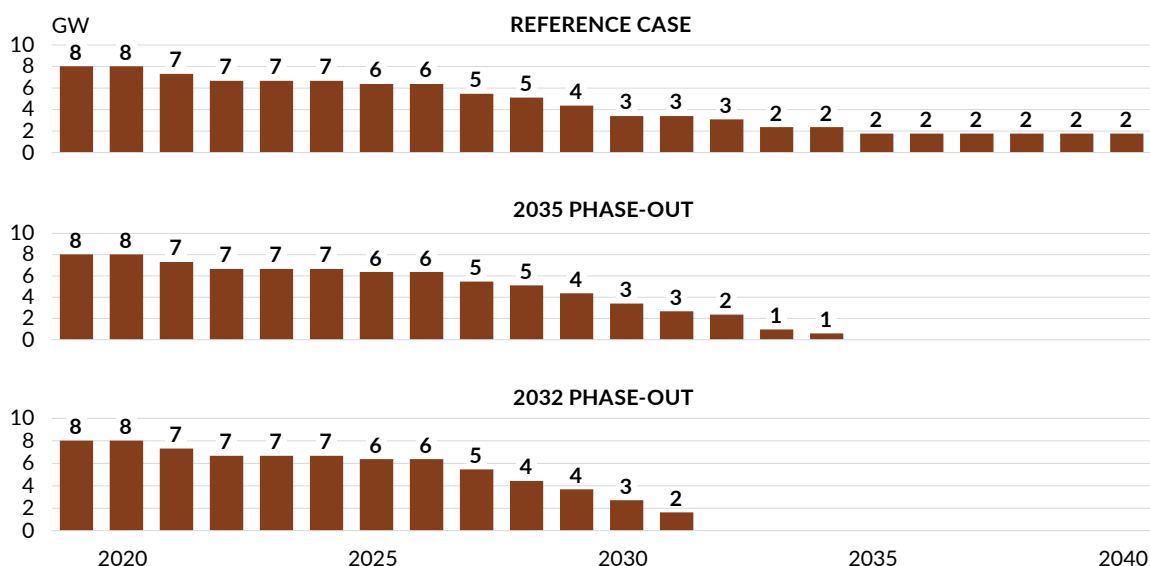
15 Ministry for Industry and Trade, 2015a.

16 Net demand excludes the power that plants consume themselves and includes grid losses.

**Lignite capacity.** Unlike the Polish lignite fleet, resource availability does not serve as a binding constraint to lignite plant operations in the Czech Republic. Rather, lignite capacities in the reference scenario are modelled so that plants live out their technical lifetimes provided they cover their fixed O&M costs. At that point, plants have the option to refurbish if viable. Following the published plans of the ČEZ group, the Czech Republic's largest lignite plant operator, we assume that operations at the Bílina mine, which has reserves of 79 million tonnes of lignite for exploitation under current operating licenses, will be extended. Should this happen, available reserves are expected to increase by an additional 150 million tonnes of lignite. Lignite capacities in the Czech Republic will decrease from 8 GW in 2020, to 3 GW in 2030, and 2 GW in 2040. This is displayed in Exhibit 22.

In light of a mandated phase-out of lignite by 2035 in the lignite phase-out 2035 scenario, we do not assume that the operational license for the Bílina mine will be extended. Reaching 0 GW of lignite capacity by 2035 requires that the Ledvice plant, commissioned in 2014, to close sooner than expected. Similarly, under the lignite phase-out 2032 scenario, we do not assume that Bílina's license will be extended. The decrease of lignite capacities from 8 GW in 2020 to 3 GW in 2030 and 0 GW by 2032 reflects an early-than-expected shutdown of the Ledvice and Kladno plants.

Exhibit 22: Lignite capacities in the Czech Republic up to 2040

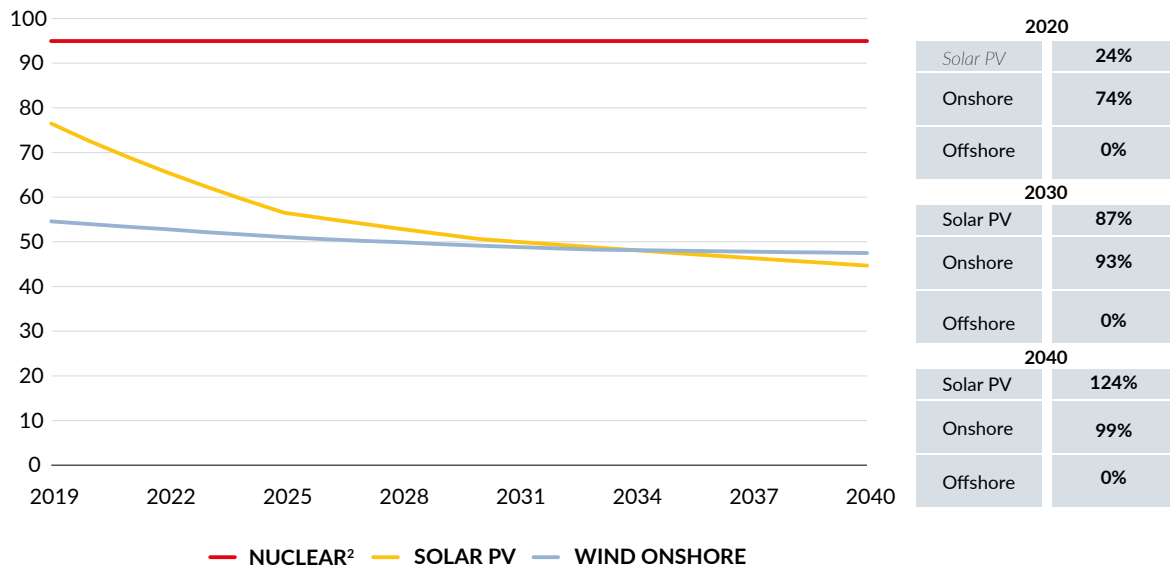


28

Source: Aurora Energy Research.  
1) Year of commissioning unit

**Nuclear.** In line with the plans of the Czech government, we assume that the existing nuclear fleet in the Czech Republic will remain operational beyond 2040. However, based on technical and economic realities, we do not expect new plants to be constructed, contrary to government announcements. This is supported by the fact that the majority of ongoing nuclear projects in Europe face significant delays and cost overruns due to unforeseen technical and design issues. Even in the absence of technological and temporal setbacks, new-build nuclear is simply not cost-competitive when compared with alternative generation technologies. This is illustrated in the following Exhibit.

Exhibit 23: LCOE of new-build nuclear and RES technologies



Source: Aurora Energy Research.

1) WACC of 9% assumed for all technologies. 2) Nuclear assumptions: CAPEX of 6.3 mEUR /MW, FOM of 84 kEUR /MW, VOM of 10 EUR/

According to Exhibit 23, the LCOE for a newly constructed nuclear facility is 24% greater than that of a solar PV plant built in 2010. As learning curves increase over the years and technology costs for solar decreases, the LCOE gap will also increase. By 2030, the LCOE of nuclear is 87% greater than that of solar. The business case for nuclear is even less favourable when compared with onshore wind. In 2019, the LCOE of nuclear was 74% greater than onshore wind. This increases to 93% by 2030. It is important to note that LCOE does not account for the intermittent nature of renewable power generation. But the intermittency of renewables in the Czech Republic is not expected to be large enough<sup>17</sup> to offset the cost advantage of renewables.<sup>18</sup>

**Renewables.** We assume RES capacities under the reference scenario will increase from 6 GW in 2020 to 14 GW in 2040. The growth of onshore wind over this time frame is expected to occur in the absence of subsidies. In this sense, the increase in onshore wind capacities from 0 GW in 2020 to 5 GW in 2040 is purely market driven.

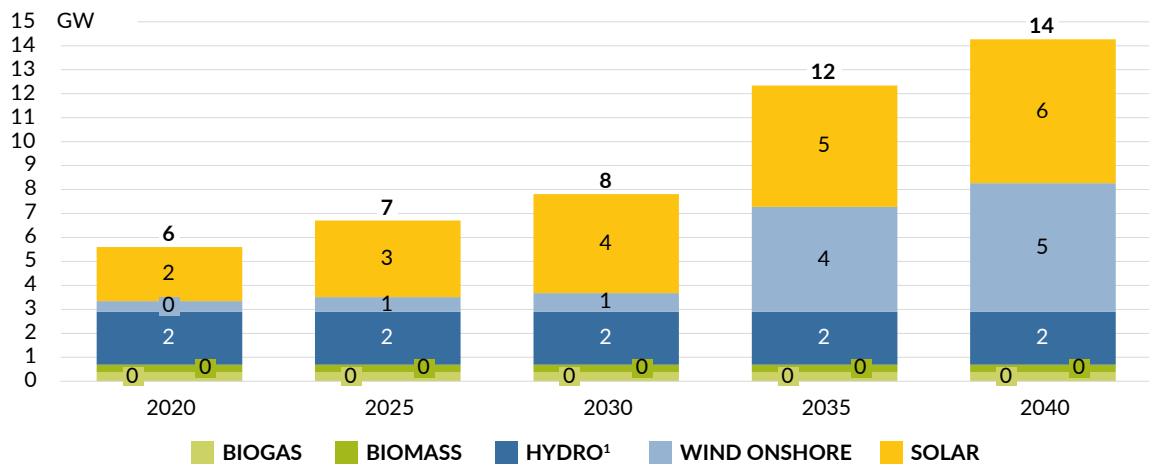
By comparison, we assume that the growth of solar from 2 GW in 2020 to 6 GW in 2040 will be supported by subsidies. This amount of capacity could easily be provided on rooftops, thereby reducing competition with other land uses.

Due to its significantly higher LCOE, we do not expect biomass to play a significant role in the power sector over the next couple of years.

<sup>17</sup> Due to the self-correlation of RES, we see onshore wind plants capturing prices that are 5€/MWh below and solar installation capturing prices that are 17€/MWh below the average of all plants in 2030. For 2040, this difference increases further. This effect has been described as the self-cannibalization of renewables.

<sup>18</sup> The observed differences are based on an assumed WACC of 9%. Under a more conservative WACC estimate for nuclear reflecting the full technological risk of such projects, the divergences between WACCs are likely to increase. Conversely, government subsidy schemes such as CfDs could reduce LCOEs for all technologies through increasing leverage on the projects.

Exhibit 24: Installed RES capacities in the Czech Republic up to 2040

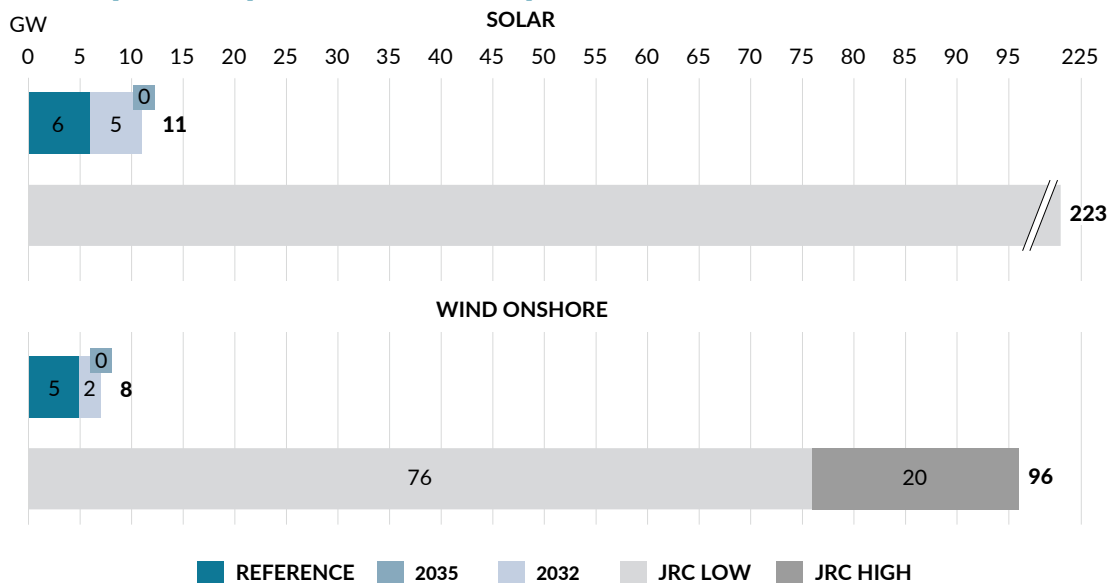


Source: Aurora Energy Research.  
 1) Hydro includes run-of-river, hydro storage and pump storage.

The wind capacities assumed are within the potentials identified in a report by the European Commission’s Joint Research Centre in 2019.<sup>19</sup> For onshore wind, this report identifies a potential of 76 GW for onshore wind in high wind conditions (defined as having load factors above 20%) in the reference scenario, i.e. if current distance regulations remain in place, and 96 GW if distance rules are removed. With very good wind conditions (>25% load factor), the report identifies a potential of 48 GW when space restrictions are low. For solar, the JRC report<sup>20</sup> identifies a potential of 223 GW for installed capacity, assuming 170W per m<sup>2</sup> on 3% of available land. The capacities we see in our scenarios lie well within these potentials. The comparison between RES buildout in the scenarios and RES potential is displayed in Exhibit 25.

30

Exhibit 25: RES capacities and potentials in the Czech Republic



Source: Aurora Energy Research, European Commission & Joint Research Centre (2019).  
 JRC for solar assumes 170W/m<sup>2</sup> with 3% of available, non-artificial land used. Light grey refers to the reference scenario with current legal requirements in place. Dark grey depicts the low restrictions scenario. The data for onshore refers to locations with capacity factors > 20%.

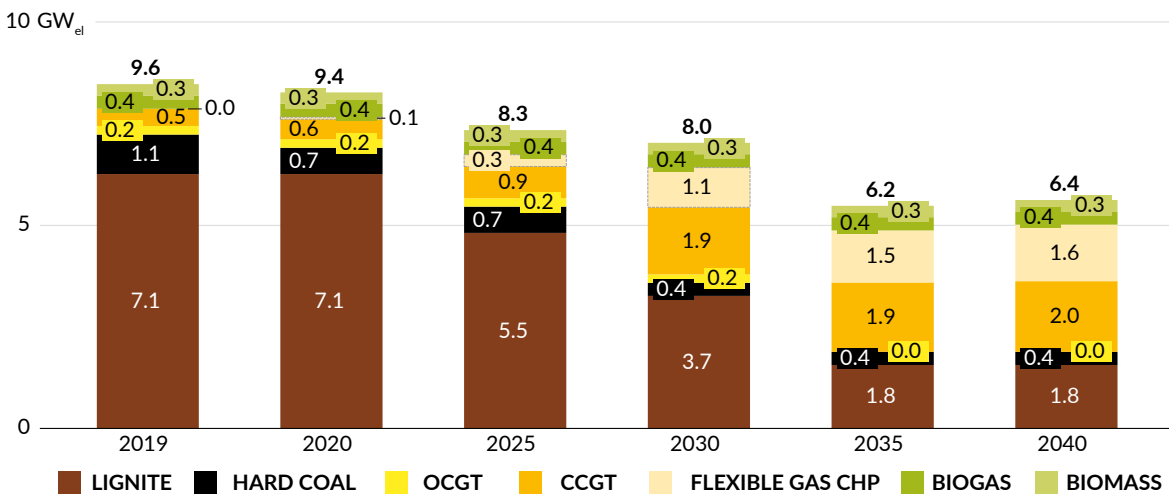
<sup>19</sup> European Commission, Joint Research Centre, 2019a.  
<sup>20</sup> European Commission & Joint Research Centre, 2019b.



**Heat generation.** We also take into account the heat provided by lignite and coal-fired power plants. We assume that for each thermal capacity<sup>21</sup> will gradually be replaced by a mixture of CCGT and other flexible CHP plants, consisting of a gas reciprocating engine, a power-to-heat (PtH) unit, and heat storage. In the reference scenario, lignite CHP capacity<sup>22</sup> is expected to decrease from 7.1 GW in 2018 to 1.7 GW in 2040. Similarly, coal CHP capacities will drop from 1.1 GW to 368 MW in 2030. The heat generation capacity leaving the system due to the retiring of coal and lignite CHPs is expected to be met by the addition of 1.9 GW of CCGT and 1.6 GW of flexible CHP capacity in 2040. This is illustrated in Exhibit 26. This is significantly less than the retiring electric capacities, because many Czech CHP plants at present produce heat as a by-product of electricity generation, and therefore only produce a small amount of heat per unit of electrical capacity.

For the purpose of this study, we assume that CHP replacement plants will run on natural gas. It should be noted, however, that these plants could also be run with green gases in general (i.e. biogas, hydrogen, etc). While this would yield positive benefits in regard to emissions, costs would be higher.

Exhibit 26: Conventional CHP capacities in the Czech Republic up to 2040



Source: Aurora Energy Research.

**Battery storage and other sources of flexibility.** The construction of battery storage in the Czech Republic is done on the basis of economics. In this sense, batteries are built if load shifting proves profitable in the model. Batteries used for balancing services are not modelled due to the limited interactions these batteries have with the wholesale market.

Furthermore, we model electric vehicles and heat pumps as described in the demand assumptions. They have the possibility of charging in a ‘smart’ manner, meaning that they respond to power prices and thus add flexibility to the system.

For the Czech Republic, we conservatively estimate 0.2 GW of demand-side response on the wholesale market. We expect this to increase to 0.8 GW by 2040.

<sup>21</sup> The thermal capacity is largely supplied by combined heat and power plants and thus overlaps with the electric capacities discussed above.  
<sup>22</sup> We classified CHP to the best of our knowledge based on publicly available data. We accept that different definitions, especially concerning the ratio of heat to electrical output, are possible. The definition made in this study shall in no way take precedence over the definition set by the Czech Coal Commission.

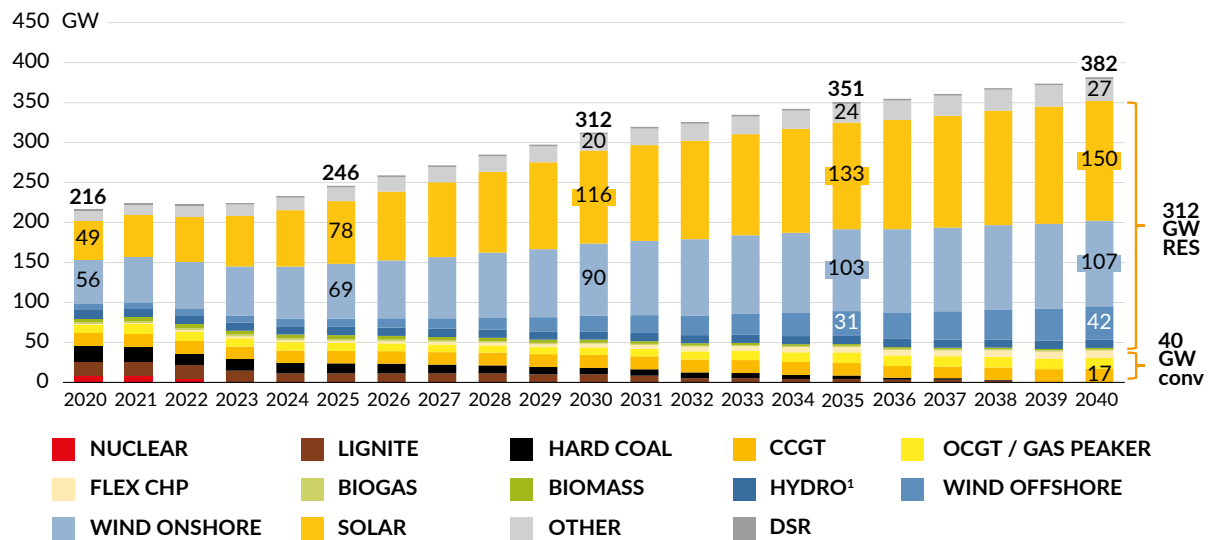
## 4. Scenario results

### 4.1. Germany

#### 4.1.1. Power market (including heat)

**Reference scenario.** Despite decreasing thermal capacities in the reference scenario, the total installed capacity in Germany is expected to increase from 216 GW in 2020 to 312 GW in 2030. By 2040, installed capacity reaches 382 GW. The primary driver behind the capacity trajectory is the growth of renewables over the projected horizon.

Exhibit 27: Installed net capacities in Germany up to 2040



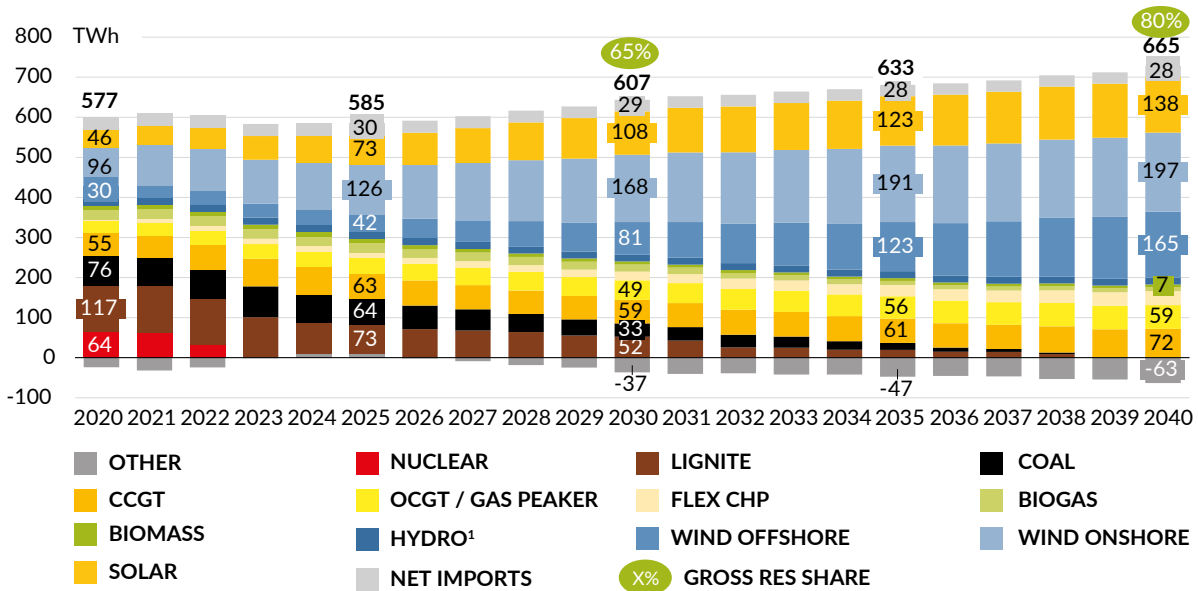
32

Source: Aurora Energy Research.

1) Hydro includes run-of-river, hydro storage and pump storage.

As Exhibit 27 shows, total hard coal and lignite capacities are expected to decrease from 20 GW and 18 GW in 2020 to 8 GW and 9 GW in 2030, respectively. In light of the German coal exit, both technologies will have completely exited the system by 2038. As a result, renewable capacities see considerable growth over the projected horizon. This is driven by the assumption that the government auctions additional renewable capacity to meet its announced targets. (For details, please refer to the assumptions section.) In fact, between 2020 and 2040, the share of renewables in Germany's capacity mix is expected to increase from 60%, or 130 GW, in 2020, to 82%, or 312 GW, by 2040. Of this, solar, onshore wind, and offshore wind make up 150 GW, 107 GW, and 42 GW, respectively.

Exhibit 28: Net generation in Germany up to 2040



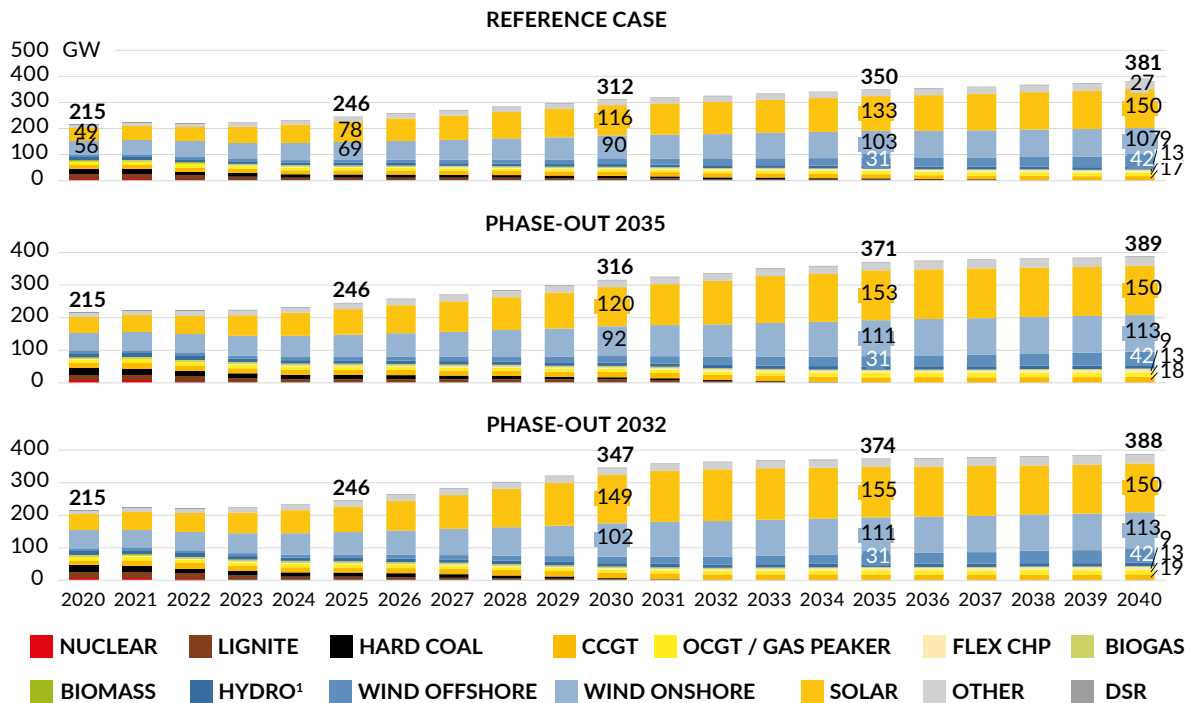
Source: Aurora Energy Research.

1) Hydro includes run-of-river, hydro storage and pump storage 2) Nuclear and lignite.

Corresponding to the rising demand described above, total net electricity generation in Germany increases from 577 TWh in 2020, to 607 TWh in 2030 and 665 TWh by 2040. In this time, generation from hard coal and lignite decreases from 76 TWh and 117 TWh in 2020 to 33 TWh and 52 TWh in 2030, respectively. As coal is phased-out by the end of 2038, the total net generation from coal and lignite-fired power plants drops to zero by 2040. The trajectory for renewables follows a different path, as shown in Exhibit 28. In 2020, generation from solar, wind onshore, and wind offshore amounts to 46 TWh, 96 TWh, and 30 TWh, respectively. By 2040, this is projected to grow to 138 TWh, 197 TWh, and 165 TWh, respectively. This is accompanied by a concurrent increase of net exports from 24 TWh in 2020 to 63 TWh by 2040.

**Lignite phase-out scenarios.** The 2035 and 2032 lignite phase-out scenarios are characterized by earlier phase-outs of lignite capacities. Renewables – onshore wind and solar – are added to compensate for lost coal power generation. Of the capacities that are phased out earlier, some are CHP plants. As discussed above, we assume that a mixture of CCGT and flexible natural gas CHP capacities will be built to replace them. By 2040, capacities approximate the timeline in the reference scenario, since here too coal leaves the system. This is illustrated in Exhibit 29.

Exhibit 29: Installed net capacities in Germany up to 2040



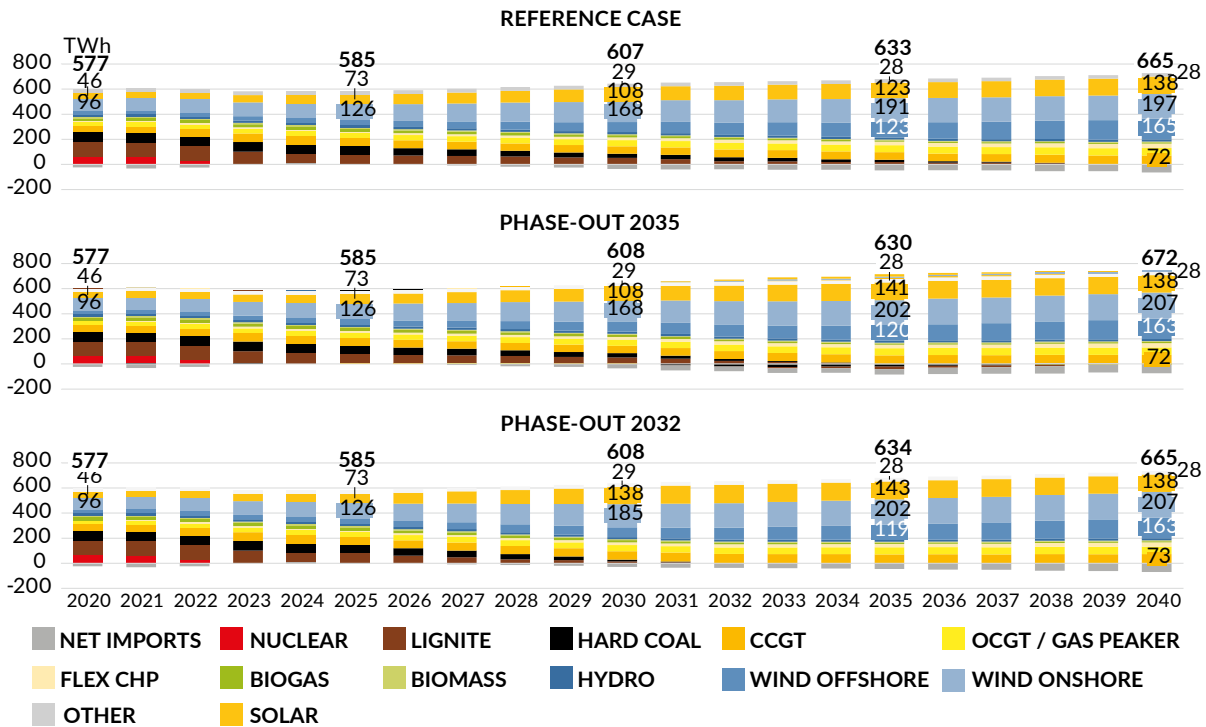
34

Source: Aurora Energy Research.

1) Hydro includes run-of-river, hydro storage and pump storage.

**2035 Lignite phase-out scenario.** Because the coal phase-out trajectory under the 2035 lignite phase-out scenario is assumed to mirror the reference case until 2030, there are no capacity differences between scenarios up to then. In 2035, however, a total of 8 GW of coal and lignite capacity over that of the reference case is expected to leave the power system. Moreover, 28 GW (20 GW solar, 8 GW wind onshore) beyond that of the reference case will be added. This leads to 371 GW of total installed capacity, with 153 GW from solar, 111 GW from onshore wind, and 31 GW from offshore wind. CCGT and gas peaker make up 13 GW, as in the reference case. To ensure that the heat demand covered by coal and lignite capacities under the reference case is met in the 2035 lignite phase-out scenario, an additional 1 GW of CCGT capacity is expected to come online in 2035, leading to a total of 17 GW of installed capacity. By 2036, an additional 3 GW of CCGT capacity will be operating beyond the reference case. After that, the gap closes as the remaining coal CHP plants close in the reference case.

Exhibit 30: Power generation in scenarios



Source: Aurora Energy Research.

1) Hydro includes run-of-river, hydro storage and pump storage.

As our demand assumptions do not change across scenarios, net generation including imports/exports under the 2035 lignite phase-out scenario is expected to remain equivalent to the reference case throughout the projected horizon. As Exhibit 30 shows, the netting of generation is partly accredited to lower exports relative to the reference case, which amounts to 30 TWh in 2035. Due primarily to the expansion of its RES fleet, the country exports 7 TWh more than it does in 2040 when compared with the reference scenario.

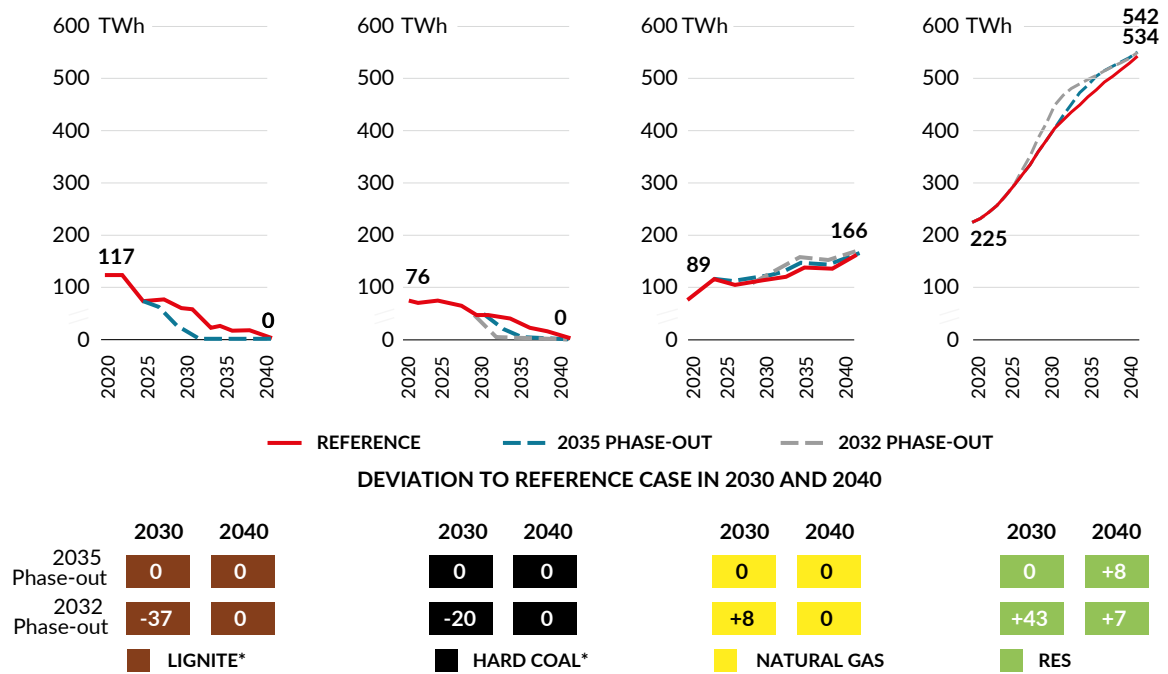
**2032 Lignite phase-out scenario.** Under a 2032 lignite phase-out scenario in Germany, hard-coal and lignite capacities fall by 12 GW to 6.5 GW compared with the reference case in 2030. By contrast, RES capacities increase such that an additional 46 GW are present in the system relative to the reference case. This adds up to a capacity of 347 GW, made up by 6.5 GW coal and lignite, 17 GW CCGT, 9 GW OCGT and gas peaker, 4 GW flexible CHP, and 287 GW renewables. The capacity difference for both coal and RES capacities are largest in 2031, at 13 GW and 51 GW, respectively.

In response to the expedited coal phase-out timeline, an additional 1 GW of CCGT capacity, relative to the reference case, enters the system as early as 2027 to make up for lost heat generation. By 2040, the difference decreases to zero. By then, the coal exit will have been achieved in all scenarios.

Total net generation under the 2032 lignite phase-out scenario is expected to remain identical to that of the reference scenario. The lost lignite generation is offset by both increased generation from renewables and lower exports.

Exhibit 31 provides an overview of power generation development by source across the scenarios.

Exhibit 31: Power generation from lignite, hard coal, gas, and renewables up to 2040



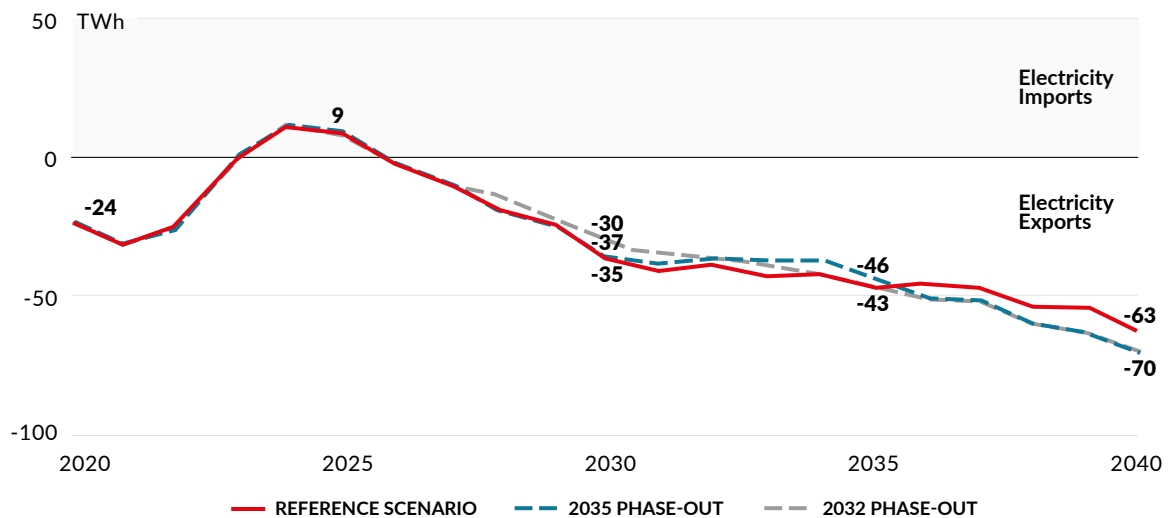
36

Source: Aurora Energy Research.

1) We assume calorific values of 10 GJ/T of Lignite and 25 GJ/T of hard coal.

Electricity export in Germany under the 2032 lignite phase-out scenario is 7 TWh lower than the reference case in 2030. According to Exhibit 32, total exports reach around 45 TWh in 2035. The difference between the scenarios increases again in subsequent years, reaching a peak of 8.5 TWh in 2039. This means that in the 2032 lignite phase-out scenario 62.5 TWh is exported, whereas in the reference case exports amount to 54 TWh.

Exhibit 32: Trade balance for electricity in Germany



Sources: Aurora Energy Research.

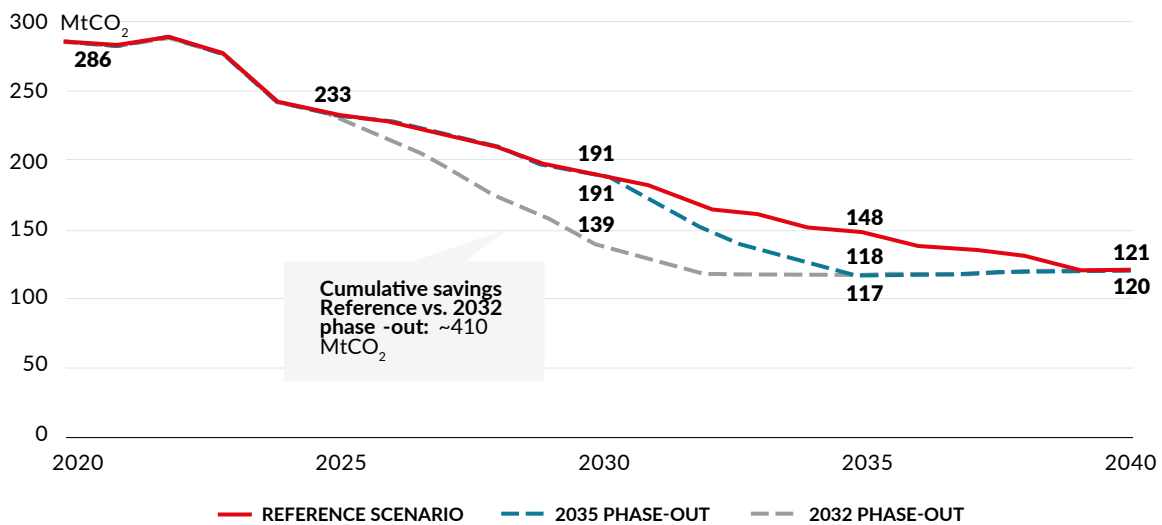
#### 4.1.2.. Climate

**Reference scenario.** As illustrated in Exhibit 33, carbon emissions under the reference scenario are expected to decrease from 286 MtCO<sub>2</sub> in 2020 to 191 MtCO<sub>2</sub> in 2030. This nearly achieves the climate target of no more than 188 MtCO<sub>2</sub><sup>23</sup> in the power sector. This climate objective could be achieved if the coal capacity target for 2030 were implemented at the beginning of the year, rather than at the end. After the complete exit of the coal and lignite fleet in 2038, carbon emissions are expected to fall to 121 MtCO<sub>2</sub> by 2040.

**2035 lignite phase-out scenario.** By comparison, under the 2035 lignite phase-out scenario, carbon emissions are identical until 2030, and drop to 120 MtCO<sub>2</sub> by 2040. The phase-out of coal capacities at the earlier end of the Coal Commission’s proposed timeline results in carbon emissions being 21% lower than the reference case in 2035. Over the forecast period, the cumulative savings of power sector emissions amount to 159 MtCO<sub>2</sub> by 2040.

**2032 lignite phase-out scenario.** Under the 2032 lignite phase-out scenario, carbon emissions stemming from the power sector are expected to decrease even more rapidly. According to Exhibit 33, the power sector will be responsible for 286 MtCO<sub>2</sub> of emissions in 2020. By 2030, emissions are expected to fall to 139 MtCO<sub>2</sub> in 2030. This amounts to a 27% drop relative to emissions under the reference case and reflects an over-fulfilment of the power sector target. This, in turn, could compensate for the failure to meet targets in some of the other sectors. In the 2032 scenario, the power sector would exceed the lower climate target for the power sector by 41 MtCO<sub>2</sub>.

Exhibit 33: Total power sector emissions in Germany across scenarios up to 2040



37

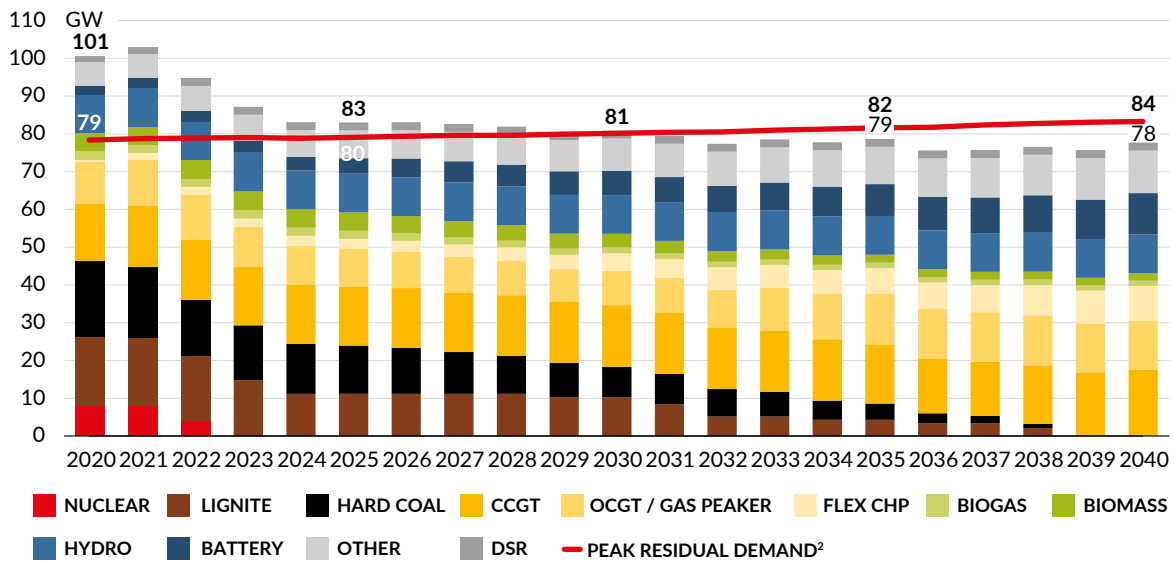
Sources: Aurora Energy Research.

By 2040, carbon emissions converge with the reference case at 121 MtCO<sub>2</sub>. This is because coal and lignite capacities in both scenarios will have completely left the system by then. In total, the early phase-out of lignite capacities results in a cumulative savings of 410 MtCO<sub>2</sub> by 2040.

### 4.1.3. Security of supply

**Capacity margin.** Under the reference scenario, the total installed dispatchable capacity is expected to decrease from 101 GW in 2020 to 81 GW in 2030. Based on the assumption that Germany hits its RES targets and coal and lignite are successfully phased out of the power system, total dispatchable capacities fall to 78 GW by 2040. The highest residual demand i.e. demand after intermittent renewables generation, increases over the projected horizon from 79 GW in 2020 to 81 GW in 2030. In 2040, the highest residual demand is expected to amount to 84 GW, which exceeds the amount of available dispatchable capacity by 6 GW. This is illustrated in Exhibit 34. During such periods, the German system relies on interconnection to meet demand.

Exhibit 34: Development of installed dispatchable capacity against highest residual demand up to 2040



38

Source: Aurora Energy Research

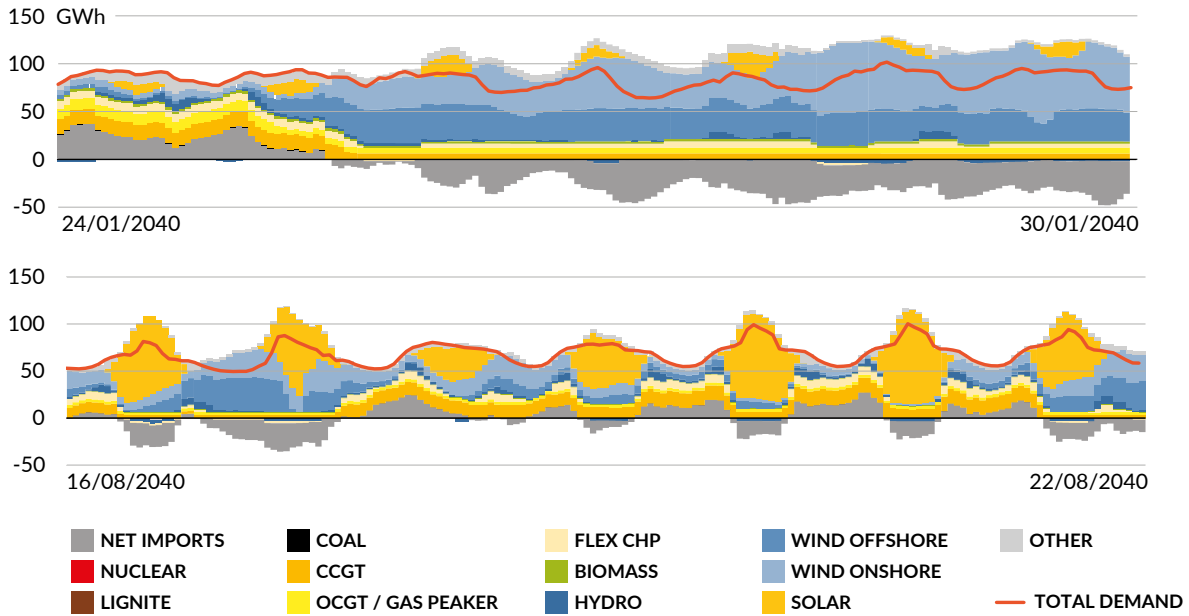
1) Hydro includes run-of-river, hydro storage and pump storage; 2) Residual demand defined as total demand (including electric vehicles and heat pumps) minus production possibilities from intermittent renewables: wind on and offshore, solar, and run of river hydro

**Generation in sample weeks.** The disparity between available dispatchable capacity and highest residual demand in Germany is expected when it comes to interconnected energy-only markets. The capacity gap in these cases is filled by a mixture of renewables and foreign capacities. Should supply in the wholesale market fall short of power demand, Germany's capacity reserve can be called on. In the modelled scenario, demand is met in all hours of the year.

A corresponding relationship exists between hourly generation and total demand in Germany. This is illustrated in Exhibit 35 for two sample weeks in 2040. This applies to each of the three scenarios because they all converge by 2040. The first scenario displays a week in January when electricity generation from renewables fluctuates from low to high. While dispatchable capacities ramp up in times of lower renewables generation, foreign imported generation also plays a role in meeting demand in the wholesale market. The second of the two sample selections represent a week in August that is characterized by a high level of renewables. The contribution from dispatchable capacities in this case is expected to be minimal. Imported generation is shown to be unnecessary to meet energy demand.



Exhibit 35: Total generation and demand for two exemplary weeks in 2040

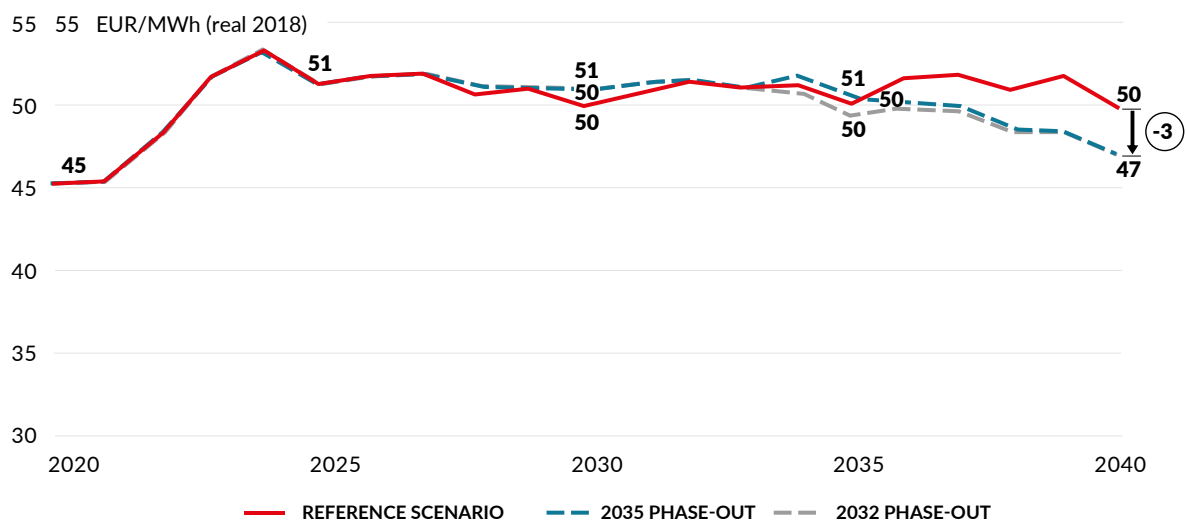


Sources: Aurora Energy Research.

#### 4.1.4. Affordability

**Wholesale power prices.** As shown in Exhibit 36, wholesale power prices under the reference scenario are expected to increase from 45 EUR/MWh in 2020 to 50 EUR/MWh in 2030 and 2040.

Exhibit 36: Average annual baseload electricity price in Germany up to 2040



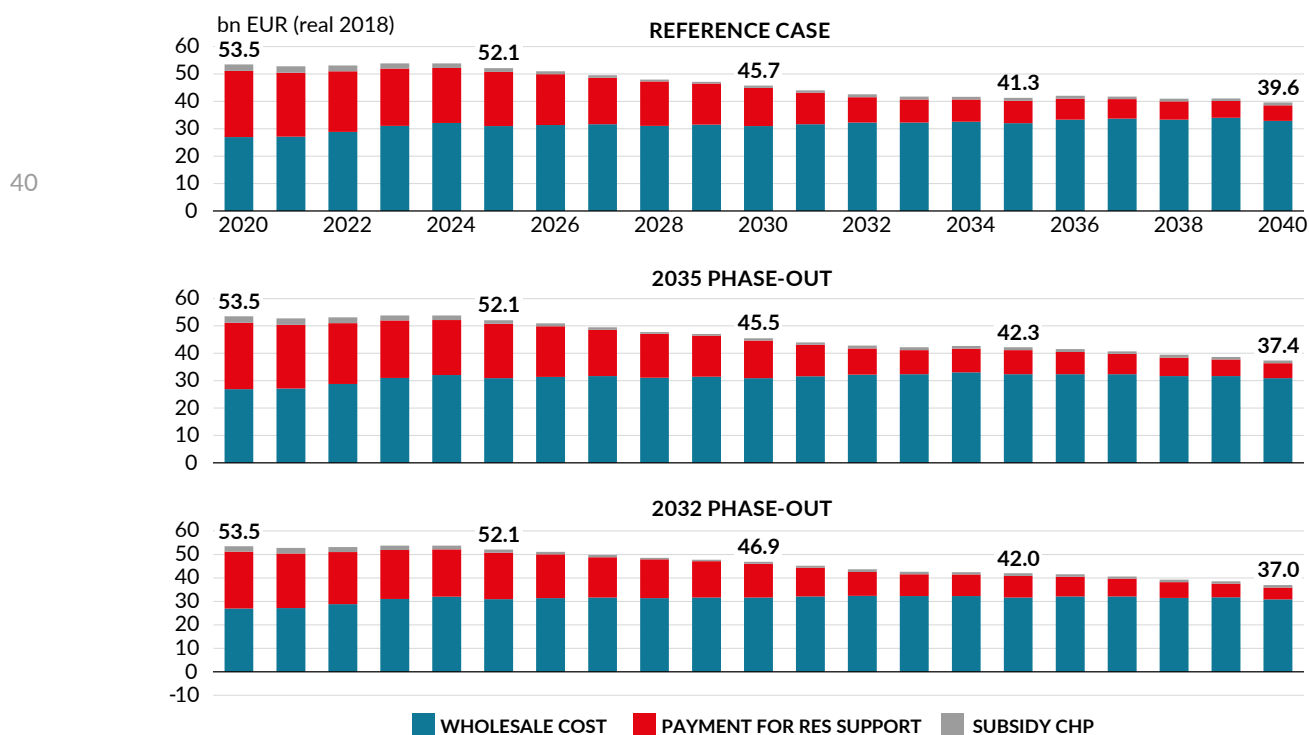
Sources: Aurora Energy Research.

Prices under the 2035 phase-out scenario exhibit a similar price trajectory up to 2030. This reflects the fact that the capacity trajectory up to 2030 mirrors that of the reference scenario. In 2035, however, the baseload price of electricity under early phase-out scenario increases to 51 EUR/MWh, a 1 EUR/MWh increase relative to the reference case. This is explained by the replacement of low marginal cost coal and lignite capacities with natural gas-fired CHP plants, which sit higher in the merit order. However, a long-run increase in RES generation pushes prices back down to 47 EUR/MWh, which is 3 EUR/MWh lower than the reference case.

Power prices under the 2032 lignite phase-out scenario begin to diverge from the reference case in the late 2020s, driven in part by the replacement of lignite generation with generation stemming from renewables and natural gas-fired CHPs. By 2030, wholesale power prices increase to 51 EUR/MWh, which is 1 EUR/MWh greater than prices under the reference case. By 2040, the baseload price of electricity falls 3 EUR/MWh below the reference case, to 47 EUR/MWh.

**System costs.** Our system cost analysis for the German market includes the cost of providing electricity in the wholesale market, as well as the cost of building generation capacities that receive support from outside the wholesale market, i.e. renewables and CHP plants. Other costs, especially for transmission and distribution grids, are not considered in this study.

Exhibit 37: German power system cost



Source: Aurora Energy Research, Netztransparenz.de.

Note: The payment for RES support is the difference between set level of RES support and achieved market revenue.

System costs in Germany decrease from 53.5 to 39.6 bn EUR between 2020 and 2040, driven predominantly by a decrease in EEG support. As highly-supported first generation renewables leave the system, cheaper newbuild renewables replace them. System costs decrease further in the coal exit scenarios. Compared to the reference scenario, the 2035 phase out results in 0.2 bn EUR lower system costs in 2030. The stronger build-out of renewables in the 2032 phase out and the therefore higher RES-subsidy charges are associated with an additional 1.2 bn EUR in system costs. By 2040, however, the early phase out scenarios are cheaper than the Reference case, since the RES support payments are lowest then. It is important to note that renewables only serve to lower the system cost if they are given long-term offtake contracts under the EEG. Without them, and without the state taking over this long-term liability, their financing costs and hence their levelized costs of electricity (LCOE) are higher. The lower-cost system is therefore not delivered automatically by the market, but needs supporting policies.

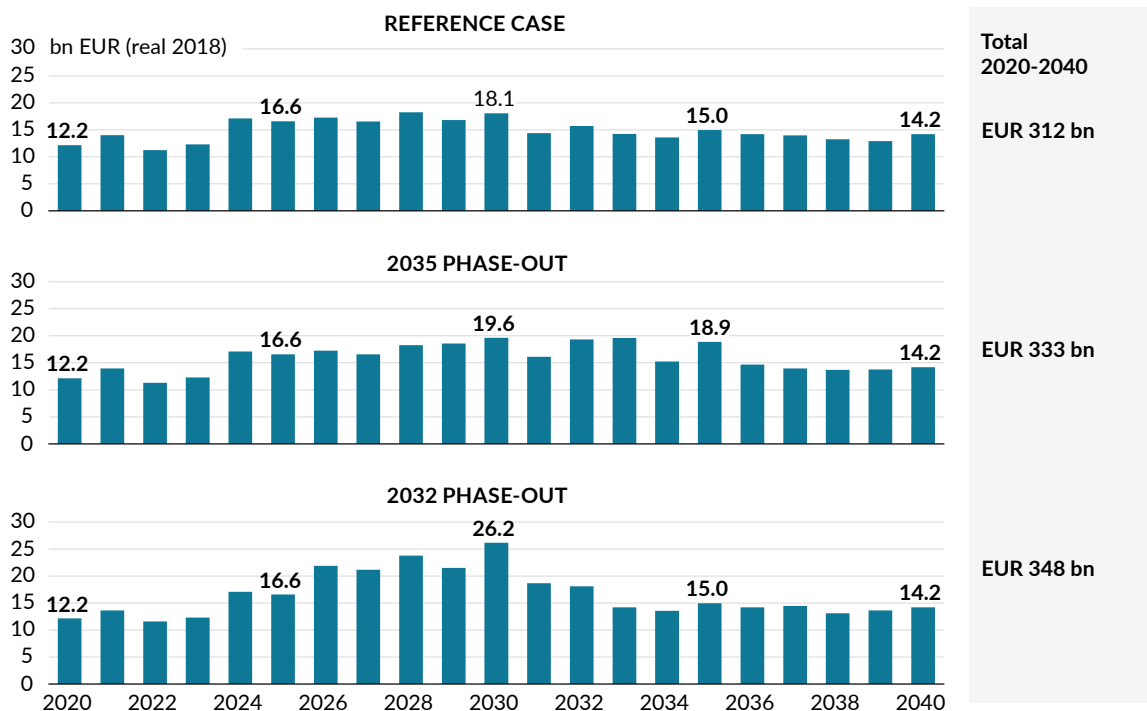
Assuming policy support for renewables, the total system costs between 2020 and 2040 in the 2035 phase-out scenario are EUR 5 bn lower over 20 years than in the reference scenario. , In the 2032 phase-out scenario, they are EUR 1.2 bn lower. This means that carbon abatement comes with a cost decrease. This leads to lower RES support payments in the long run. In the 2032 scenario, each of the 410 Mt of carbon reduction decreases system costs by in 2.9 EUR/t.

From these system costs, a significant unburdening of household and commercial consumers can be expected: under all scenarios, the EEG surcharge, currently at 6.65 ct/kWh, would decrease to 1.9 ct/kWh. Combined with the approximately 0.3-0.5 ct/kWh higher wholesale power prices, this still constitutes net downward pressure on prices over the next 20 years. This leaves some scope for grid fees to rise without leading to higher consumer prices.

**Investments.** German power sector investments increase from EUR 12.2 bn in 2020 to EUR 18.1 bn annually in 2030, then decrease to 14.2 bn EUR by 2040. The early coal exit results in an increase in investments, with the 2035 phase-out resulting in additional investments from 2029 to 2035 and the 2032 phase-out increasing investments in 2026 to 2032. Investments increase by between EUR 1.6 and 8.1 bn per year during these periods. Total investments over the next 20 years in the phase-out cases are EUR 21 bn and EUR 36 bn greater, due mostly to the slightly higher level of renewable capacity and the earlier introduction of planned additional renewable capacity (when prices are higher).

41

Exhibit 38: German power generation investments



Source: Aurora Energy Research.

### 4.1.5. Infrastructure

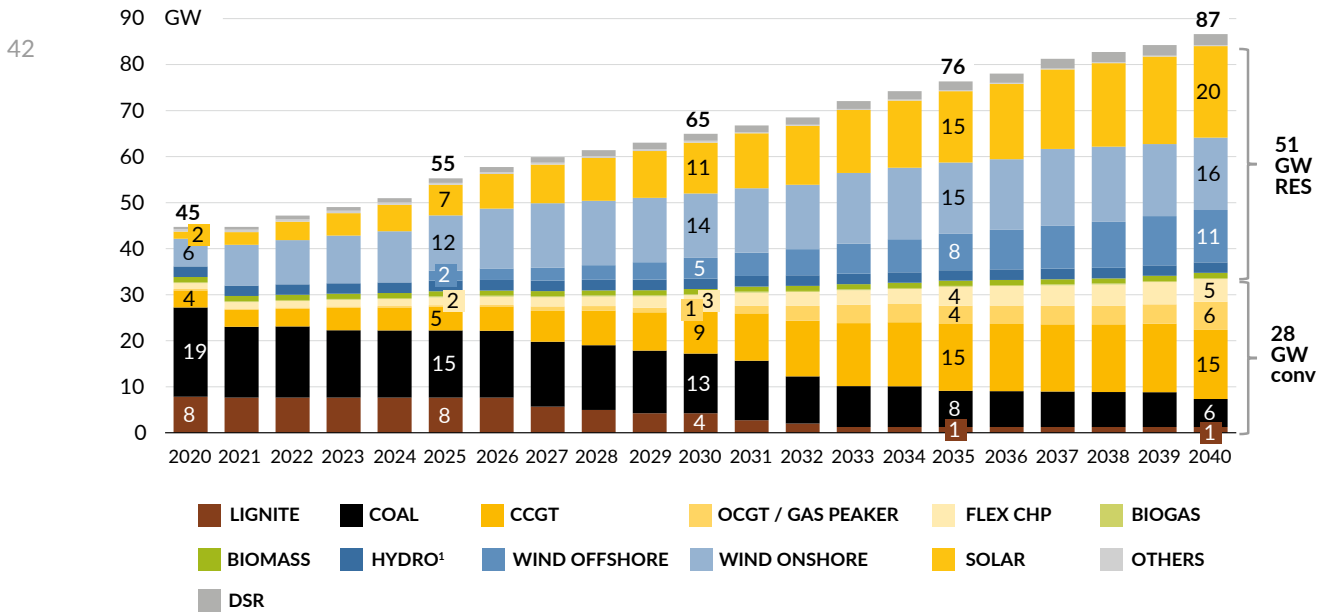
While German electricity grids are generally in a good condition, increasing the share of renewables to 65% of gross demand in 2030 and 80% in 2040 will require the expansion of both the transmission and the distribution grids. On the distribution level, grid development planning in Germany is currently geared towards 2030 and already takes into account the 65% renewables target. In the latest Grid Development Plan, the four German TSOs estimate that investments totalling EUR 61bn will be required to make the grids compatible for a 65% renewables share. Further investments after 2030 will likely be needed to handle an 80% share in 2040. However, in a recent assessment, the Federal Network Agency found that only 96 out of 164 measures proposed by the TSOs were necessary, so costs could be well below the above figure. Under current regulations, costs for grid expansion are predominantly borne by non-privileged consumers, comprising households, businesses, and non-energy-intensive industries. Further grid expansion is likely to impact consumer prices while protecting those industries most in danger of being displaced by international competition.

### 4.2. Poland

#### 4.2.1. Power market

**Reference scenario.** As the reference scenario shows, we expect the Polish power market to experience a significant shift from coal to renewables and gas even without strong political support for decarbonization.

Exhibit 39: Installed net capacities in Poland up to 2040, reference scenario

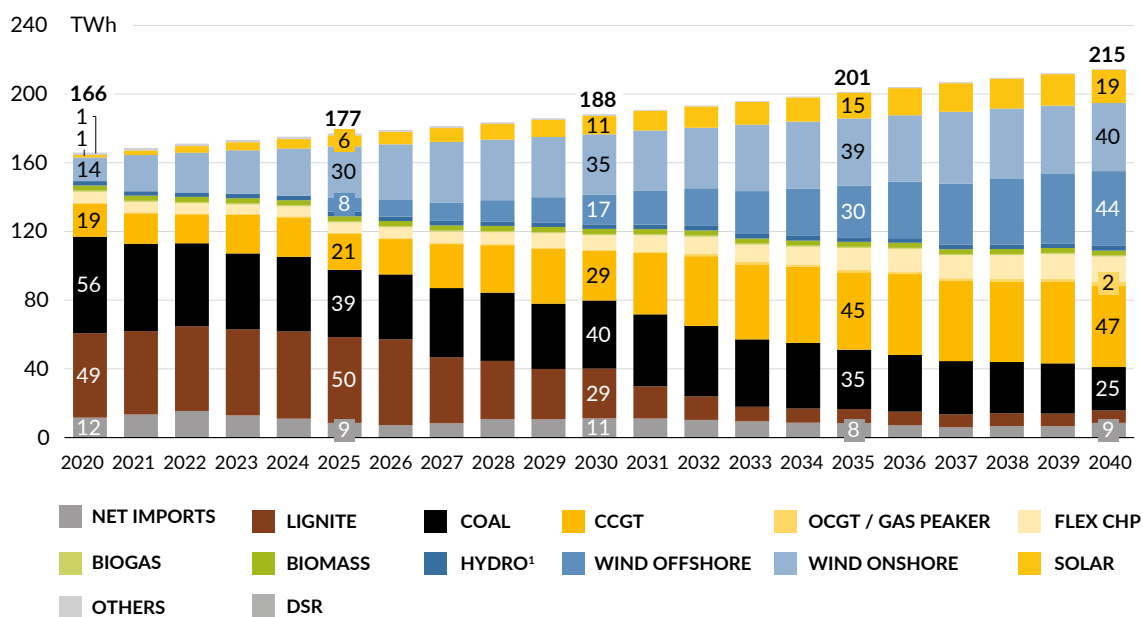


Source: Aurora Energy Research.

1) Hydro includes run-of-river, hydro storage and pump storage.

As illustrated in Exhibit 40, total installed capacity in Poland is expected to increase from 45 GW in 2020 to 65 GW in 2030 and 87 GW in 2040. Under the assumption that older units at the Bełchatów power station will close between 2028<sup>24</sup> and 2033 and that newer units will close by 2040, capacities stemming from lignite will decrease from 7.8 GW in 2020 to 1.3 GW in 2040. Hard-coal capacities follow a similar trajectory, decreasing from 19.4 GW in 2020 to 6.1 GW in 2040. By contrast, natural gas and total solar and wind capacities are expected to grow from 5 GW and 7.6 GW in 2020 to 26 GW and 47 GW in 2040. The share of renewables in the capacity mix is therefore projected to increase from 17% of the capacity mix in 2020 to 54% by 2040. As discussed in the assumptions section, we have supposed that solar and offshore wind are subsidized to this level, while onshore wind is delivered subsidy-free beyond the current pipeline of projects.

Exhibit 40: Net generation in Poland up to 2040



Source: Aurora Energy Research.

1) Hydro includes run-of-river, hydro storage and pump storage 2) Nuclear and lignite.

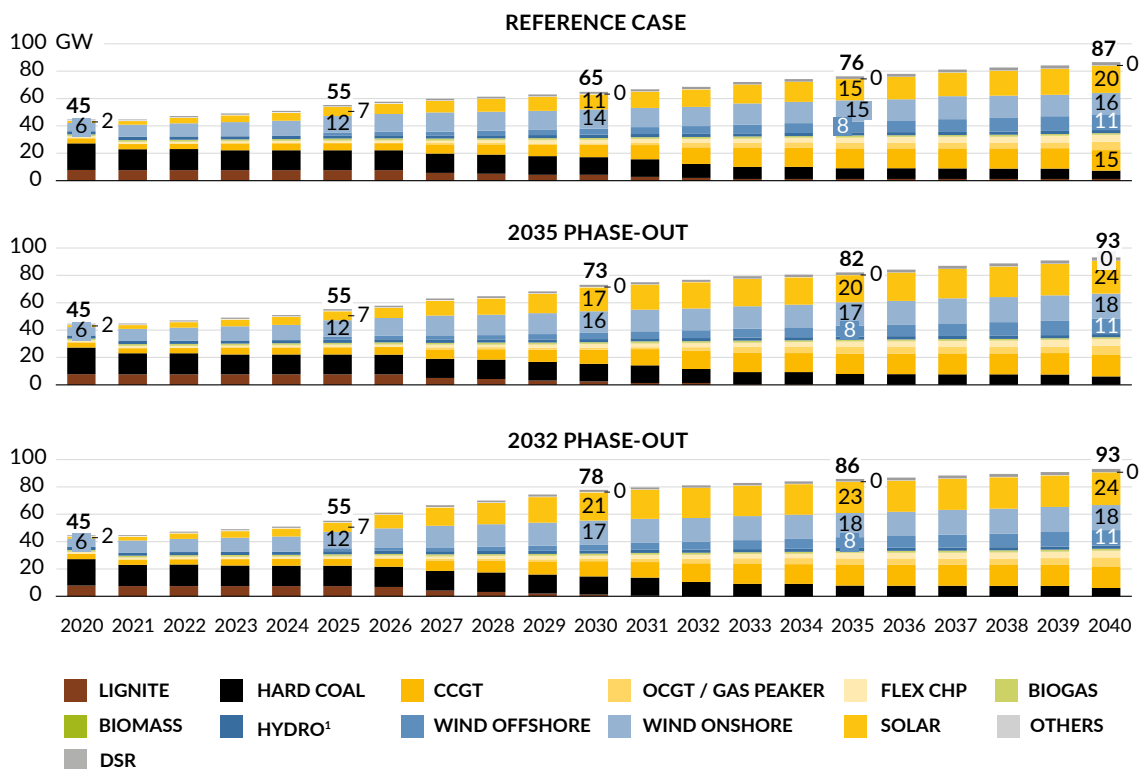
In accordance with the capacity growth illustrated above, total net generation in Poland is expected to increase from 166 TWh in 2020 to 215 TWh in 2040. In this period, generation from hard coal and lignite is expected to decrease respectively by 56 TWh and 49 TWh in 2020 to 25 TWh and 7 TWh in 2030. By contrast, renewable generation exhibits significant growth over the forecast period. In 2020, 15 TWh, or 9% of total generation in Poland, is expected to stem from RES. By 2040, this increases to 103 TWh, or 48%. Net imports during this time also decrease from 12 TWh in 2020 to 9 TWh in 2040. This is illustrated in Exhibit 41.

**Lignite phase-out scenarios.** The two lignite phase-out scenarios are characterized by the early phasing-out of lignite-fired power plants from the Polish power system. The two scenarios differ in the target year that the full exit is achieved. In both phase-out scenarios, lignite capacities that leave the system are replaced by a combination of natural gas plants and renewables.

<sup>24</sup> The capacity contracts for the Bełchatów units expire in 2028, after which they can be retired. So far, only the newbuild Turów plant has a longer capacity contract. This is illustrated in Exhibit 72.

**2035 Lignite phase-out scenario.** Under the 2035 lignite phase-out scenario, a complete exit of lignite capacities is expected by 2035. Achieving this requires that both the older and newer units at the Bełchatów power plants close by 2030 and 2035, respectively.

Exhibit 41: Capacities in the Polish scenarios



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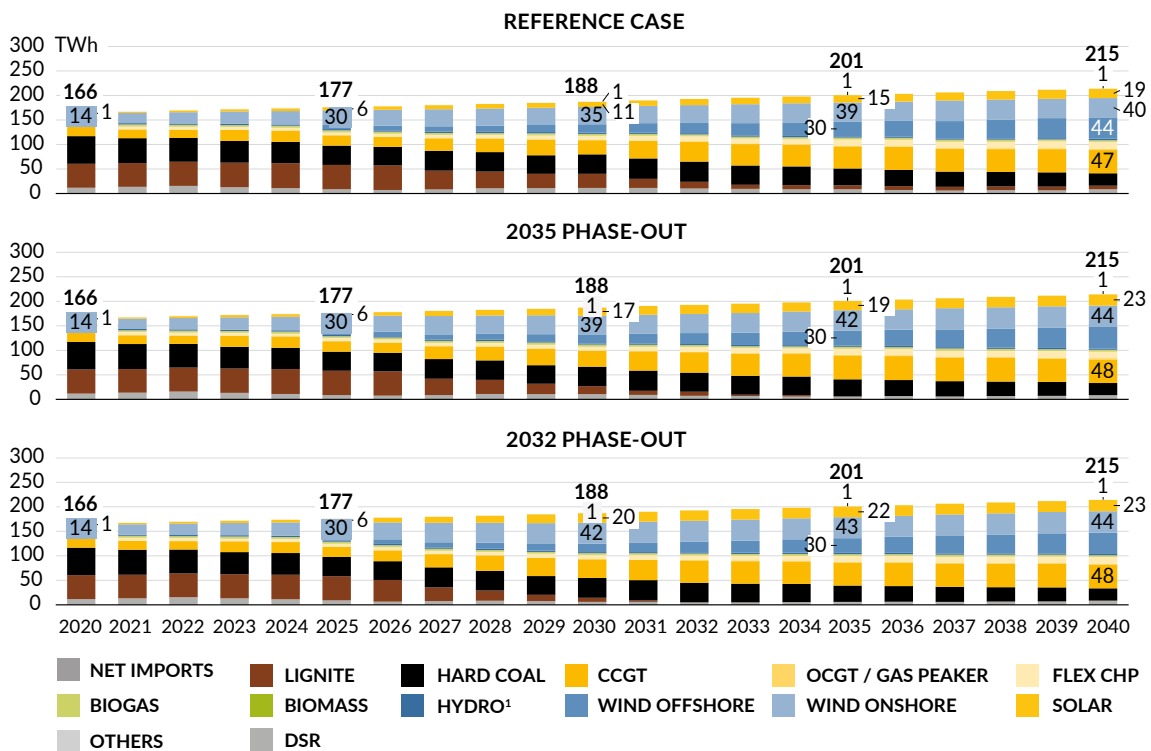
Source: Aurora Energy Research.

1) Hydro includes run-of-river, hydro storage and pump storage.

As shown in Exhibit 41, this results in lignite capacities falling 2 GW and 1 GW below the reference case in 2030 and 2040. To make up for capacities that exit the system, renewable capacities increase so that by 2030 solar and wind onshore capacities in the 2035 lignite phase-out scenario exceed that of the reference case by 6 GW and 2 GW, respectively. This difference decreases to 7 GW by 2040. In our modelling, the Polish capacity market ensures that the capacity of lignite plants retiring early is replaced by newbuild CCGT and OCGT capacities, which both increase by 1 GW in 2030 relative to the reference case. This 2 GW delta of additional CCGT and OCGT capacity persists up to 2040.

When compared with the reference case, the earlier exit of older and newer units at the Bełchatów power plant under the 2035 lignite phase-out scenario results in generation differences of -13 TWh and -7 TWh in 2030 and 2040, respectively. To reflect the growth in onshore wind and solar, generation stemming from RES is expected to be 10 TWh greater than that in the reference case in 2030. By 2040, this generation difference decreases by 8 TWh. In light of the increased renewable generation, net imports in Poland are expected to decrease, reflecting lower wholesale power prices. As shown in Exhibit 42, Poland in the 2035 lignite phase-out scenario imports 1 TWh less of electricity in 2030 when compared with the reference case. The net import difference between scenarios diminishes by 2040.

Exhibit 42: Net generation in phase-out scenarios in Poland



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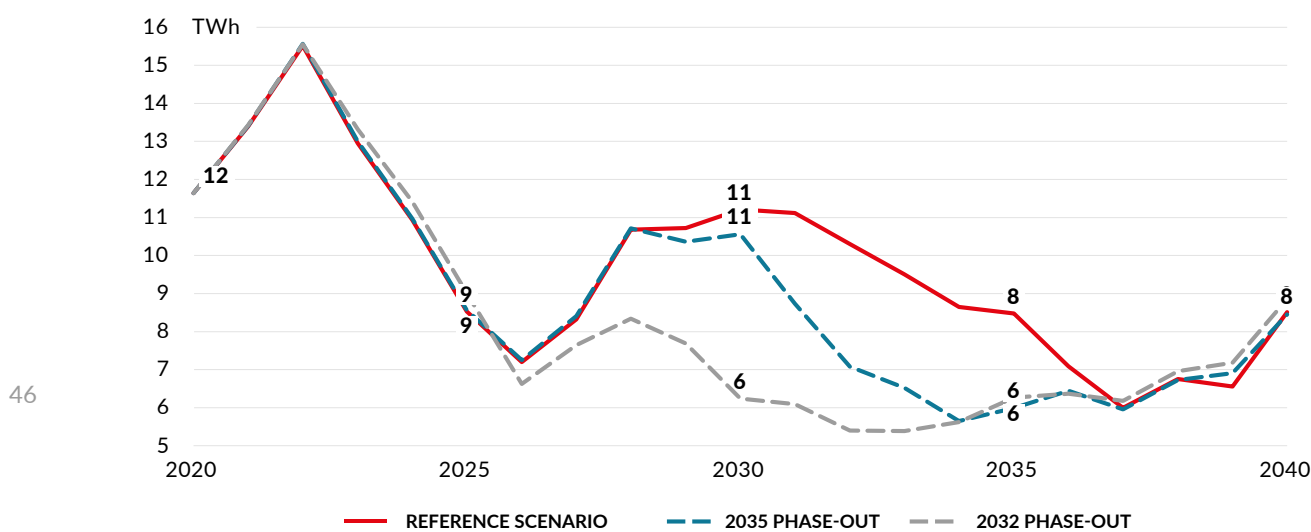
Source: Aurora Energy Research.

1) Hydro includes run-of-river, hydro storage and pump storage.

**2032 Lignite phase-out scenario.** The phasing out of lignite capacities by 2032 under the 2032 lignite phase-out scenario results in installed lignite capacities in Poland falling 3 GW below that of the reference case in 2030, and 1 GW below that of the reference case in 2040. Lignite capacities that exit the system over the projected horizon are replaced by a mixture of renewables and natural gas-fired power stations (the latter delivered by the capacity market). As illustrated in Exhibit 42, total solar and onshore wind capacities grow beyond capacities in the reference case by 13 GW in 2030 and 7 GW in 2040; CCGT and OCGT capacities are projected to increase as well, with 1 GW and 2 GW more installed capacity, respectively, than the reference case in 2030. By 2040, the natural gas capacity difference decreases to 2 GW, split evenly between the two technologies.

Net generation in the 2032 lignite phase-out scenario is expected to remain identical to that of the reference scenario up to 2025, as shown in Exhibit 42. While electricity generation stemming from lignite is expected to fall 21 TWh short of the reference scenario in 2030, generation from renewables and natural gas plants will increase, ensuring that overall net generation is unchanged. Net production stemming from RES and natural gas plants will therefore exceed that of the reference case by 16 TWh and 9 TWh in 2030, respectively. By 2040, electricity production from natural gas under the 2032 lignite phase-out scenario is expected to converge with the reference case. The export balance in this period is expected to improve relative to the reference case. As Exhibit 43 shows, net imports are 5 TWh lower in 2030, amounting to 6 TWh instead of 11 TWh in the reference scenario. By 2040, disparities in the import/export balance between scenarios disappear.

Exhibit 43: Trade balance for Poland

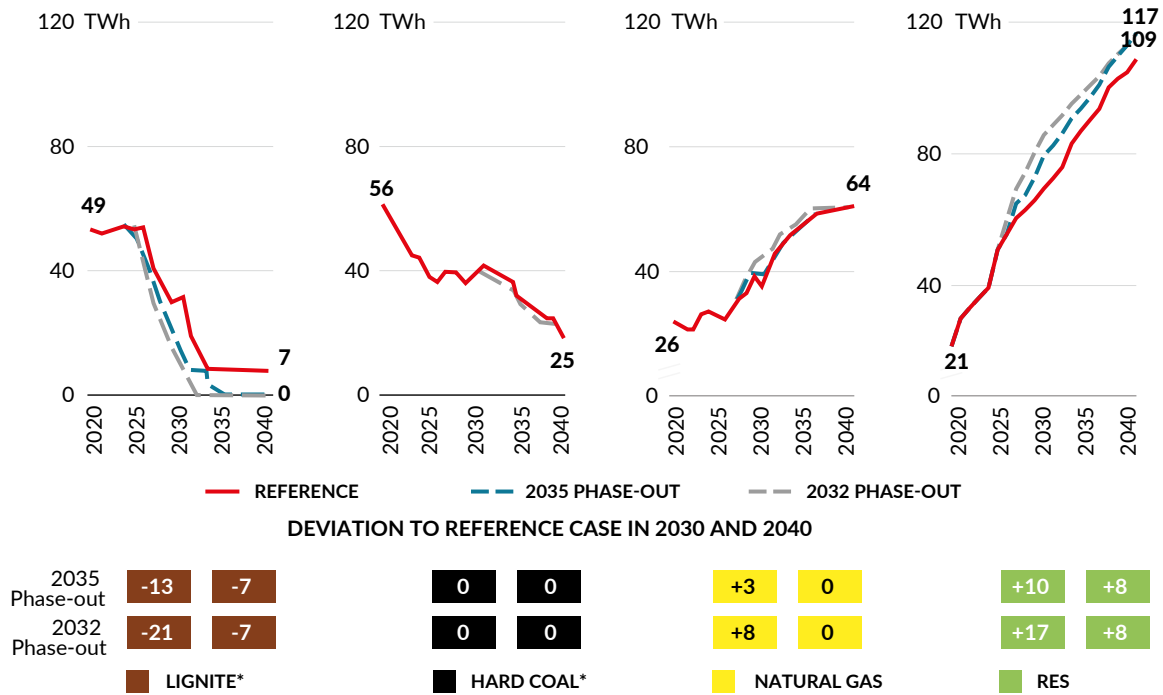


Source: Aurora Energy Research.



Exhibit 44 provides an overview of the development of power generation by source in the scenarios.

Exhibit 44: Power generation from lignite, hard coal, gas, and renewables up to 2040



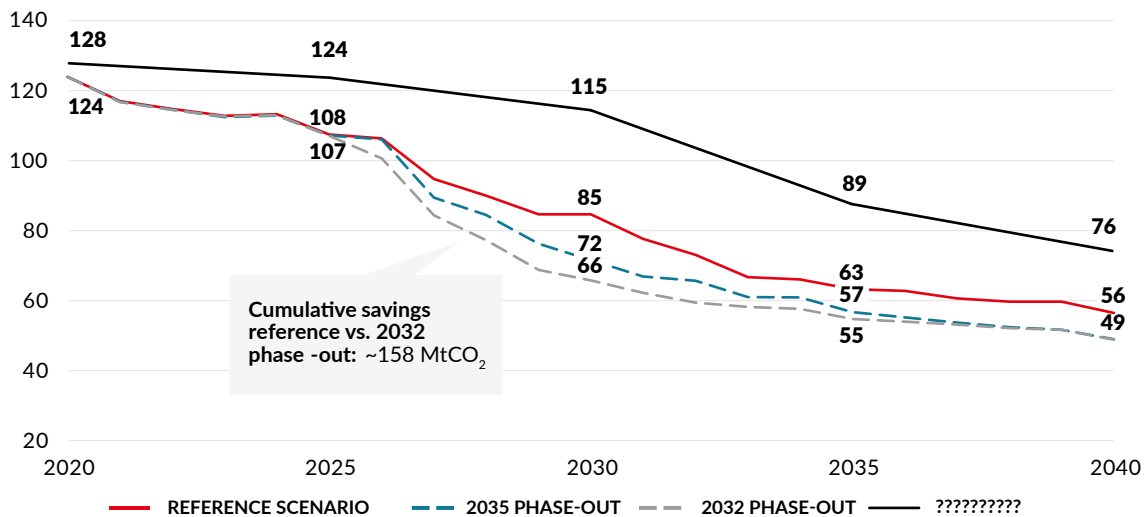
Source: Aurora Energy Research.

1) We assume calorific values of 10 GJ/T of Lignite and 25 GJ/T of hard coal.

### 4.2.2. Climate

Under the reference scenario, we expect total carbon emissions stemming from the power sector to fall from 124 MtCO<sub>2</sub> in 2020 to 85 MtCO<sub>2</sub> in 2030. Emissions further decrease in the final decade of the forecast period, reaching 56 MtCO<sub>2</sub> by 2040.

Exhibit 45: Total power sector emissions in Poland across scenarios up to 2040



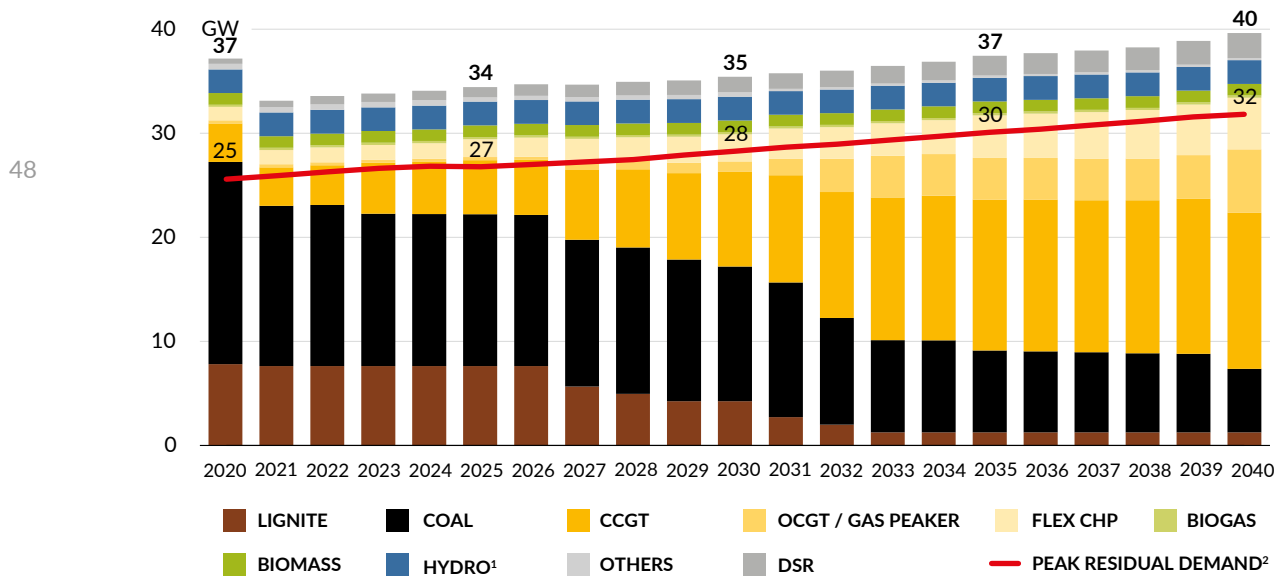
Source: Aurora Energy Research.

As Exhibit 45 shows, emissions in the 2035 lignite phase-out scenario drop to 72 MtCO<sub>2</sub> in 2030, which is 13 MtCO<sub>2</sub> or 15% lower than the reference case. By 2040, power sector emissions fall to 49 MtCO<sub>2</sub>, 13% below the reference case. Over the projected horizon, the complete phase-out of lignite-fired power plants results in a cumulative savings of 107 MtCO<sub>2</sub>. The drop in emissions is even more drastic in the 2032 lignite phase-out scenario. By 2030, power sector carbon emissions hit 66 MtCO<sub>2</sub>, which is 19 MtCO<sub>2</sub>, or 22%, lower than the reference case. The deviation from the reference case decreases slightly over the next ten years to 14% (8 MtCO<sub>2</sub> difference) by 2040. In total, carbon emissions under the 2032 lignite phase-out scenario are 159 MtCO<sub>2</sub> lower than those observed in the reference scenario.

### 4.2.3. Security of supply

**Capacity margin.** Total installed dispatchable capacity under the reference scenario is expected to increase from 37 GW in 2020 to 40 GW by 2040, with a drop in the early 2020s as capacities for which it is not profitable to become compliant with the new LCP BREF standards applicable from 2021 leave the market. Over this time frame, the highest residual demand, i.e. demand after intermittent renewables generation, is expected to remain consistently below the available dispatchable threshold, growing from 25 GW in 2020 to 32 GW by 2040. This is illustrated in Exhibit 46. Poland's is therefore likely to have a secure supply of power.

Exhibit 46: Development of installed dispatchable capacity against highest residual demand in Poland up to 2040

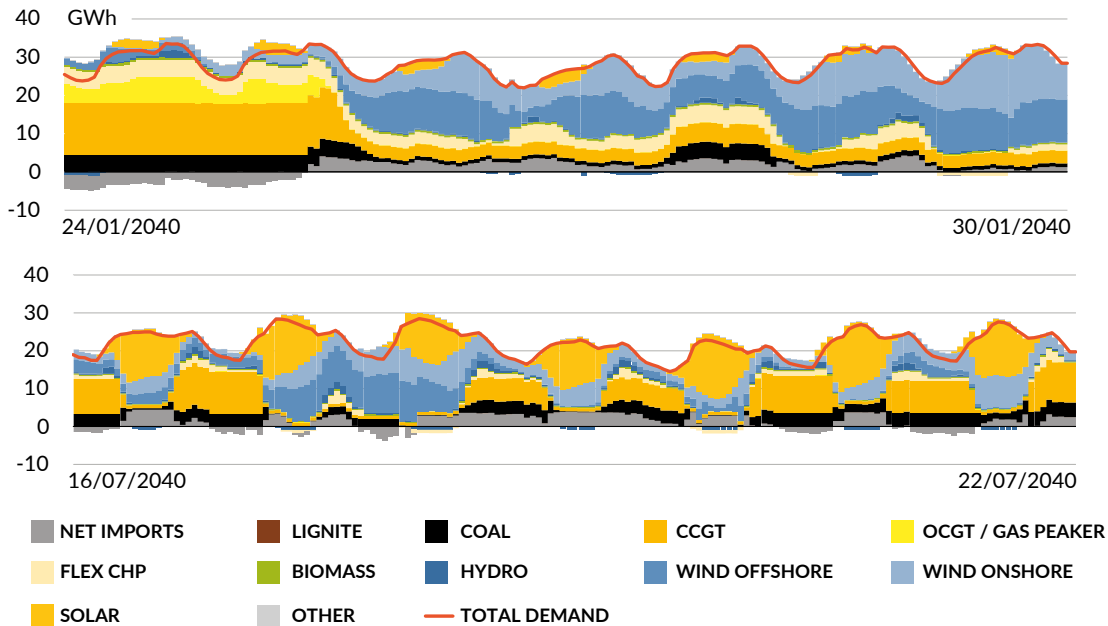


Source: Aurora Energy Research.

1) Hydro includes run-of-river, hydro storage and pump storage; 2) Residual demand defined as total demand (including electric vehicles and heat pumps) minus production possibilities from intermittent renewables: wind on- and offshore, solar, and run-of-river hydro.

The key challenge will be to ensure that new capacities are built in time to replace the coal capacities that are scheduled to retire in the mid-2020s. If planning is delayed, the security of supply could be threatened. It is thus crucial that Poland anticipate its future capacity needs early, but also that Poland keeps renewables targets and auctions in place. Reform of the capacity mechanism towards low-carbon solutions (like clean energy portfolios) is of an utmost importance.

Exhibit 47: Total generation and demand for two sample weeks in Poland in 2040



Source: Aurora Energy Research.

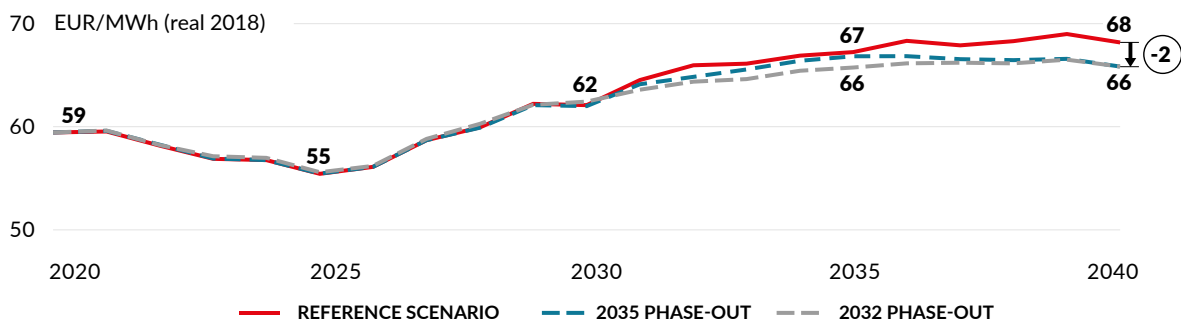
**Generation in sample weeks.** Despite the fact that total installed capacity is shown to cover average peak demand over the projected horizon, there exist hours in the forecast period in which the demand for electricity in Poland exceeds net production. These are hours in which it is more economic to meet demand with foreign capacities, making Poland a net importer. This can be seen in Exhibit 47 for two sample weeks in 2040 from the 2032 phase-out scenario. In the final week of January 2040, dispatchable capacities are shown to make up a significant share of the generation mix in low RES hours. These capacities ramp down significantly in hours with favourable wind or solar conditions, as Poland’s neighbours in the west and north in particular use more renewables, lowering power prices during these hours. The same can be seen for a sample week in August of the same year. While imports are shown to make up the difference between total net generation and electricity demand, Poland exports excess RES generation.

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#### 4.2.4. Affordability

**Wholesale power prices.** Wholesale prices in Poland under the reference scenario are projected to grow from 59 EUR/MWh in 2020 to 62 EUR/MWh in 2030. By 2040, average power prices reach 68 EUR/MWh.

Exhibit 48: Average annual baseload electricity price in Poland up to 2040



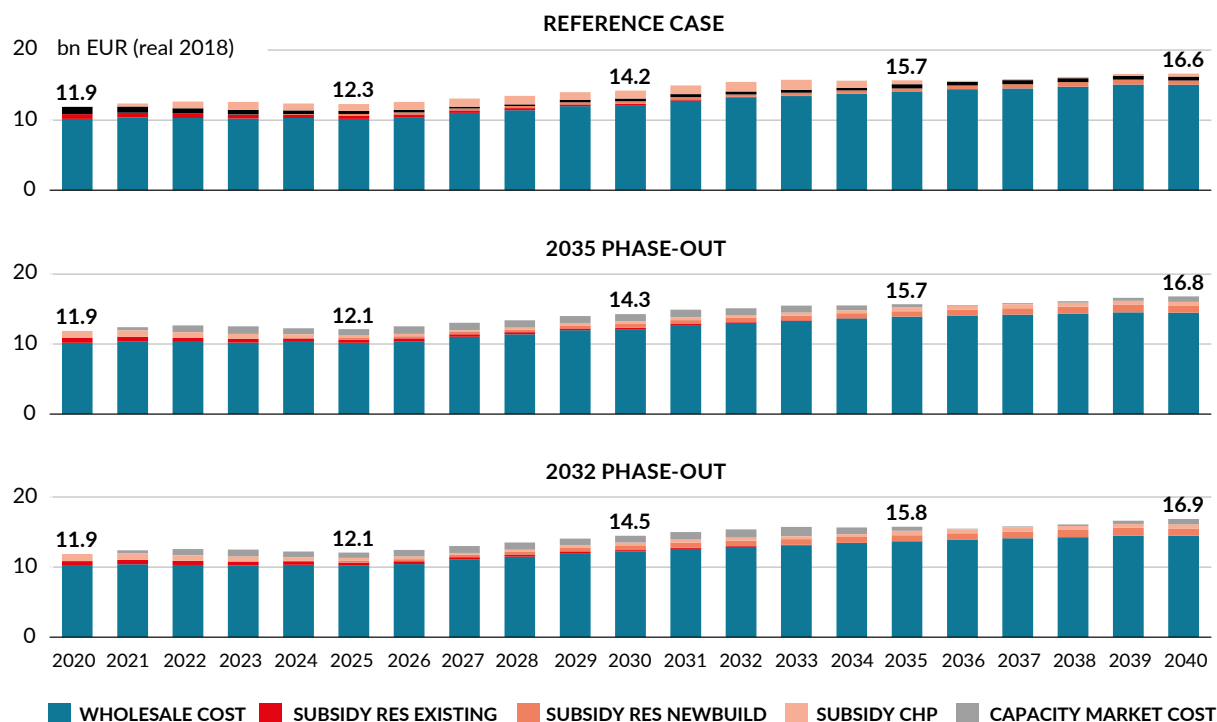
Source: Aurora Energy Research.

In the 2035 lignite phase-out scenario, average annual wholesale power prices are expected to be identical to that of the reference scenario up to 2030. Electricity prices increase from 59 EUR/MWh in 2020 to 62 EUR/MWh in 2030. At this point, prices diverge: by 2035, prices in the lignite phase-out scenario are 67 EUR/MWh, which is 0.4 EUR/MWh below the reference case. This is explained by the fact that the exit of lignite capacities is offset by significant increases in RES capacities, which have a lower marginal cost than lignite. In the long run, generation from renewables is expected to further decrease the difference to -2 EUR/MWh by 2040, as prices reach 66 EUR/MWh.

Average power prices in the 2032 lignite phase-out scenario are expected to grow from 59 EUR/MWh in 2020 to 62 EUR/MWh in 2030 and to 66 EUR/MWh by 2040. Because the phase-out of lignite capacities in Poland are not achieved until the early 2030s, average wholesale prices up to 2030 are expected to mirror that of the reference case. Driven by the increase in Polish RES production, wholesale electricity prices reach 66 EUR/MWh in 2035, 1.5 EUR/MWh lower than the reference case. The gap in prices between scenarios further increases up to 2040 as RES generation continues to grow and lower-cost marginal cost technologies increasingly set the power price.

### System costs

Exhibit 49: Polish power system costs



Source: Aurora Energy Research.

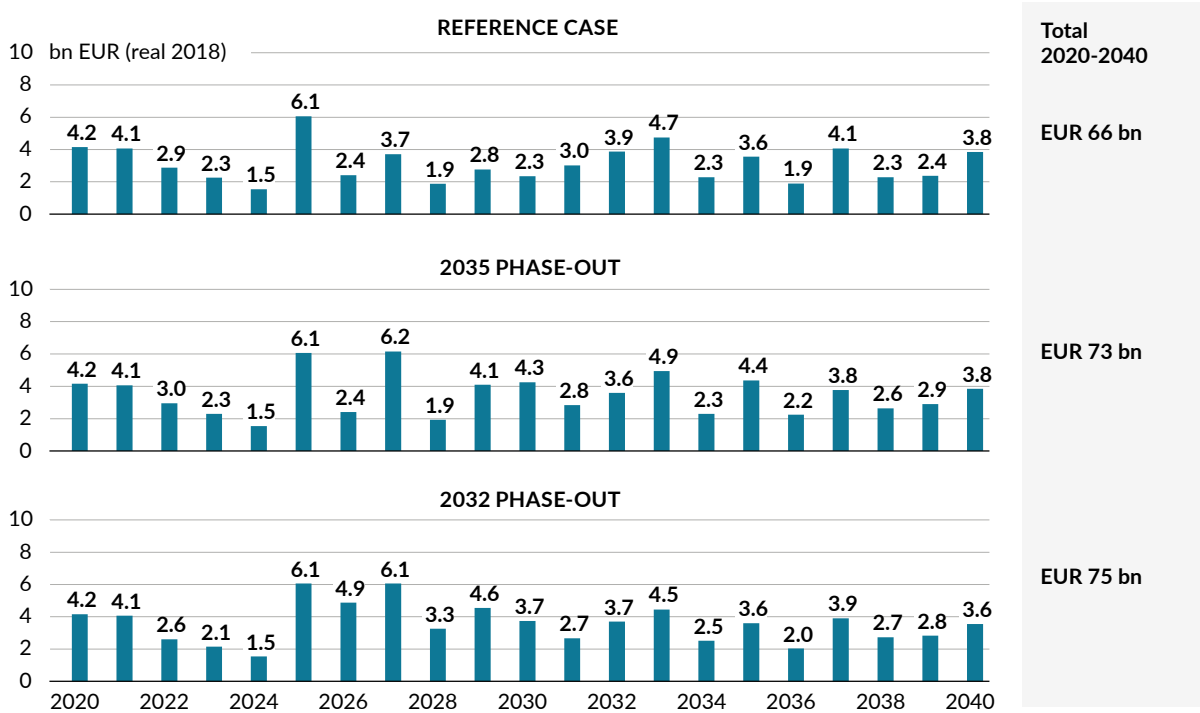
Our system cost analysis for the Polish market includes the cost of providing electricity in the wholesale market, the cost of providing capacity in the capacity market, as well as the cost of building generation capacities that receive some support from outside the wholesale market, i.e. renewables and CHP plants. Other costs, especially for transmission and distribution grids, are not considered in this study.

System costs in Poland in the reference case increase from EUR 11.9 bn to EUR 16.6 bn, driven by increasing wholesale costs as both demand and prices increase. Capacity market costs increase in the 2020s and then decrease significantly by the mid-2030s. Subsidies for CHP and renewables remain a small part of total costs. In the coal exit scenarios, power prices decrease, but additional thermal capacities need to be replaced, which leads to higher capacity market prices and slightly higher system costs in the 2020s (less than EUR 0.5 bn). The 2035 phase-out results in system costs that are EUR 0.1 bn higher than in 2030, while the 2032 phase-out results in an increase of EUR 0.3 bn.

Between 2020 and 2040, system costs in the 2035 phase-out scenario are EUR 1bn or 0.4% lower over 20 years than in the reference scenario; in the 2032 phase-out scenario, they are EUR 0.2 bn or 0.1% lower, i.e. system costs are effectively identical. This is a remarkable result, because it shows that the emission savings generated by phasing out lignite can be achieved at negative system costs if the government pursues a long-term phase-out strategy and replaces lignite that leaves the system with renewables.

**Investments.** Polish power sector investments over the next 20 years are generally range between EUR 2 bn and EUR 6 bn per year. The 2035 phase-out requires a yearly investment increase of between EUR 0.6 bn and EUR 2.4 bn as of 2027, while the 2032 phase-out requires an additional annual investment of between EUR 1.4 bn and EUR 2.5 bn per year starting in 2026.

Exhibit 50: Polish power generation investments



Source: Aurora Energy Research.

Total investments over the next 20 years in the 2035 and 2032 phase-out scenarios are EUR 7 bn and EUR 9 bn greater, respectively. This is because of their slightly higher levels of renewables capacities and because renewables capacities that would have been built anyway are built earlier, when they are still somewhat more expensive. Overall, the additional investments can be considered quite small, given the importance that lignite currently has in the Polish power sector.

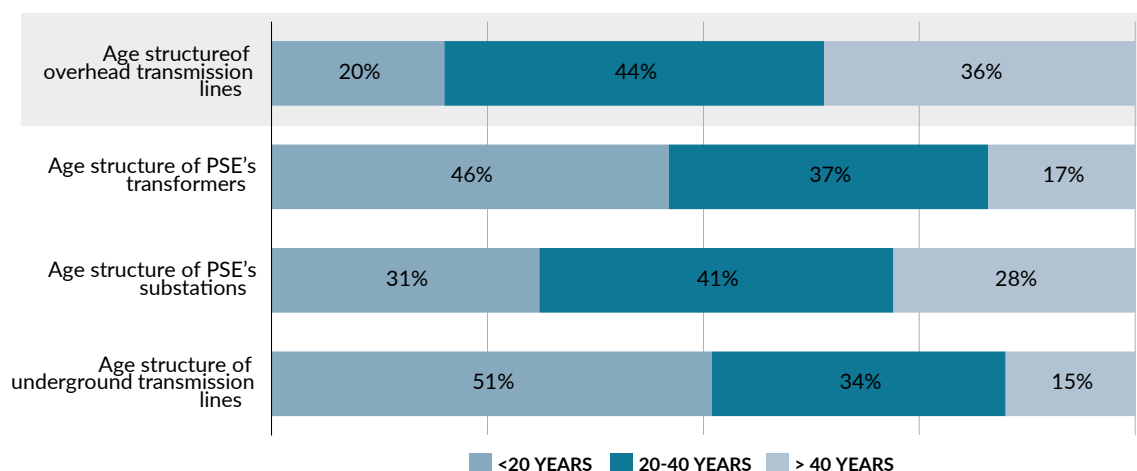
#### 4.2.5. Infrastructure

Renewable electricity sources are typically in different locations from those of the thermal electricity sources they replace and for which the electricity grid has been built. In Poland, this likely means shifting the centre of gravity of power generation northwards, from Southern and Central Poland, where most coal and lignite power generation is currently concentrated, to the Baltic Sea coast, where winds are stronger and offshore sites are available.

This shift will require new investments in the transmission grid. In its “expansion” scenario, the new draft PSE network development plan<sup>25</sup> estimates that investments totalling 3,3 billion EUR will be necessary between 2021 to 2030. But this scenario focusses on offshore wind and has a lower share of onshore wind than the scenarios presented here. This topic warrants further exploration in the future.

It should be noted, however, that most of the Polish transmission grid infrastructure is more than 20 years old. In the case of transmission lines, this is true of 80% of the infrastructure. The grid thus requires substantial investment in the next decades even without adding renewables shares. The additional costs of making the system ready for a high share of renewables is, therefore, unlikely to be much more expensive than the business as usual scenario.

Exhibit 51: Age structure of the Polish transmission grid



52

Source: UPS, Aurora Energy Research.

1) Restricting not explicitly included in PSE's statistics.

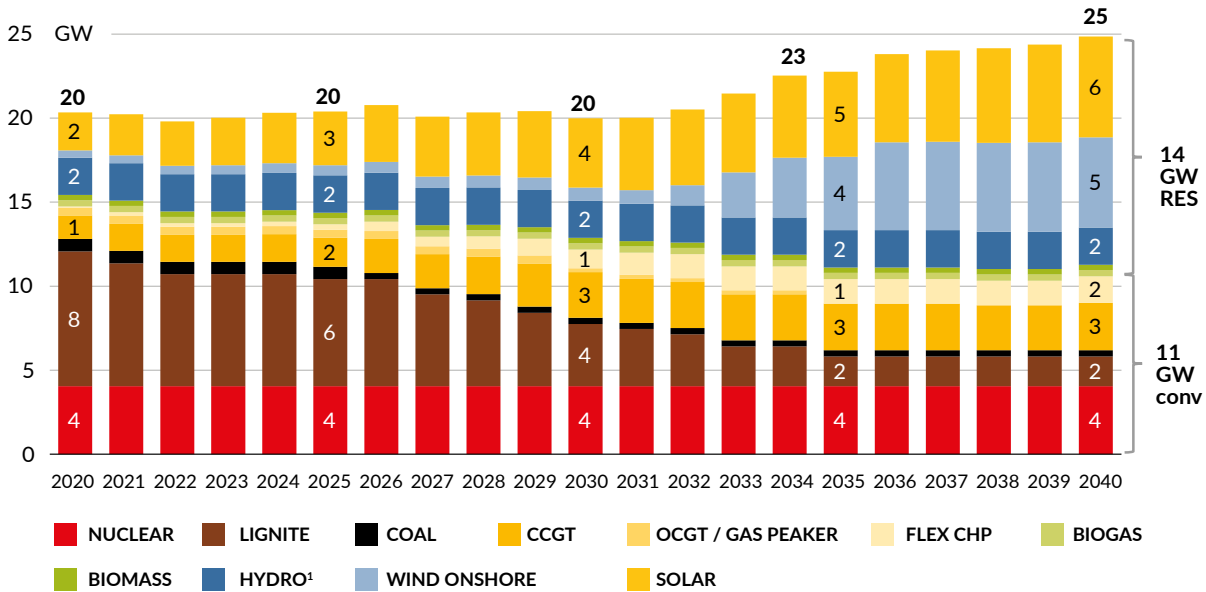
### 4.3. Czech Republic

#### 4.3.1. Power market

**Reference scenario.** In the reference scenario, total installed net capacities in the Czech Republic are expected to be 20 GW in both 2020 and 2030, as declining lignite capacities are replaced with a combination of renewables and natural gas-fired power plants. By 2040, total installed capacities reach 25 GW. This growth is largely driven by the development of wind onshore. In the final decade of the projected horizon, onshore wind capacities grow from a total of 1 to 5 GW, which takes place on a subsidy-free basis. This is illustrated in Exhibit 52.

In the absence of regulatory interventions or other non-economic constraints, we expect lignite capacity in the Czech power sector to halve between 2020 and 2030. As shown in Exhibit 52, capacities decrease from 8 GW in 2020 to 4 GW in 2030. By 2040, lignite capacities fall to 2 GW.

Exhibit 52: Total installed net capacities in the Czech Republic up to 2040

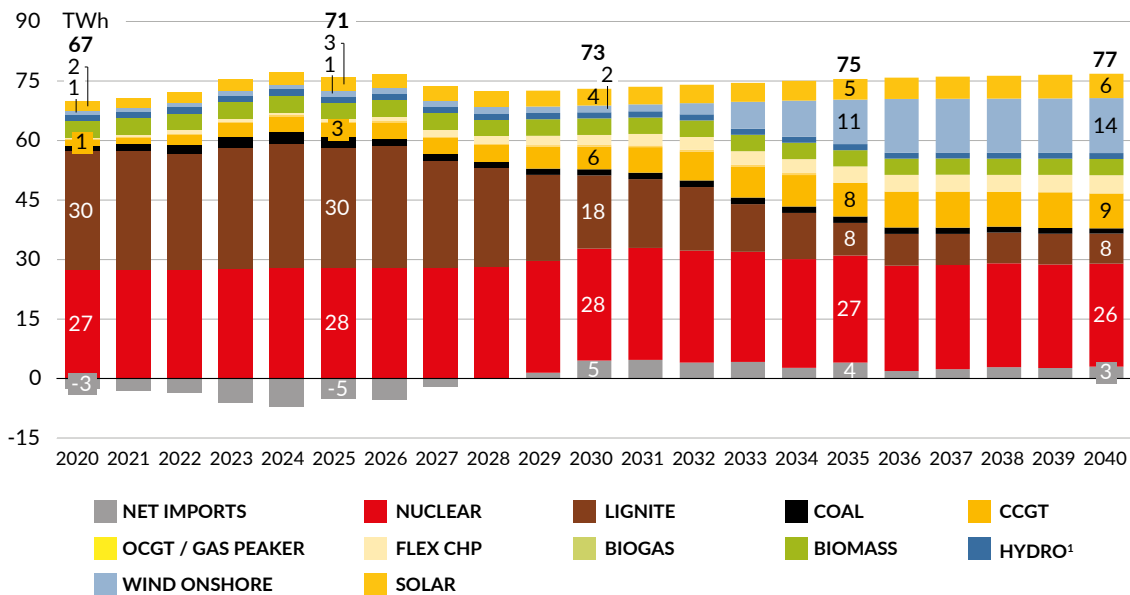


Source: Aurora Energy Research.  
 1) Hydro includes run-of-river, hydro storage and pump storage.

In light of this, electricity production from lignite is expected to decrease over the projected horizon. Between 2020 and 2030, electricity generation from lignite decreases from 30 TWh to 18 TWh. By 2040, it has fallen to 8 TWh. During the same period, the generation from RES and natural gas plants increases from 3 TWh and 2 TWh in 2020 to 20 TWh and 13 TWh in 2040. Natural gas generation in 2040 is split between CCGTs and Flex CHPs—which generate 8.8 TWh and 4.6 TWh of electricity, respectively. Power generation from biomass remains constant over the forecasting horizon. Despite increased RES generation, the Czech Republic transitions from being a net exporter of electricity to being net importer of electricity by 2040. As shown in Exhibit 53, 3 TWh of net exports in 2020 become 3 TWh of net imports by 2040, reflecting the lower share of intermittent renewables in the Czech Republic relative to its neighbouring countries, in particular Germany.

53

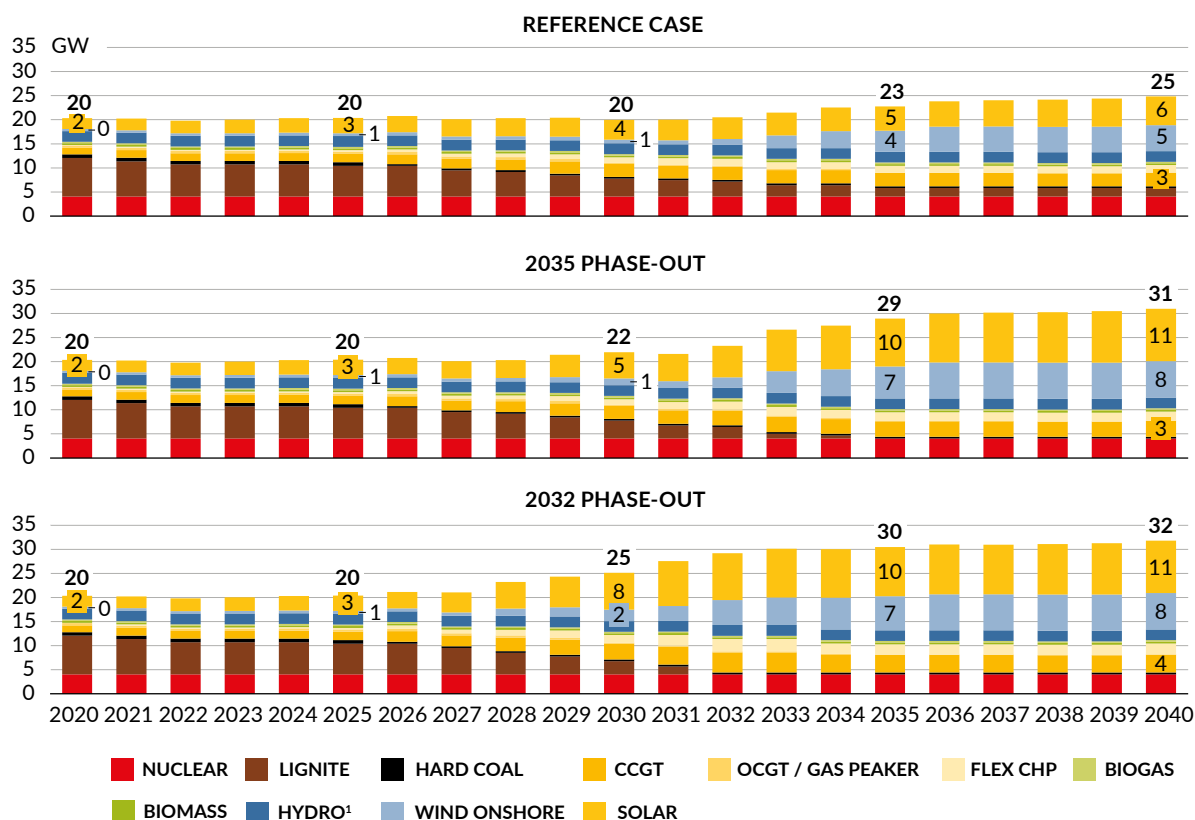
Exhibit 53: Total net generation in the Czech Republic up to 2040



Source: Aurora Energy Research.  
 1) Hydro includes run-of-river, hydro storage and pump storage 2) Nuclear and lignite.

**Lignite phase-out scenarios.** The 2035 and 2032 lignite phase-out scenarios are characterized by the phasing-out of all lignite capacities in the Czech Republic. To make up for lost electric and heat supply, onshore wind, solar, and natural gas-fired CHP capacities are added to the system in both scenarios through 2040. It should be noted that while the scenarios assume that CCGTs and flexible gas CHPs are fired by natural gas, green gases could also be utilized. Though not currently seen as an economically viable option, advances could make green technologies economically competitive given high carbon prices towards the end of the forecast period.

Exhibit 54: Capacity in phase-out scenarios relative to the reference case



54

Source: Aurora Energy Research.

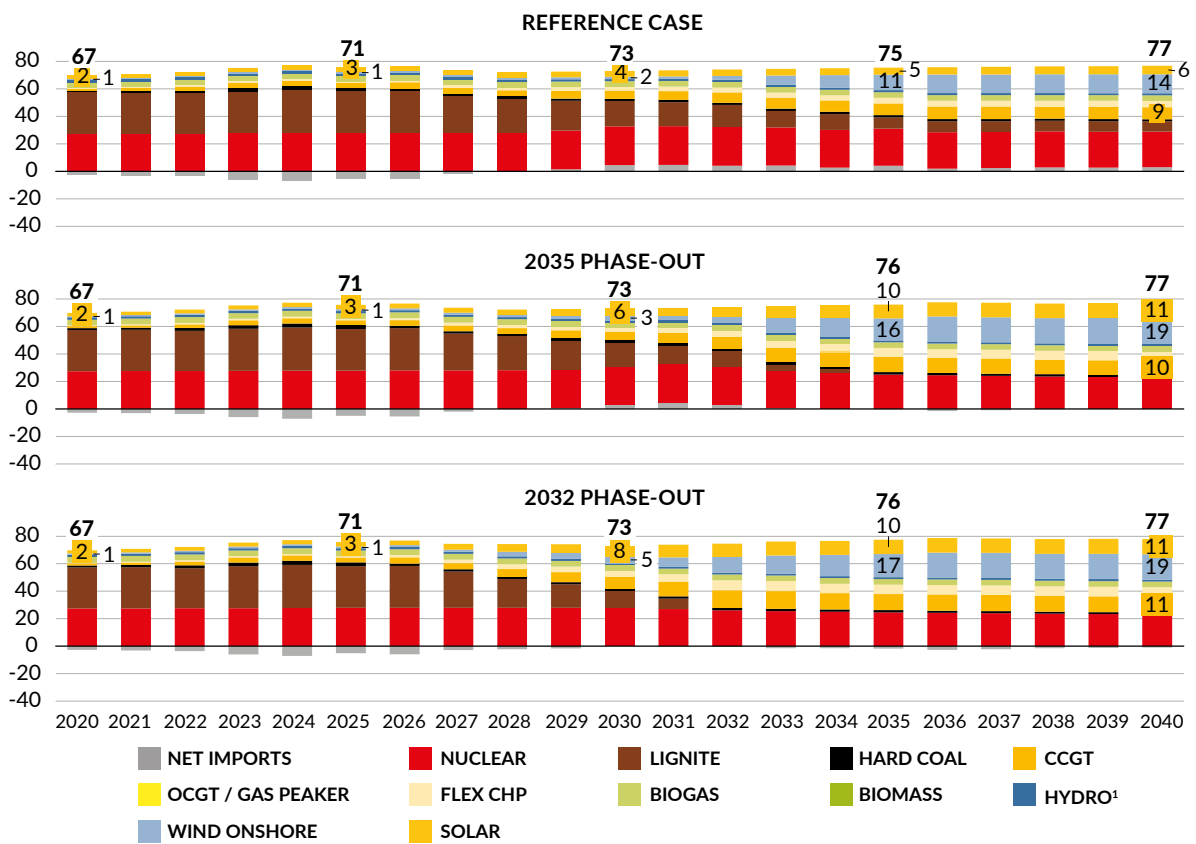
**2035 lignite phase-out scenario.** In the 2035 lignite phase-out scenario, the capacity trajectory for lignite is identical to that of the reference case up to 2030. That is to say, lignite capacities decrease from 8 GW in 2020 to 4 GW by 2030. In the subsequent year, capacities in the scenarios begin to diverge so that in the 2035 lignite phase-out scenario, the lignite fleet in the Czech Republic has completely left the power system, with 2 GW less lignite capacity than in the reference case.

As shown in Exhibit 55, most lignite capacities that exit the system are replaced with new onshore wind and solar generation units beginning in 2029. By 2030, an additional 1 GW of both solar and onshore wind capacity exist in the system relative to the reference case. By 2040, this difference grows to 5 GW and 2 GW, respectively. To make up for lost heat generation, CCGT capacities also increase. But the projected growth in CCGT capacities is fairly conservative. By 2040, the Czech power system in the 2035 lignite phase-out scenario has 3.3 GW of installed capacity, only 0.5 GW more than that of the reference case.



Despite increasing capacities up to 2040, net generation is not expected to change relative to the reference case. This is largely due to the fact that capacities and the associated generation that leave the system are replaced with a mix of RES, gas-fired power plants, and if/when necessary, imports. Generation from RES that exceeds that of the reference case is exported. As shown in Exhibit 55, lignite capacities produce 8 TWh less electricity in 2040 than they do under the reference scenario when assuming an early phase-out of lignite capacities. To make up for this, RES technologies produce an additional 10 TWh in 2040 relative to the reference case, while natural gas-fired facilities generate an additional 4 TWh. Net imports over this time frame are expected to remain significantly below that of the reference case due to the increase in RES generation. By 2040, net imports in the Czech Republic amount to 0.2 TWh, which is 3 TWh below the reference case.

Exhibit 55: Net generation in phase-out scenarios relative to the reference case



Source: Aurora Energy Research.

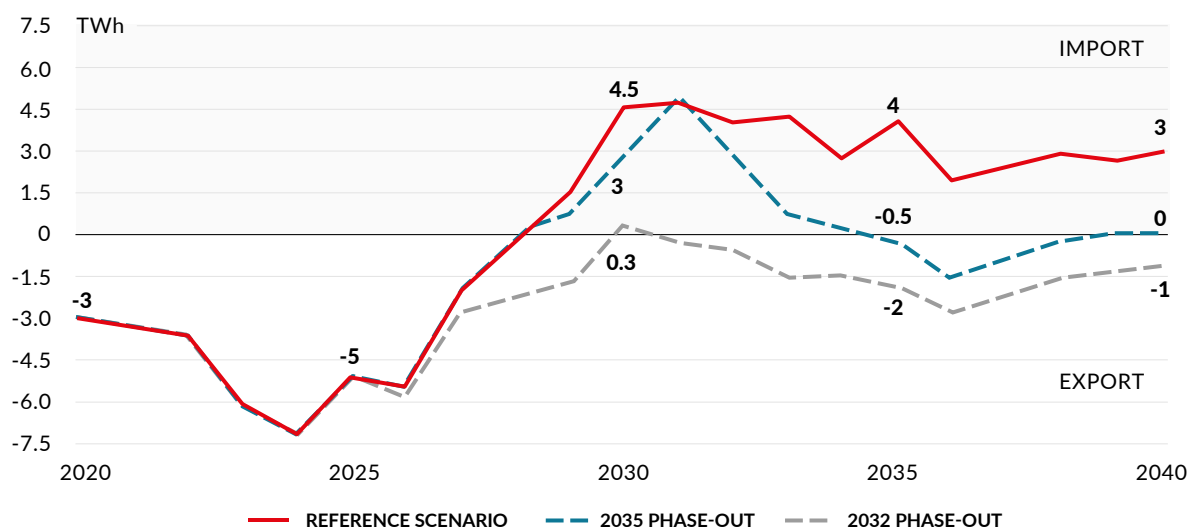
1) Hydro includes run-of-river, hydro storage and pump storage.

**2032 Lignite phase-out scenario.** In the 2032 lignite phase-out scenario, the lignite fleet in the Czech Republic is expected to completely exit the power system by no later than 2032. Consequently, the projected capacity trajectory for lignite diverges from the reference case as early as 2028. As displayed in Exhibit 55, the amount of lignite in the Czech power system decreases from 8 GW in 2020 to 3 GW in 2030, which is 1 GW lower than that of the reference case. In 2032, the capacity difference is expected to reach its peak at -3 GW before falling back to -2 GW in 2033, whereupon the difference remains unchanged until 2040. By contrast, RES capacities are expected to increase over the forecast period. In 2020, solar and wind onshore capacities make up 2.3 GW and 0.4 GW of the Czech capacity stack. By 2030, installed capacities for both solar and wind onshore have increased beyond that of the reference case by 3 GW and 2 GW, respectively. By 2040, wind onshore capacities reach 8 GW in the Czech Republic, or 2 GW greater than the reference case. For their part, solar capacities reach 11 GW, or 5 GW above the reference scenario.

Accordingly, generation from lignite is expected to decrease with the phasing out of capacities. By 2030, electricity generation from lignite is expected to fall 10 TWh below that of the reference case, to 13 TWh. Two years later, the complete phase-out of lignite capacities leaves the Czech generation stack with 16 TWh less lignite than that of the reference scenario. Meanwhile, generation from solar and onshore wind technologies are projected to grow over the same period. Specifically, generation from solar and onshore wind technologies is expected to reach 2.3 TWh and 0.9 TWh, respectively, in 2020. By 2040, generation from those technologies are expected to grow beyond that of the reference case by 10 TWh, split evenly between technologies. Solar generation reaches 11 TWh, while electricity production from wind onshore reaches 19 TWh. To account for the lost conventional heat supply under an expedited phase-out timeline, generation from flex CHPs and CCGTs increases to 6 TWh (split evenly between the technologies), which is above that of the reference case in 2040. This is shown in Exhibit 55.

In contrast to the reference case, where the Czech Republic transitions from being a net exporter to a net importer of electricity by 2040, the country remains, more or less, a net exporter of electricity in the 2032 lignite phase-out scenario. In light of increased generation from RES, net imports are expected to increase from -3 TWh in 2020 to 0.3 TWh in 2030, only to fall to -1 TWh in 2040, which is 4 TWh below that of the reference case. This can be seen in Exhibit 56.

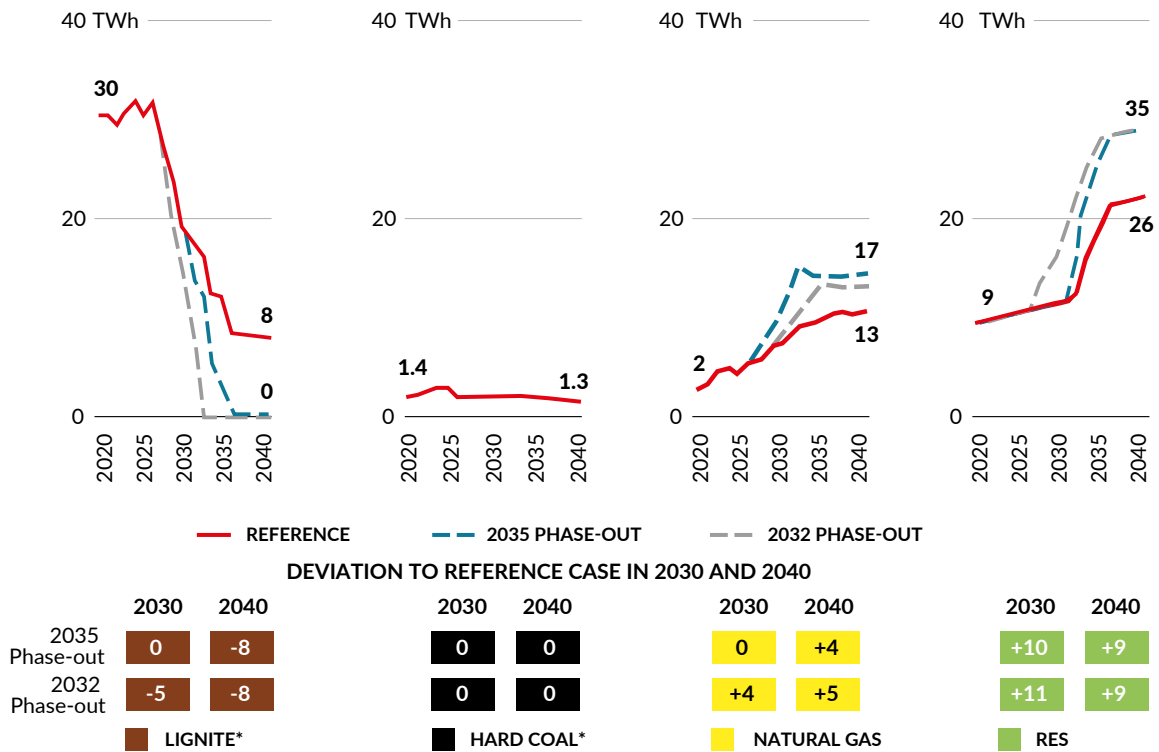
Exhibit 56: Electricity trade balance for the Czech Republic



Source: Aurora Energy Research.

Exhibit 57 provides an overview of the development of power generation by source in the scenarios.

Exhibit 57: Power generation from lignite, hard coal, gas, and renewables up to 2040

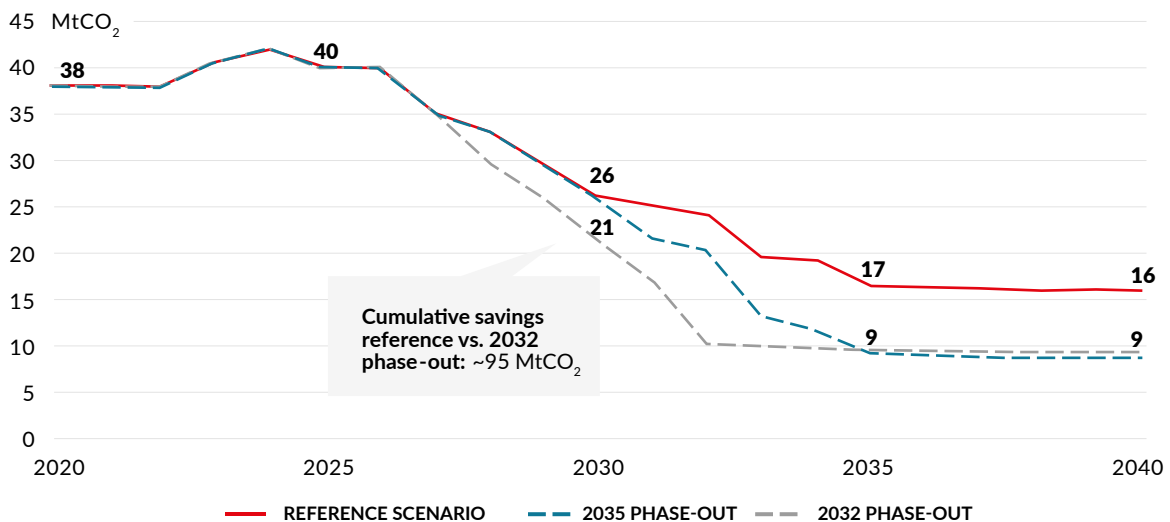


Source: Aurora Energy Research.  
 1) We assume calorific values of 10 GJ/T of Lignite and 25 GJ/T of hard coal.

### 4.3.2. Climate

Under the reference case, carbon emissions stemming from the power sector are expected to decrease from 38 MtCO<sub>2</sub> in 2020 to 26 MtCO<sub>2</sub> in 2030. By 2040, emissions are projected to fall to 16 MtCO<sub>2</sub>, a 58% decrease over the projected horizon.

Exhibit 58: Total power sector emissions in the Czech Republic across scenarios up to 2040



Source: Aurora Energy Research.

In the 2035 lignite phase-out scenario, total power sector emissions are expected to mirror that of the reference case up to 2025. Starting in 2025, the emission reduction trajectory assumes a much steeper path. Emissions fall to 26 MtCO<sub>2</sub> by 2030 and to 9 MtCO<sub>2</sub> by 2040, which is 44% (7 MtCO<sub>2</sub>) below the reference case. Over the forecast period, the 2035 lignite phase-out scenario is expected to achieve a cumulative savings of 67 MtCO<sub>2</sub> from the power sector.

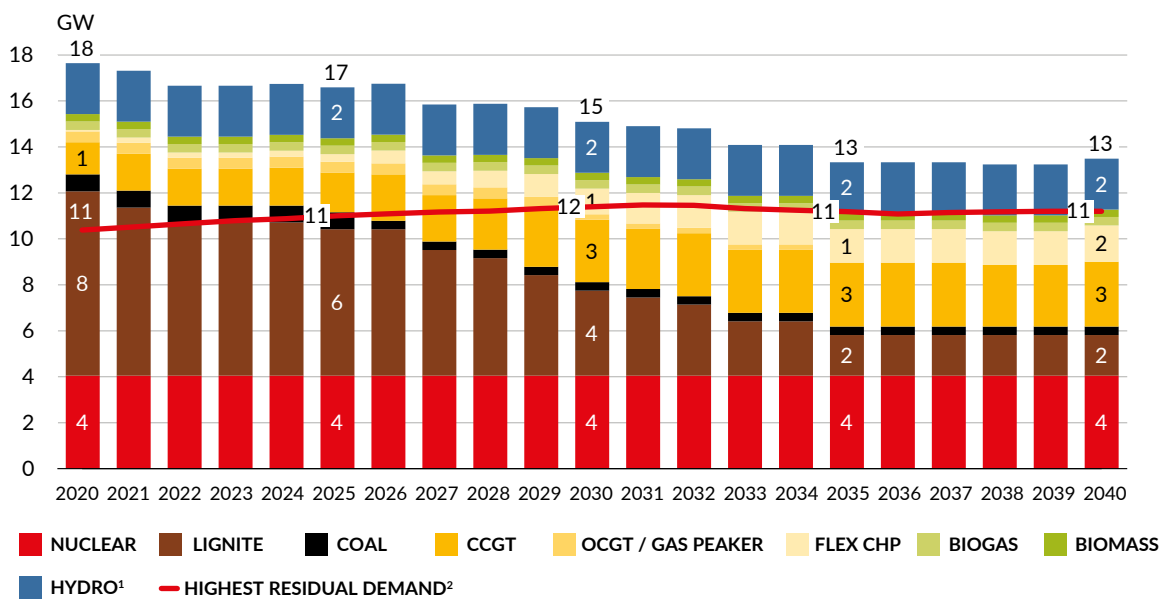
In the 2032 lignite phase-out scenario, carbon emissions from the power sector are expected to follow the same trajectory as the reference case up to 2025. Following this, emission reductions in the scenarios diverge. Power sector emissions in 2030 fall to 21 MtCO<sub>2</sub>, or about 20% below the reference case. By 2040, emissions further decrease to 9 MtCO<sub>2</sub>, which is 7 MtCO<sub>2</sub> below the reference case. Aggregate emissions over the modelling horizon are 96 MtCO<sub>2</sub> lower than those in the reference case.

### 4.3.3. Security of supply

**Capacity margin.** Total installed capacity in the Czech Republic is expected to decrease from 18 GW in 2020 to 13 GW in 2040. The highest residual demand, i.e. demand after intermittent renewables production, increases from 11 GW in 2020 to 12 GW in 2040. As displayed in Exhibit 59, we expect dispatchable capacity to remain above his peak throughout the entirety of the forecast period. In the phase-out scenarios, dispatchable capacities are 1 GW less than the reference case by 2040 but still above peak demand, even when not accounting for interconnection capacities. Security of supply can therefore be maintained even without lignite and despite the interconnected nature of the Czech system.

Exhibit 59: Development of installed dispatchable capacity against highest residual demand in the Czech Republic up to 2040

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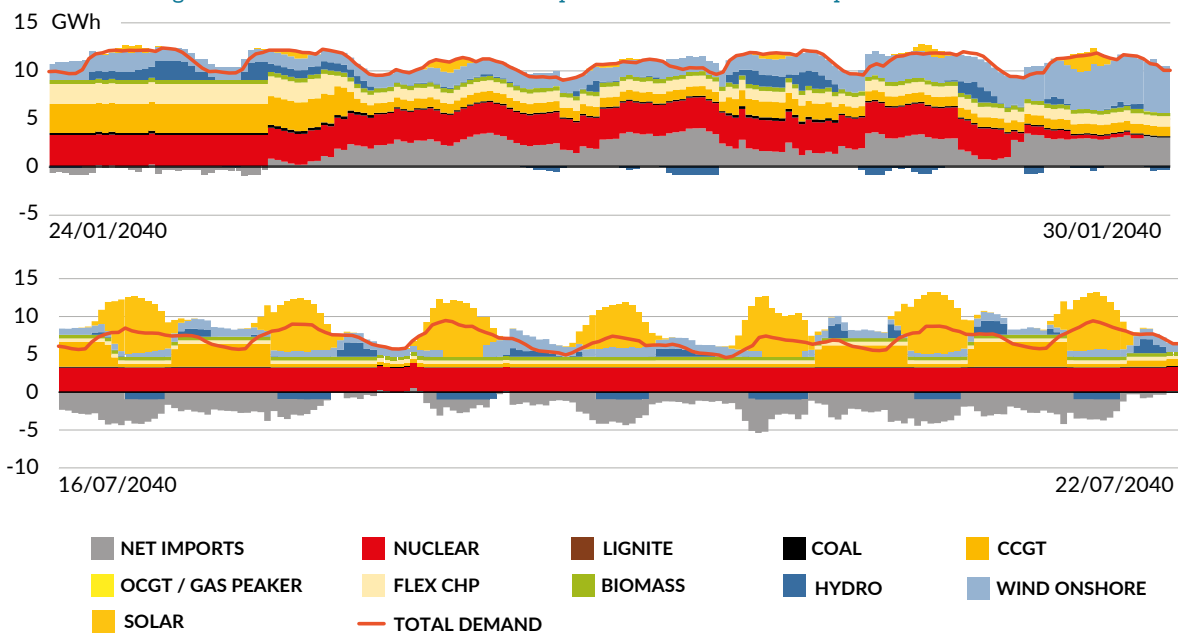


Source: Aurora Energy Research.

1) Hydro includes run-of-river, hydro storage and pump storage; 2) Residual demand defined as total demand (including electric vehicles and heat pumps) minus production possibilities from intermittent renewables: wind on and offshore, solar, and run of river hydro

Despite the fact that a significant capacity margin exists in the Czech Republic up to 2040, there are hours in a given year in which net generation in the country falls below the total demand for electricity. In these hours, the economics favour meeting demand with foreign capacities over domestic production. This makes the Czech Republic a net importer of power, as is shown in Exhibit 60 for a sample week in January 2040 for the 2032 phase-out scenario. In hours with little to no generation stemming from renewables, the demand for electricity in the Czech Republic is primarily met with the country's dispatchable fleet. The residual demand is met with imported electricity. By contrast, hours with significant RES production due to more favourable solar and wind conditions tend to see increases in Czech exports because total generation exceeds the demand for electricity. A sample week from July 2040 can be found in Exhibit 60. Utilising a mix of local and foreign production, it illustrates the ability of the integrated Czech power system to meet electricity demand in the face of variable contributions from RES assets, even in a system without lignite.

Exhibit 60: Total generation and demand for two sample weeks in the Czech Republic in 2040



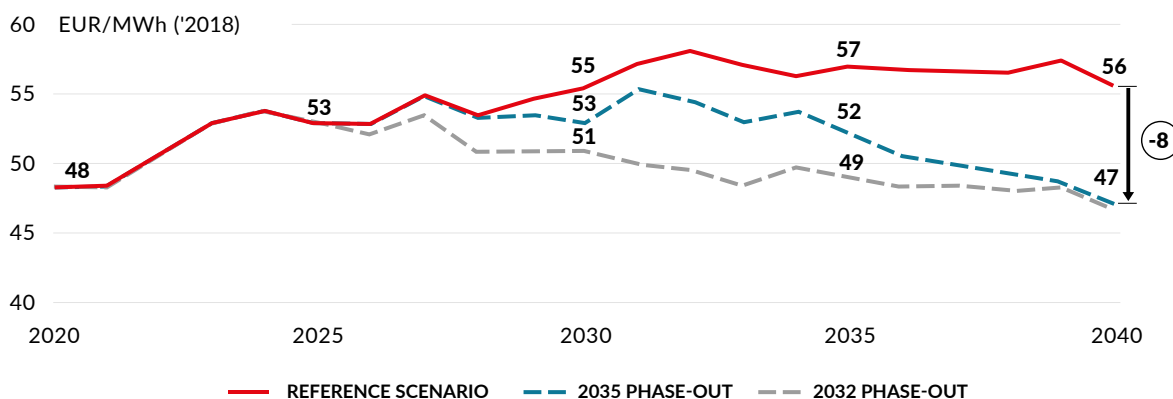
59

Source: Aurora Energy Research.

#### 4.3.4. Affordability

**Wholesale power prices.** Average annual wholesale power prices under the reference scenario are expected to grow from 48 EUR/MWh in 2020 to 55 EUR/MWh in 2030. By 2040, electricity prices reach 56 EUR/MWh.

Exhibit 61: Average annual baseload electricity price in Czech Republic up to 2040



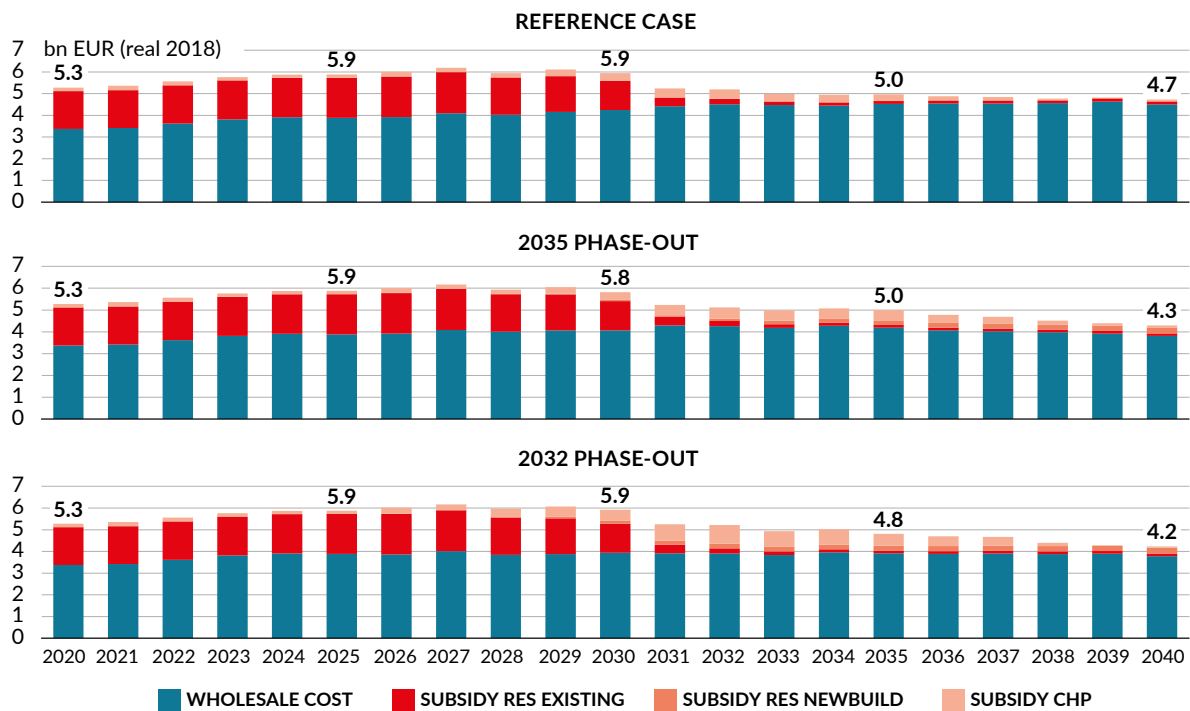
Source: Aurora Energy Research.

In the 2035 lignite phase-out scenario, wholesale power prices follow the same trajectory as that of the reference case up to 2025. At this point, average annual electricity prices increase to 53 EUR/MWh in 2030, or 2 EUR/MWh below the reference case. In the following years, average power prices fall to 47 EUR/MWh by 2040. This is largely driven by the increase in the negligible-marginal costs of RES production as lignite capacities are forced to exit the system prematurely relative to the reference case.

Wholesale prices under the 2032 lignite phase-out scenario are expected to increase from 48 EUR/MWh in 2020 to 51 EUR/MWh in 2030, 5 EUR/MWh below that of the reference case. By 2040, the difference in power prices increases to 9 EUR/MWh below the reference case, at 47 EUR/MWh. This is largely due to the fact that the price impact of the lignite phase-out is offset by the increase in generation from RES. As shown in Exhibit 61, this has a depressing effect on power prices relative to the reference case.

**System costs.** Our system cost analysis for the German market includes the cost of providing electricity in the wholesale market and the cost of building generation capacities that receive support from outside the wholesale market, i.e. renewables and CHP plants. Other costs, especially for transmission and distribution grids, are not considered in this study.

Exhibit 62: Czech power system costs



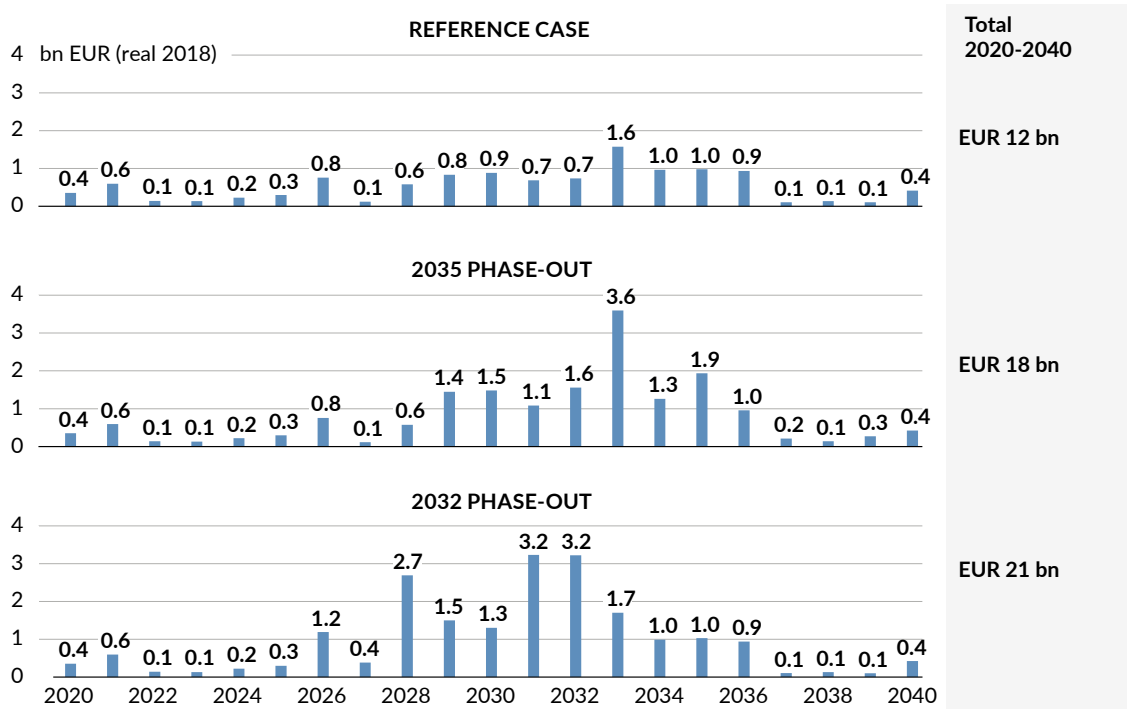
Source: Aurora Energy Research.

System costs in the Czech reference case decrease from EUR 5.3 bn to EUR 4.7 bn from 2020 to 2040. This is largely driven by decreasing costs for renewables support, as newbuilds have to be supported much less than existing renewables. This more than offsets the increase in wholesale costs as the baseload price increases from 48 to 56 EUR/MWh. The early lignite phase-out brings system costs forward: in the 2032 scenario, the cost in 2030 is higher, but in 2040, the system costs without lignite are lower, reflecting the lower cost of newbuild renewable generation.

Between 2020 and 2040, system costs in the 2035 phase-out scenario are 1.3%, lower over 20 years than in the reference scenario; in the 2032 phase-out scenario are 1.7%, lower. This is a remarkable result because it shows that the emission savings generated by phasing out lignite can be unlocked at negative system costs if the government pursues a long-term phase-out strategy and replaces lignite with renewables.

**Investments.** Investments in the Czech Republic range between EUR 0.1 bn and EUR 1.6 bn annually throughout the forecast. These increase in the early 2030s and return to current levels by 2040.

Exhibit 63: Czech power generation investments



Source: Aurora Energy Research.

The 2035 phase-out requires further investment of EUR 6 bn between 2029 and 2035, while the 2032 phase-out leads to an investment increase of EUR 9 bn between 2026 and 2032. This difference is greater than those of the other countries, because lignite plays a larger role in the Czech system and because fewer renewable plants would be built were it not for government support in the phase-out scenarios.

### 4.3.5. Infrastructure

Raising the share of renewables in the Czech grid is likely to require some investments in grid infrastructure, because renewables generation sites are likely to be in location locations from those of conventional units. Where possible, old lignite mining sites could be repurposed for renewable generation order to keep grid investments low.

A 2018 study commissioned by Czech NGOs and conducted by Energynautics<sup>26</sup> came to the conclusion that no significant grid expansion is required beyond what is planned to operate the Czech grid with 5.5 GW of solar and 2 GW of wind capacities in 2030. The PV capacities assumed in the long term for this study are very similar to those assumed in the Energynautics study, but wind capacities are significantly higher. It is therefore prudent to assume that some additional investments will be needed to accommodate the additional onshore wind, although detailed modelling would have to be conducted to determine how much.

26 Frankbold, 2018.

## 5. Conclusions

A well-managed and planned strategy to phase out lignite production responds to the challenges of an ambitious climate policy and the competitive pressure that will increase in the internal energy market. It can and should therefore be an important element of national energy policies in Poland, Germany and the Czech Republic and a contribution to the EU's 2030 targets.

- 1) In the countries of the coal triangle, the share of lignite will inevitably decrease as a result of market forces and - as in Poland - the depletion of currently exploited resources. Our analysis indicates that by 2030 electricity production from this resource, without any new political decisions, will decrease by more than half in Germany and by 40% in Poland and the Czech Republic compared to the current level.
- 2) However, a lack of coordination of this process may increase the costs of individual countries' actions. It might even undermine their effectiveness if one of the countries of the coal triangle considers that it does not have to do anything. This will make the whole EU transition more difficult and can create a series of feedback: increase of CO<sub>2</sub> emissions, increase of uncontrolled energy flows, buoy up wholesale prices or threaten the adequacy of generation capacity.
- 3) As a consequence, the countries of the coal triangle need a plan for how to get out of lignite in a coherent and coordinated way in the next 10-15 years. This will help to maintain energy security in the region - new capacities will start to emerge before existing coal-fired power plants become permanently unprofitable. Our analysis shows that both a moderate phase out in 2035 as well as an accelerated phase-out of lignite by 2032 will be possible and maintain energy security in Germany, Poland and the Czech Republic.
- 4) A common move away from lignite would be an expression of cooperation and would lead to significant reductions in CO<sub>2</sub> emissions at national and EU level. CO<sub>2</sub> emissions from power generation in Germany, Poland and the Czech Republic could drop by 2030, depending on the scenario, between 32% and even 50%. The move away from lignite should therefore be seen as one of the most important ways of reducing CO<sub>2</sub> emissions and contributing to the enhanced EU's 2030 climate target.
- 5) Wholesale electricity prices in the region will increase differently in each of the three countries, ranging from 5 to 10 EUR/MWh. This is an increase resulting from the energy transformation and not just the withdrawal from lignite. The initial price increase in all scenarios is due to coal being replaced by gas, whose variable cost is assumed to be higher. (Note that today, in 2020, this is not the case as gas prices are very low - which could very well persist.) However, as a result of the development of RES, this increase in wholesale power prices can not only be minimized but also very much reduced. In Germany and the Czech Republic prices will be slightly higher than at present. Poland remains the most expensive market in the region, but the faster development of RES reduces price differences.
- 6) Faster closure of lignite-fired power plants (until 2032) and filling the gap with renewable sources does not increase the transition costs. For all three countries of the coal triangle, total system costs will be lower the faster we close coal-fired power plants. With the significant emission reductions that can be achieved by shutting down lignite power plants, this means that we reduce these emissions at no additional cost. This also applies to the costs of integrating variable sources.
- 7) However, the transformation cannot be carried out in an unplanned manner. The condition for its success is clearly formulated objectives, which will give market participants time to make the necessary investments in new capacities, in the flexibility of the system and also in the network. It is therefore crucial to start the discussion about giving up lignite soon, because the transformation has to be prepared, also from the social side.



## 6. An Action Plan for the Future

The move away from lignite in Poland, Germany and the Czech Republic is real and represents a fundamental way of reducing CO<sub>2</sub> emissions not only in the coal triangle but also in the entire European Union. What is more, the end of lignite is inevitable, because resources are running out and there is no social and economic justification for opening up new mines. If the three coal countries phase out the production of electricity from lignite, the fossil fuel with the highest emissions, the EU can make important strides in its enhanced energy and climate policy goals for 2030. For this to happen, Germany, Poland and the Czech Republic need to adopt an ambitious coal phase-out date – 2032. Electricity emissions in the region could then be reduced by almost half.

But such a decision cannot be made without a plan. Our analysis indicates that in the baseline scenario the role of lignite-based power generation will decrease anyway. To ensure energy security and adequate generation capacity, a robust plan is needed to replace lignite. The national strategies must take this into account and replace production capacity with an optimal mix of renewables, flexibility and gas back-up capacity.

The carbon transition plan must consider the following elements:

- The strategy to phase out lignite by 2032 should be integrated in national energy and climate plans for the 2021–2030 period.
- The joint elimination of lignite by Poland, Germany and the Czech Republic may be one of the flagship projects under the EU economic recovery programme and the European Green Deal. If the project is included in official EU plans, it should receive additional EU funding.
- Funding from the Just Transition Fund is key to the success of the lignite exit strategy. Therefore, the countries of the coal triangle must confirm their decision as soon as possible so that as many regions as possible can prepare transition plans and benefit from the Fund's resources. The Fund, whose budget has recently been increased to EUR 40 billion, is designed to help regions during the 2021–2027 period.
- Special attention should be placed on the transition at Bełchatów, the world's largest lignite power plant and the largest CO<sub>2</sub> emitter in Europe. The lack of a strategy for Bełchatów, the lack of credible plans for the future, and bias towards the Złoczew open-pit mine and the operation of the power plant would result in the exclusion of the region from the Just Transition Fund until 2027.
- The phase-out of lignite requires joint planning of network development by national TSOs and coordination with ENTSO-E. For example, in the case of the Bełchatów power plant, which is at the centre of the Polish transmission system, it is necessary to plan not only the replacement capacities but also what will happen to the networks and how to adapt them to such major changes.
- It is essential to maintain mechanisms that support clean and low-carbon capacity. Poland will have to reform the capacity mechanism and maintain RES auctions. Without clear regulatory perspectives that conform with the EU framework, investors will not make the necessary investments.
- In order to phase out lignite, policy-makers must figure out the role of natural gas in the energy systems of the future. How much coal can natural gas replace? It is necessary to create a strategy for natural gas in the power and heating sectors and to keep in mind that the Union has set the goal of achieving climate neutrality in 2050.
- As the electricity market evolves, market reforms are needed to increase the flexibility of the system and the possibilities of RES integration if new renewable capacity is to replace phased-out lignite.

# Appendix 1. The Role of Lignite in the Power Sectors of Germany, Poland and the Czech Republic today

## 1. Germany

### 1.1. Market overview

Energy policy in Germany is driven by the aim of ensuring that electricity generation remains sustainable, affordable and secure – the cornerstones of what is known as the “energy triangle”.

The sustainability component of the energy triangle has several dimensions. The government has identified two specific areas in which it hopes to increase sustainability: the phase-out of nuclear energy by 2022 and the reduction of carbon emissions by deploying renewable energy sources and increasing energy efficiency. Ultimately, greenhouse gas emissions must be reduced by 80% to 95% below the 1990 baseline by 2050. The energy triangle defines interim ten-year intervals, as shown in Table 2 below. The German government supports a European initiative to make the EU climate neutral by 2050, which if enacted would translate into more ambitious climate targets for Germany.

Table 1: German energy transition objectives (total greenhouse gas emissions)

Year	% reduction in total GHG below 1990
By 2020	40%
By 2030	55%
By 2040	70%
By 2050	80% to 95%

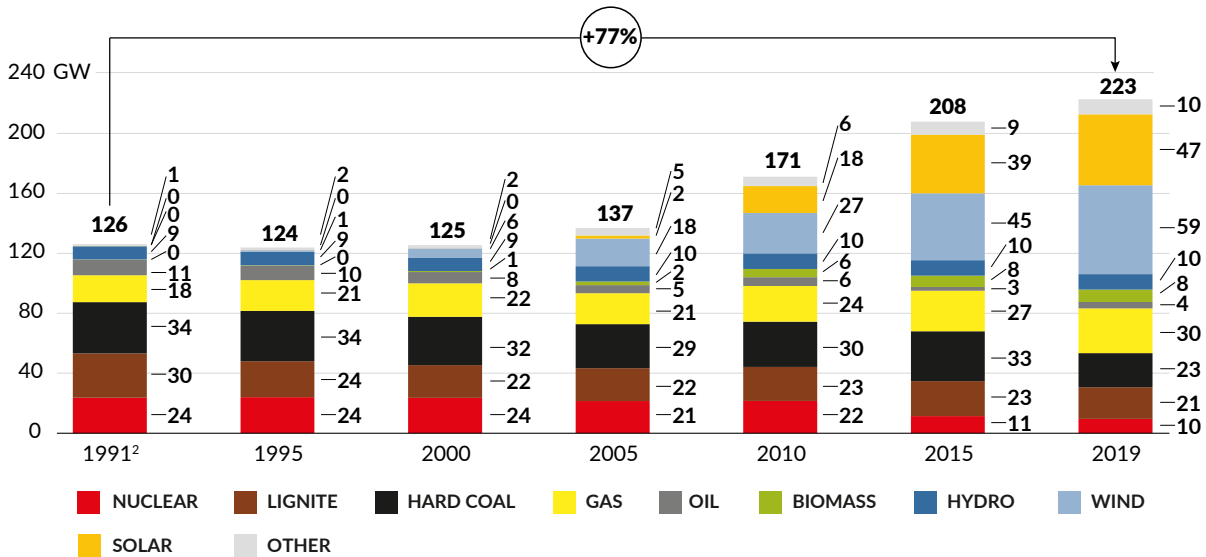
Source: Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, Climate Action Plan 2050, 2016.

Energy security consists in the stable operation of energy infrastructure and in sufficient access to primary energy. Furthermore, it requires that an adequate amount of generating capacity is available at all times. This is especially important for Germany as it transitions its energy mix from one that is characterised by a large share of dispatchable conventional generation to one dominated by intermittent renewables. Right now, Germany has an energy-only market design with free wholesale price formation and a strategic reserve that operates outside the wholesale market. The government has committed itself to phasing out nuclear power generation by the end of 2022 and coal power generation by no later than 2038.

The affordability component of the energy triangle means that the energy system must be operated as cost efficiently as possible. This will help keep energy prices to a minimum for consumers, reducing the risk of energy poverty and ensuring economic competitiveness.

The German power mix has diversified over the past few years, with an increasing capacity in renewables. As Exhibit 1 shows, the prominence of lignite in Germany’s capacity mix has decreased since 1991, when lignite made up 23% of the country’s total power generation capacity, with 30 GW installed. By 2000, lignite made up only 22 GW of the total 126 GW of installed capacity, accounting for roughly 17% of the capacity mix. By 2017, lignite constituted roughly 11% of total capacity. All the while, the share of power from intermittent renewables and gas-fired power plants has grown significantly.

Exhibit 1: Total installed capacity in Germany, 1991–2019

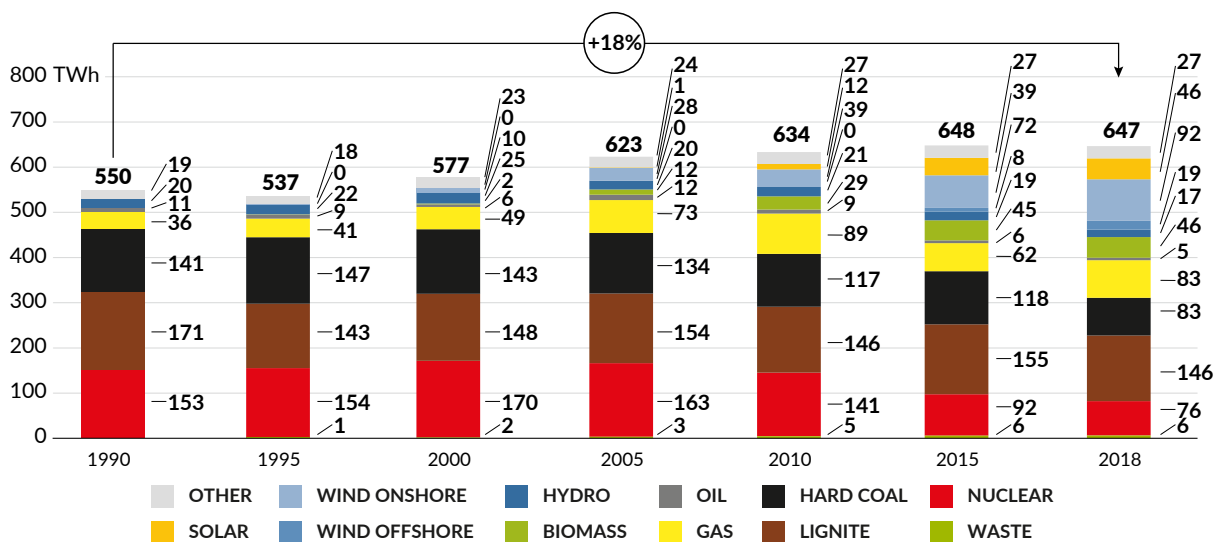


Sources: BMWi, Aurora Energy Research.

1) Technology categories used by BMWi possibly different from Aurora classification. 2) Data on installed capacity is only available from 1991.

During this time, total electricity generation in Germany increased from 550 TWh in 1990 to 647 TWh in 2018. The share of lignite in the generation mix decreased from 31% in 1990 to 23% in 2018. This is illustrated in Exhibit 2. In that period, the share of renewables increased steadily. Starting from 3%, its share in gross generation reached 35% in 2018. Onshore wind is the largest single RES in the energy mix, generating 14% of gross power in 2018.

Exhibit 2: Gross generation in Germany, 1990–2018



Sources: BMWi, Aurora Energy Research.

1) Technology categories used by BMWi possibly different from Aurora classification.

In Germany, four transmission system operators (TSOs) are responsible for the operation and maintenance of transmission lines and interconnectors. Today, Germany's energy system is interconnected with those of Austria, Belgium, the Czech Republic, Denmark, France, Luxembourg, the Netherlands, Norway, Poland, Sweden and Switzerland.

Developments in the German electricity market can be best understood by considering some fundamental policies. In 2016, the German government introduced Electricity Market 2.0 ("Strommarkt 2.0") to create a capacity reserve that would operate alongside an energy-only market (EOM). Under this new market design, capacity provisions in the EOM are remunerated implicitly through supply obligations on futures markets, spot markets and electricity procurement contracts.

In order not to distort competition and not to impede price developments in the wholesale market, the capacity reserve is made up of plants outside the wholesale market. The plants are kept on standby to ensure security of supply in the case of specific, exceptional and unforeseeable events. In return, they are remunerated for generation, operation, maintenance and opportunity costs. Activating the reserve costs no less than 20,000 EUR/MWh. For this reason, the capacity reserve is only used when the supply of electricity cannot meet demand.

Additionally, the 2016 Electricity Market Act requires 2.7 GW of lignite capacity to be transferred into a lignite standby reserve ("Sicherheitsbereitschaft"). Plants kept on standby remain operational for four years before being decommissioned. Despite being able to operate, these plants can only be called when there is a supply shortage. Plants have to be notified two weeks before their capacities are needed, making it highly unlikely that plants in the lignite reserve will ever run again.

In an effort to reach its 2030 greenhouse gas emissions target, the Commission for Growth, Structural Change and Employment published a report outlining a possible trajectory for Germany's coal exit. In this scenario, all coal-fired power plants will be required to leave the system by 2038 and preferably by 2035. As a result, total coal capacity would decline from 42 GW in 2018 to 30 GW by the end of 2022. By the end of 2030, total coal capacity in the system is projected to equal 17 GW, with 9 GW stemming from lignite.

Lignite plants located in the Rhineland are likely to be the first affected by the decision to phase out coal. The decommissioning roadmap requires that 5 GW of lignite capacity leave the system by 2023 (relative to 2017). Accounting for existing plans, however, would only require the closure of an additional 3 GW by 2022—all of which is expected to occur in western Germany. By the end of the 2020s, capacities located in East Germany will be increasingly affected. Specific closure dates and compensation fees are to be negotiated bilaterally between operators and the government.

The 13th amendment of the Atomic Energy Act requires all nuclear facilities to be shut down by 2022. At the same time, Germany plans to reduce its greenhouse gas emissions by 40% by 2020 and by 55% by 2030, relative to 1990 levels. To assist the power sector in increasing its renewables share, the government passed the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG), which requires that the electricity generated from RES constitute 40–45% of gross electricity consumption by 2025, and 55–60% by 2035. To facilitate this, the EEG introduced a market premium scheme and competitive auctions to determine the support level for RES plants. In its most recent coalition treaty, the German government set an even higher target for the renewables share – 65% by 2030.<sup>27</sup>

While there are several key players involved in conventional power generation, LEAG and RWE are the most prominent in the lignite sector. Smaller operators include Uniper and EnBW.

RWE, with its four subsidiaries, is Germany's largest power producer. In 2018, the company generated 67 TWh of electricity from lignite, corresponding to 10 GW of installed capacity. The company owns and operates all of the lignite mines and lignite-fired plants in the Rhine region of Germany. The company's portfolio also extends beyond conventional generation and includes both European and American markets. Outside of electricity generation, the company is active in storage system construction and energy trading.<sup>28</sup>

27 A corresponding law is in the process of being enacted.

28 RWE, 2018.

LEAG (Lausitz Energie AG) is Germany's fourth largest power plant operator and the largest energy company in the eastern part of Germany. In 2018, LEAG generated roughly 55 TWh of electricity from lignite, corresponding to 8 GW of installed capacity. Its portfolio comprises mining, refining, electricity and heat generation from lignite. The company is the sole owner and operator of the four open-pit mines and three lignite-fired power plants in Lusatia. Additionally, LEAG also owns one of two units at the Lippendorf plant near Leipzig.<sup>29</sup>

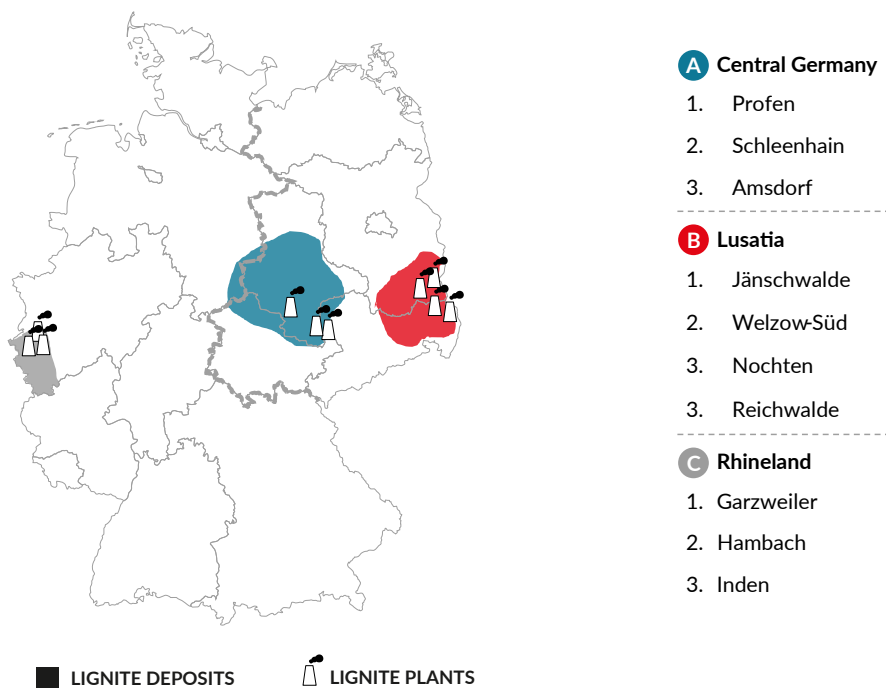
Besides electricity generation, LEAG's lignite-powered plants supply Leipzig and towns in Lusatia with roughly 3 TWh of district heat on an annual basis.

## 1.2. Lignite plants

Historically, lignite was an important source of power in Germany. As described above, lignite made up 23% of Germany's power generation mix in 2018, down from 31% in 1991 and from 23% in 2010.

Due to their integration with mining, lignite-fired power plants are often located at the mouths of open-pit mines. As a result, lignite plants in Germany are concentrated in the Rhineland (10 GW), Lusatia (7 GW) and Central Germany (3 GW).

Exhibit 3: Lignite regions and plants in Germany



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Source: Aurora Energy Research.

The lignite plants in the Rhineland make up a total of 10 GW of installed capacity, all of which are owned by RWE. The bulk of Rhineland's lignite capacity stems from four plants in particular: Frimmersdorf (0.5 GW), Neurath (4.2 GW), Niederaußem (3.4 GW) and Weisweiler (2 GW). Together, these plants were responsible for emissions in 2018 amounting to roughly 75 million tCO<sub>2</sub>. In October 2017, the remaining blocks of the Frimmersdorf plant were transferred to the lignite reserve, where they will remain for four years before being decommissioned. Blocks E and F at the Niederaußem power plant followed suit in 2018 and Block C at Neurath in 2019.

Table 3: Lignite plants in the Rhineland

Plant	Block	Owner	Commissioning Year (retrofit)	Net Elec. Capacity (MW)	CO <sub>2</sub> Emissions (in 2018) <sup>30</sup>	Lignite Standby Reserve
Frimmersdorf	P, Q	RWE	1955–1970	440	0	Oct 2017–Oct 2021
Neurath	A	RWE	1972	294	32.1 MtCO <sub>2</sub>	
	B	RWE	1972	294		
	C	RWE	1973	292		Oct 2019–Oct 2023
	D	RWE	1975	607		
	E	RWE	1976	604		
	F	RWE	2012	1060		
	G	RWE	2012	1060		
Niederaußem	C	RWE	1965	295	25.9 MtCO <sub>2</sub>	
	D	RWE	1968	297		
	E	RWE	1970	295		Oct 2018–Oct 2022
	F	RWE	1971	299		Oct 2018–Oct 2022
	G	RWE	1974 (2008)	628		
	H	RWE	1974 (2009)	648		
	K	RWE	2002	944		
Weisweiler	E	RWE	1965	321	16.8 MtCO <sub>2</sub>	
	F	RWE	1967	321		
	G	RWE	1974	663		
	H	RWE	1975	656		

Source: BNetzA, 2019.

The lignite plants in Germany's Lausitz region (Lusatia) constitute a total of 7 GW of installed capacity, all of which are owned by LEAG. This capacity is split between three plants: Boxberg, Jänschwalde, and Schwarze Pumpe. In 2018, emissions from these plants amounted to approximately 54 million tCO<sub>2</sub>. As it stands, Blocks E and F currently reside in the capacity reserve, where they will remain for four years from the respective date of transfer. After this, they will be decommissioned.

Table 4: Plants in Lusatia

Plant	Block	Owner	Commissioning Year (retrofit)	Net Elec. Capacity (MW)	CO <sub>2</sub> Emissions <sup>31</sup>	Lignite Standby Reserve
Boxberg	N	LEAG	1979 (1993)	465	19 MtCO <sub>2</sub>	
	P	LEAG	1980 (1994)	465		
	Q	LEAG	2000	857		
	R	LEAG	2012	640		
Jänschwalde	A	LEAG	1981 (1996)	465	22.8 MtCO <sub>2</sub>	
	B	LEAG	1982 (1996)	465		
	C	LEAG	1984 (1996)	465		
	D	LEAG	1985 (1996)	465		
	E	LEAG	1987 (1996)	465		Oct 2019– Oct 2023
	F	LEAG	1989 (1996)	465		Oct 2018– Oct 2022
Schwarze Pumpe	A	LEAG	1997	750	12.4 MtCO <sub>2</sub>	
	B	LEAG	1998	750		

Source: BNetzA, 2019.

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The lignite plants in Central Germany make up nearly 3 GW of installed capacity. This is split between Lippendorf (1.8 GW) and Schkopau (0.9 GW). While both blocks at the Schkopau power plant are owned by Uniper, one block at the Lippendorf plant is owned by EnBW, while the other is owned by LEAG. Emissions in 2018 stemming from these plants amounted to nearly 18 million tCO<sub>2</sub>. The Czech investor EP Energy, a sister company of LEAG, holds a minority stake in the Schkopau plant.

Table 5: Lignite plants in Central Germany

Plant	Block	Owner	Commissioning Year (retrofit)	Net Elec. Capacity (MW)	CO <sub>2</sub> Emissions <sup>32</sup>	Lignite Standby Reserve
Lippendorf	LIP S	EnBW	1999	875	11.7 MtCO <sub>2</sub>	
	R	LEAG	2000	875		
Schkopau	A	Uniper	1996	450	6.1 MtCO <sub>2</sub>	
	B	Uniper	1996	450		

Source: BNetzA, 2019.

31 CarbonBrief 2019.

32 CarbonBrief, 2019.

Lignite plays a limited role in the heating sector. CHP plants generated 221 TWh of heat in 2017, 8% of which came from lignite-fired plants. In 2017, lignite CHP plants in Germany produced a total of 17 TWh of heat, which was used for both district heating as well as industrial purposes.<sup>33</sup> As illustrated in Table 4, 12 TWh of heat, or roughly two-thirds of total heat generation, came from lignite CHP plants with less than 200 MW of installed electric capacity. Heat generation for these plants generally make up a larger share of total production. The opposite holds true for larger lignite plants in Germany. With heat constituting a smaller share of total production, lignite plants greater than 200 MW<sub>el</sub> were responsible for 5.1 TWh of the total heat generated from lignite CHPs in Germany. Heat output in those plants is mostly used for on-site purposes such as drying lignite.

Table 6: Heat generation from lignite CHP power plants in Germany

Plant	Owner	Heat production (TWh <sub>th</sub> /a)	Heat share of production (%)	Use
Boxberg	LEAG	0.1	125MW <sub>th</sub> /1400MW <sub>el</sub>	District Heating
Jänschwalde	LEAG	0.3	305MW <sub>th</sub> /2140MW <sub>el</sub>	District Heating
Lippendorf	EnBW/LEAG	1.0	460MW <sub>th</sub> /1870MW <sub>el</sub>	District Heating
Neurath	RWE	0.1	9MW <sub>th</sub> /4211MW <sub>el</sub>	District Heating
Niederaußem	RWE	0.1	245MW <sub>th</sub> /687MW <sub>el</sub>	District Heating
Schkopau	Uniper	1.3	200MW <sub>th</sub> /980MW <sub>el</sub>	Industry
Schwarze Pumpe	LEAG	1.8	120MW <sub>th</sub> /1600MW <sub>el</sub>	Industry
Weisweiler	RWE	0.4	183MW <sub>th</sub> /1255MW <sub>el</sub>	District Heating

Note: Only plants with an electric capacity > 200MW included.

Source: Heat outputs: BMWi, 2019. All other data: UBA, 2019.

### 1.3. Lignite mining

Today, Germany is the world's second largest lignite producer, followed by China, Russia, and the United States. There are three centres of lignite mining in Germany. One is the Rhineland in North Rhine-Westphalia, the other two (Lusatia, Central Germany) are located in the eastern part of Germany. Following reunification, the latter faced considerable economic decline and has since struggled with weak economic growth relative to its western counterparts. Characterised by low levels of industrialisation, weak service sectors, and comparatively little innovation, eastern states have received economic relief from lignite mining in the form of well-paid and unionised jobs for citizens and tax revenue for municipalities. In more recent years, however, the dominance of the lignite sector in community structures has decreased considerably as national climate protection efforts increase in stringency and ambition.

The lignite mines in North Rhine-Westphalia (NRW) are located between Aachen and Cologne. Covering a total area of 2,500 km<sup>2</sup>, the NRW lignite basin contains approximately 2.3 billion tonnes of commercially extractible lignite. The mines in Rhineland are the largest in Germany in terms of sector productivity and employment. Production from the mines amount to nearly 100 million tonnes on an annual basis, accounting for more than half of the country's lignite production. Lignite is extracted in three mines that are owned and operated by RWE Power AG (Rheinisch-Westfälisches Elektrizitätswerk Power AG). These are the Garzweiler, Hambach, and Inden open-pit mines. 85% of lignite from these mines is used for electricity production in RWE's local power plants: Weisweiler (1.8 GW), Frimmersdorf (0.6 GW), Neurath (4.2 GW), and Niederaussem (3.35 GW). The remaining share is used either for heating or in processing plants.



Table 7: Mines in the Rhineland

Mine	State	Operator	Start of Operations	Annual Production	Available Reserves	Plants served
Garzweiler (I and II)	North-Rhine Westphalia	RWE Power AG	1940/2006	35 Mt	0.7 billion tonnes	Neurath, Niederaußem
Hambach	North-Rhine Westphalia	RWE Power AG	1978	35 Mt	1.3 billion tonnes	Neurath, Niederaußem, Frimmersdorf
Inden	North-Rhine Westphalia	RWE Power AG	1982	20 Mt	0.3 billion tonnes	Weisweiler

Source: Aurora Energy Research.

Lusatia, which comprises the eastern states of Brandenburg and Saxony, is Germany's second largest mining region in terms of extracted volume. The region has a total of 11.8 billion tonnes of lignite reserves; however, only 3.3 billion tonnes of lignite reserves are commercially extractable. In 2018, a total of 60.7 million tonnes were extracted from the four LEAG (Lausitz Energie Bergbau GmbH) owned-and-operated open-pit mines: Jänschwalde, Welzow-Süd, Nochten, and Reichwalde. 94% of the extracted lignite was used for electricity and heat generation in LEAG's regional lignite plants: Jänschwalde (3 GW), Schwarze Pumpe (1.6 GW), and Boxberg (2.6 GW).

Table 8: Mines in Lusatia

Mine	State	Operator	Start of Operations	Annual Production	Available Reserves <sup>34</sup>	Plants served
Jänschwalde	Brandenburg	LEAG	1976	9 Mt tonnes	68 Mt	Jänschwalde
Welzow-Süd	Brandenburg	LEAG	1959	22 Mt	490 Mt	Schwarze Pumpe
Nochten	Saxony	LEAG	1968	16 Mt	373 Mt	Boxberg, Schwarze Pumpe
Reichwalde	Saxony	LEAG	1985	14 Mt	331 Mt	Jänschwalde, Boxberg, Schwarze Pumpe

Source: Aurora Energy Research.

The Central German lignite fields are located in the states of Saxony and Saxony-Anhalt and are the smallest of Germany's mining areas. As the oldest of Germany's mining districts, the lignite mined in Central Germany accounted for up to 50% of total production up until 1960. Since then, however, production in the region has declined considerably. Today, the region has 10 billion tonnes of lignite reserves, of which 2 billion tonnes are commercially extractable. There are three operational mines in Central Germany: Profen, Vereinigtes Schleenhain, and Amsdorf. Together, the mines produce a total of 18 million tonnes of lignite annually. Owned and operated by MIBRAG (Mitteldeutsche Braunkohlengesellschaft), the lignite extracted from Profen and Vereinigtes Schleenhain is used for electricity and heat generation in the Schkopau, Deuben, Lippendorf, and Wühlitz power plants. Amsdorf is operated by Romonta, and produces bituminous coal used in the manufacturing of montan wax.

Table 9: Mines in Central Germany

Mine	State	Operator	Start of Operations	Annual Production	Available Reserves	Main plants served
Profen	Saxony-Anhalt	MIBRAG	1941	8 Mt	115 Mt	Schkopau
Schleenhain	Saxony	MIBRAG	1949	11 Mt	228 Mt	Lippendorf
Amsdorf	Saxony-Anhalt	Romonta	1959	0.3 Mt	n.a.	Amsdorf

Source: Kommission WSB, Abschlussbericht, 2019.

The presence of the mining sector in the Rhineland, Lusatia, and Central Germany has had a decisive impact on the employment structure of these regions. The sector is responsible for the direct employment of approximately 20,900 people.<sup>35</sup> The breakdown by mining region is presented in Table 10. Direct jobs constitute those relating to mining, power plants, or the rehabilitation of former mines. Relative to all employed people subject to mandatory social insurance, the proportion of people directly employed in the lignite sector amount to 2% in Lusatia, 1.1% in the Rhineland, and 0.3% in the Central German mining area.<sup>36</sup>

Table 10: Direct employment in the lignite sector by mining region in 2018

	Rhineland	Lusatia	Central Germany
Lignite jobs (direct)	9,986	8,375	2,379

Source: RWI, 2018.

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The association for coal economics (Statistik der Kohlenwirtschaft e.V.) assumes that every direct job in the lignite sector yields 2.5 indirect jobs. They report that roughly 70,000 people in Germany rely on the lignite industry for employment.<sup>37</sup>

The accelerated reduction and termination of coal-fired power generation is expected to create structural shifts in Germany's mining regions. To promote structural development and assist these regions in smooth structural transitions, the German Coal Commission recommended the allocation of up to 40 billion euros in grants over the next two decades to communities adversely affected by the closure of lignite plants. The government is currently in the process of translating the recommendations into law.

Another topic discussed in the context of German coal mining is recultivation. By law, operators are obliged to bear the costs for the rehabilitation of mining areas. In the event of an earlier closure, provisions for that purpose have to be available earlier than originally planned. The Coal Commission recommended, therefore, that this be factored in when determining the level of compensation for a coal exit.

<sup>35</sup> Statistik der Kohlenwirtschaft e.V., 2019.

<sup>36</sup> RWI, 2018.

<sup>37</sup> Statistik der Kohlenwirtschaft e.V., 2018.

As it stands, the Coal Commission has recommended that no new permits be issued in Germany for lignite mines tied to electricity generation. There are, however, discussions surrounding both expanding and extending operational licenses for existing mines. In the Rhineland, RWE's plans to expand the Hambach mine are currently on hold as the local government and RWE have agreed on a moratorium for the clearing of the Hambach Forest until the fall of 2020. RWE has announced that maintaining the forest would be "technically possible". MIBRAG is engaging in discussions to expand the Schleenhain mine in Central Germany; however, it is unlikely that concrete expansion plans will materialise from these talks. Meanwhile in Lusatia, LEAG is considering a decision to further expand its Welzow-Süd mine, which would enable extraction to continue until 2045. However, the new governing coalition in Brandenburg, consisting of SPD, CDU, and the Greens has announced that it will not approve the expansion project. Moreover, the realisation of both expansion projects and operating contract extensions across Germany are contingent on the outcome of negotiations between lignite plants operators and the German government in regard to the coal exit. At present, while the presence of commercially extractable reserves may permit the operation of mines beyond 2038, it is likely that the closure of mines will accompany the coal phase-out, since power plants make up the bulk of lignite demand.

Germany's coal phase-out has triggered important discussions surrounding the "reclamation" of open-pit mines. By law, operators are obliged to bear the costs for the rehabilitation of the mining areas. With earlier closures, provisions for reclamation have to be available earlier than anticipated. Because this leaves operators with a shorter time frame to acquire these funds, the Coal Commission recommends that such an eventuality be factored in when deciding on the appropriate level of compensation for coal phase-outs.

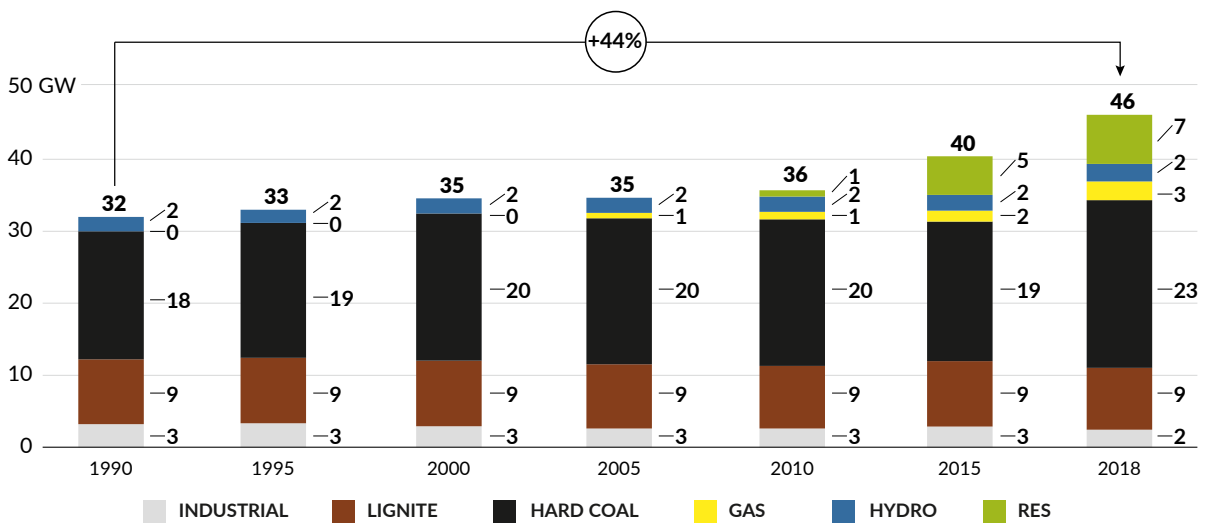
## 2. Poland

### 2.1. Market overview

The Polish power sector is dominated by coal and lignite, both in capacity and generation. Total installed capacity in Poland increased from 32 GW in 1990 to 46 GW in 2018. As gas and renewables entered the Polish energy system, the share of lignite in Poland's capacity mix decreased from 28% in 1990 to 19% in 2018. In absolute terms, however, the amount of installed lignite capacity in Poland has remained nearly constant. In 1990, Poland had a total of 9 GW of lignite capacity. By 2018, this had decreased to 8.6 GW.

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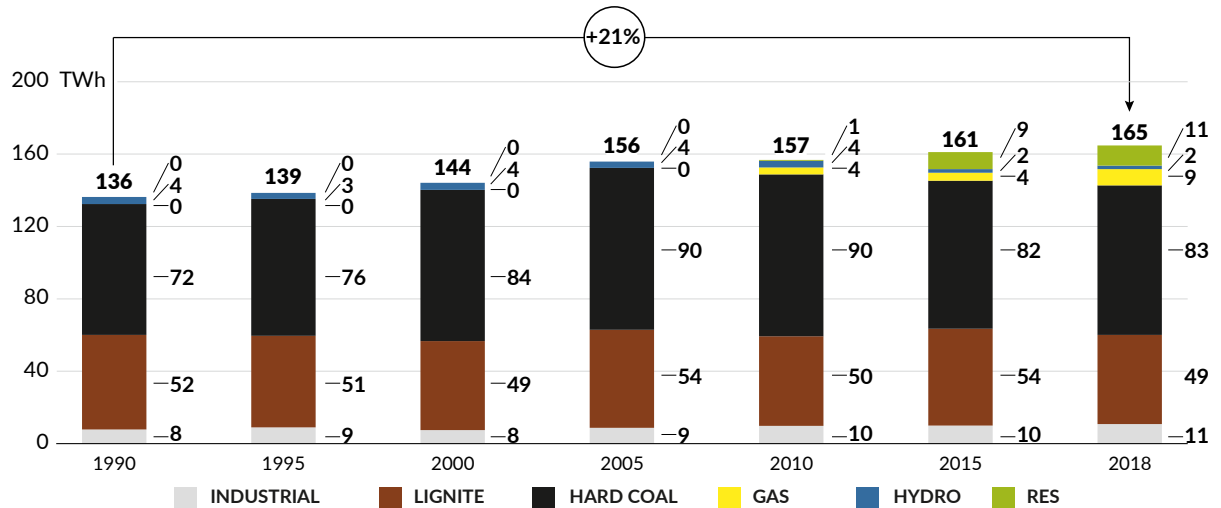
Exhibit 4: Installed capacity in Poland from 1990 to 2018



Source: Aurora Energy Research.

Accordingly, total electricity generation in Poland increased from 136 TWh in 1990 to 165 TWh in 2018. During this time, the share of generation stemming from lignite decreased from 52 TWh in 1990, or 38% of the country's generation mix, to 49 TWh. By 2018, lignite accounted for 30% of total electricity generation in Poland. This is illustrated in Exhibit 5.

Exhibit 5: Electricity generation in Poland from 1990 to 2018



Source: Aurora Energy Research.

74 Transmission lines and interconnectors to neighbouring countries are managed by PSE, the national transmission system operator. Poland is fully integrated into the European grid system, synchronously interconnected with Slovakia, the Czech Republic and Germany. The country also maintains interconnection capacities in direct current with Sweden and Lithuania and in radial connection to Ukraine and Belarus (though the latter is out of operation).

The Polish electricity market design is liberalised, with power traded over the counter as well as on the exchange. As for the outlook of the lignite sector, the RES support schemes and the Polish capacity market are noteworthy. Given that a significant portion of the Polish power fleet is expected to retire in the coming years (due to age, lack of profitability and/or the inability to comply with EU environmental standards) unless modernised, security of supply has become a topic of growing concern. As coal power plants retire, planned capacity reserve margins are expected to decrease proportionately to the point of nonfulfillment. Maintaining generation adequacy in Poland, therefore, requires that existing assets be refurbished, and/or new assets enter the system. To incentivise capacity additions, in 2018 Poland introduced a capacity mechanism that explicitly remunerates these providers in the capacity market.

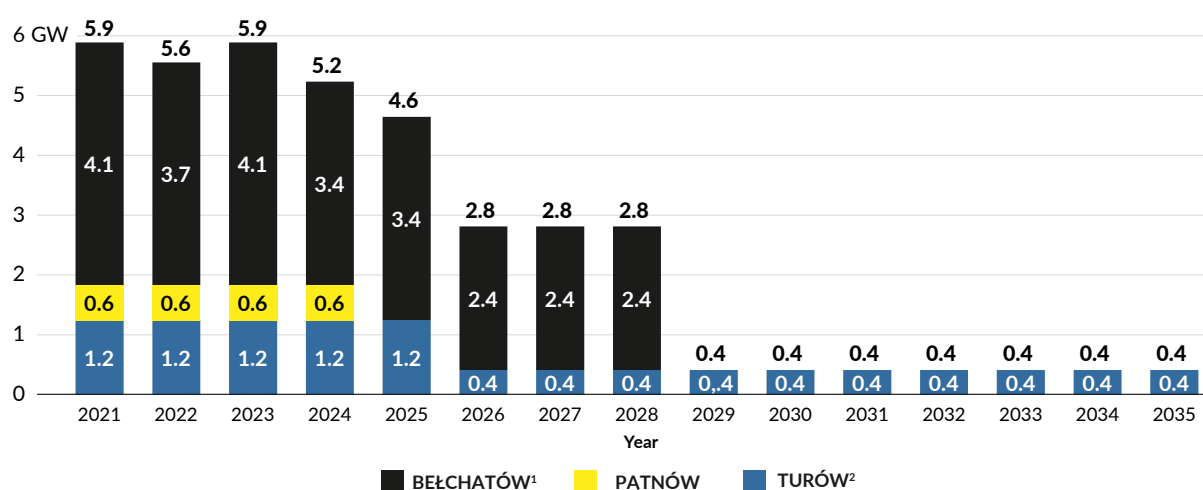
The Polish capacity market is based on two types of auctions:

- A main auction held 5 years prior to delivery, offering contracts ranging from 1 to 17 years
- A supplementary auction held once a year before delivery, offering quarterly contracts

Regardless of the type, auctions take the form of a Dutch auction, meaning that prices are paid-as-cleared, and auctions are concluded when capacity targets are reached. To avoid strategic bidding, participants are not permitted to drop out of the auction at a price below a specified threshold. The length of contracts offered depends on the required amount of CAPEX to refurbish existing assets and/or invest in new capacities. 'Green bonuses' of two additional years are granted to generation facilities that emit less than 450 gCO<sub>2</sub>/kWh.

A 2019 update to the Electricity Directive and Electricity Regulation introduced an emission limit that power plants must meet to remain eligible for capacity provision subsidies. Known as the “550-gram rule”, capacity payments for assets that emit more than 550 gCO<sub>2</sub>/kWh will be phased out after 2025. This effectively impacts the entire coal fleet in Poland, including lignite plants. There is a grandfather clause for capacity contracts signed before the end of 2019. That is to say, lignite plants that received multi-year contracts in the 2019 capacity auction (for delivery in 2024) can continue to receive capacity payments after 2025.

Exhibit 6: Capacity auction results for lignite units in Poland



Source: Forum Energii.

1) Of the Bełchatów capacity, 996 MW running to 2025 were awarded in the 2021 auction. 2) All of the Turów capacity was awarded in the 2021 auction.

Before 2016, the primary mechanism supporting the growth of renewables was the green certificate system. Under this system, renewable electricity producers received tradeable green certificates equivalent to the amount of electricity they fed into the grid. These certificates were purchased by electricity sellers, who were required to cover their sales of electricity with a predetermined minimum share of renewable energy.

In July 2016, the green certificate scheme was phased out in favour of a tendering mechanism for renewable support. Although existing generation is still covered under the previous scheme, new-build and modernised renewable assets in Poland receive support via auctions. These are carried out on a technology-by-technology basis and designed such that different technologies compete within ‘baskets’ characterised by targeted volumes and budgets. Support is awarded to renewables exhibiting the lowest cost profiles until either the budget or the volume target is met. The support comes in the form of a two-sided sliding feed-in premium for 15 years. There is significant uncertainty as to the level of renewables that will be supported under the CfD scheme, as is evidenced by the changing capacity assumptions in the drafts of the government’s Polish Energy Policy 2040 and its National Energy and Climate Policy.

The Polish power sector is dominated by the following key players: PGE, Enea, Energa, PKN Orlen, Tauron, and ZE PAK. The first four are partly state-owned. Only PGE and ZE PAK are active in power generation from lignite.

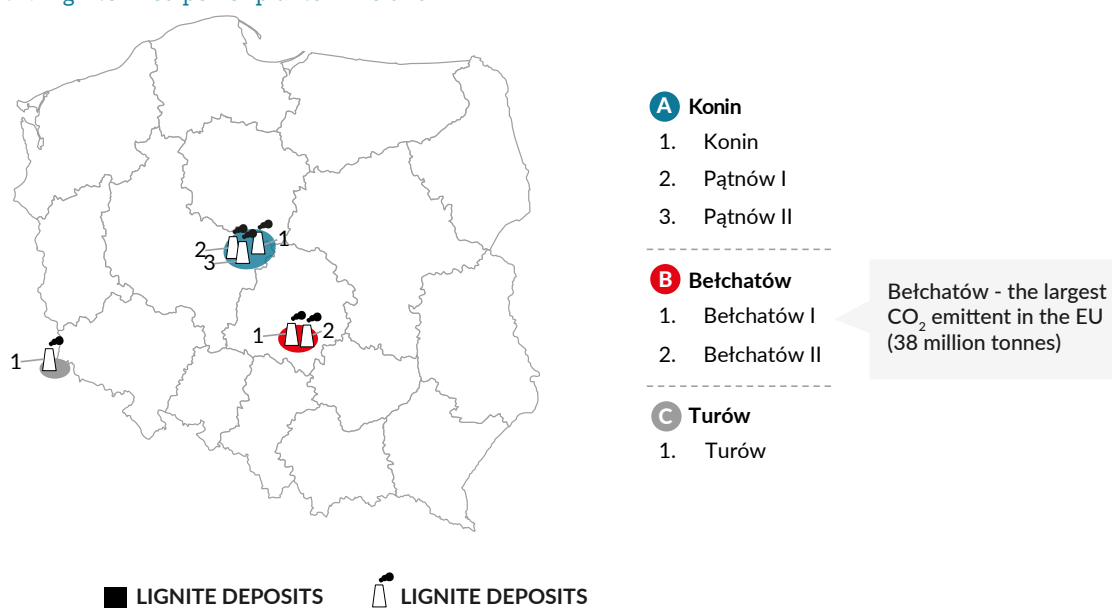
PGE is the largest generating company in Poland. In 2018, its installed capacity amounted to roughly 16 GW, corresponding to 65 TWh of total electric generation. As it stands, the state-owned company operates the world’s largest lignite-fired power plant, Bełchatów, which boasts a capacity of 5 GW, in addition to four other lignite and hard-coal plants with capacities of roughly 1.5 GW each. The company recently added Opole, a 1.8 GW hard-coal plant, to its portfolio. Over 90% of the company’s electricity production stems from hard coal and lignite. In addition to generation electricity, the PGE Group also plays an active role in lignite extraction and electricity distribution.

ZE PAK is Poland's largest privately-owned electric generation company, with a total of 1.9 GW of generating capacity. The majority of this stems from two lignite power plants, Pałnów and Konin. In 2018, ZE PAK produced around 6 TWh of electricity. Besides power generation, the company consists of vertically integrated entities active in lignite extraction, heat production, and electricity trading.

## 2.2. Lignite plants

At present, there are a total of 4 operational lignite plants in Poland: Bełchatów, Turów, Konin, and Pałnów. Together, lignite-fired power plants were responsible for 49.3 TWh of generation in 2018, which was slightly below the 51.9 TWh produced in 2017. The decrease in generation is largely due to the closure of the Adamów power plant, a 600 MW facility owned and operated by ZE PAK. The shutdown of Adamów took force in January 2018 as the power plant was unable to meet EU's environmental standards. It is to be substituted with a large-scale PV.

Exhibit 7: Lignite-fired power plants in Poland



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Source: Aurora Energy Research.

The Bełchatów power plant is a 13-unit lignite-fired power plant owned and operated by PGE. While 12 of the units were commissioned between 1982 and 1988, the 13<sup>th</sup> unit was only added in 2011. Its purpose was to allow for the modernisation of the existing units. With a total net electrical capacity of 5,136 MW, the Bełchatów power plant is the largest thermal power station in Europe. The power station produces an average of 32.3 TWh of electricity on an annual basis, requiring over 42 million tonnes of coal from the local Bełchatów mine. Despite the fact that some units have been retrofitted and upgraded to increase efficiency, the plant was responsible for over 38 million tonnes of CO<sub>2</sub> emissions in 2018, making it the heaviest polluter of all the power plants in Europe. In June of 2019, PGE permanently closed unit 1 of the lignite-fired plant.

Table 11: Details on the Bełchatów power plant

Plant	Block	Owner	Commissioning Year (retrofit)	Net Elec. Capacity (MW)	CO <sub>2</sub> Emissions in 2018
Bełchatów I	2	PGE	1983	347	38 MtCO <sub>2</sub>
	3	PGE	1984 (2008)	356	
	4	PGE	1984 (2009)	356	
	5	PGE	1985 (2011)	356	
	6	PGE	1985 (2012)	369	
	7	PGE	1985 (2013)	366	
	8	PGE	1986 (2013)	366	
	9	PGE	1986 (2016)	366	
	10	PGE	1987 (2016)	366	
	11	PGE	1988 (2014)	366	
	12	PGE	1988 (2015)	366	
	Bełchatów II	1	PGE	2011	

Source: Aurora Energy Research.

The Turów power plant is located in Bogatynia, Poland. The power station originally consisted of 10 units commissioned between + 1962 and 1971—all of which were owned and operated by PGE. At present, however, only 6 of the original units remain, totalling 1,356 of net capacity. In 2018, the Turów power station was responsible for a total of 6.9 million tonnes of CO<sub>2</sub> emissions. This is expected to increase with the addition of a 490 MW unit. The construction of Unit 11 at the Turów power plant began in 2014 and is expected to come online in 2020. The additional capacity is expected to increase the demand for coal from the Turów open-pit mine from an average of 7 to 10 million tonnes annually.

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Table 12: Details on the Turów power plant

Plant	Block	Owner	Commissioning Year (retrofit)	Net Elec. Capacity (MW)	CO <sub>2</sub> Emissions in 2018
Turów	1	PGE	1962 (1998)	214	6.9 MtCO <sub>2</sub>
	2	PGE	1962 (1998)	214	
	3	PGE	1962 (2000)	214	
	4	PGE	1963 (2004)	238	
	5	PGE	1964 (2003)	238	
	6	PGE	1964 (2005)	238	
	11	PGE	2020	448	n.a.

Source: Aurora Energy Research.

The Konin power plant was first commissioned in 1958, making it the oldest lignite-fired power station in Poland. The plant is owned by ZE PAK and has a net capacity of 248 MW<sub>el</sub>, corresponding to 0.34 TWh of the electricity generated in 2018. In 2006, the power plant received a permit to produce heat as well, which it supplies to the town of Konin and the surrounding areas. In 2012, a 55 MW<sub>el</sub> biomass unit was added to the plant, signalling the beginning of the plant's transition from lignite to biomass. ZE PAK currently has plans to create a second 50 MW<sub>el</sub> biomass-fired generation unit that will operate in conjunction with the first. As a result, the Konin plant will be a completely biomass-fired plant in several years' time.

Table 13: Details of the Konin power plant

Plant	Block	Owner	Commissioning Year (retrofit)	Net Elec. Capacity (MW)	CO <sub>2</sub> Emissions in 2018
Konin	1	ZE PAK	1958	155	0.2 MtCO <sub>2</sub>

Source: Aurora Energy Research.

The Pątnów power plant was originally an 8-unit lignite-fired power plant located slightly west of Warsaw. Owned by ZE PAK, these units first came online in 1967. In the early 2000s, 2 of the units were decommissioned. Shortly thereafter, the company decided to construct Pątnów II, a 464 MW brown coal-fired unit. At present, the Pątnów power station has a total net capacity of 1,563 MW. In 2018, the Pątnów I and Pątnów II produced 3.4 TWh and 2.3 TWh of electricity, respectively, and together emitted slightly over 7 million tonnes of CO<sub>2</sub>.

Table 14: Details of the Pątnów power plant

Plant	Block	Owner	Commissioning Year (retrofit)	Net Elec. Capacity [MW]	CO <sub>2</sub> Emissions in 2018
Pątnów I	1	ZE PAK	1968	202	4.6 MtCO <sub>2</sub>
	2	ZE PAK	1968	202	
	3	ZE PAK	1969	182	
	4	ZE PAK	1969	182	
	5	ZE PAK	1973	182	
	6	ZE PAK	1974	182	
Pątnów II	9	ZE PAK	2008	431	2.5 MtCO <sub>2</sub>

Note: On 31 December 2019 ZE PAK closed down unit 4, and on 30 June 2020 units 3 and 6.

Source: Aurora Energy Research.

The vast majority of Polish lignite plants are primarily used for power generation and their heat output is limited to negligibly small internal heating needs. The only exception to that is the Konin lignite plant, which serves heat needs in the nearby city of 70,000 inhabitants. Nevertheless, ZE PAK is in the process of switching this plant to biomass fuel. Therefore, lignite is not expected to have any significant impact on the future of heating.

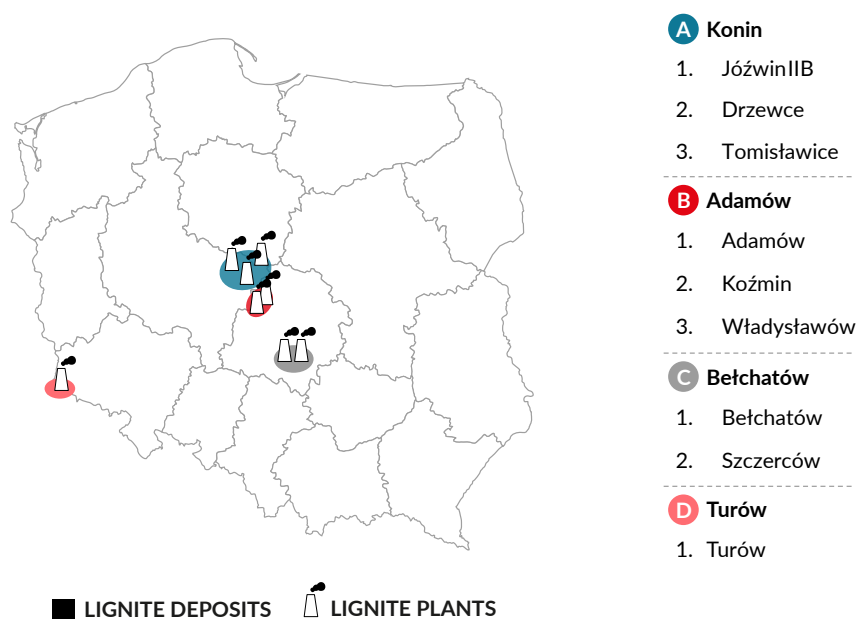
### 2.3. Lignite mining

Due to an abundance of accessible local reserves, lignite was thought to play an integral role in ensuring a secure supply of affordable electricity to Polish consumers. Furthermore, lignite mines are highly labour-intensive, providing many local jobs.



As it stands, Poland is one of the largest lignite producers in the world, due in part to having over 150 lignite deposits.<sup>38</sup> Lignite-bearing areas cover roughly one-third, or 70,000 km<sup>2</sup>, of the country. Despite its abundance, not all of the country's lignite is exploited. Rather, lignite production stems primarily from four mines in the western and central regions of Poland: Bełchatów, Turów, Konin, and Adamów. These mines produce about 60 Mt of lignite annually—98.7% of which is used to supply mine-mouth power plants.<sup>39</sup>

Exhibit 8: Lignite mining regions and mines in Poland



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Sources: Aurora Energy Research, Energy Policy –Widera et. al.

The Bełchatów lignite basin is located in the central part of Poland, south of Łódź, and encompasses two fields: Bełchatów and Szczerców. Owned by PGE, the Bełchatów mine is the largest in Poland in terms of lignite extraction and supplies nearly two-thirds of total production in the country. In 2017, total lignite production from the mine amounted to 42.6 million tonnes—the majority of which went to supply the Bełchatów Power Plant. As it stands, PGE has plans to continue operating the Bełchatów mine at least up to 2040. PGE is currently seeking a concession to open a new field in Złoczew, which has a reserve of 600 million tonnes. According to PGE, lignite from this deposit is expected to provide additional fuel for its mine-mouth power plant for the upcoming decades.

Table 15: Lignite fields in the Bełchatów mine

Mine	Deposit	Operator	Start of Operations	Annual Production	Available Reserves	Plants served
Bełchatów	Bełchatów	PGE	1999	38.5 Mt	1 000 Mt	Bełchatów
Bełchatów	Szczerców	PGE	2002	9.5 Mt	720 Mt	Bełchatów

Source: PGE Górnictwo i Energetyka Konwencjonalna S.A., 2019.

38 Wídera, Kasztelewicz & Ptka, 2016

39 Ministerstwo Energii, 2018.

The **Turów mine** is located in the southwest of Poland in the Turoszów lignite basin and includes the Turów open-pit mine. Owned by PGE, the Turów mine can produce up to 15 million tonnes of lignite in a given year. In 2017, the mine supplied 6.9 million tonnes of lignite—the majority of which went to the Turów Power Plant. With reserves of 340 million tonnes, the mine could remain operational at least until 2045.

Table 16: Lignite fields in the Turów mine

Mine	Deposit	Operator	Start of Operations	Annual Production	Available Reserves	Plants Served
Turów	Turów	PGE	1968	6.9 Mt	340 Mt	Turów

PGE Górnictwo i Energetyka Konwencjonalna S.A., 2019.

The **Konin mine** is located in the Pątnów-Adamów-Konin lignite basin in central Poland between Warsaw and Poznań. Owned by the ZE PAK group, the mine produces approximately 15 million tonnes of lignite on an annual basis. As of 2019, the mine has an estimated 36.5 million tonnes of industrial reserves in the pits currently being exploited. These are distributed across three fields: Józwin IIB, Drzewce, and Tomisławice. Lignite mined from these fields are used for both electricity and heat generation in three local mine-mouth plants: Pątnów I (1,200 MW), Konin (583 MW), and Pątnów II (464 MW).

Table 17: Lignite fields in the Konin mine

Mine	Deposit	Operator	Start of Operations	Annual Production <sup>40</sup>	Available Reserves	Plants served
Józwin IIB	Konin	ZE PAK	1971	5.6 Mt	56 Mt	Konin, Pątnów I, Pątnów II
Drzewce	Konin	ZE PAK	2010	1.4 Mt		Konin, Pątnów I, Pątnów II
Tomisławice	Konin	ZE PAK	2011	2.4 Mt		Konin, Pątnów I, Pątnów II

Source: Aurora Energy Research.

The Adamów mine is located in Turek in central Poland and owned by the ZE PAK group. As of 2019, the company reported the mine to have a total of 5.2 million tonnes of remaining industrial reserves across its 3 fields: Adamów, Koźmin, and Władysławów. With an overall production capacity of 5 million tonnes of lignite annually and the closure of the Adamów power plant in early 2018, the Adamów mine is not expected to remain open for much longer.

Table 18: Lignite fields in the Adamów mine

Mine	Deposit	Operator	Start of Operations	Annual Production	Available Reserves	Plants served
Adamów	Turek	ZE PAK	1979	3.5 Mt	17 Mt	Adamów
Koźmin	Turek	ZE PAK	n.a.	-		Adamów
Władysławów	Turek	ZE PAK	1976	Closed in 2012		Adamów

Source: Aurora Energy Research.

The mining sector in Poland has been shown to have meaningful effects on the local labour market. Between 2010 and 2014, lignite-rich regions in Poland saw unemployment rates roughly 2 percentage points below the national average. Remuneration rates for those employed in the sector, as of 2015, were nearly 1.8 times higher than the national average. In addition to favourable wages, lignite workers also receive relatively generous benefits and social payments.

In 2015, the coal and lignite mining sector provided more than 100,000 jobs.<sup>41</sup> Lignite makes up 10% of this sector. 6,300 employees were directly employed by mine operators, while 4,100 of these were indirectly employed by external firms that provide services to mines. Since then, the number people employed directly or indirectly in the mining sector has decreased to approximately 9,000.

Plans to open new open-pit mines are currently under discussion. PGE aims to develop the Złoczew mine, whose reserves amount to a total of 600 million tonnes. According to PGE, the coal would be used to supply the Bełchatów power plant for the upcoming decades. Still, the social opposition and high costs question the viability of this investment, which future remains undecided. Until recently, the company also sought a concession for opening Gubin 2, a new mine located on the German-Polish border. The opening of Gubin 2, according to PGE, would warrant the construction of an adjoining lignite plant. However, at the end of August 2019, the deadline for filing an environmental permit to open the mine expired. Until now no official announcement on abandoning of this project has been made.

Similarly, ZE PAK has considered opening a new open-pit mine in eastern Poland. According to the company, the mine, referred to as Ościstowo, has an estimated 41 million tonnes of commercially extractable reserves. As lignite resources dwindle elsewhere, the Ościstowo open-pit mine would serve as a crucial fuel supplier to the Pątnów I and Pątnów II power plants, as all of ZE PAK's existing mines, excluding Tomisławice, are expected to close over the next three years. Although ZE PAK is formally continuing the project, certain risks are associated with the investment: local opposition or the long process of obtaining environmental permits. At the same time, ZE PAK has already begun investing in other generation technologies.

Prior to opening a mine, operators need to obtain an environmental permit and ensure compliance with local spatial development plan. In 2017, the Regional Directorate for Environmental Protection in Poznań refused to issue an environmental decision for the Ościstowo mine. ZE PAK has appealed from this decision, but so far the proceedings (after returning to the first instance and a second refusal) has not been ended. Therefore, ZE PAK is not able to obtain a license. Problems related to environmental decision also concern the operation of Tomisławice mine, located next to the protected under the EU Natura 2000 network Gopło lake. According to the European Commission, the environmental decision was issued in violation of the EU directive. The European Commission calls for a re-assessment of the environmental and appropriate impact of the Tomisławice mine adapt its operation.

Historically, the procedures for obtaining concessions in Poland were one of the more significant barriers to the implementation of projects. Last year, the were ideas to allow the government to open new coal mines without consultation with or permission from local authorities and impacted communities, but the party's proposals were met with strong opposition. At any rate, there is no economic basis for opening new mines at this time.

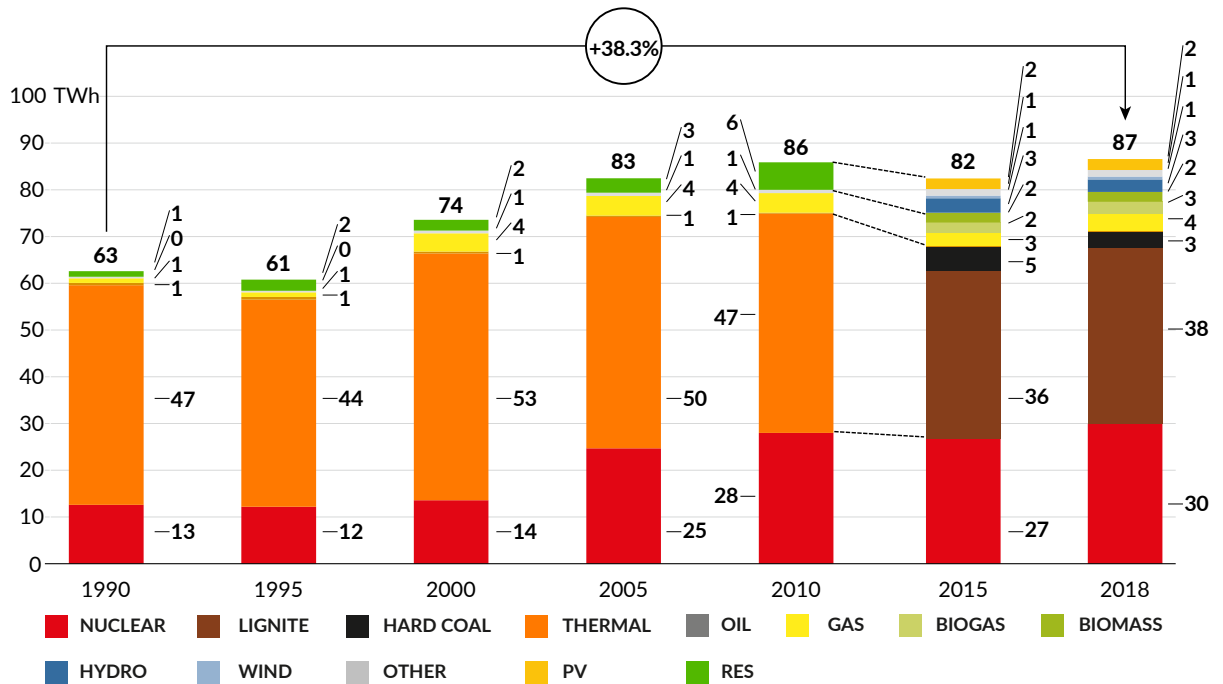
### 3. Czech Republic

#### 3.1. Market overview

The Czech electricity sector is dominated by conventional power generation, largely met by local production. Traditionally, lignite has been the primary source for electricity generation. However, for environmental as well as strategic and economic reasons, there policy-makers have been pushing to replace it. The CO<sub>2</sub> price enforced by the EU Emission Trading Scheme (ETS) renders power generation from lignite less attractive than it used to be, lignite reserves are dwindling and becoming more expensive to extract and a diversification of supply stands to provide more security. These strategic targets will be discussed after presenting the **historical development of power generation**.

41 IISD, 2019.

Exhibit 9. Electricity generation capacities in the Czech Republic



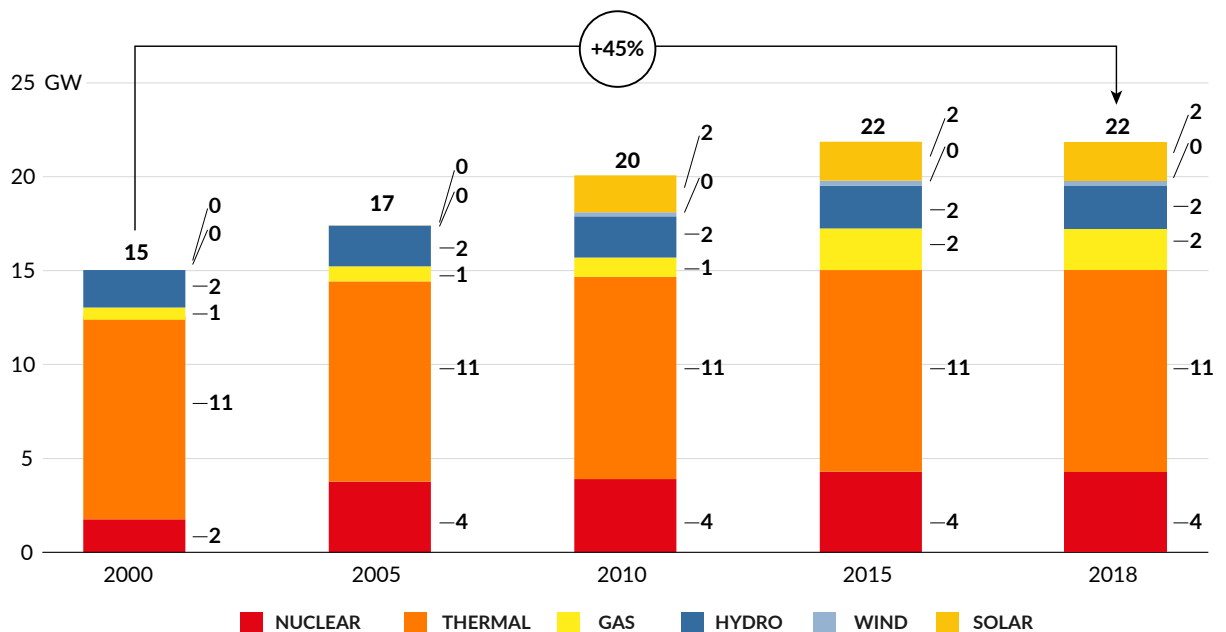
Sources: Eurostat, ERÚ, Aurora Energy Research.

Note: Technology grouping between Eurostat and ERÚ differs. Separate data thermal and renewable generation is available from 2011 onwards only. Before 2011, biogas is aggregated in gas. Biomass, coal and lignite are accounted for in thermal generation.

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Total power generation in the Czech Republic amounts to 88 TWh, with an installed capacity of 22.3 GW, as shown in Exhibit 9.<sup>42</sup> The amount of electricity generated rose from 60 TWh in the 80s to 80 TWh in the 2000s. In that period, generation drew on a relatively stable mix of technologies.

Exhibit 10. Electricity generation in the Czech Republic



Source: Aurora Energy Research, ERÚ, ENTSO-E

Both in terms of generation and installed capacity, lignite dominates the electricity mix. 43% of gross electricity generation in 2018 came from lignite combustion, followed by nuclear energy with 34% (4.3 GW). Natural gas and hard coal each contribute 4% of generation. The share of these conventional technologies has been relatively constant over the past 20 years. The amount of nuclear energy last increased significantly in the early 2000s, when the Temelín nuclear reactors went into operation. Renewables make up 13% of electricity generation (4 GW installed capacity). Their share has increased moderately since 2009, when they amounted to 6%. The increase was driven by PV expansion in the beginning of this decade. As for generation, biogas is the most dominant renewable energy source, producing 2.6 TWh in 2018. This is shown in Exhibit 10.

The Czech electricity sector is well integrated with all its neighbours. The Czech Republic has been a net exporter of electricity over the past years. Exports are mostly to Slovakia and Austria, while imports dominated the interconnectors to the German and Polish border. Prices often converge with the German bidding zone. There are no current plans of building new interconnections with neighbouring countries. Instead, officials have opted to evaluate the development of cross-border physical flow

The market coupling of the Czech, Slovak, Hungarian, and Romanian day-ahead markets started in September 2012. The Central Allocation Office allocates the cross-border capacity of power transmission for Germany, Poland, and Austria. Capacity allocation with Slovakia is based on long-term assignments.

The electricity market design of the Czech Republic is compliant with EU regulation. It is liberalised, and electricity can be traded on the PXE (Power Exchange Central Europe). Prices are derived from an energy-only market. Still, the latest monitoring of capacity adequacy<sup>43</sup> has indicated the need for new capacities and voices are now calling for the creation of a strategic reserve. At this time, the Czech government plans to meet this need with new nuclear capacity.<sup>44</sup> OTE is the market operator. Its job is to set standards and mediate between market participants. Policies are outlined by the Ministry of Industry and Trade (MIT) and regulated by the Energy Regulating Office (Energetický regulační úřad, ERÚ).

A core document for strategic energy policy in the Czech Republic is the State Energy Policy (SEP), which was approved in 2015.<sup>45</sup> It aims to achieve security, competitiveness, and sustainability. It sets targets for the Czech electricity sector in view of the energy trilemma:

#### Sustainability

- A 40% reduction in CO<sub>2</sub> emissions relative to 1990 values by 2030
- A 20% increase in energy efficiency, resulting in a net final energy consumption of 1060 PJ<sup>46</sup>

#### Security of supply

- 80% of annual gross electricity generated must stem from domestic primary energy sources (RES, waste, hard coal, lignite, nuclear fuel) in 2040
- Diversification of primary energy sources within defined target corridors
- Maintain a positive electricity balance and ensure generation adequacy
- Import dependence for fuels shall not exceed 65% by 2030 and 70% by 2040<sup>47</sup>

To meet the domestic supply requirement, the SEP has indicated technology corridors for gross electricity generation in 2040.

<sup>43</sup> Ministry for Industry and Trade, 2019a.

<sup>44</sup> World Nuclear News, 2019.

<sup>45</sup> Ministry for Industry and Trade, 2015b.

<sup>46</sup> Eurostat methodology.

<sup>47</sup> Here, nuclear fuel is counted as an imported source.

Table 19: Technology corridors in SEP

	Minimum [%]	Maximum [%]
Nuclear	46	58
RES and other	18	25
Natural Gas	5	15
Lignite/Hard coal	11	21

Source: Aurora Energy Research.

#### Competitiveness

- Energy expenses shall not exceed 10% of total household expenses

Of all energy sources, the share of nuclear energy increased the most in the Czech State Energy Plan. The current National Action Plan of the Development of Nuclear Energy<sup>48</sup> wants to expand its nuclear plants by one block each and put the new units into operation by 2035. The government<sup>48</sup> plans to open additional units in the 2040s once coal production declines.

The future of lignite and coal is currently under discussion. In August 2019, the Czech Coal Commission was launched, consisting of 19 representatives from ministries, NGOs, academia, industry, and the regions. Their purpose is to agree on a date for phasing-out coal. The government has proposed that coal capacities be reduced to 10–15% by 2040, followed by a moderate phase-out through 2050. NGOs have criticized the plan for its lack of ambition, however.<sup>49</sup> The commission will assess the implications of a coal phase-out on household and heating plans and on mining regions. Its recommendations will be published no later than autumn 2020.

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To comply with the EU directives on the promotion of the use of energy from renewable sources, the Czech Republic has committed itself to obtaining 13% of its final energy consumption from renewables by 2020.<sup>50</sup> In the transport sector, 10.8% of gross final energy consumption is to be renewable. The Czech draft for the National Energy and Climate Plan (NECP) submitted to the European Union in 2018 outlines the country's trajectory for after 2020. The Czech Republic plans to cover 22% of its gross final energy consumption by renewables,<sup>51</sup> though this is below the 23% suggested by the governance formula.

The Czech Republic has developed schemes for monitoring, research, training and awareness. It also supplies subsidies for small hydro power plants. A generous feed-in tariff led to a substantial increase in PV in 2010–2011. In 2013, the government withdrew its support for non-hydro RES.

The Czech electricity sector is concentrated around three key market players. The largest power supplier is the utility ČEZ Group, in which the Czech state owns a 70% stake. It generates around two-thirds of electricity in the Czech Republic. The second and third largest utilities, EP Energy and Sev.en Energy Group, own less than 5% of installed capacity each.<sup>52</sup>

ČEZ Group is the largest energy company in the Czech Republic. It owns a generation capacity of about 13 GW<sup>53</sup>, supplying 67% of Czech electricity (59 TWh). ČEZ Group comprises almost 100 subsidiary companies, some of which are active in mining, others as utilities. ČEZ Distribuce functions as one of four distribution system operators in the country. ČEZ controls the majority of Czech lignite plants, most of which are located in the Ústí region.

48 Ministry for Industry and Trade, 2017.

49 Radio Prague International, 2019.

50 European Environment Agency, 2019.

51 Euractiv, 2020.

52 International Energy Agency, 2016.

53 ČEZ, 2017.

EP Energy is the second largest utility in terms of capacity, covering 4% of Czech electricity generation (3.7 TWh)<sup>54</sup> and with an installed capacity of 1.1 GW. Furthermore, they are the Czech Republic's largest supplier of thermal heat.

EP Energy owns shares of other energy companies that are active in the Czech market such as United Energy or Pražská Teplárenská, the biggest heating supplier in Prague. Internationally, it is the owner of MIBRAG, which operates German lignite mines, and has a minority stake in the Schkopau power plant. EP Energy is a subsidiary of the Czech holding EPH, which also owns other energy companies such as LEAG, an important player in the German lignite market.

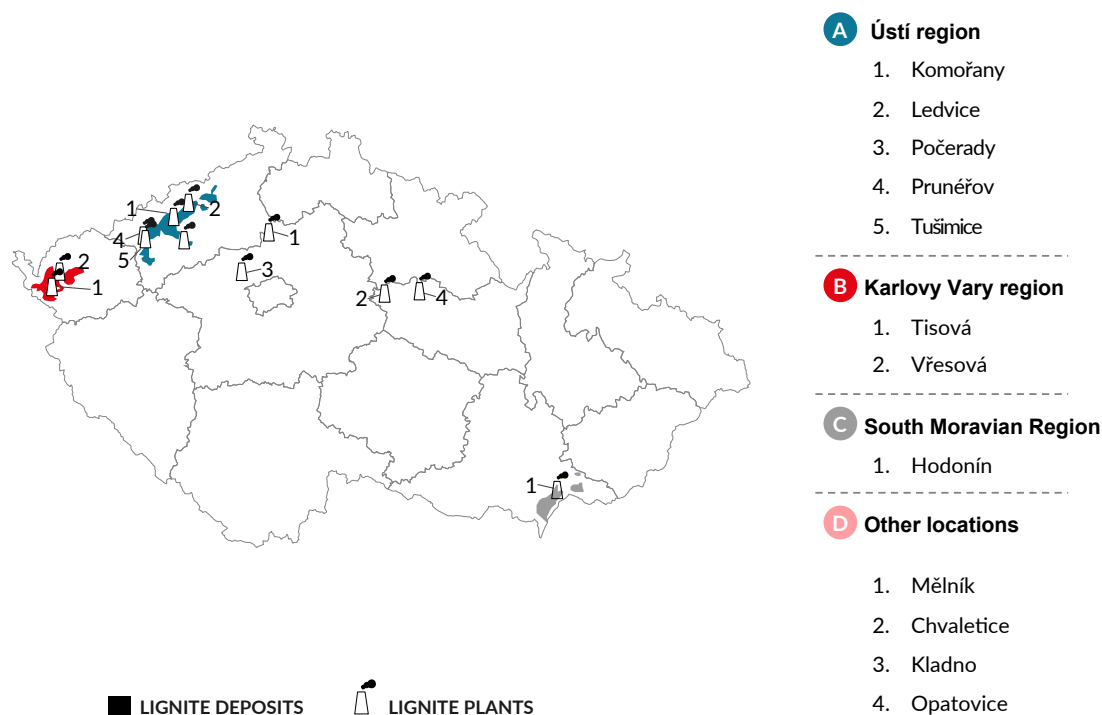
Sev.en Energy group is the result of a merger between the mining groups Severní Energetická and Czech Coal in 2016. In the Czech Republic, it owns the two largest lignite mines (ČSA and Vršany) as well as a lignite power plant (Chvaletice) with an installed capacity of 820 MW, generating 4.8 TWh (5.5%) of electricity in 2018.<sup>55</sup> In early 2020, the Počeradý power plant was added to the portfolio.<sup>56</sup> The group also supplies heat from its Kladno and Zlín plants.

### 3.2. Lignite plants

As described above, lignite has been an important source of power generation in the Czech Republic. Coal-fired power plants makes up almost half of the Czech power generation mix. This value has declined from two-thirds in 1990, when nuclear power plants went online. Since 2010, absolute generation from lignite has been decreasing. This trend is likely to continue. The State Energy Policy seeks to reduce lignite to 11% and hard coal to 21% of the Czech electricity mix by 2040.

Lignite-fired power plants are often located at the mouths of open-pit mines. As a result, lignite plants in the Czech Republic are concentrated in the Ústí region. In contrast to Germany and Poland, some plants are further away from the mining areas due to the higher calorific value of Czech lignite.<sup>57</sup> Therefore, lignite plants can be also be found in the greater Prague area despite its absence of mines.

Exhibit 11: The largest lignite power plants and deposits in the Czech Republic



Sources: Aurora Energy Research, CEZ, Sev.en Energy, Carbonbrief.

54 EP Energy, 2019a.

55 7energy, 2019.

56 ČEZ, 2020.

57 Ministry of the Environment of the Czech Republic, 2018.

The following paragraphs provide an overview of the largest lignite-fired plants. For the models underlying this study, plants smaller than 200 MW<sub>el</sub> are aggregated and therefore not discussed in this chapter.<sup>58</sup> These smaller plants amount to a total lignite power plant capacity of 1.95 GW.

The largest lignite plants in the **Ústí region** constitute a total of installed capacity of 4 GW. Most of them are owned by ČEZ and fuelled by the nearby mines.

Table 20: Lignite fuelled power plants in the Ústí region

Plant	Block	Owner	Commissioning Year (retrofit)	Elec. Capacity (MW)	CO <sub>2</sub> Emissions (Mt CO <sub>2</sub> -eq, in 2018)
Komořany		EP Energy	1958	239	1.23
Ledvice	4	ČEZ	1966 (1998, 2007)	110	2.05
	6		2014	660	
Počeradý	2	ČEZ <sup>59</sup>	1970 (1996)	200	6.22
	3		(1996)	200	
	4		1971 (1996)	200	
	5		1971 (1996)	200	
	6		1977 (1994)	200	
Pruněřov I	1	ČEZ	1967–1968 (1995)	110	2.74
	2			110	
	3			110	
	4			110	
Pruněřov II	3	ČEZ	1981–1982 (2012–2016)	250	3.86
	4			250	
	5			250	
Tušimice	1	ČEZ	1974–1975 (2007–2012)	200	4.98
	2			200	
	3			200	
	4			200	

Source: Aurora Energy Research.

<sup>58</sup> An exception is the now smaller Hodonín plant that was important considering historical output and regional factors.

<sup>59</sup> From 2024 on it will be owned by Sev.En.



The operator of the lignite mines in the **Karlovy Vary** region, Sokolovská uhelná, also owns two power plants in the area. The Tisová power plant was the first large power plant built in Czechoslovakia and is now a central pillar of regional heat supply. The Vřesová plant is a gas plant, fuelled by gasified lignite. With lignite fields depleting and lignite quality decreasing, the output of these two plants has declined.

Table 21: Lignite fuelled plants in the Karlovy Vary region

Plant	Block	Owner	Commissioning Year (retrofit)	Elec. Capacity (MW)	CO <sub>2</sub> Emissions (Mt CO <sub>2</sub> -eq, 2018) <sup>60</sup>
Tisová <sup>61</sup>		Sokolovská uhelná	1954-1960 (1997)	272	1.72
Vřesová		Sokolovská uhelná	1995 (2013)	400	2.4

Note: The plant operates as a CCGT, fuelled by gasified brown coal.

Source: Aurora Energy Research, Jaszczur Dudek et al., 2020.

As lignite supply in local mines has declined, the Hodonín plant in the southeast of the country has been increasingly fuelled by biomass. Currently, one block at Hodonín is entirely powered by biomass, and the second is co-fired. Since biomass fuels are more expensive than lignite, running hours of this plants are low and only about one-third of the installed capacity is used.<sup>62</sup>

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Table 22: Lignite fuelled plants in the South Moravian region

Plant	Block	Owner	Commissioning Year (retrofit)	Elec. Capacity (MW)	CO <sub>2</sub> Emissions (Mt CO <sub>2</sub> -eq, 2018)
Hodonín		ČEZ	1975	105	0.67

Note: Since 2008, one block runs entirely on biomass; the other is co-fired by lignite and biomass.

Source: Aurora Energy Research.

As stated above, the calorific value of Czech lignite is high enough that coal can be shipped to plants at a distance from the mines. The plants displayed in Table 23 focus on the capital area of Prague, where a considerable amount of the country's demand is located. These plants amount to an installed capacity of 2.6 GW.

<sup>60</sup> CarbonBrief, 2019.

<sup>61</sup> Svetenergie.

<sup>62</sup> ČEZ, 2019.

Table 23: Lignite fuelled plants in non-mining regions.

Plant	Block	Owner	Commissioning Year (retrofit)	Elec. Capacity (MW)	CO <sub>2</sub> Emissions (Mt CO <sub>2</sub> -eq in 2018) <sup>63</sup>
Chvaletice	1-4	Sev.en Energy	1978 (2018-2021)	820	5.1
Kladno	B4-B8 <sup>64</sup>	Sev.en Energy	2000	406	1.51
Mělník <sup>65</sup>	I	ČEZ	1960	240	7.80
	II		1971 (1998)	220	
	III		1981 (1998)	500	
Opatovice		EP Energy	1959	328	2.24

Source: Aurora Energy Research.

Lignite can produce heat in addition to power. More than half of Czech final energy demand is used for heating and cooling, amounting to ca. 160 TWh.<sup>66</sup> Of this share, around half is used for space heating – supplied by individual heating and district heating. Process heating accounts for more than one-third of the heat energy balance in the Czech Republic.

Lignite is present in all types of heat supply. In the heat provided by CHP plants, lignite makes up 55% of heat supply.<sup>67</sup> But in individual on-site heat generation and in heat for district heating, lignite constitutes 10% of supply.

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The dominant actor in the heating market is EP Energy, which delivers ca. 5 TWh annually.<sup>68</sup> All its lignite plants are CHP with a focus on heat rather than electricity, supplying almost 3.5 TWh. The table below shows the thermal capacities for Czech lignite CHP plants.

<sup>63</sup> CarbonBrief, 2019.

<sup>64</sup> Block K4, K5 and K7 cofire biomass in fluid boilers, [https://www.mzp.cz/ipcc/ipprc4.nsf/\\$pid/MZPVHGYKO58V](https://www.mzp.cz/ipcc/ipprc4.nsf/$pid/MZPVHGYKO58V).

<sup>65</sup> Mělník I has not been part of the modelling since it is heating plant without any power generation.

<sup>66</sup> Aalborg University, 2018.

<sup>67</sup> ERÚ, 2019.

<sup>68</sup> EP Energy, 2019b.

Table 24: Heating provision by large lignite power plants (CHP)

Plant	Owner	Heat production (TWh <sub>th</sub> /a) <sup>69</sup>	Thermal capacity / Electric capacity	Use
Chvaletice	Sev.en Energy	0.04	60MW <sub>th</sub> /820MW <sub>el</sub> <sup>70</sup>	District heating
Hodonín	ČEZ	0.2	250MW <sub>th</sub> /105MW <sub>el</sub>	District heating
Kladno	Sev.en Energy	0.3	14% of generation	District heating
Komořany	EP	2.2	1076MW <sub>th</sub> /239MW <sub>e</sub>	District heating, industrial
Ledvice	ČEZ	0.28	380MW <sub>th</sub> /770MW <sub>el</sub>	District heating, industrial
Mělník I/II/III	ČEZ	2.7	340MW <sub>th</sub> /960MW <sub>el</sub>	District heating
Opatovice	EP	1.2	932MW <sub>th</sub> /363MW <sub>el</sub>	District heating, industrial
Prunéřov	ČEZ	0.25	500MW <sub>th</sub> /1190MW <sub>el</sub>	District heating
Tisová	Sokolovská uhelná	0.1	n.a./522MW <sub>el</sub>	District heating
Tušimice	ČEZ	0.21	120MW <sub>th</sub> /800MW <sub>el</sub>	District heating
Vřesová	Sokolovská uhelná	0.56	n.a./400MW <sub>el</sub>	District heating, industrial

Source: Aurora Energy Research.

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### 3.3. Lignite mining

The Czech Republic puts its lignite reserves at 737 million tonnes.<sup>71</sup> Currently, it meets demand for lignite solely from domestic supplies. Czech open-pit mines are located mostly in the northwest of the country, close to the German border. The North Bohemian Basin is the largest, followed by the Sokolov Basin. In the Hodonin / Vienna area, the last mine closed in 2014 for economic reasons.<sup>72</sup> The Moravia-Silesia (Ostrava) region in the northeast of the country depends on hard coal mining and industry as well, but this report focusses on lignite regions.

The North Bohemian Basin, the largest territory for lignite mining, is located in the northwest. Four active mines across an area of 1 400 km<sup>2</sup> stretch between the cities of Kadaň, Chomutov, Most, Teplice and Ústí nad Labem, all of which are located in the Ústí nad Labem region. They supply nearby lignite power stations in Ledvice, Tušimice, Prunéřov, and Počerady. This region constitutes the core of Czech electricity generation from lignite.

<sup>69</sup> If not indicated else, data is taken from the respective company's website.

<sup>70</sup> In the model, this plant is considered a CHP and its heat output is replaced. However, given the small share of heat in generation and capacity, it is contested whether to treat this plant as a CHP plant in the Czech Coal Commission.

<sup>71</sup> Euracoal, 2019.

<sup>72</sup> Klempa et al., 2016.

Table 25: Mining areas in the North Bohemian Basin

Mine	Region	Operator	Start of Operations	Annual Production	Available Reserves	Plants served
Bílina Mines	Ústí nad Labem	Severočeské doly (ČEZ)	1950	10 Mt	246 Mt, thereof 150 Mt in 2035 plans <sup>73</sup>	Ledvice
ČSA (Czechoslovak Army Mine)	Ústí nad Labem	Sev.en Energy	1901	2.5 Mt	15 Mt <sup>74</sup>	Komořany, Chvaletice
Nástup Tušimice Mines (DNP)	Ústí nad Labem	Severočeské doly (ČEZ)	1967	13.5 Mt	172Mt, <sup>75</sup> with 34 Mt planned for 2038	Tušimice, Prunéřov
Vršany mine	Ústí nad Labem	Vršanská uhelná (Sev.en Energy)	1987	7 Mt	249 Mt, with 139 Mt planned for 2045	Počerady, (Chvaletice)

Source: Aurora Energy Research.

The Sokolov Basin is located west of the North Bohemian Basin. It covers an area of about 200km<sup>2</sup>. Mining started in the 18<sup>th</sup> century. While the older and smaller Medard field closed after being depleted, mining continues at Jiří, an open-pit mine close to the city of Sokolov. The mining area is connected to the Družba site, but a landslide prevented further mining there. In 2017, Sokolovská uhelná, the company operating the mines, bought the nearby Tisová power plant and consolidated its activities in the region.<sup>76</sup>

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Table 26: Mining areas in the Sokolov Basin

Mine	State	Operator	Start of Operations	Annual Production	Available Reserves <sup>77</sup>	Plants served
Družba mine	Karlovy vary	Sokolovská uhelná	1889	Closed after a landslide, but may be mined via Jiří mine	55 Mt, with 40 Mt planned for 2040	
Jiří mine	Karlovy vary	Sokolovská uhelná	1981	6.5 Mt	50 Mt, with 40 Mt planned for 2030	Tisová, Vřesová

Source: Aurora Energy Research.

The Hodonín Basin is located in the southwest of the country. The last mine, Mír, closed operations in 2014. Though they contain additional reserves, that are not economic to extract.<sup>78</sup>

<sup>73</sup> ZSDNP, 2019.

<sup>74</sup> ibid.

<sup>75</sup> Severočeské doly, n.d.

<sup>76</sup> ČEZ, 2017b.

<sup>77</sup> ZSDNP, 2019.

<sup>78</sup> Ministry of the Environment, 2019.

Employment in mining regions is characterised by a high concentration of industrial jobs and few opportunities for young professionals. The unemployment rate is above the national average<sup>79</sup> and the regions count among the country's poorest. The regional economy is heavily focused on the industrial sector, where employees earn comparably high wages. The Ministry for Industry and Trade reports that 6,400 people were directly employed in the lignite mining sector in 2018.<sup>80</sup> However, the regions benefit little from the industrial sector because wealth generation occurs in later stages of the supply chain. In 2017 and 2018, the national government adopted plans to diversify the economy with the support of EU cohesion funds (Re:Start).<sup>81</sup>

The Ústí region is one of the regions with the highest population density in the Czech Republic, home to over 820,000 inhabitants.<sup>82</sup> However, local patriotism and mining traditions are articulated to a lesser extent than, for instance, in German regions. This can be explained by the fact that most of the population migrated to the area after World War II. Historically, the region has been dominated by the industrial sector. It accounts for 41% of the region's GDP<sup>83</sup> and 33% of employment.<sup>84</sup> In 2017, 8,600 persons were directly employed in the mining and quarrying sector, making up 2% of the 385,200 people employed in the region.<sup>85</sup> This concentration is among the highest in Europe.<sup>86</sup> As no regional data is available for lignite mining, these numbers refer to an aggregate of all mining types. On a national level, lignite makes up approximately 30% of mining jobs.

The situation in the Karlovy Vary region is similar to that in the Ústí region. Here, industry accounts for 30% of regional GDP<sup>87</sup> while making up 36% of those employed. In 2017, 3,400 out of the 150,000 people, or 2.2% of those employed in the region, worked directly in the mining and quarrying sector.<sup>88</sup> These numbers cover all mining types, as no regional data is available for lignite mining. Naturally, lignite makes up approximately 30% of mining jobs.

A third lignite region in the Czech Republic is located in the southeast.<sup>89</sup> This region had already undergone large structural changes when the local mines stopped operating and the Hodonín power plant cut its workforce by more than half. As it stands, 1,200 of the 578,000 people employed in the region (0.2%) work directly in the mining and quarrying sector. Here too, the data reflects the aggregate of all mining types because no regional data is available specifically for lignite. On a national level, lignite makes up approximately 30% of mining jobs.

When it comes to structural change and re-cultivation in the Czech lignite mining sector, the outlook is highly contested. In 1991, the governmental resolution 444 placed limits on the lignite mining regions in Northern Bohemia. They define the areas that could be mined for the Czechoslovak Army Mine, the Jan Šverma Mine,<sup>90</sup> the Vršany Mine, the Bílina Mine and the Nástup– Tušimice Mine. The resolution was adopted by the post-Soviet government in response to the protests that had helped feed the Velvet Revolution. Its aim was to curtail air pollution and the displacement of communities. Concerns about local populations continue to shape Czech mining regulations. A 2013 amendment prohibits the displacement of people for the purposes of mining. It is uncertain, however, whether the territorial definitions of the mines set by the 444/1991 resolution will remain in place. For instance, the boundaries of the Bílina mine were extended in 2008 and 2015. Also, there is ongoing political debate about whether to repeal the 1991 resolution; the country's current president has called for its abolishment. Doing so would affect the times that mines and lignite power plants can operate and in Bílina and Vršany mines would increase to approximately twice their current size. Reserves are estimated to be large enough that mining could continue until well into the next century.<sup>91</sup>

79 The country average for the Czech Republic in 2019 is around 2%, below the EU-28 average of 6.3%. Eurostat, 2019.

80 Ministry for Industry and Trade, 2019b.

81 Re:Start supports the two major lignite regions, Ústí and Karlovy Vary. The third region is the highly industrialized hard-coal region Ostrava. Eurostat, 2019.

82 Czech Statistical Office, 2018a.

83 Ibid: 92.

84 Ibid.

85 Bruegel, 2018.

86 Czech Statistical Office, 2018b.

87 Ibid: 79.

88 Czech Statistical Office, 2018c.

89 Kralovehradecký Kraj, 2019.

90 Ministry of the Environment of the Czech Republic.

At the same time, the government has implemented strategies to strengthen regional economies and facilitate structural change. The most important of the strategies is the 2017 "Strategic Framework for economic restructuring."<sup>92</sup> It outlines seven pillars for action:

- Entrepreneurship and innovation
- Direct investments
- Research and development
- Human resources
- Social stabilisation
- Environment
- Infrastructure and public services

Recultivation is addressed in the action plans, which are updated yearly. EUR 1.5 bn is to be allocated over the duration of three years. This budget is in addition to the reserve funds that mining companies are obliged to create, as per the mining act.<sup>93</sup>

Mining companies are responsible for creating funds to pay for the clean-up of environmental damage. 75% of these funds are for towns and municipalities in the affected regions; one-quarter goes to a governmental fund, which recultivation projects can use. The Czech Coal Commission has formed a working group dedicated to the subject of recultivation.

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92 Re Start, 2019.

93 Zákon č. 44/1988 Sb

## Appendix 2. The Aurora power market model

The projections in this report are based on Aurora Energy Research's in-house Electricity System model for the EU (AER-ES EU). AER-ES EU is a dynamic dispatch model built for the emulation of the EU power market in half-hourly granularity. The model contains a fully specified Capacity Market module that iteratively determines economically consistent capacity contract allocations throughout the coming decades, along with the Capacity Market prices needed to trigger the required investments in generation capacity, given an externally set level of supply security.

The key structural features of the AER-ES EU model include:

1. Dynamic dispatch of plants, considering ramping costs and rate restrictions and the stochastic availability of plants and individual generators
2. Emulations of the entire German, Polish, and Czech power generation system, simulating each plant in each respective country at hourly granularity
3. Detailed modelling of Capacity Market mechanisms (if applicable), reflecting current policies
4. A financial module to capture investment decisions; short- and longer-run economic prospects in terms of NPV financial returns or direct government contracting determine whether fossil fuel plants mothball, de-mothball, retire or are built
5. Endogenous interconnector flows based on the estimated gradient between domestic and foreign electricity spot prices
6. Foreign EU countries are endogenously modelled to identify electricity spot prices; dispatch decisions are based on hourly market conditions and take into account prices and the scarcity potential of neighbouring states
7. Load profiles for heat-and electricity CHP plants based on industry and district heating demands

The key elements of AER-ES EU parameterisation include:

1. Plant characteristics (e.g., efficiencies, ramping costs and rate restrictions) calibrated based on data starting from 2005
2. Demand projections rely on historical consumption levels while incorporating future behavioural change and load shifting as a consequence of the adoption of new technologies (e-mobility, heat pumps)
3. An econometrically-estimated uplift function, calibrated based on four years' worth of generation and spot price data
4. Stochastic wind calibrated to historic output across and within plants, producing an accurate picture of the entire wind fleet in Germany, Poland, and the Czech Republic

The Aurora power market model provides a medium-term outlook that draws on a fully specified set of policies. The central policy views have been developed by Aurora experts together with group members. The model is run in a rational expectations mode that assumes internally consistent decisions in all market actors.

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