

Assessment of Options for Replacement of the Bełchatów Lignite Power Plant



REPORT



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enervis energy advisors GmbH

Schlesische Str. 29-30

10997 Berlin

+49 (0)30 695 175 0

www.enervis.de

kontakt@enervis.de

Authors enervis

Julius Ecke

Rita Kunert

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1 Introduction & Background

Introduction

Tightening global and European CO₂-reduction targets require the decommissioning of lignite-fired generation assets, raising manifold issues regarding feasible capacity replacement.

In the case of the Belchatów lignite power plant in Poland, concentrating almost 12% of domestic power generation capacity at one site, the power system effects of the plant's retirement are combined with socio-economic considerations.

In order to address these issues, the technological feasibility, climate impact, cost and employment effects of alternatives have to be quantified and assessed comparatively.

Against this backdrop, ClientEarth Poland asked enervis energy advisors GmbH to conduct a study with an energy economic assessment of the options for replacement of Belchatów Lignite Power Plant.

Objectives

The analysis was carried out in two phases.

The starting point of phase one was the scoping of technological options for the replacement of Belchatów's capacity. Subsequently, an assessment capturing the impact of the options (in regards to emissions, cost and employment) was carried out.

In the second phase, the replacement options were incorporated into enervis' fundamental European Power Market model in order to quantify and compare systematic effects.

2 Executive Summary

Aligning the power system with globally declining RES costs

It is increasingly important to align system design with technological 'mega trends'. While conventional generation technologies tend to suffer from increasing costs, or in the case of nuclear, demonstrate little potential for cost reductions, RES is becoming increasingly competitive.

This manifests in different ways, foremost: RES rely increasingly less on subsidies.

A coal phase-out cuts emissions

The Coal Exit scenario brings down CO₂-emissions by 38% and other emissions by 42-64% vs. Reference. The global climate and the health of the Polish population will benefit.

An earlier phase-out of Belchatów plays an important role in this development, contributing approx. 5% of this reduction.

A coal phase-out reduces costs

A scenario with less coal and more RES is more cost efficient than the Reference scenario. Savings of €64 bn equal 9.5% of overall system costs and thus represent a significant potential to contribute to the cost efficiency of the Polish economy.

An earlier phase-out of Belchatów plays an important part, delivering €4 bn to this reduction.

Substituting coal with RES is technically feasible

Security of supply is assured in the Coal Exit scenario given that natural gas (and potentially storage) can be utilised as back-up.

High shares of RES can be integrated in the system with little curtailment. The system should be designed to supply a high level of flexibility.

RES enable Polish import independency

RES allow for a reduction of import dependency in the power sector, effectively cutting power imports.

Switching from coal to gas leads to more gas demand, but demand levels are in line with the Polish strategy of diversifying source countries (LNG, Baltic pipeline).

RES provide employment opportunities

Direct employment is higher by 45% in Coal Exit vs. Reference and total employment is also continuously and significantly higher.

Even though this is an estimate, it clearly indicates significant employment opportunities for the Polish workforce by expanding renewables and phasing out coal.

Phasing out coal has multiple benefits

A consistent Coal Exit strategy by 2035 allows less CO₂, fewer negative health effects, fewer power imports and lower system costs while providing employment opportunities.

Phasing out coal therefore provides for a diverse set of benefits.

Further ambitions beyond Coal Exit necessary

CO₂-emissions from the power sector decline sharply at first but stabilise at a certain level. This demonstrates the need for ambitions beyond a coal exit and the need for Deep-Decarbonisation technologies to cut emissions further (RES & storage or CO₂-neutral or renewable gas).

3 Scoping of Replacement Options

In this chapter a qualitative assessment of replacement options for Belchatów was conducted.

Forecasted cost developments make RES increasingly competitive while other generation technologies become less attractive (lignite, coal, gas).

The cost-efficiency of generation technologies can be compared using a simple, synthetic measure: Levelized Cost of Energy (LCOE). LCOE measures average lifetime costs of producing electricity using a given technology. LCOE in a given year represents average generation costs of a plant commissioned in that year over its full lifetime, including the effects of expected changes in fuel costs.

The following graph shows the development of average costs of new units of different technologies.

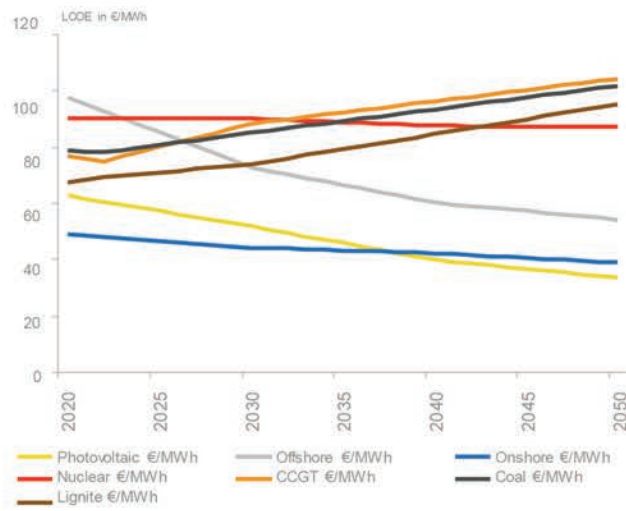


Figure 1: LCOE of Technologies¹

Three trends are clear:

- Renewables are still seeing cost reductions, highest for offshore wind
- Conventional technologies are seeing rising costs given rising CO₂- and fuel prices.
- Nuclear is forecasted to have stable costs (here based on ASSET project funded by EU-Commission)

It is therefore increasingly important to align the Polish power system with technological 'mega trends'. Here, Renewables (RES) are seeing further cost reductions, highest for offshore wind, while conventional technologies are seeing rising costs given CO₂- and fuel price increases.

¹ This was calculated with normalized full load hours (4000 for CCGT and 5000 for Coal), not taking into account potential strong reduction in utilization of conventional technologies. This is based on a compilation of different sources including ASSET (2018), Fraunhofer ISE (2018), BWE / INES (2018), Agora Energiewende 2017, Coal costs include add. costs vs. market prices (e.g. transport costs).

Gas-based generation has significantly lower emissions compared to lignite while wind/PV create no emissions at all.

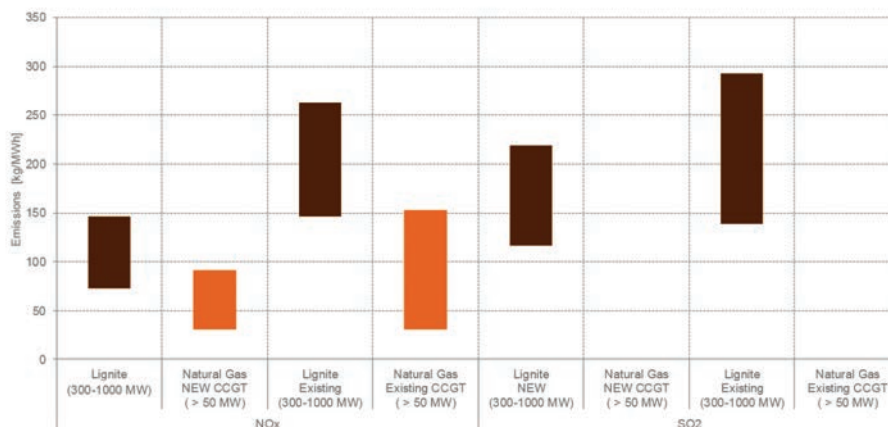


Figure 2: Non CO₂-Emissions of Lignite & Natural Gas²

Next to costs, emissions play an important role in regards to the assessment of technologies. The above graph shows non-CO₂-emissions of technologies per MWh. Clearly, gas-based generation has significantly lower emissions compared to lignite while wind / PV cause no emissions at all and were therefore not added to the graph.

While lignite has high direct employment vs. renewable options...

The following graph shows estimates for direct employment per MW of installed capacity. Assumptions for RES are based on employment effects for construction and operation of units. For RES employment effects have been averaged over the lifetime of plants (e.g. 20 years).

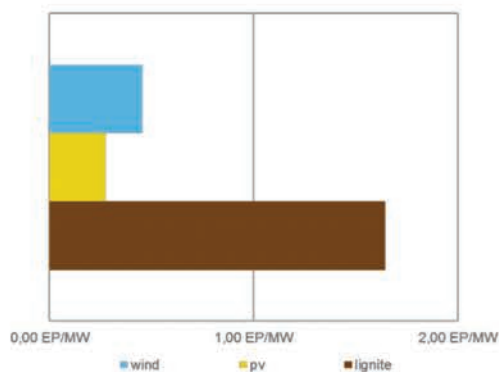


Figure 3: Estimates for direct employment per MW³

For the interpretation of employment effects, it needs to be taken into consideration that each MW of lignite needs to be substituted by more than one MW (e.g. three MW) of renewables due to lower utilisation of RES.

... RES provide valuable indirect employment opportunities

The following graph shows estimates for total employment per MW of installed capacity. Total employment includes indirect employment effects beyond operation and construction (e.g. manufacturing).

² Emission standards according to BAT-AELs.

³ Sources: WISE (2019) numbers for PV and wind onshore averaged over lifetime of units for the period of 2021 – 2030. For lignite, 2018 numbers of operators were taken.

For RES employment, average European figures were used, since data for RES-industries in Poland has shown strong annual fluctuations (see Observ'ER 2017 & 2018). For lignite, total employment was estimated based on direct employment and indirect employment multiples (approx. 2.5).

Whereas lignite provides more direct employment per MW, RES provide valuable indirect employment opportunities.

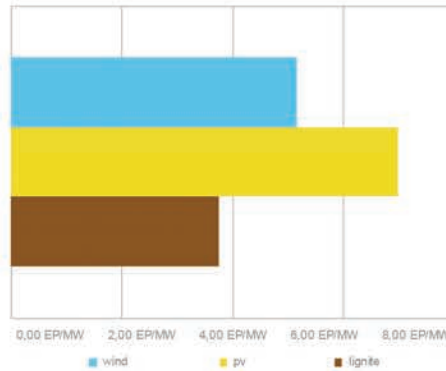


Figure 4: Average total employment of technologies⁴

A mix of technologies is best suited to replace lignite. enervis' Power Market Model will optimise the combination of replacement technologies.

The following matrix shows a qualitative ranking of replacement options vs. lignite.



Figure 5: Overview of Replacement Options⁵

While different technologies have different strengths and weaknesses, a mix of technologies is best suited to replace lignite. Therefore enervis' Power Market Model was used to optimize the combination of replacement technologies.

⁴ Sources: for RES: Fragkos et al. (2018): Employment creation in EU related to renewables expansion. For lignite: DEBRIV, EEFA, Öko-Institut.

⁵ Security of Supply: One bar was added for PV because of its contribution to summer peak demand.

4 Power Market Model, Scenarios & Core Assumptions

This chapter establishes the core assumptions for the modelling and the main scenario framework.

4.1 enervis' Power Market Model

enervis can derive the investments in power plants based on a techno-economic modelling approach. Interactions between regions are captured via interconnection capacities.

The following graph shows a schematic overview of inputs, outputs and the method of enervis' European power market model.

enervis Market Power is a comprehensive market model for the analysis of power markets. It is based on a comprehensive range of fundamental energy market data. Based on our experience from European markets, we are able to dynamically apply our modelling approach to a wider geographic scope.

The enervis power market model is a Europe-wide model that integrates the interactions of most of entso-e markets/regions via interconnectors. Each market region is modelled in high granularity, consisting of a unit-wise power plant fleet, renewable installations, hourly demand, weather data and country-specific assumptions (e.g. market design, policy framework, transport cost of commodities, renewable expansion targets and support mechanisms). Hence, the model incorporates all relevant market drivers and provides a comprehensive view on future developments of market prices zones as well as regions.

The marginal-cost optimisation model of European power markets analyses the deployment of generation technologies and investment into new capacities based on a large set of assumptions and input data in high temporal and spatial resolution.

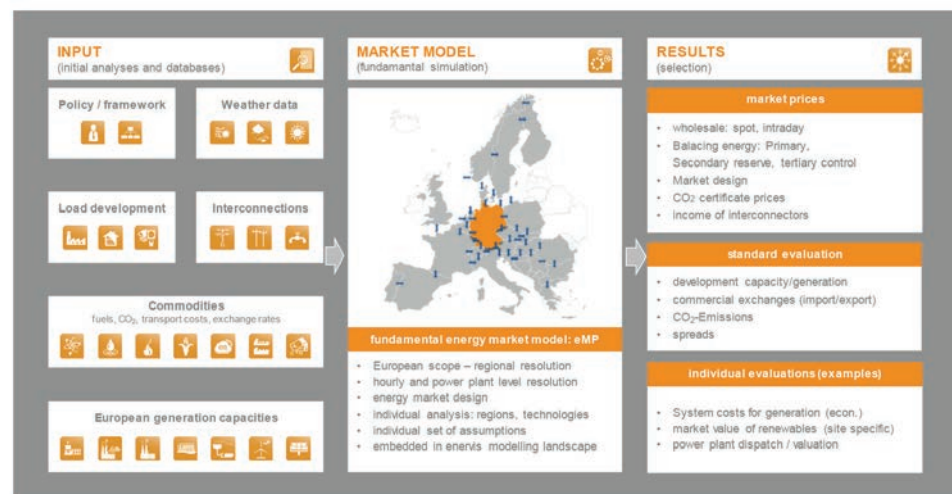


Figure 6: enervis' Power Market Model

4.2 Definition of Scenarios

Two scenarios for the Polish power sector from 2020 to 2050 were modelled. The Reference scenario functions as a baseline for the sake of comparison, while the Coal Exit scenario describes more sustainable development with less coal and more renewables.

For better interpretation of the results, it is beneficial to first look at the assumptions of the scenarios and the modelling. The assumptions were chosen based on discussions with stakeholders. Within this study, two scenarios describing two possible future strategies for the Polish power sector up to 2050 were modelled. The following table describes the underlying assumptions for Poland⁶ in the two scenarios in more detail, with the columns representing the scenarios and the rows the important characteristics.

	Reference Scenario	Coal Exit Scenario
Fuel and CO ₂ Prices	Until 2022: futures quotes Q1 2019 Long-term: IEA WEO 2018 "New policies Scenario"	
Nuclear Capacities	No future commissioning of nuclear capacities in Poland	
Bełchatów Lignite Power Plant	Trajectory according to plant lifetime and projections based on PEP 2040	Stepwise closure of Bełchatów blocks B02-12 before 2030, B14 by 2035
Other Coal Capacities		National coal phase-out in Poland by 2035
Gas Capacities	Deployment according to economic feasibility within the scenario	
Renewable Energy Capacities	Mid-term trajectory for Wind Onshore, Offshore and PV based on PEP 2040 and current projections	Replacement of Bełchatów generation by mix of Wind Onshore and PV
		Additional deployment of Wind Onshore and PV capacities according to economic feasibility (LCOE)
Power Demand	Increase in demand according to PEP 2040 projections (avg. 1.7% p.a. 2018-2040) due to E-mobility & GDP growth. Total 230 TWh in 2040.	

Figure 7: Overview of Core Assumptions

- The **Reference** scenario functions as a baseline for the system level assessment and is based on the current national energy policy⁷ with the exception that nuclear energy was excluded from the scenario. The latter is based on a general assessment of the (low) likelihood of successful deployment of nuclear plants in Poland. The Reference scenario has relevant coal capacities until 2050 and deploys only very few renewables. The missing generation to cope with the growing demand is delivered by gas and imports.⁸
- The **Coal Exit** scenario assumes the adoption of an ambitious climate action strategy including a national phase out of coal- and lignite-fired capacities by the end of 2035, instead relying more on the deployment of RES. Most Bełchatów units will be phased out by 2030. Generation using coal is substituted by RES, while gas provides Security of Supply.

An additional sensitivity allows for a deeper analysis of the effects of Bełchatów's capacities (see chapter 9).

⁶ In all other European regions, assumptions on the basis of respective current national energy policies and projections are adopted and unaltered between the two scenarios of this study. i.e., for Germany we currently assume and model a coal phase-out by 2038 as proposed by the "Kommission für Wachstum, Strukturwandel und Beschäftigung" (WSB) in February this year.

⁷ i.e. Draft "Energy Policy of Poland until 2040" (PEP2040).

⁸ Note that in terms of remaining technology choices, the Reference scenario is a rather conservative one, translating into respective higher system costs (differences) due to the minor role of increasingly cost-competitive RES.

4.3 Trajectory for Bełchatów Lignite Power Plant Capacity

The oldest blocks of Bełchatów LPP are phased out by 2030 while the newest stays online until 2035.

One of the most relevant assumptions is the trajectory for Bełchatów Lignite Power Plant capacity in both scenarios.

The following graph shows the two variants of capacity development of Bełchatów Lignite Power Plant adopted in this study.

In the Coal Exit scenario, blocks B02-B12⁹ of the Bełchatów site (commissioning 1983-88) are to be retired first, and before 2030. Block B14 (commissioning 2011) will then be phased out by 2035.

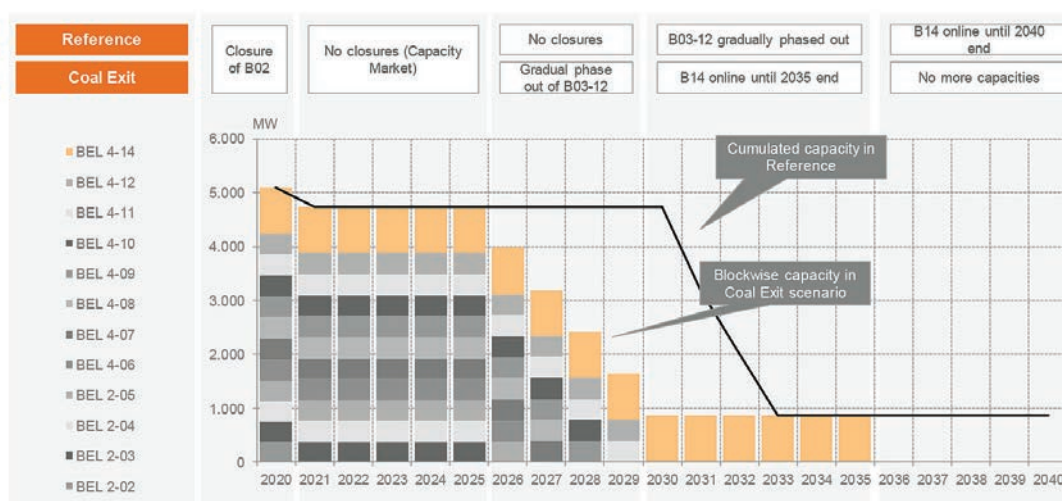


Figure 8: Capacity Trajectory for Bełchatów Lignite Power Plant¹⁰

Compared with the development in the Reference scenario, we see that the retirement of most blocks is accelerated by approx. five years.

⁹ B01 was decommissioned in June 2019, see PGE website.

¹⁰ Sources: TSO Polskie Sieci Elektroenergetyczne (PSE) power plant list status (30.11.2018), Polska Grupa Energetyczna (PGE) publications and announcements, PSE capacity auction publications, own analysis.

4.4 Fuel and CO₂-Price Assumptions

Commodity prices will see moderate to significant increases in the long run, according to IEA's World Energy Outlook 2018.

A crucial input of all model-based power market scenarios is the long-term development of commodity prices (fossils fuels and CO₂-certificates in the EU- ETS) which determine the marginal generation cost of respective conventional generation technologies.

To derive the price trajectory for each commodity up to 2050 in this study, an established approach is employed. Short- and mid-term (up to 2022), average future quotes of the current quarter (Q1 2019) for the front years are used, while in the long-term we rely on the projections in the most recent "World Energy Outlook" (2018)¹¹.

The following graph illustrates the resulting trajectory.



Figure 9: Fuel and CO₂-Price Assumptions in both Scenarios¹²

After shorter-term fluctuations, a long-term upward price trend compared to today's level in all commodities relevant for conventional generation technologies is clearly visible.

This affects both the marginal generation costs of the underlying assets and in turn wholesale power prices, as well as the technology specific LCOE (see also chapter 3).

¹¹ Published annually by the International Energy Agency (IEA). Here data from the "New Policies Scenario", representing a medium development in terms of global energy and climate policy and hence widely used for Reference / Best Guess scenarios, is used. Commodity prices beyond 2040 are extrapolated assuming a continuation of the latest price gradient.

¹² Sources: market data Q1 2019, IEA (2018). All prices are real 2019. In this graph, country specific transport and structuring cost is not included.

5 Capacity and Generation

In this chapter, the development of capacity structure and power generation from the two scenarios are presented. Here, we show the core results building on predefined assumptions and respective simulations.

5.1 Capacity Structure

The decline in coal capacities in the Coal Exit scenario is replaced by a mix of RES and gas-fired capacities, resulting in a higher backup reserve outside the power market compared to the Reference scenario. Reference deploys significant based-fired capacities.

Based on exogenously set capacity trajectories, cost assumptions and further parameters, the power market model outcome describes a capacity development over the total period up to 2050 for the Polish and all other major European market zones.

The following graph shows the development of power generation capacities in Poland in the period 2020-2050. Here, we include market driven plants as well as backup capacities required to guarantee an equal level of security of supply across the technology portfolio.¹³

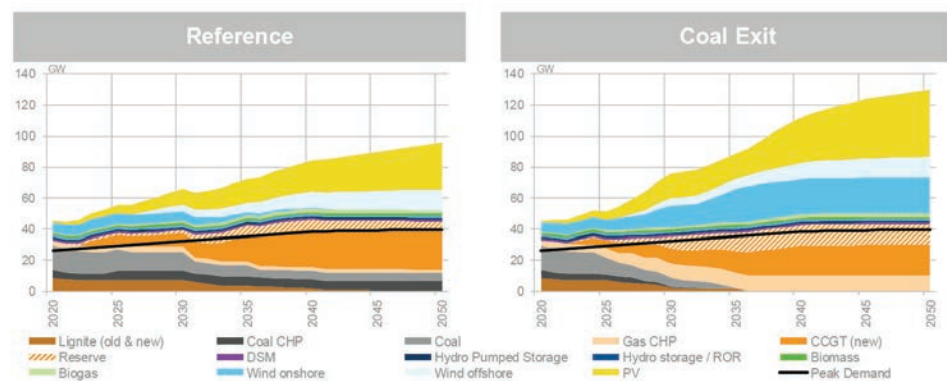


Figure 10: Development of Capacities and Peak Demand 2020-2050

In the **Reference** scenario (left), a lack of political backing for wind onshore and low ambition in regards to PV expansion result in a low renewable deployment while significant coal capacities stay online through to 2050. Demand is met by deploying CCGT¹⁴ and OCGT which is a result of the model-run.

In the **Coal Exit** scenario (right), onshore wind and photovoltaics offset the decline of coal capacities from the mid-2020s. Where the expansion exceeds the level of the Reference scenario, it is driven by cost-effectiveness of the technologies (market-based deployment¹⁵). Cogeneration from coal-based assets is replaced by gas-fired CHP¹⁶ capacities.

Security of supply (SoS) is assured in both scenarios by newly built units and an additional back-up reserve. Here, we assume a margin of 9% on top of the national yearly peak load (excl. interconnectors) to be met by the derated dispatchable capacities. The level of reserves beyond peak load was modelled

¹³ In this analysis, Open Cycle Gas Turbines (OCGT) are assumed as underlying technology for providing backup capacity to the power system and thus included in the system cost considerations.

¹⁴ Combined Cycle Gas Turbine (CCGT).

¹⁵ The expansion of onshore wind is limited to 23 GW in the Polish system, based on an estimate of technical potential by the Polish Wind Energy Agency (PWEA).

¹⁶ Combined Heat and Power (CHP).

based on the assumption that spare capacity needs to be deployed within Poland. It is therefore important to note that from a capacity point of view all scenarios are able to cover the national peak load at any given time and SoS is on the same overall level in all scenarios, per default.

The more gas-heavy capacity mix in the Reference scenario results in less need for additional backup capacity compared to the more RES-heavy Coal Exit scenario.

5.2 Generation and Demand

Phasing out coal while fostering the expansion of renewables allows for an overall balanced mix and a neutral import / export balance.

Besides the commissioning and decommissioning of capacities, the model determines the hourly dispatch of the fleet to meet power demand. This section analyses the structure of power generation resulting in the Reference and the Coal Exit scenarios, as illustrated in the following graph.

Polish GDP growth is a major driver for future development of electricity demand (black line). Even though GDP growth and increases in power productivity balance out to a certain extent, overall GDP growth dominates and we assume the following development of power demand¹⁷. This growing demand defines a key challenge that both scenarios have to cope with.

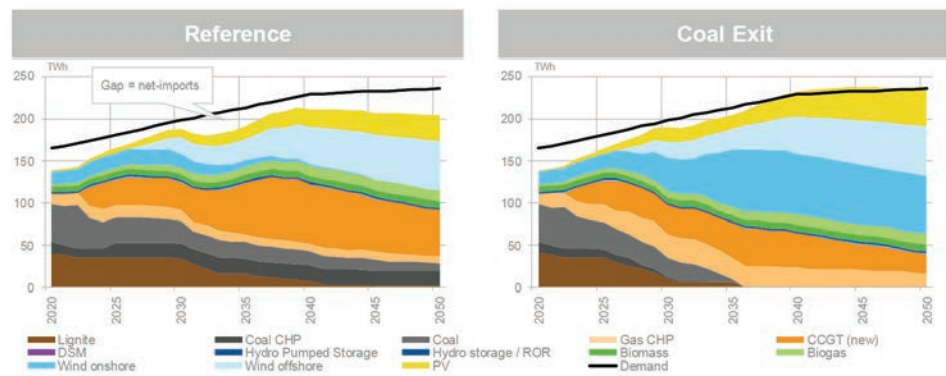


Figure 11: Development of Generation and Demand 2020-2050

In the Reference scenario, without nuclear generation and a low level of renewables, the system relies strongly on gas-based generation and imports from neighbouring regions.

In the Coal Exit scenario, while coal declines, a substantial increase in renewables and to a lesser degree gas (incl. coal-to-gas CHP replacements) dominate the outcome in the long-term. Overall generation aligns well with demand, allowing for a balanced import / export situation.

¹⁷ Including the demand from electric vehicles. Development through 2040 is taken from PEP2040 projections and a milder increase extrapolated 2040-2050. For the sake of scenario comparability, the PEP2040 demand curve has been adopted in both scenarios analysed in this study. The official demand projections are increasingly considered to overestimate growth in power demand: however, no updated numbers have been published. It is hence important to note that a more moderate increase in power demand to be met by the power system would decrease system cost, but this effect would be applicable in both analysed scenarios.

5.3 Import / Export Balance

Poland remains a net-importer of electricity in the Reference scenario while the trade balance evens out in the long run in Coal Exit.

Trade-flows of power between Poland and its neighbours complement the capacities of domestic power generation. They are influenced by the technology mix on both sides as well as the availability of interconnection capacities between markets. The following graph shows the annual net-balance of electricity traded with neighbouring regions for the Polish power sector.

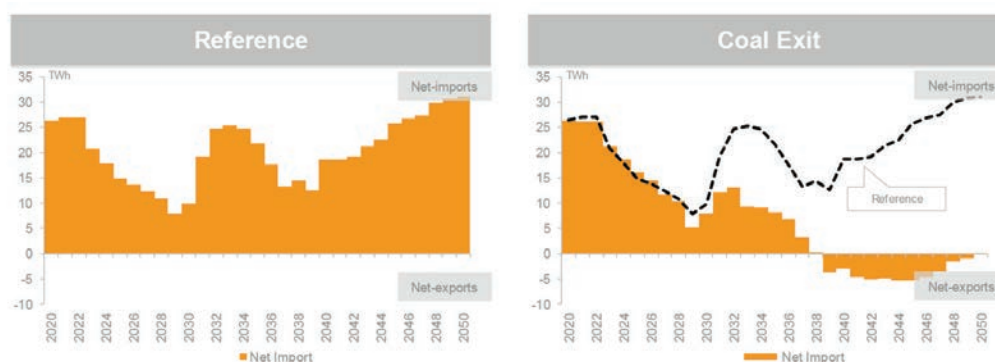


Figure 12: Development of Import / Export Balance in Poland 2020-2050

Due to a relatively expensive generation mix compared to neighbouring regions which will see increasing shares of renewables, Poland remains a net-importer of electricity in the Reference scenario.

As the Coal Exit strategy deploys significantly more domestic renewables, the export balance is about even in the long run after a decade of net-exports. RES allow for a reduction in import dependency in the power sector, while conventional generation cannot meet the growing Polish power demand.

6 Fuel Demand & Emissions

In this chapter we will look at the development of fuel demand as well as CO₂ and other emissions in the power sector.

6.1 Development of Fuel Demand

Both scenarios see an increase in gas demand, stronger even in the Reference scenario due to the lack of RES expansion.

The following graph shows the development of fuel demand of the power sector in both scenarios.

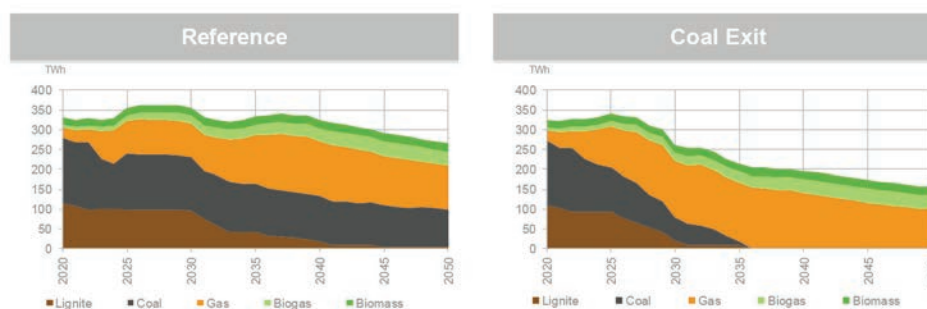


Figure 13: Development of Fuel Demand 2020-2050

In the Reference scenario, long-term fuel demand consists of mostly hard coal and gas. It is important to note though that hard-coal is assumed to be imported long-term by many studies (see Wise / enervis 2017).

In the Coal Exit scenario, gas demand also increases. Additional RES & storage or CO₂-neutral gas could help to cut natural gas demand further. Note that gas demand is in cogeneration by a significant degree.

Both scenarios therefore see an increase in gas demand. At first, the increase is stronger in the Coal Exit than in the Reference scenario, though both scenarios reach a similar level in 2050.

Switching from coal to gas leads to more gas demand, though demand levels are in line with the Polish strategy of diversifying source countries (LNG, Baltic pipe).

We assumed that the additional capacity provided by these two projects here (122 TWh) from 2022¹⁸ onwards can be absorbed by gas-based power generation.

This implies that gas demand in both scenarios can be met by additional gas import capacity from the north / LNG with still some capacity left for the heating sector.¹⁹

Gas demand of both scenarios can be met by additional gas import capacity from the north / LNG.

¹⁸ Source: Compilation based on GAS system (2018): GAS INTERCONNECTION POLAND – LITHUANIA (GIPL) STATUS AND POTENTIAL IMPACT ON THE BALTIC STATES MARKET.

¹⁹ No modelling in regards to demand of the heating sectors was conducted.

6.2 CO₂-Emissions

The Coal Exit scenario leads to a substantial and sustained decrease of CO₂-emissions starting in the mid-2020s. Coal Exit therefore brings down CO₂-emissions by 38 % vs. Reference.

The following graph shows the development of fossil CO₂-emissions from the power sector.

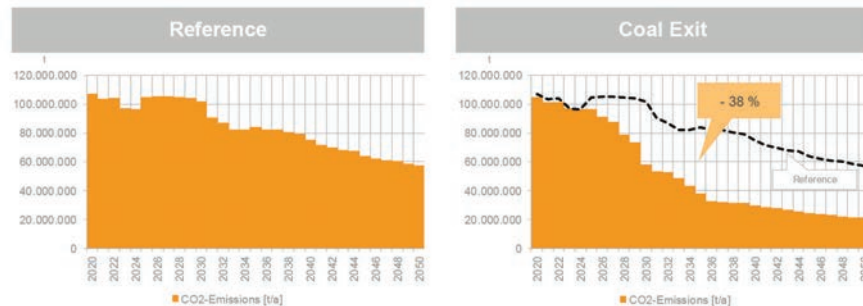


Figure 14: Development of CO₂-Emissions 2020-2050

While CO₂-emissions already decline in the Reference scenario due to age-based phase out of the most CO₂-intensive plants, in Coal Exit the reduction is both earlier and significantly higher.

The Coal Exit scenario leads to a sharp decline in CO₂-emissions in the period from mid-2020 to 2035 due to the closure of all coal and lignite plants in that period. Yearly CO₂-emissions almost halve in the Reference scenario by 2050 due to the technical retirements of coal-based assets.

Overall CO₂-emissions decline by almost 1 bn t in the period 2020-2050 (total CO₂-emissions of 2.6 vs 1.6 bn t). The Coal Exit scenario therefore brings down CO₂-emissions by 38% vs. Reference.

A certain level of emissions persists due to remaining gas-based generation. This demonstrates a need for Deep-Decarbonization technologies²⁰ to cut emissions further (RES & storage or CO₂-neutral or renewable gas).

6.3 Other Emissions

Overall, the Coal Exit scenario brings down other emissions by 42-64% vs. Reference. This translates to health benefits for the Polish population and a prolonged lifetime.

Next to CO₂, other emissions are also of importance. As established in chapter 7, non-CO₂-emissions play a role in regards to health and environmental (non-climate) impacts via external costs. The main driver is health impacts, mostly due to air pollution. Health impacts manifest in Poland and neighbouring countries.

Against this backdrop, the following graph shows the development of non-CO₂-emissions from power plants.

- In **Reference** (left) we see a decline due to retrofitting measures and planned closures of coal-fired capacities, the levels of SO_x, NO_x and dust emissions then stagnate.

²⁰Deep-Decarbonization technologies are technologies to cut emissions at relatively high but stable (not exponentially increasing) CO₂-abatement costs. They are therefore suitable to reduce "the last" remaining emissions of sectors (e.g. moving from -80 % to -95 % vs. 1990).

- In **Coal Exit** (right) SOx and dust emissions are reduced to close to zero while NOx remains stable on a low level after initial sharp decline due to a sustained share of gas generation.

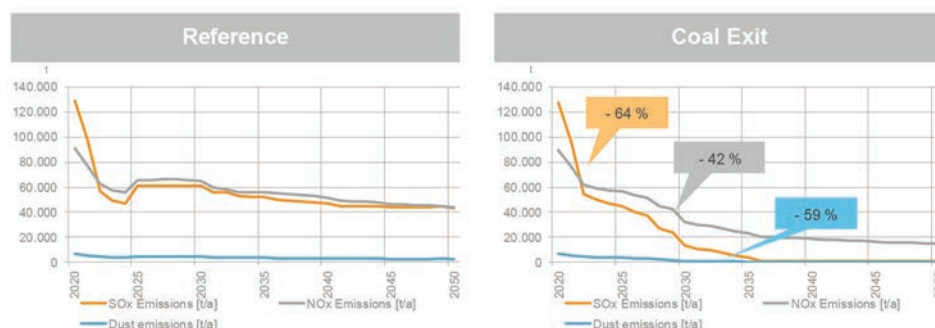


Figure 15: Development of other Emissions²¹

Overall, the Coal Exit scenario brings down other emissions by 42 - 64 % vs. Reference. This translates to health benefits for the Polish population and a prolonged life expectancy.

²¹ Sources: Estimates are based on BREF limits for plants.

7 Total Costs of Power Generation

In this chapter total costs of power generation of the different scenarios are analysed.

To assess the energy economic efficiency of the scenarios we look at "Total Costs of Power Generation", which take all power generation related costs into consideration.

How do different energy mix scenarios perform in terms of costs? To answer this question, we compare the cost of different scenarios, taking into account the following components of energy production costs: CAPEX, OPEX (fixed and variable, i.e. independent and dependent on the actual volume of electricity produced by the given power plant), Fuel, CO₂-emissions (EU ETS costs), DSM, net imports. Fuel costs include expenditures stemming from fuel used for heat generation in CHPs.

The economic assessment of the energy mix also takes into account health and environmental (non-climate) impacts via so called external costs. The main driver is health impacts, mostly due to the air pollution. Health impacts manifest in Poland and its neighbouring countries. Climate change impacts are not included in this analysis, as we already calculate CO₂ costs within the EU ETS system.

These costs are together defined as "Total Costs of Power Generation". The costs of network development are not included in the calculation as we assume that they are dominated by the investments present in all scenarios.

Coal Exit scenario has significantly lower total costs of power generation: savings equal to 9.5 % of overall system costs are achieved.

In the Reference scenario, costs start to increase from 2022 onwards. A consistent Coal Exit strategy stabilizes system costs vs. the increasing costs of the Reference scenario.

Against this backdrop, the following graph shows overall costs of the scenarios. The bars represent sums of all above mentioned cost components over 2020-2050.

Coal Exit scenario has lower total costs of power generation, the savings amount to 64 bn. € The difference equals 9.5% of overall system costs and thus represents relevant savings. A consistent coal exit strategy therefore contributes to cost efficiency of the Polish economy.²²

²² When analysing cost differences from scenario comparison, the technologically conservative nature of current Polish energy policy and thus the Reference scenario of this study as mentioned in section 4.2 has to be kept in mind. Consequently, allowing for more RES expansion in the Reference scenario would narrow the observed differences to some extent, while systematic conclusions remain valid.

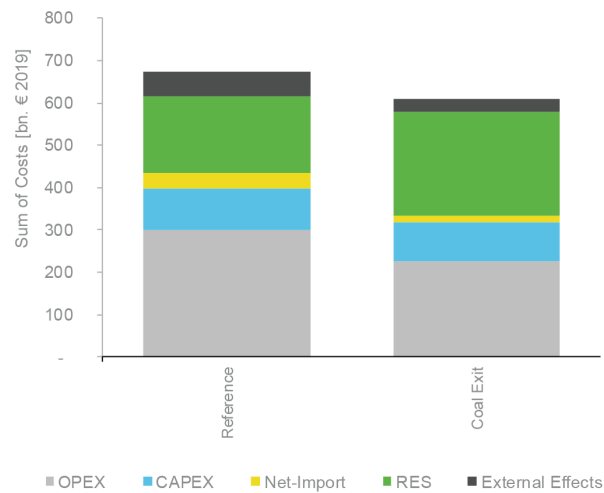


Figure 16: Sum of Costs of Scenarios

If we look at the cost differences in more detail, we see that the Coal Exit scenario has higher costs for RES, but these prove to be a „good investment“, cutting costs for OPEX, CAPEX and imports. On top of that, less external effects basically imply better health for the Polish population.

8 Employment Effects

Next to costs and other energy economic results, employment potential plays an important role in regards to the assessment of technologies.

Therefore, in this chapter, an assessment of employment opportunities was prepared.

8.1 Direct Employment Effects

Overall level of direct employment in operations & construction in lignite, wind and PV is significantly higher in the Coal Exit scenario.

Using forecasted capacities from the power market model and assumptions regarding the level of employment per technology (see chapter 3) an assessment of employment potential for each scenario was prepared. Here, PV, wind onshore and lignite were analysed, while other technologies, like hard-coal, were not included.

The following graph (left) shows overall direct employment for construction and operation in both scenarios as well as differences. As a result of this, for a short period, 2026 until 2031, direct employment is higher in Reference, then Coal Exit scenario dominates until 2050.

The following graph (right) also shows overall levels of direct employment in operations & construction (in lignite, wind and PV) measured in FTE-years (“Full Time Equivalent”) until 2050. Employment effects from construction were averaged out over the lifetime of units (this levels out employment effects of construction over time).

If we look at overall levels, employment is significantly higher in the Coal Exit scenario. The estimate amounts to an employment higher by 45% in Coal Exit vs. Reference.

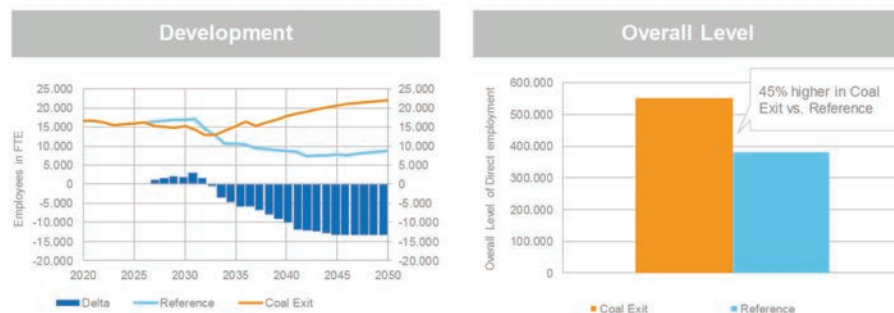


Figure 17: Comparison of Direct Employment²³

8.2 Total Employment Effects

Using different assumptions regarding the level of total employment per technology (see chapter 3) an assessment of total employment in lignite, wind and PV was prepared.

For RES employment, average European numbers were taken, since data for RES-industries in Poland has shown strong annual fluctuations (see

²³ Sources: Own calculation based on different sources.

Overall level of total employment in lignite, wind onshore and PV is continuously and significantly higher in Coal Exit scenario. Even though this is a rough estimate, it clearly indicates relevant employment opportunities for the Polish workforce provided by the Coal Exit scenario.

Observ'ER 2017 & 2018). For lignite total employment was estimated based on direct employment and indirect employment multiples (approx. 2.5).

The following graph (left) shows total employment (incl. manufacturing etc.) in both scenarios as well as differences. Total employment is continuously higher in Coal Exit scenario.

The following graph (right) also shows overall levels of total employment (in lignite, wind and PV) measured in FTE-years ("Full Time Equivalent") until 2050. Clearly, total employment continuously and significantly higher in Coal Exit vs. Reference. Employment is higher in Coal Exit vs. Reference by 76%.

Even though this is a rough estimate, this clearly indicates relevant employment opportunities for the Polish workforce provided by the Coal Exit scenario.

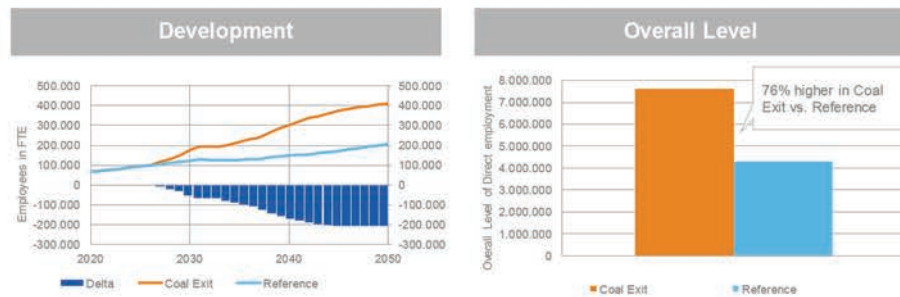


Figure 18: Comparison of Total Employment²⁴

²⁴ Sources: Own calculation based on different sources.

9 Sensitivity: Focus on Bełchatów

A second version of the Coal Exit scenario was modelled to capture analytically the effect of Bełchatów within the Coal Exit pathway by performing a sensitivity analysis. Hence, all parameters are kept equal as in the Coal Exit scenario, except for the trajectory of Bełchatów capacities and their substitution via RES.

This allows the question of which share of the results in an overall Coal Exit are caused by Bełchatów (vs. all other coal plants) to be answered.

Between 2026 and 2032, Bełchatów phase-out will result in higher PV and wind onshore capacities and slightly higher backup which inverses in the long run due to an additional market-based gas investment cycle.

The following graph (left) shows the development of generation capacities in the original Coal Exit pathway from 2020-2050 as previously presented.

In the centre, we show Coal Exit Sensitivity where all other plants phase out as assumed previously and only Bełchatów runs as designed in the Reference scenario.

On the right we see the difference between the scenarios. Phasing out Bełchatów reduces lignite capacity between 2026 and 2032 (below the x-axis). Lignite is offset by renewable capacities (above the x-axis). Interestingly, lignite replacement is complemented by a market-based investment cycle in gas which reduces the need for backup capacities outside the market.

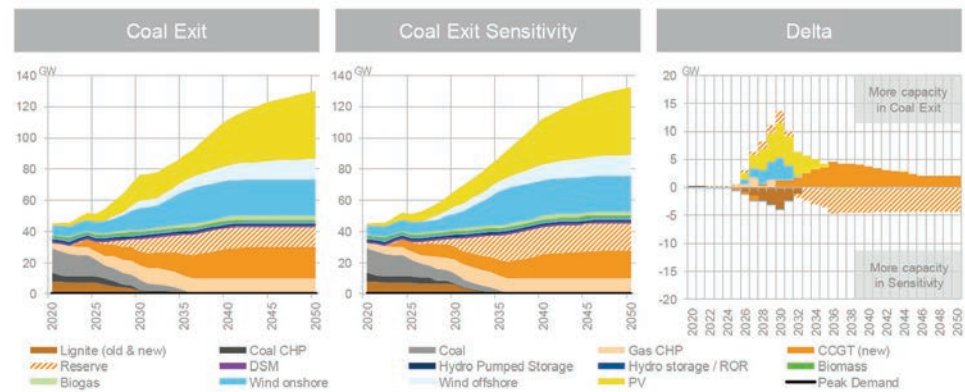


Figure 19: Focus on Capacity Structure Differences of Bełchatów

Phasing out Belchatów earlier is responsible for 50 mln t savings in CO₂-emissions of the overall 1 bn. t reduction of the Coal Exit scenario.

The following graph shows overall CO₂-emissions from the power sector in the two scenarios. The left bar represents values for the Reference scenario, while the bar on the right represents values for the Coal Exit scenario. In between, we have 'deconstructed' the difference to analyse which part of the effect is caused by phasing out Belchatów approx. five years earlier and which part is caused by all other effects together.

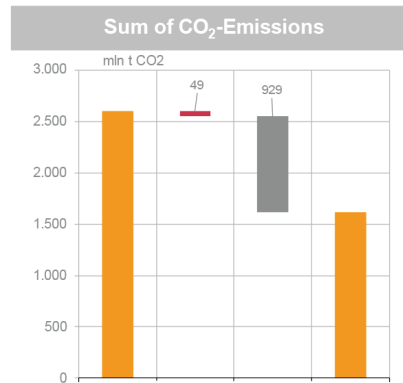


Figure 20: Focus on CO₂-Emission Effect of Belchatów (I)

The sensitivity analysis focusing on Belchatów shows that phasing out the blocks contributes to overall savings in CO₂ in the Coal Exit scenario. Phasing out Belchatów earlier is responsible for approx. 50 mln t savings of the overall 1 bn t reduction in the Coal Exit scenario.

The effect seems relatively small because of the temporal limitation and a slight increase in emissions from gas-based generation after 2032. The following figure sheds light on the development of CO₂-emissions over time (left and center) in the Coal Exit and the Sensitivity scenarios and focuses on the cumulated effect in the most relevant period (right).

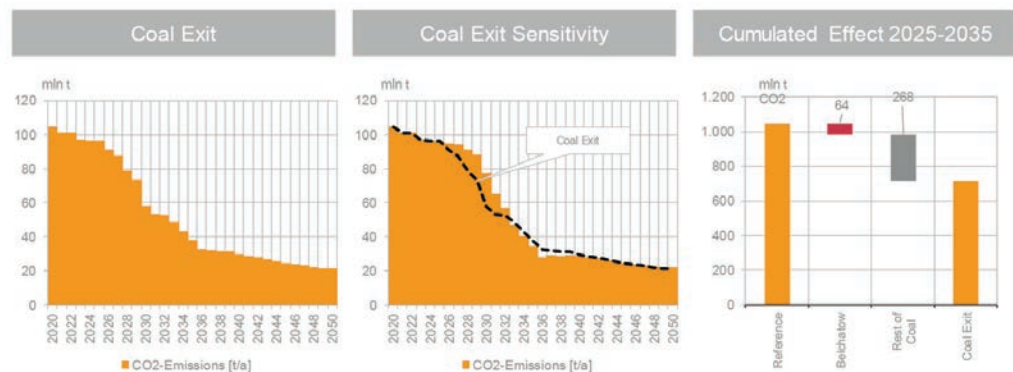


Figure 21: Focus on CO₂-Emission Effect of Belchatów (II)

While phasing out the coal and lignite fleet in the Coal Exit pathway in general leads to a sharp decline in emissions between 2025 and 2035, the effect of earlier Belchatów retirement accounts for almost 20% of the savings in this period. Later on, emissions savings are partly and temporarily offset by a slight increase in gas generation, also explaining the slightly lower savings attributed to Belchatów when looking at the total time frame.

The following graph shows the overall costs of the scenarios. The bars represent the sums of cost components over 2020-2050. The left bar represents values for

Phasing out Belchatów earlier is responsible for €4 bn savings of the overall €64 bn savings of the coal exit strategy.

the Reference scenario, while the bar on the right represents values for the Coal Exit scenario. In between, we have 'deconstructed' the difference, to analyse which part of the effect is caused by phasing out Belchatów approx. five years earlier and which part is caused by all other effects together.

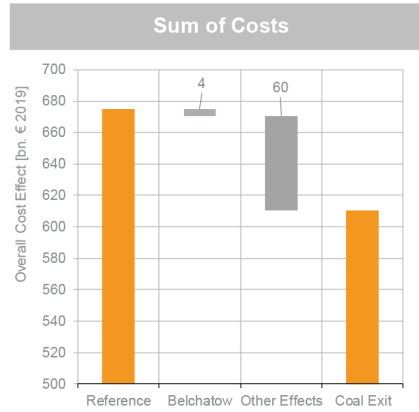


Figure 22: Focus on Cost Effect of Belchatów

Phasing out Belchatów earlier is responsible for €4 bn in savings of the overall €64 bn in savings of the coal exit strategy. The additional sensitivity analysis focusing on Belchatów shows that phasing out the plant earlier contributes to the overall savings of the Coal Exit scenario.

enervis energy advisors GmbH
Schlesische Str. 29 - 30
10997 Berlin
Fon: +49 (0)30 69 51 75 - 0
Fax: +49 (0)30 69 51 75 - 20
kontakt@enervis.de
www.enervis.de

