Energy in Belchatow After Lignite

Future-proofing energy generation in Belchatow, Poland

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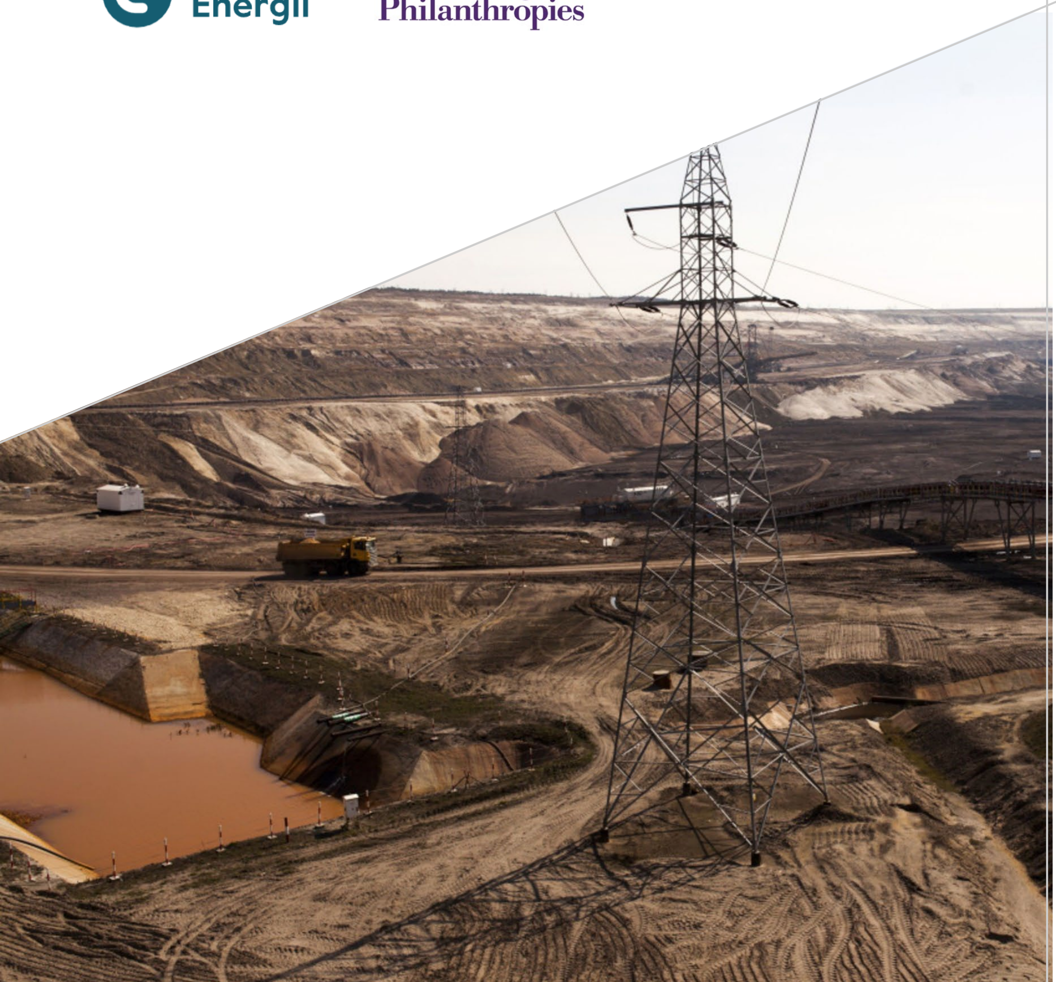


BloombergNEF

Contents

Executive summary

5.1GW

Belchatow lignite power plant capacity in 2022

75%

Drop in Polish lignite generation over 2021-30 in BloombergNEF high gas/low CO2 price scenario

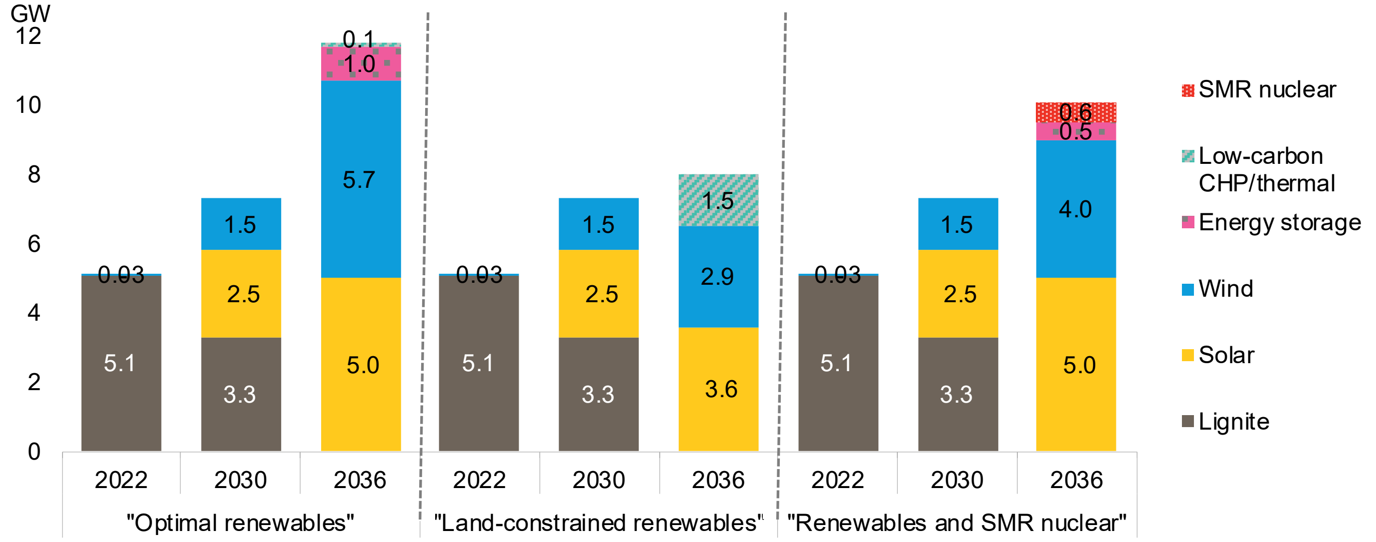
6-11GW

Renewable energy capacity in the Belchatow area, proposed by this report for replacing lignite generation

A gradual transition from lignite to a mix of renewables and low-carbon firm capacity before 2030 maintains Polish energy security and lowers power system costs. At 5.1GW, the Belchatow lignite plant is the sixth largest coal-fired power plant on Earth. Local lignite resources will likely run out by 2036, forcing the plant to shut. What power-generating sources could succeed this significant contributor to Polish power supply, and by when? This report examines the current and future economics of lignite, the feasibility of replacing it with other technologies, and offers preliminary options for a regional transition plan.

- War and energy crisis have boosted demand for lignite generation, but the medium- and long-term outlooks are bleak for the fuel. The mines that serve Belchatow are expected to be depleted by 2036 but BloombergNEF projects Poland's lignite generation to drop well before that. Lignite is a carbon intensive fuel, and Poland's generation from lignite drops by 85% over 2021-2030 in BNEF's base case outlook for Poland. A drop of 75% is seen even if high gas prices persist, due to rising carbon prices and renewable capacity additions.
- Much of the generation at Belchatow could be replaced by new generating capacity pre-2030 (Figure 1), even if some lignite units remain as back-up capacity. Belchatow is located at a major grid connection point, which could be repurposed to support up to 6-11GW of wind and solar plus 1-1.5GW of new firm capacity.

Figure 1: Three potential scenarios for replacing lignite generation at Belchatow with alternative fuels/technologies



Source: BloombergNEF. Note: The chart illustrates potential capacity mixes that could maximize the use of the grid connection. All scenarios can replace 80% of Belchatow's 2021 generation. SMR is small modular reactor and CHP is combined heat and power.

- Freeing part of Belchatow's existing grid connection pre-2030 to new technologies has the potential to maintain Polish energy security and create new economic opportunities in the region. Some 2.5GW of solar and 1.5GW of wind capacity could use the connection by 2030 following the retirement of 1.8GW lignite capacity (Figure 1). Like lignite, solar and wind generation is not reliant on global commodity markets, once built. These technologies can support the delivery of a cheaper electricity mix and lower emissions, without compromising energy security.
- New capacity being developed elsewhere in Poland will weaken the economics of lignite generation at Belchatow. A total of 6GW of offshore wind is expected online by 2030 and 4GW of gas power plants are under development. However, much of this is being built in the north of Poland, far away from centers of power demand in the south.
- Belchatow is located in central Poland, and new capacity built on this site could reduce strain on Poland's grid. Up to 80% of Belchatow's generation could be replaced with 5.7GW of onshore wind and 5GW of solar located within a 20-30km radius of the current plant. Such new generation would also mitigate the risk that the valuable grid infrastructure around Belchatow becomes stranded.
- Any planned new capacity in Belchatow needs a grid connection permit before development can proceed. However, the existing grid connection cannot be allocated to new projects until grid operator PSE receives formal notification that the lignite units will close. The Lodz region, which is home to Belchatow, has prepared a draft plan for a just transition away from lignite, but the plan lacks concrete procedures for enabling and attracting investment in new local generating capacity.
- Proven clean technologies paired with batteries and a smaller gas-, biomass- or waste-fired power plant would offer the most cost-optimal and energy secure replacement. Solar and wind are the cheapest available technologies and, when co-located, can achieve a stable generation profile, given local resources. By 2036, 6.4-10.7GW of wind and solar with 1-1.5GW of firm capacity could replace 80% of lost generation at Belchatow. To realize this, however, permitting restrictions for onshore wind projects must be addressed.
- A build-out of local wind and solar would not hinder potential investments in emerging energy technologies in the region as well. This could include a small-scale nuclear reactor, a hydrogen power plant or new forms of energy storage. Such technologies are not mature enough to be available today and are unlikely to significantly contribute to Polish energy security by 2030, but they present long-term opportunities for the local economy as lignite generation declines and eventually ends.
- Belchatow can demonstrate how coal regions that plan a just transition and create enabling environments for new energy investments can flourish. Without such a plan, however, Belchatow's generation risks being replaced by new generation sources elsewhere in Poland. Freeing up the grid connection and easing permitting of new generation capacity would attract investment to the region. Planning this process well would support a socially just transition. This would enable one of Europe's most important energy-generating regions to continue playing a significant role in the production of cheap and clean energy.

Section 1. Introduction and context of Belchatow

The Belchatow plant in Poland is Europe’s largest coal-fired power plant and ranks among the six largest coal plants in the world. It burns lignite, a low-energy density brown coal that is mined locally. Belchatow holds a unique position in the Polish power system, supplying almost a sixth of annual generation. However, the plant’s economics are expected to deteriorate rapidly by 2030 and its owner predicts lignite mines to be depleted by 2036. A robust plan for what comes next after lignite will be crucial for maintaining Polish energy security, particularly in light of the current energy crisis.

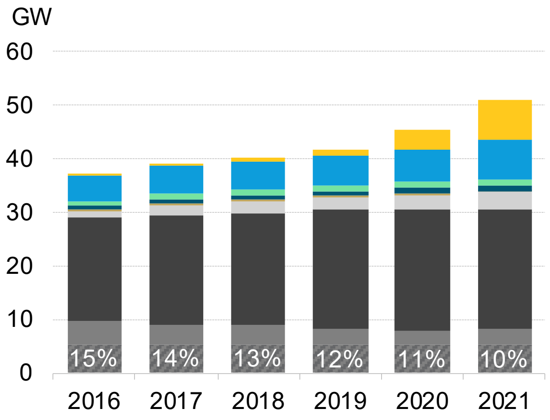
1.1 Overview

Belchatow’s eventual closure presents a challenge, but also an opportunity, for the economic development of the Lodz region and transition of the Polish electricity system. Successful energy transformation in the region could serve as an example to other coal regions around Europe and the world, showing that even large-scale power plants and highly fossil-fuel dependent regions can transition their power supplies while ensuring system adequacy.

At 5.1GW, Belchatow is the world’s largest lignite power plant and Poland’s largest power plant of any kind. Commissioned in the early 1980s, it is currently owned and operated by state-owned utility Polska Grupa Energetyczna (PGE). Its output is set to decline sharply by 2030, or latest in the 2030s, as PGE has announced a plan for all units to be shut over 2030-2036.

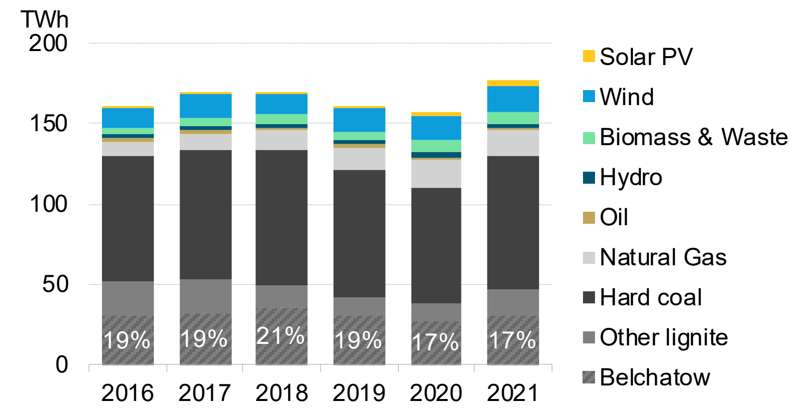
Belchatow was 10% of Poland’s installed capacity in 2021, down from 15% in 2016 (Figure 2). Its 28TWh of generation represented 17% of Poland power generation in 2021, down slightly from 19% in 2016 (Figure 3). Its shrinking share is mainly due to the addition of renewable generation capacity with solar PV accounting for the most growth.

Figure 2: Poland installed capacity



Source: BloombergNEF, ARE (achievable power).

Figure 3: Poland power generation



Source: BloombergNEF, ARE

1.2 Transition challenges and opportunities

Despite the looming closure of its largest single revenue-generating asset and job provider, the Belchatow region has a potential major energy transition opportunity. This report explores specifically how much existing lignite generation at Belchatow could be replaced with lower-carbon power generation technologies. While not all the technologies discussed here will necessarily be implemented and timelines for each would differ, the opportunities for replacing lignite are substantial. This report also focuses on potential opportunities for economic development in the area affected by lignite closures, and on how to ensure power system adequacy after the lignite plant closes.

Belchatow closure plans are incomplete

Significant volumes of renewable, gas and nuclear capacity are being built and planned across Poland today. However, just 3% of that – 600MW of solar and 100MW of wind – is planned for the Belchatow area and it is unclear when this will be completed. The Lodz region's Territorial Just Transition plan outlines no concrete plans for incentivizing investments in new generation capacity. Without a clear post-lignite strategy, Belchatow risks losing its significance in the Polish power system once its lignite plant closes.

PGE has suggested a timeline of one or two Belchatow units closing each year between 2030 and 2036,[1] but has given no formal closure notices to the grid operator. Without a formal plan, the operator cannot grant grid permits to potential new projects, which would make use of the current plant's grid connection. There are also no comprehensive plans for alternative economic activities in the region, raising the prospect of high unemployment once the power plant closes.

The current energy crisis has highlighted the critical importance of energy security to Poland even as the country seeks to transition toward newer energy technologies. Published in June 2021, the Lodz Territorial Just Transition Plan (TJTP) outlines a potential transition for the Belchatow area.[2] It shows how the region's emissions could drop by replacing jobs provided by the lignite complex with a range of other possible industries.

Lignite generation in the area could drop by 77% over 2021-2030, according to the draft Just Transition plan and Polish transmission grid operator PSE expects national lignite generation to drop by 78% 2021-2032, under their mid-scenario for carbon price development.[3] These expectations are fundamentally out of line with PGE's plan to keep several units still operating 2031-2036, and the company has not publicly indicated how much it expects the plant to generate over this period.

Barring new investment in lignite fields in Belchatow, the power plant will be unable to operate post-2038, perhaps sooner.[4] Lignite is typically mined locally due to its low energy density and high associated transportation costs. The older of the two Belchatow lignite mining fields is being prepared for a 2026 closure, while the newer nearby Szczerców field has permission to operate

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1 PGE Group: Just transition for Belchatow region becoming a fact (link)

2 Territorial Plan of Just Transformation of the Lodz Region (link, in Polish)

3 Based on PSE's development plan for meeting current and future electricity demand for 2023-2032. Main document for stakeholder consultation in March 2022. The mid-scenario assumes European Union Emissions Trading scheme carbon prices of 100 euros per tonne of CO2 by 2030.

4 Representatives of PGE have stated that due to high demand for lignite generation during ongoing energy crisis, lignite resources are depleting faster than anticipated. To allow for the plant to operate until 2036, the company is exploring mining the area between the Belchatow and the Szczercow fields.

until 2038. In 2021, PGE concluded that developing a new lignite field at Zloczew would be unprofitable[5] and that the mine would be too small to fuel 5.1GW of generation.

While other regions in Poland have ambitious goals for deploying new generation capacity, Belchatow's plans to date are limited. Most activity is planned in the north of the country, with 10.9GW of offshore wind due online by 2035 and a new nuclear power plant planned for the mid-2030's in the Pomerania region. New onshore wind projects are also concentrated in the north due to lower population densities and good wind speeds. Grid operator PSE is drawing up preliminary plans to increase grid capacity for north-south flows.

Around 4GW of new gas power plants have won 17-year capacity contracts and are expected to be built, despite Poland's and the EU's plans to cut reliance on Russian gas. None of these is planned for the Belchatow region as no major gas pipelines serve the area. If limited to PGE's current modest plans for solar and wind, Belchatow faces the risk of lost economic opportunity, with its 5GW grid connection due to remain mostly unused after the lignite plant closes.

PGE's plans for new renewables in the Belchatow area remain early stage and limited in scale. BNEF estimates that the utility's proposed 600MW of solar and 100MW of wind would replace only around 4% of the lignite plant's 2021 generation. PGE's announced plans to sell the lignite plant to a yet-to-be-established nationalized entity – the National Energy Security Agency (NABE)[6] – adds to this uncertainty. It is possible that PGE is reluctant to make thorough plans for the Belchatow area until they have more details around how and when the potential shift of ownership to NABE will take place.

Belchatow can benefit from EU Just Transition Funding

Belchatow currently also risks missing out on financial support from the EU Just Transition Fund (JTF). The JTF is a key tool to support the territories most affected by the social and economic impacts of the transition towards climate neutrality. The EU adopted a six-year partnership agreement with Poland in June 2022,[7] stating that five Polish regions could be recipients of up to 3.85 billion euros in JTF funding. To qualify, Belchatow must show it is taking defined steps towards climate neutrality and that these steps will be implemented by 2030. This includes setting an official timeline for ceasing or significantly scaling down fossil fuel extraction and use.

The EU has not publicly disclosed how far Belchatow would have to cut its emissions by 2030 to qualify for JTF support. The funds are committed until 2027, but if the program's first phase is successful it is likely to be extended in the future. Belchatow does not have to completely transform by 2027 to qualify, but the region must show it is taking first steps towards transitioning its local economy by then and that these first measures will be implemented entirely by 2030.

The European Commission does not expect the full 5.1GW lignite plant to be decommissioned by 2030, as this would be unrealistic from an economic and energy security perspective. However, a clear decommissioning schedule with notice given to the grid operator and an early decommissioning of the least effective units totaling 1.5-2GW would likely suffice to secure the JTF support. This is also realistic from an energy security perspective. The generation of the units

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[5] Sawicki: There will still be no new open pit in Złoczew, but this one will live in its shadow (link, in Polish)

[6] The Polish government wants to spin-off all the country's coal power plants to NABE. Ministry of State Assets: NABE becomes a fact (link)

[7] EU Cohesion Policy: Commission adopts 76.5 billion euros Partnership Agreement with Poland for 2021 – 2027 (link)

closing first could be replaced by renewable energy generation many years before the last unit of Belchatow closes.

1.3 The Belchatow lignite area

In 2021, the Belchatow lignite complex in central Poland employed some 7,500 people across the two opencast lignite mining fields and the power plant. This is more than 13% of the population in the nearby town of Belchatow. The complex thus critically important to the local economy and nearby municipalities have benefitted from the investment and employment the power plant has brought for over three decades. Much of the area surrounding the complex is agricultural land, with the power plant located some 10km from the Belchatow town.

Figure 4: Belchatow opencast lignite mine

Source: Flickr

The entire Belchatow lignite complex stretches around 20km from east to west, and 5km from north to south. This includes the power plant, the two opencast lignite mining fields and a dumpsite of landmass extracted while building the lignite mines (Figure 4). Fuel for the plant is transported some 5-15km from the Belchatow and Szczerców opencast mines.

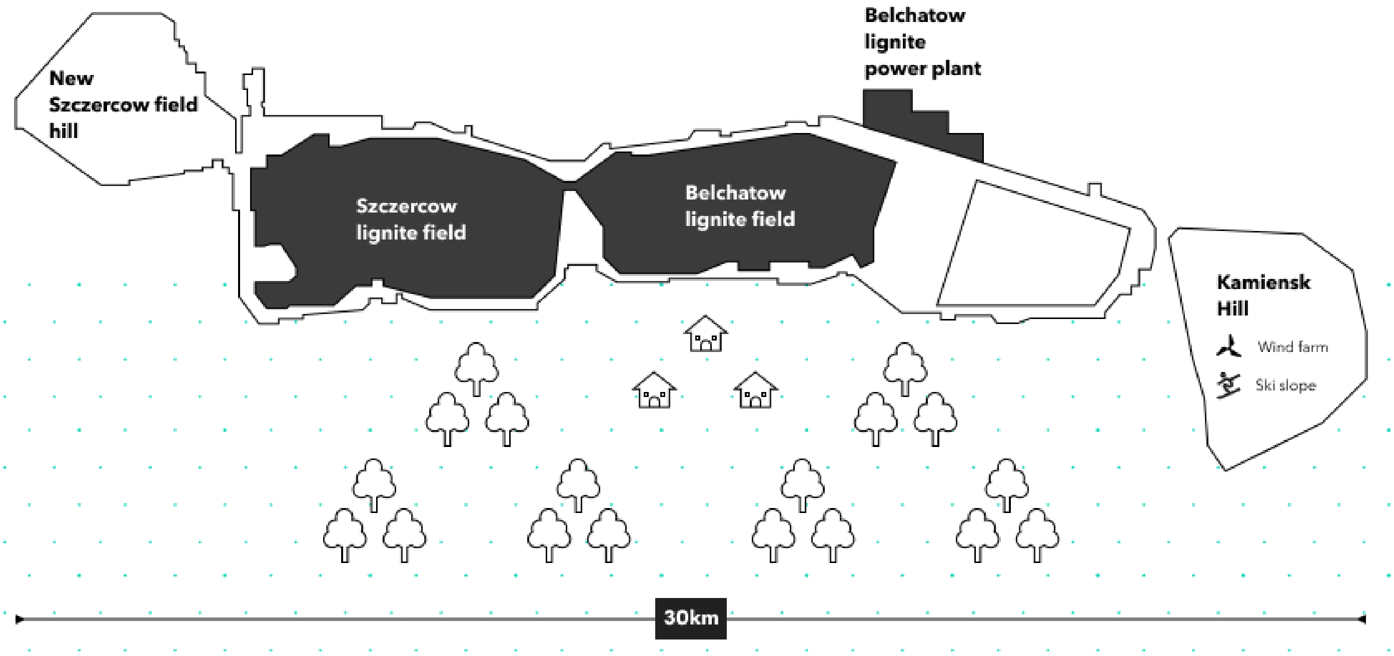
Two hills have been formed at the outskirts of the area: Kamiensk Hill and the newly formed New Szczerców Field Hill.[8] The 406-meter high Kamiensk has undergone full land-reclamation and reforestation, as dumping on this site ended in 1993. This hill is dedicated to recreational activities, including a ski slope. There is also a 30MW wind farm operating on Kamiensk Hill.

Water is continuously pumped out of the lignite fields while excavation is ongoing. After the fields are no longer mined, the land will be shaped and a shoreline prepared for the site to become naturally filled by water. Over time, the two holes in the ground that are currently lignite mining

[8] PGE: The "twin" of Góra Kamieńsk was Established Next to the Bełchatów Mine (link)

fields, will slowly become artificial lakes (Figure 5). After post-mining landscaping, it will take more than 20 years before water levels in the former mines reach levels high enough to be considered lakes. Artificial filling can speed the process by a few years, and there are examples of German post-mining lakes that were filled in less than 10 years.[9] PGE has estimated that the deepest point of the lakes, once created, will be 170 meters.

Figure 5: Map of the Belchatow lignite area



Source: BloombergNEF

[9] For example, the filling of Lake Zwenkau started in 2007 and was finalized in 2015, while lignite mining ended in 1999. For more on fast filling of mining pit lakes, see *Filling and management of pit lakes with diverted river water and with mine water -- German experiences*, 2011 (link).

Section 2. The outlook for lignite generation

BNEF expects most Polish lignite and hard coal plants to become uneconomic by 2031 due to high fuel costs and a rising EU carbon price. For Belchatow, its oldest units are likely to become uneconomic pre-2030 as capacity payments supporting the plant are due to end in 2028.[10] Belchatow's power generation faces significant carbon price risk, and the Polish power system must be prepared for changes even well before lignite mining ceases at Belchatow.

2.1 Overview

All units at the Belchatow power plant are currently expected to be completely closed by 2036 at the latest. This is because local lignite resources are running out, and investments in mining new sites are not financially viable. Additional fuel supply would not guarantee longer operation, as BNEF modelling shows that the power plant is likely to become unprofitable as early as 2029 and no later than 2031, depending on commodity prices.[11]

The current energy crisis and the associated high gas prices have created renewed demand for lignite. However, 2020 generation patterns highlighted Belchatow's future challenges. That year, power demand was unusually low due to measures surrounding the Covid-19 pandemic. This allowed renewables to supply a proportionally higher share of generation and resulted in lignite getting crowded out.

During 2020, Belchatow's capacity factor averaged at 57% while in 2021, it rose to 63%, according to PSE data. Analysis of other lignite plants globally shows that lignite plants tend to become uneconomic at capacity factors below 65% and are increasingly likely to close as a result.[12] Rising carbon prices are already impacting the plant and PGE closed its oldest unit at Belchatow in 2019. Overall, the plant's annual generation dropped more than 15% from 2018-2021 due to market conditions.

Drivers of running costs at Belchatow

The economic viability of lignite generation at Belchatow is contingent on one side by running costs and on the other by revenues from wholesale power sales, ancillary grid services and capacity market payments. If the cost of lignite generation is relatively cheaper than other generation, then lignite lands higher in the "merit order" of various plants and can sell more power on the wholesale market.

The most important cost components for running the power plant are fixed costs, fuel costs and EU carbon allowance costs. Lignite plants are typically built for economies of scale, with somewhat higher fixed costs than hard coal power plants. Power plants can earn revenue from

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[10] A total of six blocks are supported by the capacity market until 2028. This includes the newest 858MW block and five 360-380MW

[11] See Appendix for details on power system modelling as well as hard coal, gas and carbon prices.

[12] For more, see BNEF analysis of Australian lignite power plants: *1H 2022 Australia Market Outlook, Australian Coal Update: Detailed Plant Analysis, Australian Coal Update: Drivers of Retirement* (full reports available to BNEF and Bloomberg Anywhere clients: link, link, link)

ancillary services to the grid operator, or through capacity payments but the wholesale power market is the most important revenue stream. If wholesale power prices drop below the production cost of lignite power for many hours during a year, the plant becomes unprofitable.

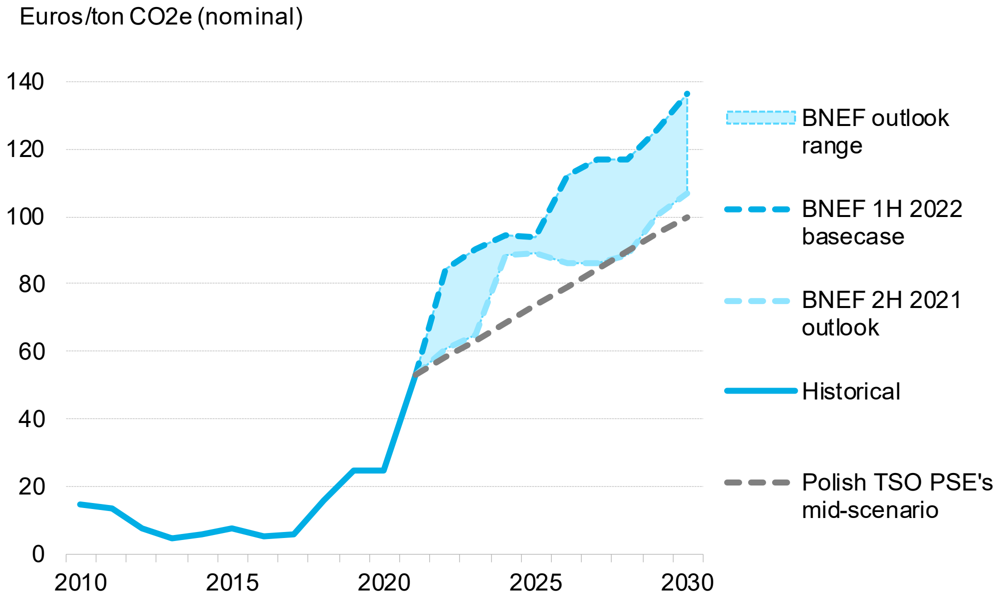
Lignite's high emissions intensity make EU carbon allowance costs more impactful than actual fuel costs since 2018. Together, the carbon and fuel costs make up the majority of short-run marginal costs, which determine the merit order of technologies on the wholesale market.

2.2 Outlook

Belchatow produced around 33.2MtCO2 of CO2 emissions in 2021, making it the single largest point source of carbon emissions in Europe. It also generated 2% of the EU's power sector CO2 emissions while providing 1% of its power generation in 2019.[13] The power plant alone was responsible for almost 10% of Poland's total estimated CO2 emissions in 2021.[14] The emissions intensity of Belchatow electricity was approximately 1,200gCO2/kWh in 2021, almost 70% higher than the average emissions intensity of Polish electricity and more than 400% higher than the EU average.

Given all of the above, the carbon cost for running Belchatow is significant. The older units' emissions intensity remains particularly high, despite being refurbished 2011-2018 to comply with the EU's Industrial Emissions Directive. BNEF expects the EU carbon price to exceed 100 euros per ton of CO2 by 2028 (Figure 6). The Polish transmission system operator, PSE has a slightly lower estimate in its "mid-scenario" and expects the price to reach 100 euros/ton in 2030.

Figure 6: EU Emission Trading System carbon price scenarios



Source: BloombergNEF, PSE. Note: nominal prices are not adjusted for future inflation. The shaded area reflects uncertainty around the price, as markets and policy change.

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13 Based on emissions reported to the EU Emissions Trading System compliance database

14 European Environment Agency estimate for Poland 2021 CO2 emissions

The carbon price is a key mechanism intended to enable the EU reach its climate targets and it is unlikely to get adjusted downward through policy changes in the long run. Even if the short-term solutions recently proposed by EU member states to alleviate impacts of the energy crisis over 2022-2024 were implemented, carbon prices would rise again post-2025.

Lignite's high emissions intensity makes its generation incompatible with Polish and European 2030 climate targets. Lignite plants would need to generate less than 10% of the time to be compatible EU's targeted 2030-2040 emissions reductions.[15] At capacity factors that low, it would not be financially possible to keep a lignite plant online without any out-of-market payments. However, Belchatow is to be excluded from new contracts awarded by the Polish capacity market[16] from 2025 onwards because of its high emissions, and its last capacity market contracts expire in 2028.

Lignite becomes Poland's most expensive power source by 2030

As Poland's renewable energy fleet grows, lignite plants are on the verge of becoming uneconomic despite their relatively low fuel costs. Renewables effectively have no fuel costs, and at times of high wind and solar generation, they can depress power prices, sometimes even to zero. Lignite plants are relatively inflexible and must stay online during times of low power prices to be able to generate later when needed. Polish lignite is estimated to cost between 14-28 euros (PLN 65-130, USD 15-30) per ton, and has an energy content of around 2,000kcal, two thirds lower than that of globally-traded hard coal. However, Polish lignite power plants do not disclose their fuel costs as they acquire fuel locally. As a result, actual lignite costs for the Belchatow plant could be higher or lower than the estimated national average.

Lignite became among the most expensive generation technologies in Poland in 2020, both on a short-run marginal and levelized cost basis. Then in late 2021, natural gas overtook lignite as most expensive to run in Poland as global gas prices reached record highs. However, BNEF expects gas to become cheaper than lignite again over 2025-2030, as the EU carbon price rises[17] and natural gas prices rebalance thanks to greater LNG inflows into Europe. Even in a scenario with sustained high gas prices, gas and lignite costs converge by 2028 (Figure 7). Unlike lignite, gas has the advantage of participating in the Polish capacity market beyond 2028.

Belchatow is not considered an efficient cogeneration plant, as it produces significantly more electricity than district heat. Belchatow-generated power is likely to be more expensive than the electricity generated by any of the 6GW of high-efficiency cogeneration plants now operating in Poland. When global hard coal prices retreat from the record heights of the 2022 energy crisis and domestic hard coal prices follow suit, many Polish hard coal plants are also likely to produce cheaper power than Belchatow. In BNEF's summer 2022 outlook, this happens around 2026.

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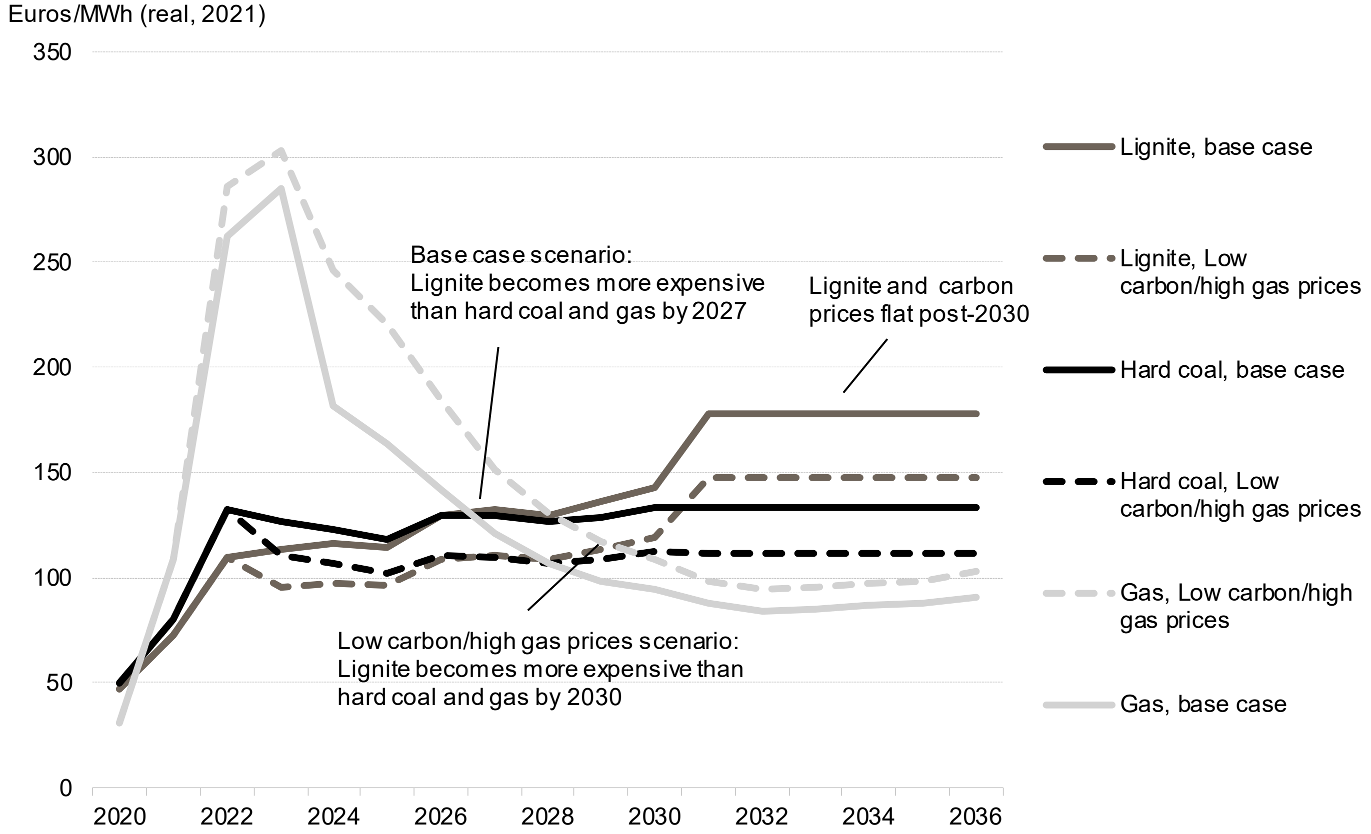
15 Based on BNEF *European Energy Transition Outlook 2022* Net-Zero Scenario. Available for BloombergNEF and Bloomberg Anywhere clients (web | terminal).

16 Subsidies to generation capacity emitting 550gCO2/kWh must be phased out by 2025 under EU rules (link)

17 BNEF *1H 2022 EU ETS Market Outlook* is available for BloombergNEF and Bloomberg Anywhere clients on (web | terminal).

Figure 7: Poland short-run marginal costs for fossil fuel generation under BNEF's base case scenario and low carbon / high gas price scenario



Source: BloombergNEF. Note: Short-run marginal cost excludes fixed costs. Base Case Scenario builds on the BNEF European Energy Transition Outlook's Economic Transition Scenario for Poland, but has updated fuel and carbon costs. BNEF carbon price forecast ends in 2030, after which price is kept flat in model. See Appendix for more on the scenarios and methodology.

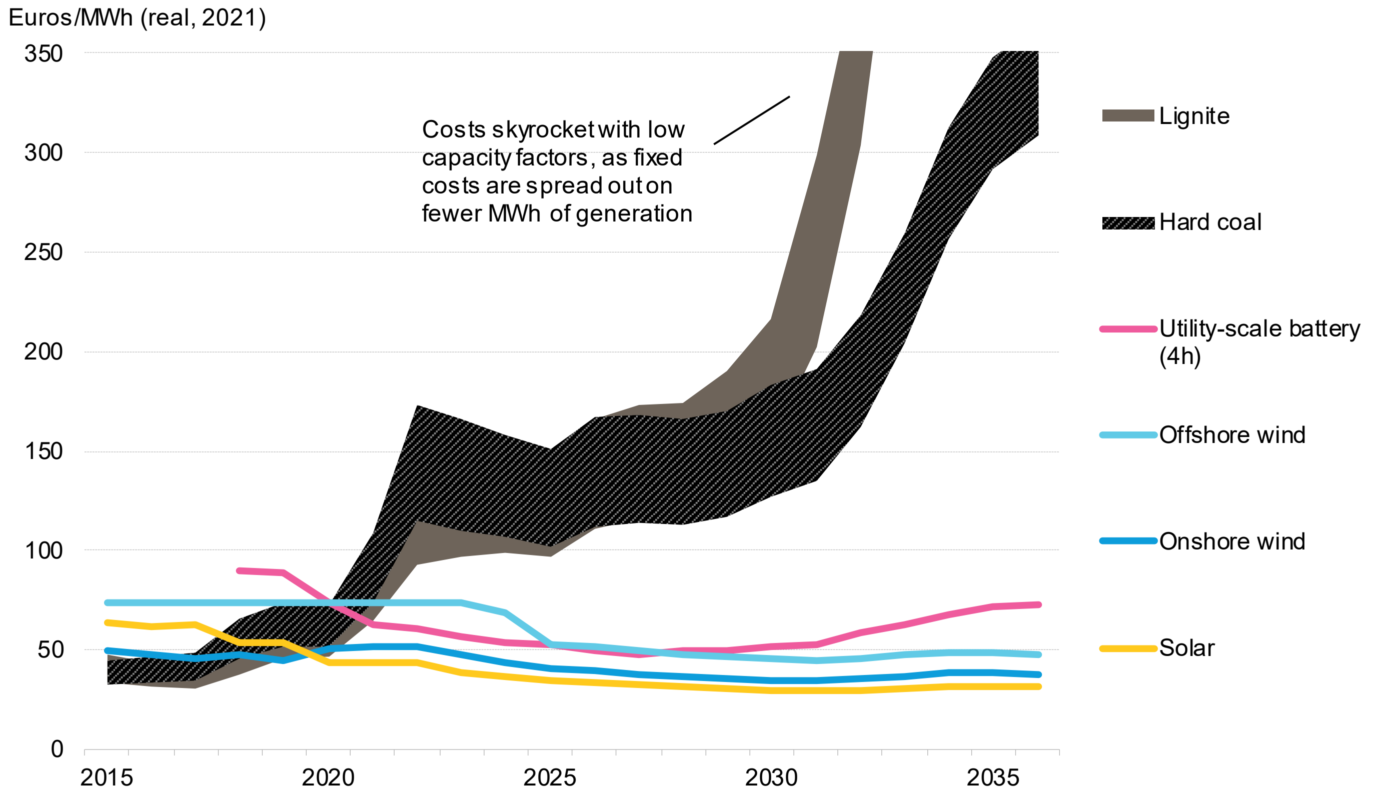
At the moment, the short-run marginal cost of lignite is below that of hard coal, but BNEF expects this to reverse by 2025 (Figure 7) due to rising carbon costs. Lignite will continue to be the cheaper fuel to get out of the ground and to the plant. The differentiator will be that the emissions intensity of electricity produced, which is 10-20% higher for lignite than for hard coal. Thus, the carbon penalty will be higher for lignite.

Even under a scenario where carbon prices remain lower, lignite remains less competitive than hard coal. With a carbon price 20% below our base case, hard coal becomes cheaper to run than lignite in Poland by 2028. This dynamic could even be accelerated should hard coal prices fall, which occurs as soon as 2025 in the latest BNEF projection. Global gas prices also drop by 2026, reaching pre-pandemic levels around 2030, based on BNEF's summer 2022 forecast. Low gas prices would increase gas generation, crowding out both coal and lignite.

Poland's rising share of renewable energy is also likely to depress lignite capacity factors for all the country's lignite plants below economically critical levels before 2030, based on the existing pipeline of wind and solar projects tracked by BNEF. Since 2020 it has been cheaper to build new solar, onshore wind and offshore wind, than to continue operating existing lignite plants, on a levelized cost basis, BNEF estimates (Figure 8). The cost of building new solar, onshore wind and even offshore wind capacity have remained much lower than running existing lignite, coal, or gas plants over 2021-22 – despite higher global commodity prices and supply chain constraints.

Today, solar and wind are lower cost options than lignite even when batteries are attached to the projects. By 2030, the cost difference between renewables and fossil fuels widens further. These dynamics result in lignite's share of generation falling from 30% to 3% in 2030, compared to hard coal's share going from 53% to 14% over the same period, according to BNEF analysis. Poland's newest hard coal power plants are also less emissions intensive than Belchatow and more often benefit from efficient cogeneration of district heat.

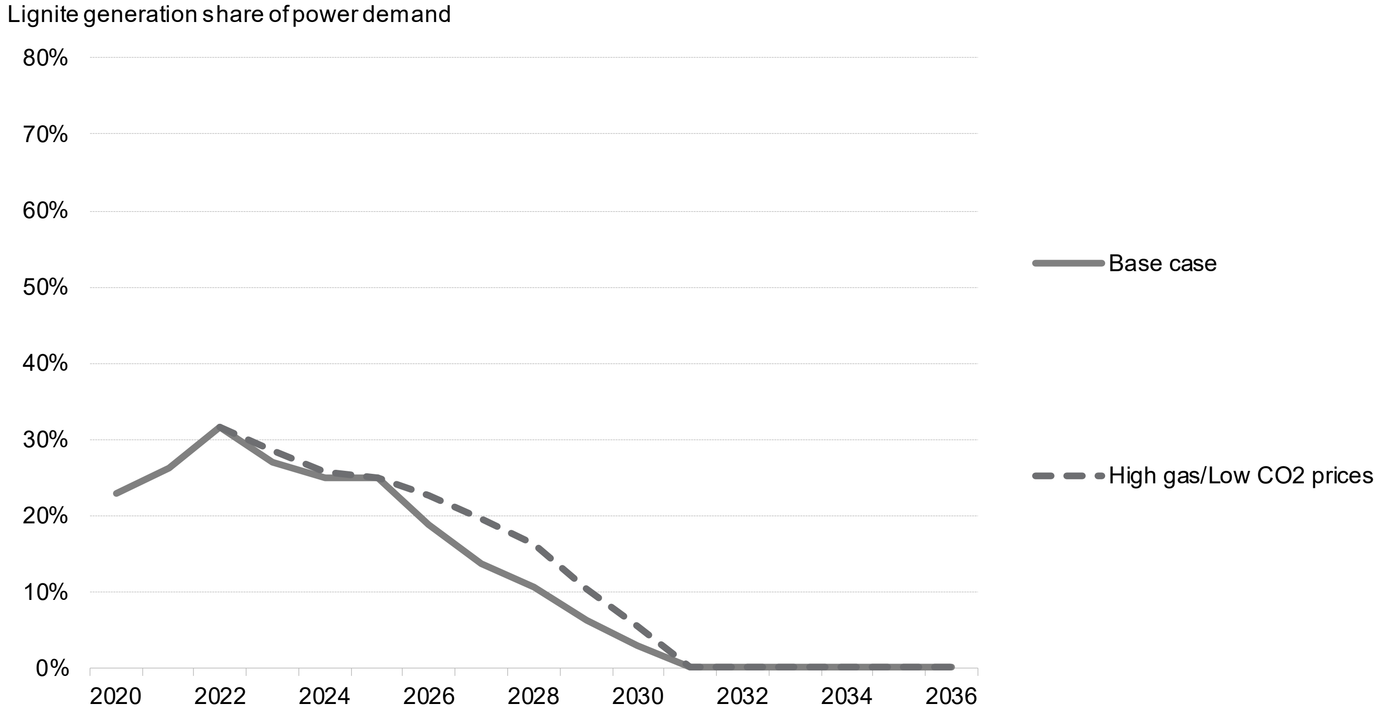
Figure 8: Average cost of electricity from new-build renewable energy and batteries versus average cost of lignite and hard coal in BNEF Poland outlook Base Case Scenario



Source: BloombergNEF. Note: Includes fixed costs. Base Case Scenario builds on the BNEF European Energy Transition Outlook's Economic Transition scenario for Poland, but has updated fuel and carbon costs. See Appendix for more on the outlook. Batteries become on average more expensive over time as more batteries means less utilization for an individual battery.

BNEF expects that economic drivers will cause 1.5-2GW of Belchatow's lignite capacity to retire by 2030. BNEF's least cost modelling shows that lignite generation would contribute to meeting less than 10% of Polish power demand by 2029, and the share would drop to 0% by 2031 (Figure 9). See Appendix for more on future scenarios. The growth in renewable energy capacity and generation pushes out lignite from the merit order.

Figure 9: Lignite generation share of annual demand in Poland



Source: BloombergNEF. Note: The share of lignite is modelled from 2022 onward with the assumption that net-imports are zero and power generation equals demand. See Appendix for scenario modelling methodology.

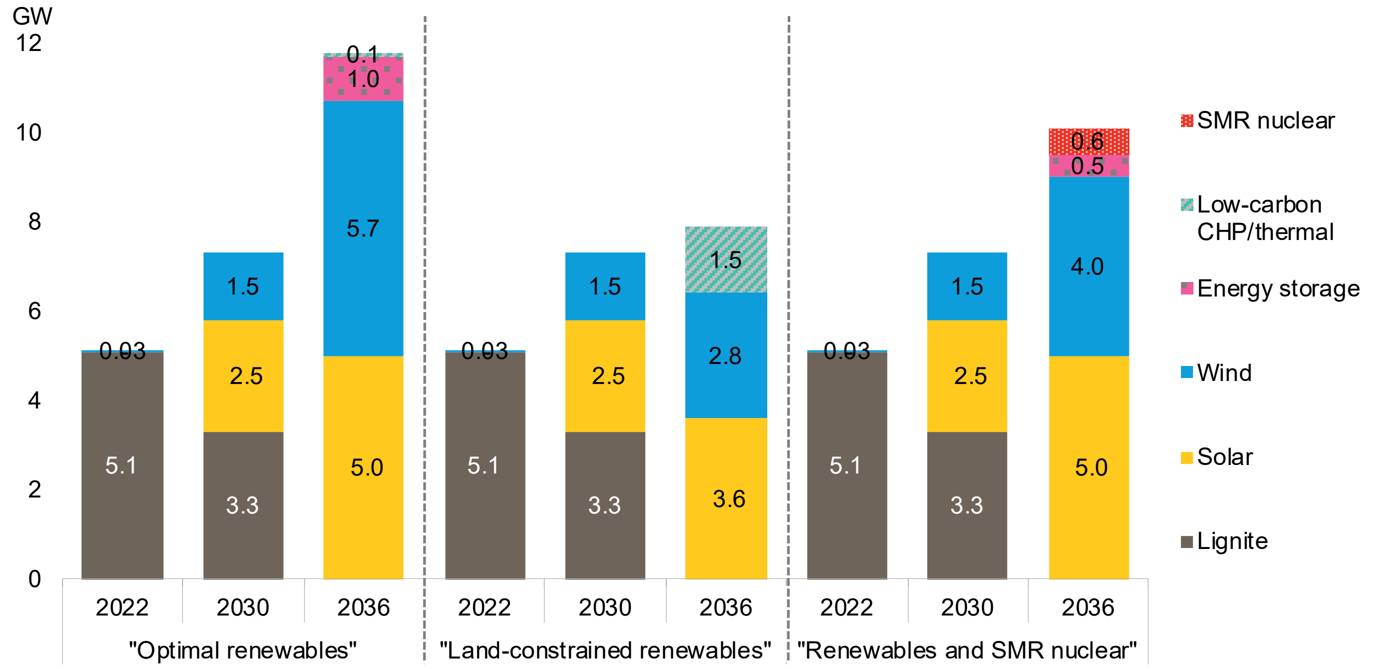
Section 3. Alternative generation technologies

Recent events have underlined the critical importance of Poland maintaining sufficient and secure access to power generation. To ensure this, lignite generation at Belchatow cannot drop by the estimated 77% through 2030 envisioned under the Lodz Territorial Just Transition Plan without a clear strategy to replace it with other sources of power. The availability of a large grid connection in the area makes Belchatow quite suitable for alternatives. This section explores the fuels and technologies that could succeed lignite and evaluates the potential for deploying them at scale.

3.1 Overview

Given the enormous role Belchatow plays on the Polish grid today, no single technology on its own can replace the plant's entire generation. Rather, a suite of new technologies would need to be deployed to make up for the shortfall. Figure 10 sketches at a very high level three potential alternatives. Each would bring its own set of challenges and opportunities and each should be evaluated on overall cost and ability to provide sufficient energy security the Polish power system. How each interfaces with the EU Emission Trading System (ETS) should also be taken into consideration.

Figure 10: Three potential generation capacity mixes to replace current Belchatow lignite power



Source: BloombergNEF. Note: The chart illustrates potential capacity mixes that could maximize the use of the grid connection. All scenarios can replace 80% of Belchatow's 2021 generation. SMR is small modular reactor and CHP is combined heat and power.

Poland has a large pipeline of planned power projects, including potential new solar, onshore wind, offshore wind, gas and nuclear capacity. Understandably, however, there are significant concerns that closing Belchatow in its current form would endanger Polish energy security. Most new energy projects are currently planned for the north of Poland but new generation is also needed in the central and southern regions to ensure a stable grid.

Without major new investment in the Belchatow region, many local jobs stand to disappear as the lignite power plant closes. New energy projects would mean new jobs while bolstering energy security, and a robust Just Transition plan supported by EU funding would help ensure that the new jobs are filled by the local workforce. These could include those that employ variable renewables, such as solar and wind, as well as firm capacity, such as gas or hydrogen, energy-from-waste or small-scale nuclear.

3.2 Comparative economics of energy technologies

The current energy crisis has laid bare the inextricable link between energy costs and energy security in Poland and in Europe. In this section, we explore the potential costs of producing from the various energy technologies that could succeed lignite at Belchatow.

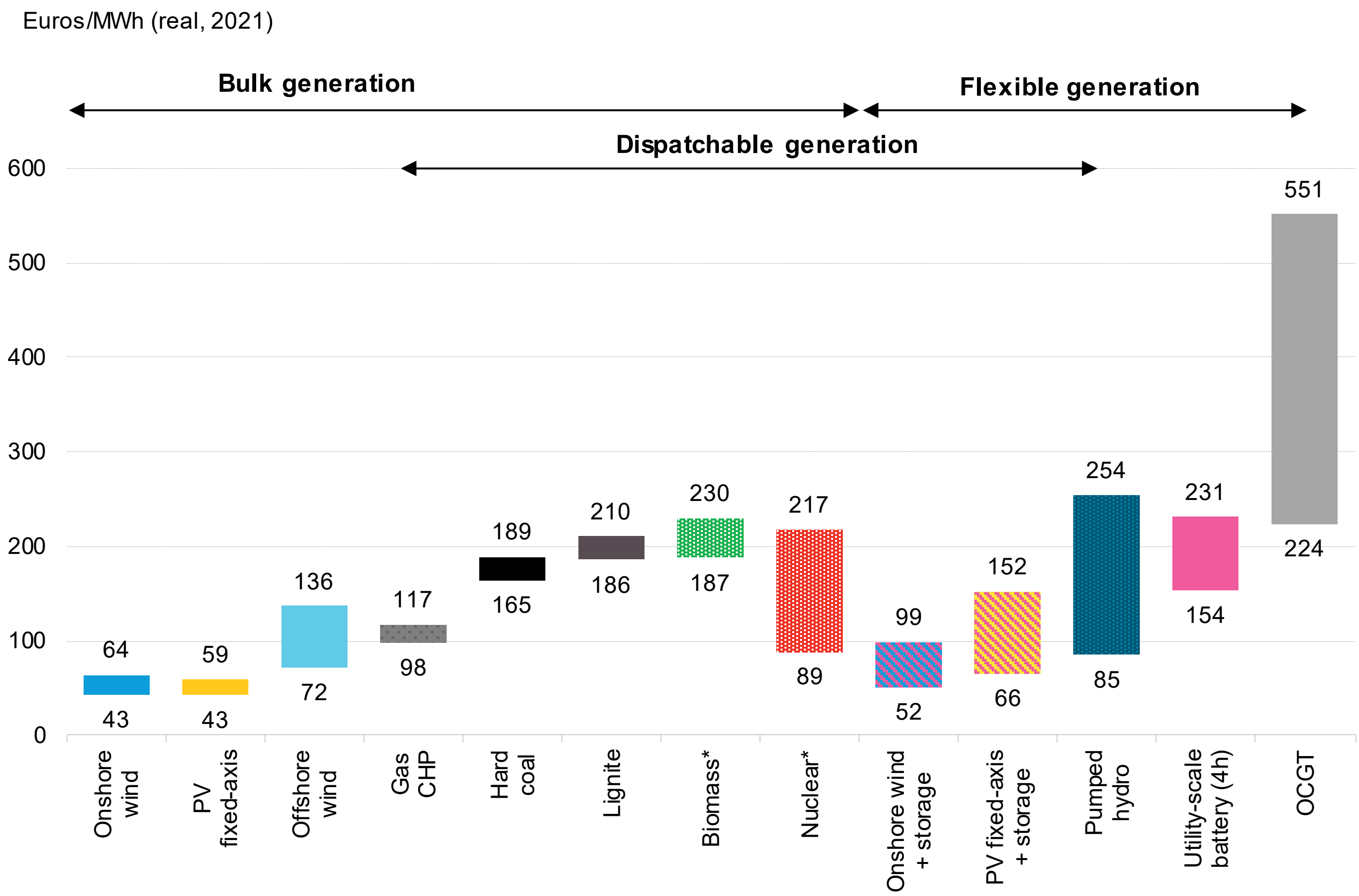
Today, solar and wind are the cheapest sources of new-build bulk generation[18] available in Poland, on a levelized cost of electricity (LCOE) basis (Figure 11).[19] Most flexible capacity is more expensive, but they add value to the grid which is not captured in any LCOE measurement. For flexible capacities that generate only for limited hours per year, another useful cost metric is the capex per megawatt installed. See section *3.5 Firm and flexible capacity alternatives* for more on this.

Gas combined heat and power (CHP) plants are among the cheaper sources of thermal bulk generation, as their economics benefit from high efficiencies from combined heat and power output. The LCOE estimate for gas assumes that gas fuel prices will decrease from the record levels of 2022 and reach approximately 35-50 euros/MWh during the lifetime of the project. New coal and lignite plants are among the more expensive options for bulk generation.

18 Bulk generation is suitable for high volumes of power generation, in contrast with flexible capacity.

19 The Levelized cost of electricity (LCOE) is a common metric for comparing the cost of different generation technologies. The 2022 LCOEs reflect cost of projects where development starts in 2022, but the year of operation varies with typical development times per technology. See Appendix for more about how levelized cost of electricity is calculated.

Figure 11: Poland/Germany 2022 levelized cost of electricity ranges per technology

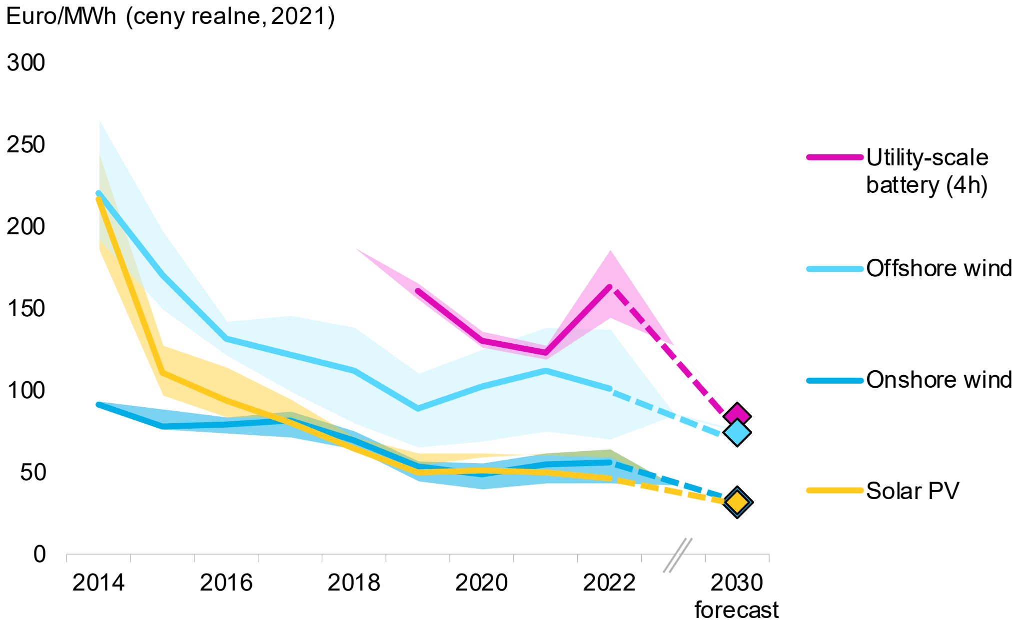


*Source: BloombergNEF. Note: All LCOE data is based on the BNEF 1H 2022 LCOE Outlook (web | terminal), but coal and gas prices have been updated. Polish LCOE data is used for gas CHP (combined heat & power), coal, lignite and onshore wind. All other LCOE data is based on German projects as costs are similar across the two countries, with financing costs somewhat higher in Poland (we find the typical cost of debt at 2% in Germany versus 4% in Poland). *All LCOEs considers delays and cost overruns. This is particularly reflected in the nuclear LCOE, which uses UK as a proxy. Biomass LCOE uses Spain as proxy.*

BNEF's has a wide range for its nuclear LCOE estimate. Project delays and budget overruns for projects put the upper range for the nuclear LCOE estimate higher than originally planned for these projects. There are no commercially operating small modular nuclear reactors (SMR), so no reliable LCOE is available for this technology. The US Energy Information Administration (EIA) has estimated an LCOE of around 80 euros/MWh in 2027 for SMRs, but the LCOEs of the first reactors will be significantly higher.

The LCOE of solar PV has fallen more than 90% since 2009, and BNEF expects costs to continue to decline over the next decade, albeit not as steeply (Figure 12). BNEF analysis finds that the cheapest electricity mix in Poland can be achieved when wind and solar account for most of overall generation and more expensive, flexible technologies generate only during the few hours or days when wind and solar output is low.

Figure 12: Historic LCOEs and 2030 projection for renewables and batteries, Poland



Source: BloombergNEF. Note: Color ranges reflect varying LCOE's across different projects. Germany used as proxy for offshore wind and batteries.

3.3 Belchatow's role on the grid

The major grid infrastructure built around Belchatow was designed to receive and wheel the project's massive output elsewhere. Such infrastructure is highly valuable and with proper planning could be repurposed to accommodate generation from other sources. Developing new capacity in time for the planned lignite closures would improve grid stability and security, allowing the grid operator to select optimal grid solutions and adjust accordingly.

Closing Belchatow without replacing generation would waste grid investment

It would certainly be possible to shut the Belchatow power plant without replacing it with any other capacity, but doing so would compound grid congestion and lower overall system reliability. Belchatow's generation could be replaced by projects planned elsewhere in the country as some 20GW of new capacity is planned before 2035. Most of the current project pipeline is in the north of the country, however. Belchatow on the other hand is located further south, near major demand centers.[20]

Adapting the grid to zero generation near Belchatow would increase the north-south flows and require construction of additional links. The transmission grid operator is planning a new High Voltage Direct Current (HVDC) cable to accommodate this, but a single link will not guarantee sufficient power supply in the south. The capacity of this potential link has yet to be disclosed, but existing European HVDC cables have 2GW or less capacity. In general, transporting power from

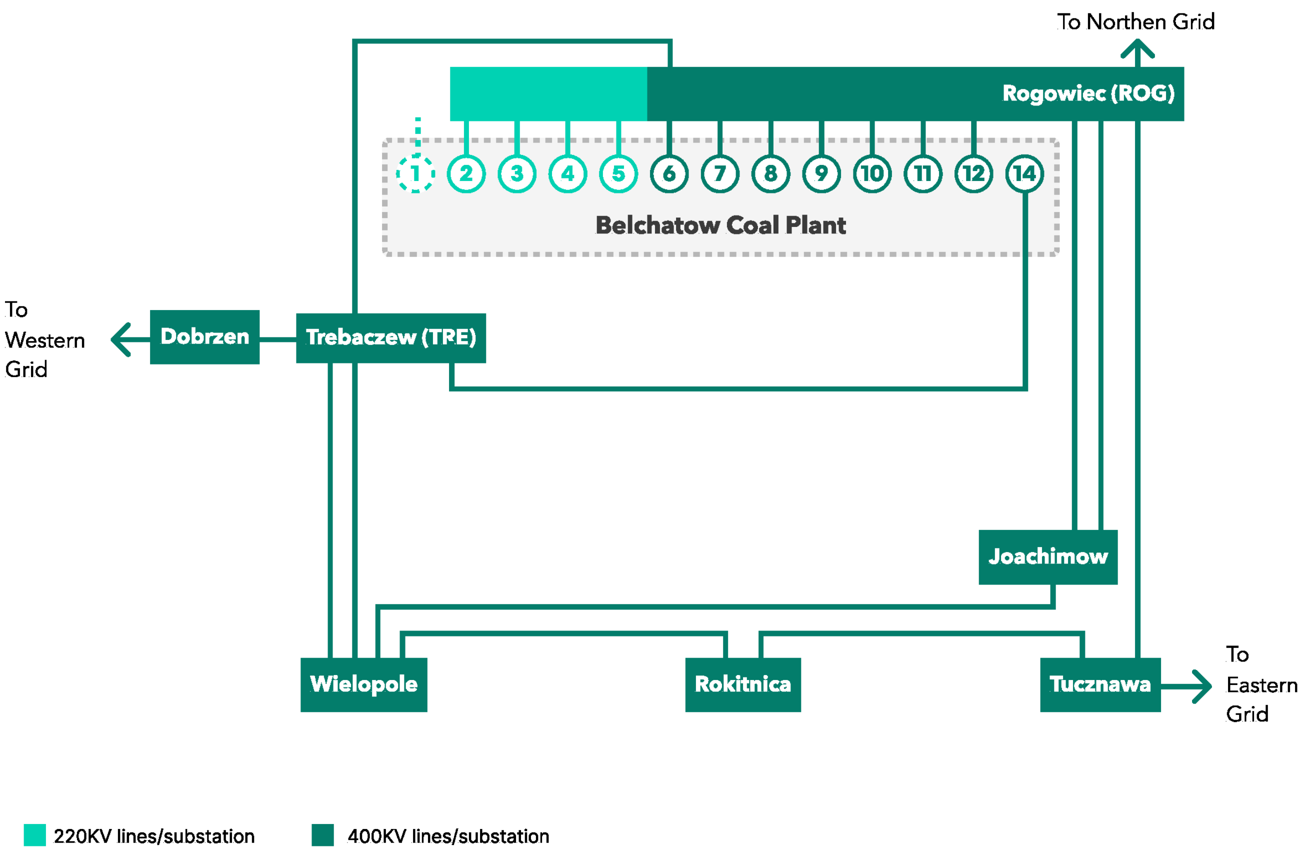
[20] PSE grid plan consultation (link)

further distances to load centers weakens system reliability and increases raises energy losses in transmission. Construction of additional links in Poland could take many years to complete, hurt network reliability, and result in higher energy losses.

More optimal would be to build new generation capacity near Belchatow to exploit existing grid connections. The existing grid around Belchatow has high utilization and is rarely congested, even when lignite generation is at full output. Although, minor congestions happen occasionally on the lines connecting Rogowiec and Joachimow. The city of Czestochowa, with a steel mill is located nearby is likely to continue to be a large demand center. Having generation located near demand centers reduces power transmission losses. The availability of the existing grid and the nearby demand center supports the idea that new generation capacity should be built in Belchatow.

Belchatow today has 12 generating units injecting power into three nodes on the grid. Eleven units have nameplate capacities of 360-380MW apiece and are connected to the 400kV Rogowiec substation via two nodes (Figure 13). Total capacity connected to Rogowiec tops 4GW, making it one of Europe's largest substations. Belchatow's largest, power-generating unit is 858MW and connects to the Trebaczew substation at a different location. While Rogowiec and Trebaczew feed the Polish grid in many different directions, the areas around Piotrkow Trybunalski and Lodz specifically rely on Rogowiec. The city of Częstochowa is served by the Joachimow substation but is also ultimately also highly reliant on Belchatow for power supply.

Figure 13: Grid configuration around the Belchatow lignite-fired power plant



Source: BloombergNEF, PSE. Note: Belchatow had 13 units until 2019, when unit 1 was closed. No unit is numbered 13.

It is crucial for the declining output and eventual shutdown of Belchatow to be planned well in advance, so that the grid can be reconfigured to account for its lost output. Currently, the 40-year old Rogowiec substation is undergoing renovations, which suggests the grid operator expects further generation from Belchatow for years to come. The upgrade was announced after an incident at the substation in June 2021 resulted in the loss of 3GW in power exports. The Polish grid was unprepared for the outage and its frequency temporarily dropped below safe limits.

The substation upgrade will help avoid future unplanned power losses, but the investment risks being wasted if there is no or limited generation at Belchatow after 2030. A 2022 consultation document[21] by transmission system operator PSE states that the upgrade will help transmit power output from Rogowiec. This suggests PSE is counting on future generation from Belchatow, but not necessarily lignite generation. The grid operator's own "mid-carbon" price scenario sees lignite generation dropping by 78% by 2030. To make use of the current substation investment, new generation capacity would be required. The substation will be technically easier to manage after the upgrade, which could also make it easier to transmit variable renewable energy from Belchatow.

Poland's grid can be upgraded to accommodate intermittent resources

Poland's power grid and the grid surrounding Belchatow both have been built to deliver reliable, dispatchable firm capacity to demand centers. Adding intermittent renewable resources would potentially create variability and stability challenges. However, technologies are available to address these concerns.

Variability

New capacity connected at Belchatow should be at least partially firm rather than fully variable. While renewable energy can replace much of current lignite generation, some complementary firm capacity would make it easier for the grid operator to manage variability in renewable energy output. There are ways to achieve this with batteries, pumped storage, or on-site demand.

Coupling firm capacity with renewable generation at Belchatow could also help manage variability of cross-borders flows to Germany, Czechia and Slovakia. Some firm capacity near Belchatow would help ensure that this power flows in the right direction and avoids "loop flows".[22] Extreme variations in renewable generation could make these flows harder to manage, but there are technological solutions to mitigate the issue. This could include new phase shifting transformers[23] installed at the Polish-German border to help control flows.

The effects of variability in solar and wind generation can also be partially managed by flexible onsite demand, which consumes power during times of high generation. This would flatten any spikes in generation fed into the grid. Locating the demand next to generation also reduces the risk of temporary congestion on the transmission grid. Large-scale heat pumps, described in section 3.5 is an example of flexible demand. Technically, a large grid connection such as

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21 Draft development plan for meeting the current and future electricity demand for 2023-2032 (link, in Polish)

22 Loop flows occur where electricity trading inside one bidding zone causes unscheduled power flows that have an impact on other zones. This can cause power to flow unexpectedly to neighbouring countries.

23 A phase shifting transformer (PST) is a specialised type of transformer, typically used to control the flow of active power on three-phase electric transmission networks (link).

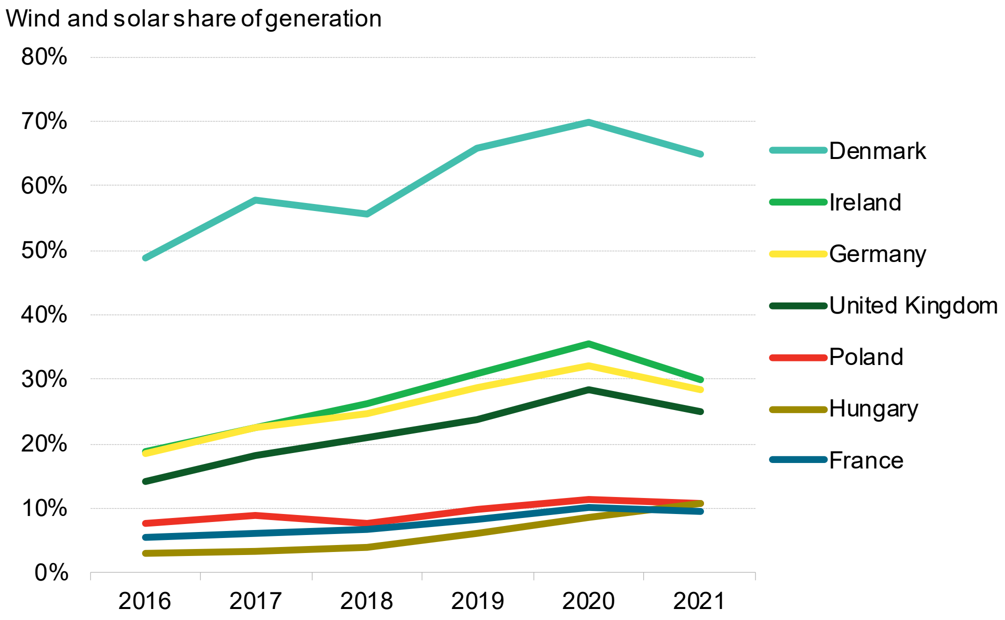
Belchatow’s could also be used to accommodate power demand instead of power supply, but a standalone addition of demand would put even more strain on North-South power flows in Poland. Flexible demand could however help absorb output from local variable renewables and help balance the grid through demand response.

Stability

Grids have been shown to be able to operate stably with high shares of wind and solar penetration. In Denmark, for instance, 2020 wind and solar generation was 70% with no major grid destabilization. This was achieved due to a high level of interconnection with neighboring countries. Most European countries are building new cross-border grid connections. Less interconnected power systems have also achieved high shares of wind and solar. For example, Ireland achieved 35% wind in 2020. Its transmission system operator Eirgrid is now preparing for 80% wind/solar by 2030 (Figure 14). The share of solar and wind generation has more than doubled over 2016-21 even in countries highly reliant on nuclear power, like Hungary and France.

Poland has the potential to use renewables much more extensively to enhance its energy security as its wind and solar generation was just 11% in 2020 and 2021. PSE has said[24] it is preparing for 50% renewable electricity in Poland by 2032.

Figure 14: Wind and solar share of generation 2016-2021, select European countries



Source: BloombergNEF.

The Polish grid is already preparing for shut down of other lignite plants. The Patnow, Konin and Adamow plants, located some 100-150km from Belchatow are to be gradually shut. Some 1.3GW of these have already shut, with another 1.2GW due for closure by 2029 at the latest. This generation will be at least partially replaced as 1.4GW of new gas and renewables projects have already applied for grid connection permits around Patnow, Konin and Adamow, according to

24 Draft development plan for meeting the current and future electricity demand for 2023-2032 (link, in Polish)

PSE.[25] Shutting a few units at Belchatow within a similar timeframe is possible so long as adequate adjustments to the grid are made and replacement generation is developed on time.

Today, variable renewable energy typically does not offer grid services for frequency regulation and voltage control. This is likely to change by 2030, however. British transmission system operator National Grid started contracting grid stability services from renewable energy generation in February 2022.[26] Subsequently, contracts for reactive power and constraint management services have been awarded to wind farms. New technological solutions are also emerging. So called grid-forming controls can be applied to wind turbines to set up desired frequency and voltage, according to trials by the US National Renewable Energy Laboratory.[27] Solar power can best provide grid services if paired with energy storage. Read more about energy storage below in chapter *3.5 Firm and flexible capacity alternatives.*

Grid inertia

"Inertia" is one aspect of a stable power system that existing variable renewable energy technologies cannot effectively replace. Inertia refers to the reserve energy stored in spinning turbines that serve the grid. Thermal generation provides synchronous power generation with turbines spinning at the desired frequency. Replacing the Belchatow lignite plant with non-synchronous capacity, such as wind and solar would reduce grid inertia. To maintain the appropriate level of inertia, existing turbines from the lignite plant could be used as so-called synchronous condensers. This means the old turbines would be repurposed and use small amounts of power from the grid to spin instead of burning lignite to generate power.

Synchronous condensers[28] (also called synchronous compensators) are well-used on many European grids. In the UK, where wind provides a high share of power generation, two gas turbines were converted to synchronous condensers in 2021. UK grid operator National Grid offered a 6-year stability contract to the former power plant where the turbines are located for providing the service.[29] This contract made it profitable to convert the turbines. PSE's latest grid consultation plans to spend 85 million euros (400 million PLN) on new synchronous compensation devices before 2032.

Batteries can also react within seconds to adjust grid frequency. Read more about energy storage grid services and firm capacity alternatives in section *3.5 Firm and flexible capacity alternatives*.

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[25] Transmission grid operator Polskie Sieci Elektroenergetyczne: Grid plan consultation (link)

[26] National Grid ESO: Landmark moment as renewables get 'green light' to support the grid (link)

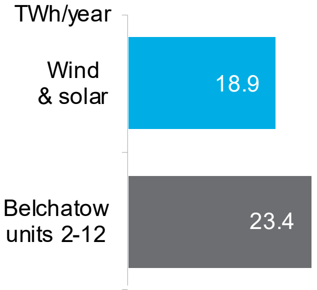
[27] Landmark Demonstration Shows How Common Wind Turbine Can Provide Fundamental Grid Stability (link)

[28] ENTSO-E Technopedia: Synchronous Condenser (link)

[29] Deeside Power Station begins world first power system stability contract with National Grid ESO (link) and Scotland's wind success story bolstered by £323m stability investment (link)

3.4 Variable renewables

Figure 15: Optimal solar and wind generation vs. old lignite



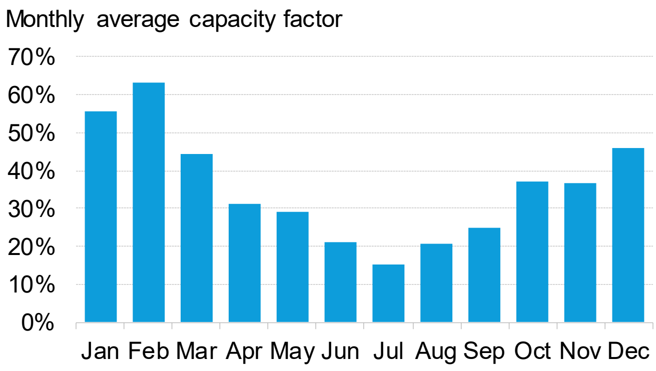
Source: BloombergNEF, PSE

Annual wind and solar generation could replace 80% of Belchatow's 2021 lignite generation, based on local weather patterns and land availability. The optimal combination to best exploit the current 5.1GW grid connection would be 5.7GW wind and 5GW solar PV. BNEF calculates this combination would result in the highest economic value as measured on a net present value basis.[30] Belchatow's oldest units are likely to close first and could be replaced by renewable energy before 2030. Should the 11 older units with a 4.2GW grid connection close first, they could be replaced by some 4.8GW of wind and 4.2GW of PV.[31] This capacity could replace 80% of the electricity produced by Belchatow's older 11 units, producing between 18-21TWh per year, depending on the weather.

An additional 900MW of wind and 800MW of solar would be optimal for the grid connection of the newest 860MW unit, once that is shut down. That would bring total wind build in the area to 5.7GW and solar build to 5GW. Even if land-use is restricted to 50% less wind and 30% less solar, these technologies could replace half of Belchatow's generation. The sections *Solar PV* and *Onshore wind* below provide details on the technical potential of these technologies.

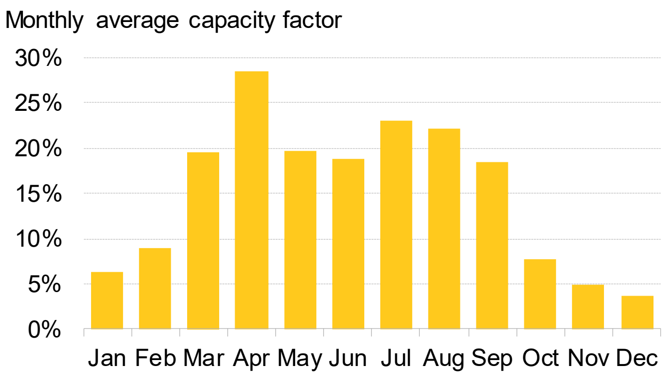
A wind and solar combination has the potential to create a better overall generation profile than either technology could on its own (Figure 16 and Figure 17). Oversizing and combining wind and solar capacity relative to the grid connection can smooth output. Wind alone would generate at a low output for more than half the hours over a year.[32] The profile for PV alone looks even worse, with low output for three quarters of the hours in a year. Combined, however, solar and wind generation drop to almost zero less than 10% of the hours.

Figure 16: Projected wind power average monthly capacity factors based on Belchatow weather data



Source: BloombergNEF. Note: capacity factors based on a 2.5MW wind turbine with 126-meter hub height.

Figure 17: Projected solar PV average monthly capacity factors based on Belchatow weather data



Source: BloombergNEF & PVGIS

30 Net Present Value represents the project's equity cash flow from the start of development to the end of operation, discounted at an internal rate of return level (IRR) of 6%.

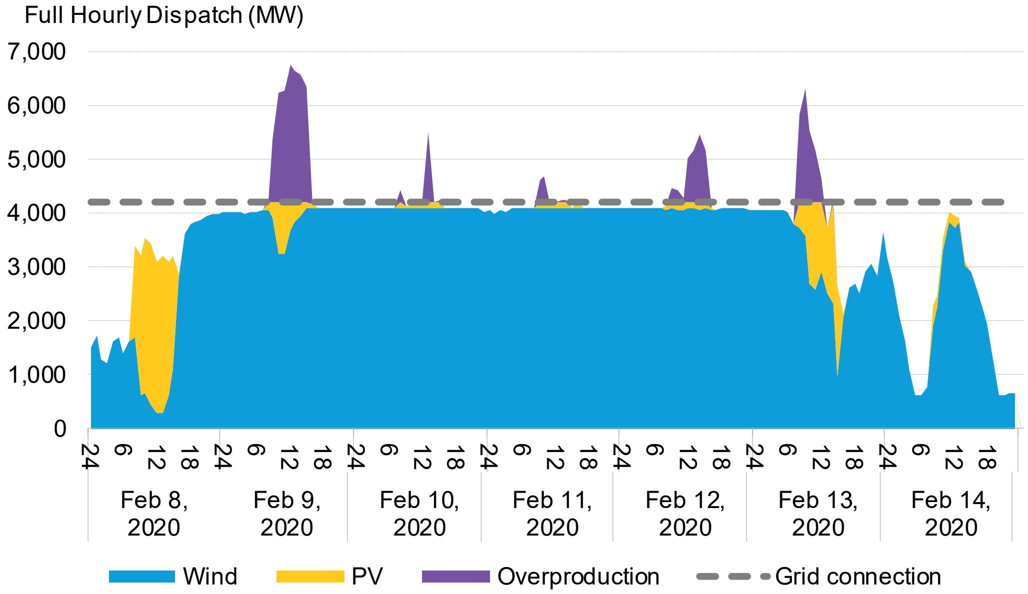
31 This calculation assumes a mix of tracking and fixed axis solar PV. The rated capacity of solar is given in direct current (DC), and usually 20% higher than the inverter's alternating current (AC) capacity.

32 Analysis based on weather patterns over 2017-2020. Low output is defined as below 20% of maximum output.

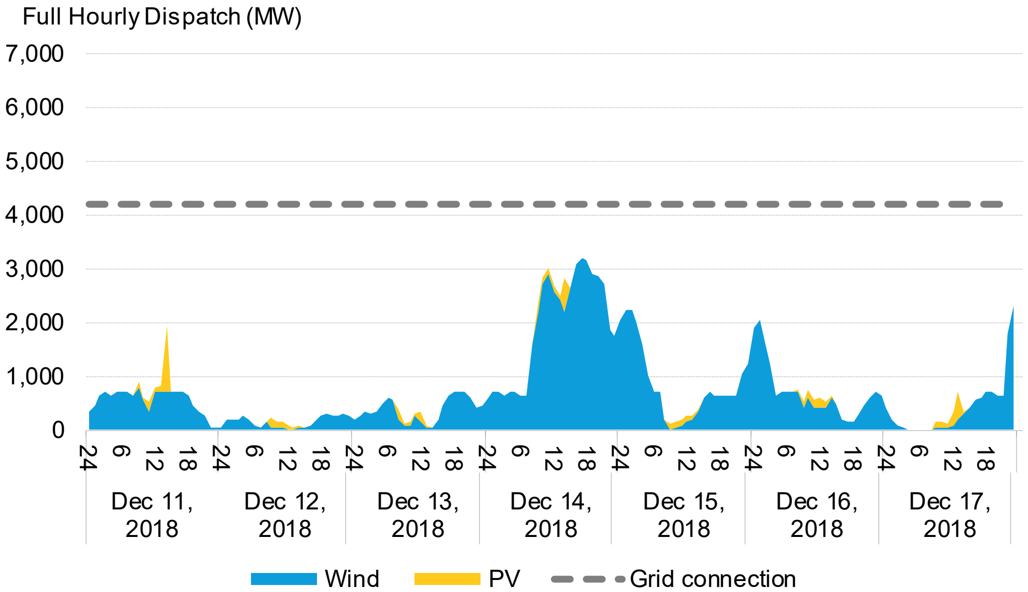
Oversizing and combining wind and solar capacity relative to the grid connection can also smooth output. If 9GW of wind and solar capacity were added at the site of the older Belchatow units' 4.2GW grid connection, 94% of power produced during a year could be exported to the grid. Adding a 300MW battery would increase the share of export to the grid to 95%. Combined solar and wind generation drop to almost zero for less than 10% of the time. Figure 6 shows how a week of high or extremely low renewable energy output in this location could look like.

Figure 18: Renewable energy generation and a 4.2GW grid connection usage

Example week with high generation



Example of lowest weekly generation over 5 years

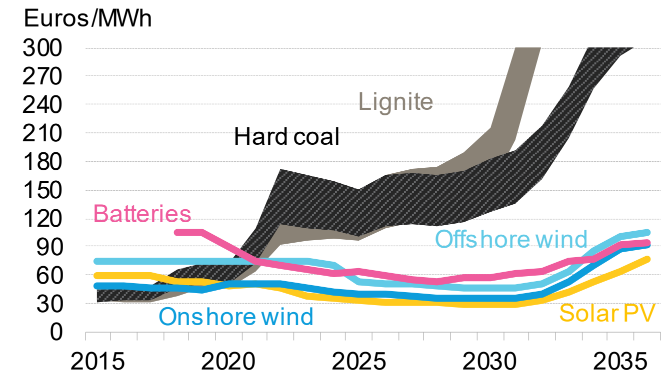


Source: BloombergNEF

Even if small amounts of surplus generation can't be accepted by the grid and must essentially be discarded, the levelized cost of wind and solar remains competitive with most other energy generation technologies. Figure 19 shows that the marginal cost of renewable energy and batteries remain well below that of coal, even when accounting for curtailment.

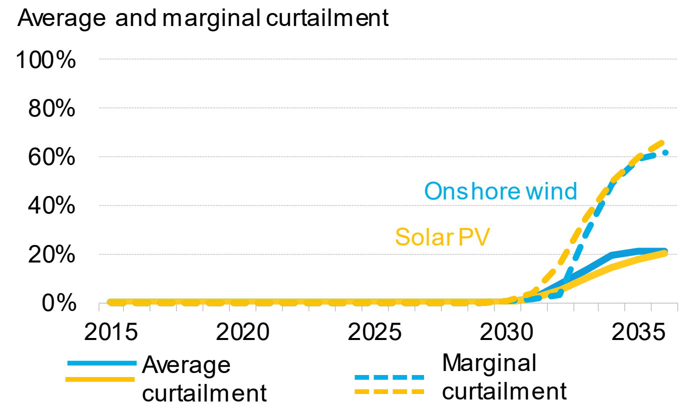
The cost of solar and wind generation start approaching that of coal and lignite only if more than 30% of generation is curtailed. This does not happen for wind in BNEF's outlook, but marginal[33] PV costs could rise sharply after 2040 if it provides more than a quarter of Polish generation.

Figure 19: Marginal LCOE of renewables with curtailment vs. average cost of hard coal and lignite, Base Case



Source: BloombergNE. Note: Renewable costs on a levelized cost basis increase as curtailment reduces run time, spreading costs over fewer hours

Figure 20: Modelled marginal and average renewable energy curtailment in Poland, Base Case



Source: BloombergNEF

Demand can become better at adapting to times of surplus generation, and new economic activities might emerge to make use of the hours of cheap electricity. Power systems and markets can be designed to account for solar and wind generation to periodically exceed demand. Accompanied by appropriate grid investments to support more flexible demand, the levels of curtailment modelled in the BNEF base-case scenario for Poland may not materialize (Figure 20).

It is worth noting that the wind and solar costs could rise in the future if much generation cannot be exported to the grid (Figure 19). However, BloombergNEF modelling shows that because of falling capital expenditures, solar and wind will continue to have the lowest LCOE even if some generation is effectively wasted.

Variable renewables can also offer grid services to manage voltage or frequency. Wind and solar can already bid into Polish capacity markets, albeit with heavy de-rating factors. Polish law stipulates that wind farms can only bid into the capacity market with an assumed availability of 15.3%. The capacity market does not yet recognize that wind combined with solar could achieve better availability, but this could change in the future. See section *Firm and flexible capacity alternatives* for more on technologies that can complement wind and solar.

[33] The marginal LCOE shows the cost of adding new generation capacity. If most of the output by the new capacity is curtailed, its average cost/MWh will be very high as it adds very few MWh of new production. Marginal curtailment is a theoretical measure, showing curtailment of the last added generation unit. If marginal curtailment is 80%, it means that only 20% of the theoretical output of a generation unit will be useful for meeting power demand.

Table 1: Advantages and challenges of wind and solar

	Solar	Onshore wind
Advantages	**Favorable economics.** Solar is the cheapest source of energy in Poland on an LCOE basis. **Few permitting issues.** Solar rarely faces strong local opposition and projects generate no noise.	**Favorable economics.** Onshore wind is the second-cheapest generation technology in Poland as of 2022 and some wind projects can match the economics offered by solar.
	Clear business case. Solar is supported financially through the existing renewable auction scheme, which is scheduled to run until 2027. The auctions provide revenue certainty which also tends to lower project financing costs.	**High capacity factors during winter**. Wind output is typically higher during the winter, which coincides with high power demand. This is a huge advantage, as heat pump installations are growing in Poland and heating needs are often high in the winter. Onshore wind can also take part in Poland's renewable energy auctions, scheduled to be held until 2027.
Challenges	**Uneven generation profile.** Solar generation is lower in the winter when power demand is often high. Solar also generates only during the day and does not help meet electricity demand during evenings. **Significant land-use**. Ground-mounted, utility-scale PV is the cheapest source of solar energy. However, this requires significant amounts of land which cannot be used for other purposes. Rooftop solar is somewhat costlier due to higher installation costs. **Land requirements.** Must be on flat land or south-facing slopes, away from trees creating shade.	**Minimum distance rules and permitting.** The existing "10H-rule" makes it almost impossible to build new onshore wind around Belchatow, but the planned change to a 500-meter minimum would unlock opportunities. There is still a risk that municipalities will be slow to adopt the new rule due to local opposition.
Innovation opportunities	**Floating solar on artificial lakes.** The old lignite mines will flood and become artificial lakes at some point after 2040. **Agri-solar**. Solar can be co-located with some specific types of agriculture. Systems can be situated on rooftops of barns, greenhouses and other farm buildings. Plants preferring shade, such as certain berry bushes, can also grow under solar panels.	**Large-scale turbines and economics of scale.** Onshore wind is a mature technology but installing larger turbines at higher heights means that projects can achieve economies of scale. Recent innovation includes using less energy intensive materials for turbine construction. New technologies enable wind turbine ramp rates to be controlled which reduce rapid fluctuations that are challenging for the grid.

Source: BloombergNEF

Solar PV

Electricity produced by PV is about 50% cheaper than that of lignite, even if Poland is not among the sunniest countries in the world. Solar systems generate only during the day, which means that the power grid needs sufficient flexibility to cope with the variation in output. Potential solar generation in Belchatow could reach especially high capacity factors during summer months (Figure 17).

Solar panels fitted on an axis that tracks the sun can achieve slightly better generation profiles than fixed panels. Fixed-axis panels in Belchatow would achieve annual capacity factors between 11-12%, depending on the weather year. This rises to 14-15% for single-axis tracking panels.

Belchatow is a suitable location for solar, but grid-scale projects require significant space. The best locations are either on flat land or south-facing slopes. Therefore, the shaping of the landscape during post-mining land reclamation will be of great importance for solar power suitability in Belchatow. The deepest points of the Belchatow and Szczercow lignite fields will be flooded with water once mining ends. However, it is possible to reclaim the land on the shallower edges of the open-cast mines and repurpose this land for solar plants.

BloombergNEF estimates that the south, south-west and south-east facing slopes of the retired mines could accommodate at least 1GW of solar PV. The 3,367km^2 large area around the Belchatow mines and power plants, as defined in the TJTP, could accommodate up to 5GW of solar, if 2.5% of land is dedicated for this purpose.[34] This level of land-use could be possible if installing a mix of rooftop and ground-mounted solar. More conservative land-use at 1.7% would allow for 3.6GW of solar. This shows that PGE could go significantly beyond its current plan to build 600MW of solar at Belchatow.

Onshore wind

Wind resources in the Belchatow region are generally good, ranging from 5-8 meters per second at 100 meters height, depending on location. Only the coastal regions in the north of Poland achieve higher average wind speeds.

Wind has a significant opportunity to displace lignite generation as its capacity factors are much higher than those for solar. Average annual capacity factors in Belchatow are estimated to range between 27-35%, depending on the exact location and turbine heights. Wind speeds tend to be higher during the winter, which coincides with higher power demand in Poland. Over 2016-2020, the average capacity factor for wind was above 50% for December-February. High wind generation potential during these winter months could become especially important as heat pump adoption in Poland increases.[35]

The Lodz Voivodship already has over 350MW[36] of onshore wind capacity installed, with Belchatow's nearest wind farms being the 30MW Kamiensk Hill and the 6MW Ekopal Rzasnia projects. The region's highest turbines, which tend to generate most, are around 200 meters tall.

The primarily obstacle to more wind development in Belchatow is permitting and minimum distance rules. The local municipalities (gminas) will soon have the power to reduce the legal minimum distance between residential buildings and wind turbines to 500 meters once parliament (Sejm) approves the government's proposed changes to the existing "10H-rule". That rule requires a turbine be located no closer to a home than a distance equivalent to 10 times the turbine's blade at maximum heigh. This can result in turbines being barred from being built less than 2km the nearest home.

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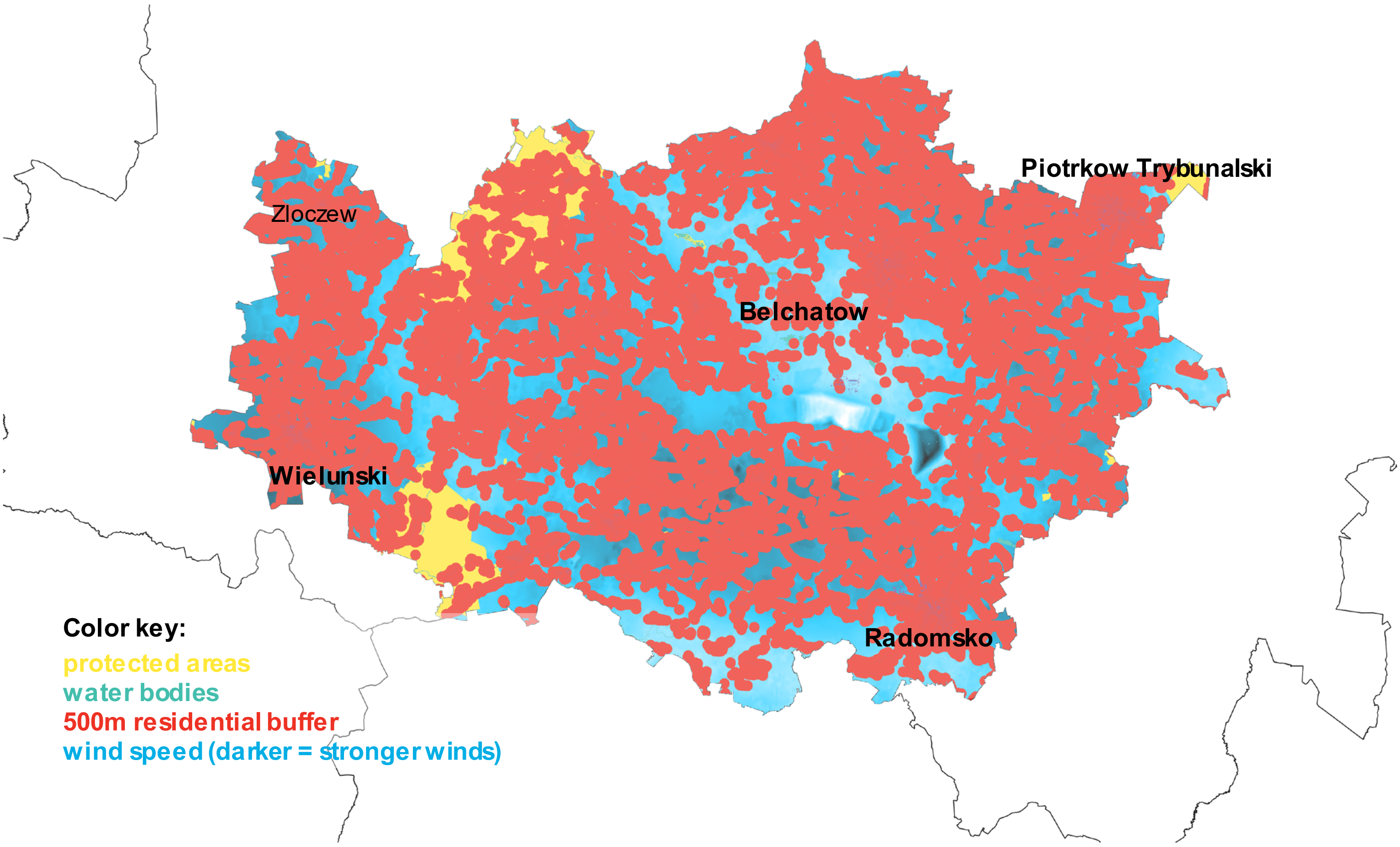
34 For comparison, renewable energy in all of Germany is expected to cover 2.5% of land by 2032, and the government is committing 2% of land to onshore wind by 2032. For more, see "Wind-an-Land-Gesetz" (link)

35 Poland country profile of heating sector energy transitions policy is available to BloombergNEF and Bloomberg Anywhere clients (link)

36 Data according to Polish government's *List and map of wind farms in the Łódź Voivodeship* (link)

There is land available for 5-15GW[37] of onshore wind to be built in the area defined in the Belchatow area's TJTP, which includes all municipalities that are clearly impacted by a reduction in Belchatow's lignite generation. The area spans some 3,367km2. However, the potential for wind build can only be unlocked once the new minimum distance rule has been included in Local Spatial Development Plans (land-use plans) of all the relevant *gmina*. There are 35 municipalities in the defined area. Cooperation between neighboring municipalities in adopting the new minimum distance rules in their local land-use plans will be crucial in ensuring that wind power potential in the region can be realized.

Figure 21: Belchatow region with constraints for onshore wind development and average wind speeds



Source: BloombergNEF, Geoportal.Gov.PL

A key benefit of wind projects is that they can be co-located with other land-use. The example of Kamiensk Hill, where turbines operate alongside a nearby ski slope, shows that wind power can successfully be combined with recreational areas. Wind turbines can also be co-located with agriculture.

[37] The range of wind potential depends on power density, which is a function of turbine capacity and spacing, both of which are a function of the landscape and wind resource (amongst other things)

3.5 Firm and flexible capacity alternatives

"Firm" capacity generally refers to power-generating resources that can produce power at desired quantities at specified times. Capacity that can start generating on short notice is generally regarded as "flexible". The Belchatow lignite power plant provides firm capacity but not great flexibility. The benefit of thermal power plants like Belchatow is that they provide inertia for the grid, with turbines that spin at the right frequency. Nuclear, hydropower, gas and coal power plants are traditional providers of grid inertia. For more about grid inertia see section *3.3 Belchatow's role on the grid*.

Belchatow's lack of flexibility will not serve it well as the Polish power system evolves. Based on typical lignite plant characteristics, Belchatow needs at least four hours from start-up to the point when it can produce at full output. Once a generation unit is running at full speed, it typically needs to generate for at least eight hours. For comparison, the startup time is only 60 minutes for an efficient combined-cycle gas turbine (CCGT) and only 15 minutes for a peaking open-cycle gas plant. Variable renewable energy in Poland is already growing, and as offshore wind starts generating post-2027, opportunities for flexible power plants will become more prevalent and increasingly important to the system. Batteries could provide flexibility to complement renewables and offer grid stability services.

The alternatives for thermal generation in Belchatow before 2030 are primarily limited to natural gas, bioenergy and energy-from-waste. Other options, such as nuclear, are described in section *3.6 Options post-2030*. A gas power plant could be supplied by natural gas or bio-methane, but the Belchatow lacks pipeline infrastructure. Batteries could provide flexibility to complement renewables and offer grid stability services.

Energy storage

Grid-scale batteries can help compensate for the loss of firm capacity, as the units of the Belchatow power plant start shutting down. Batteries deployed at Belchatow could provide grid services to be procured by PSE and could serve to smooth onsite renewable energy generation across different hours of the day. In theory, a 1GW or larger battery could boost the net present value of the 5.7GW wind and 5GW solar projects described in chapter *3.4*, if daily fluctuations in Polish power prices remained similar to those seen in 2021. In practice, however, battery projects are rarely that large. The world's largest battery, as of September 2022, is a 400MW project in California.

Batteries are most valuable in markets where prices fluctuate most and Poland is expected to see greater variability in coming years as more renewables join the grid. A solar-plus-storage plant operating at Belchatow could charge up during daytime hours if power prices are low, then discharge (and sell) power during the higher-priced evening hours instead. Batteries can also benefit from other revenue streams. A 200-500MW lithium-ion battery system would be feasible at Belchatow, especially if the project is supported by the capacity market or can earn revenue for grid services. Such a battery would potentially be Europe's largest on the grid.

Battery storage is set to benefit from increased access to grid service markets

Poland's battery market is currently quite small, with four grid-scale projects operating totaling 34MW. Another 6MW is in the pipeline. However, demand in is poised to grow rapidly thanks to an improved policy environment. As a start, in 2021 Poland implemented legislation simply to avoid batteries from having to pay taxes both when charging and discharging.

Polish energy storage projects can potentially benefit from contracts under Poland's capacity market though that has yet to occur so far. In 2021 such contracts were awarded to gas and biomass power plants instead. That could change in future rounds, however, as fewer gas projects submit bids. The Polish renewable energy auction legislation also enables support for hybrid renewable projects, which can also include battery storage.

Batteries are well-suited for providing grid stability services. Grid operators across Europe procure these services on ancillary service markets, where different technologies can bid to secure payment contracts. Batteries have been successful in securing contracts for different frequency regulations services for competitive prices. Batteries are well suited for Frequency Containment Reserve (FCR) that needs to be activated within seconds and automated frequency restoration (aFRR) that is typically activated in less than five minutes. However, Poland's grid operator PSE is less advanced in procuring grid services from batteries than others elsewhere because coal plants still provide many of these services. However, Poland will be joining the common European aFRR market in 2024. This can provide additional revenue streams for batteries. PSE might also start allowing batteries to provide these ancillary services by 2030.

Lithium-ion batteries is cheapest source of energy storage

The most common energy storage technology for newly built energy storage projects in Poland is lithium-ion batteries. Utility-scale lithium-ion batteries are economically competitive for short discharge durations, typically below four hours, and are cheaper than most other storage technologies, even when they store the energy for up to 8 hours (Figure 22).

In the immediate term, lithium-ion is the technology of choice at Belchatow due to its comparative low cost and availability. Belchatow owner PGE has said it seeks to build a 200MW/820MWh lithium-ion battery in the north of Poland (Zarnowiec) to help integrate more wind energy to the grid.[38] While it has yet to secure EU support for that battery, it could seek to build a similar project at Belchatow.

As thermal generation in Poland falls, PSE could soon begin compensating batteries for providing grid services which could make subsidy-free battery investments viable. Lithium-ion batteries would also add economic value to renewables projects, especially when paired with solar PV that generates only during the day. However, they are less helpful if renewable energy output is low for several days. This leaves room for additional energy storage technologies. The deployment of a lithium-ion battery system at Belchatow would not exclude the option of adding long-duration energy storage in the 2030s, once Belchatow's last units have closed (Figure 22).

The most established long-duration energy storage technology (suitable for over six hours of discharge) is pumped hydro. Poland has six large pumped hydro storage plants with a total capacity of 1.4GW. However, Belchatow does not currently have a lake or other suitable body of water for pumped hydro. The chapter *3.6 Options post-2030* discusses the future possibility of building pumped hydro once the former lignite mines are flooded with water sometime after 2040.

Underground compressed air storage is the second-cheapest long-duration storage technology – but only if the air can be stored in underground caverns. However, there are no suitable caverns for compressed air in Belchatow and above-ground compressed air needs large tanks, which explains why their capex costs/kwh tend to be 30-300% higher than for below-ground projects. Other storage technologies, such as liquid air, flow batteries and gravity storage are generally not yet cost competitive. However, subsidies could potentially alter this.

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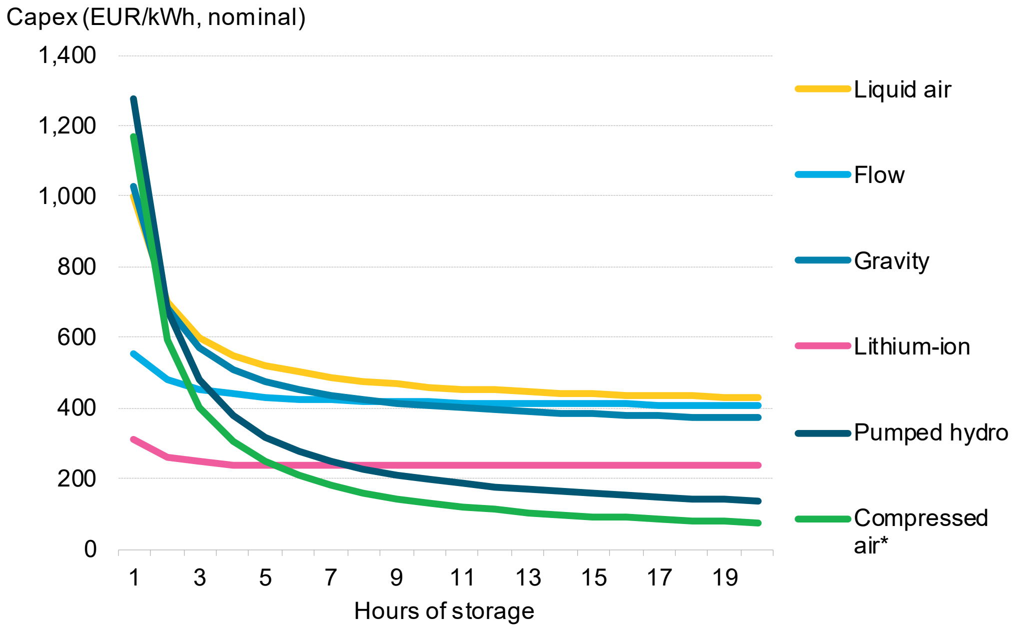
[38] PGE Group will build the largest energy storage project in Europe (link)

Figure 22: Capex and duration of energy storage technologies



*Source: BloombergNEF, NREL, Jacobs U.K, PNNL. Note: *Compressed air cost reflects projects with underground storage. Energy storage costs vary widely depending on geographical location and geological constraints. Above chart shows the typical costs in 2021.*

A project that that employs one of these new storage technologies at Belchatow could potentially qualify for grant support from the EU. Already, Polish utilities Tauron and Enea have received EU funding for storage projects on distribution grids and to test different technologies. The EU Innovation Fund has also supported new battery manufacturing capacity in Gdansk, raising the possibility that Belchatow could install a domestically-made battery that uses innovative technology.

Thermal power plant

Belchatow might never again need large-scale thermal power plants, if sufficient renewable energy paired with adequate storage can be built. However, a thermal plant has the added benefit of producing heat, which can serve local homes and businesses. The Belchatow lignite plant currently provides around 0.6TWh (2 million gigajoules) of heat to the town of Belchatow.[39]

A replacement thermal plant could also act as back-up when local renewables generation falls. BNEF modelling shows that as renewable energy output grows, the Polish power system will need greater flexibility. By 2035, most of the country's thermal power plants are likely to generate power at annual average capacity factors below 50%. This means that thermal plants that are not CHP plants are likely to serve as back-up generators rather than baseload providers.

[39] Heat plant capacity requirement depends on the assumed difference between average daily heat demand and peak daily heat demand during extreme winter colds.

Table 2: Advantages and challenges of alternative thermal power plants

	Gas-fired CHP plant	Gas-fired peaker plant	Energy-from-Waste	Biomass
Advantages	**High efficiency.** CHP efficiency reduces cost and emissions Provides both power and local district heat	**Ideal for balancing renewables output.** Rapid response times can help stabilize grid during changes in renewables generation	**Locally available fuel.** **Suitable for CHP**, providing heat and power	**Renewable energy** with low emissions **Suitable for CHP**, providing heat and power
Challenges	**Expensive gas grid connection.** Not suitable for rapid renewables balancing	**Expensive gas grid connection.** **Lower efficiency** makes baseload generation costly	**Limited fuel** supply as reliant on local waste **Limited in size**, typically below 30MW **Misaligned with EU recycling strategy.**	**Sourcing sustainable biomass.** Imported wood pellets can be unsustainable, but local supply and waste biomass is limited
Innovation opportunities	**Use biogas blend** to lower emissions. **Conversion to hydrogen.** **Co-locate with large heat pump** for better balancing abilities.	**Use biogas blend** to lower emissions. **Conversion to hydrogen.**	**Alternatives to direct combustion.** Anaerobic digestion or waste gasification to make synthetic fuels are considered more sustainable alternatives.	Using biomass waste streams, such as straw from agriculture or sawmill dust and scraps Carbon capture and storage for negative emissions.

Source: BloombergNEF

BNEF expects that thermal power plants would replace less than 15% of Belchatow's current generation. If a thermal plant is built primarily to satisfy local heating needs, only 2-3% of Belchatow's power generation would be replaced. A CHP plant of less than 130-190 MWth and an electrical capacity of less than 70-100MW would be enough to meet local heat demand.

Renewable energy is set to remain significantly cheaper than both biomass and natural gas, despite gas prices recovering to pre-pandemic levels. Belchatow is not connected to the gas transmission grid and connecting a gas power plant larger than 500MW could prove very challenging. Energy-from-waste plants are typically 50MW or smaller and are limited by locally available waste streams.

Industrial-scale heat pumps as an alternative to CHP plants

A large-scale heat pump can contribute to the stable operation of the power grid, even if it consumes electricity rather than produces it. This is because it can be operated as highly flexible demand. In a modern, insulated district heating network the pipes can act as storage of hot water. This provides some flexibility in when to operate the heat pump, and production of more heat can be delayed or accelerated by a few hours to better follow patterns of renewable energy production.

The heat pump technology is already familiar to many homes in Poland, but large-scale heat pumps can also be installed to produce heat for district heating networks. This is more efficient as it does not require many homes to install a new heating technology. Many homes in the town of Belchatow are currently served by district heat from the Belchatow lignite plant.

Heat pumps run on electricity to produce heat by extracting heat from the environment. The efficiency of this technology means that it is possible to create 3-4 times more heat with a heat pump than with a standard electric radiator. Large-scale heat pumps can even provide heat for high-temperature networks of 90°C. For example, Helsinki, Stockholm and Rotterdam have installed large-scale heat pumps to decarbonize their district heating networks.

Building a gas power plant at Belchatow

Poland has around 4GW[40] of new gas power plants planned to come online before 2030, supported by the capacity market, in addition to 3GW of existing gas power plants. The key benefits of building a new gas power plant in Belchatow is the efficiency and generation flexibility of this technology. The capacity market is also providing support for gas turbines, which means that they can be profitable even at limited running hours per year.

The key challenges for relying on gas as a replacement to lignite in Belchatow lie in the lack of gas infrastructure in the area, volatile gas prices, the historical reliance on Russia for supply, and long-term transition risks such as the need to transform the gas power plant to run on zero- or low-emissions fuels. Alternative fuels such as green hydrogen or biomethane can be blended with or replace natural gas, contingent on appropriate infrastructure and asset compatibility.

There are several types of gas power plants, each with different potential benefits and use cases. The most common are combined cycle gas turbine (CCGT), combined heat and power (CHP), open cycle gas turbine (OCGT) and reciprocating engine.

CCGTs benefit from a typical efficiency of 60%. This high efficiency can be achieved due to a combination of a gas and steam turbine. Modern CCGT plants can provide good flexibility, with start-up times of just 60 minutes. This means that they can be turned on with little notice and even out fluctuations in renewable energy generation. However, efficient CCGT plants have a relatively high capex which makes them expensive if they only run for a few hours per year.

Adding combined heat and power (CHP) functionality to a CCGT can increase the efficiency to 85%, meaning less than 15% of the fuel's energy potential is lost. A CHP plant can be either a CCGT plant or only a steam power plant, with steam turbines being the cheaper option for a plant producing primarily heat. Belchatow already has a district heating network heated by the lignite plant. However, the local heat need is quite small at around 0.6TWh per year, so a CHP plant with less than 70-100MW electric capacity would be sufficient. Adding more electric capacity than this would reduce the efficiency gains of CHP.

Open-cycle gas turbines (OCGT) and reciprocating engines are best suited for intermittent generation, ramping up only to meet demand peaks or when renewable generation drops. Both technologies can ramp up within 15 minutes, with reciprocating engines being able to respond within as little as two minutes. OCGTs have lower efficiency, often less than 35%. Reciprocating engines have similar efficiency, but often require more maintenance than an OCGT. These power plants have lower capex costs than CCGT plants.

Risks to natural gas supplies

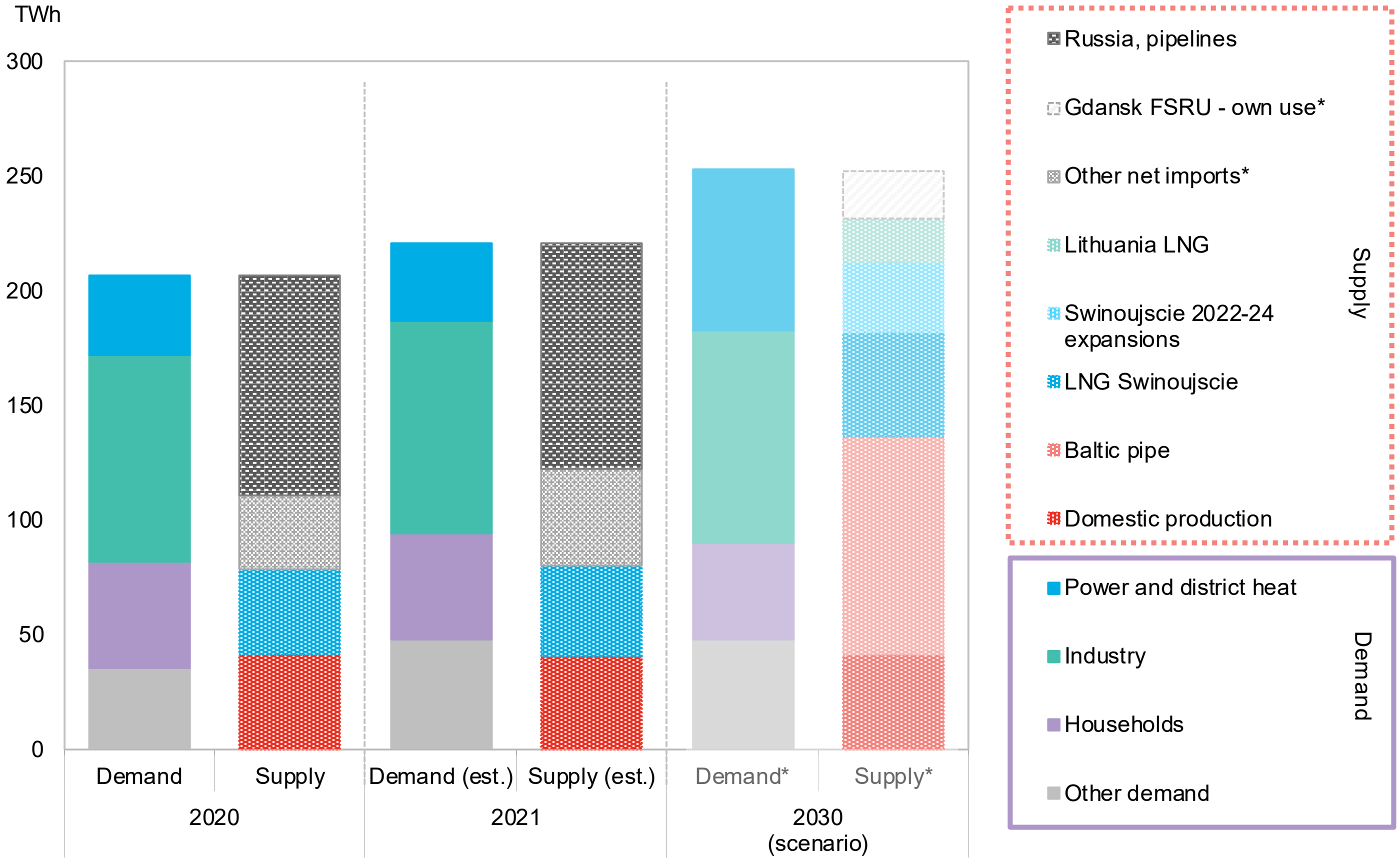
Investing in a new gas power plant at Belchatow might seem risky choice when Europe is suffering from an energy crisis caused by a drop in gas supplies from Russia. Prior to the current war, about half the gas Poland consumed originated from Russia, but the country started preparing several projects to diversify its gas supply even before 2022. Because of this, Poland

[40] Ostroleka C, Dolna Odra, Grudziadz and Adamow have secured capacity market contracts. Other projects have also been announced but investment decisions are not finalized.

could theoretically double the volume of gas it burns in the power sector by 2030 – without relying on Russian imports. This means there would be enough gas for a new plant at Belchatow.

In the short term, Poland is filling its annual 19-21Bcm[41] demand with domestic production, piped Norwegian gas and liquified natural gas (LNG) imported from overseas. Longer term, the technical potential for biogas or bio-methane production is around 2Bcm, according to a 2015 study.[42] However, Poland's potential for greater gas consumption in the power and district heating sectors is limited by its LNG regasification capacity.

Figure 23: Polish gas supply and gas sources, historic and future scenarios



*Source: BloombergNEF, Eurostat. Note: *The 2030 demand and supply are scenarios. The supply side accounts for gas pipeline and LNG projects that have received a formal investment decision or are under construction. LNG terminals are assumed to operate with an 80% utilization. Other net imports is assumed to be at zero in the 2030 scenario. Household gas demand is assumed to decrease by 10% because of energy efficiency improvements, whereas power sector gas burn is assumed to double.*

Polish annual gas burn in the power sector could range from as low as 3Bcm to as high as 9Bcm per year over 2030-2036, BNEF projects.[43] The higher end of the range assumes gas prices would fall from current record highs to pre-pandemic levels by 2030. Even with a potential doubling in gas burn in Polish power plants, we do not anticipate a gas shortfall assuming key

41 Gas demand in 2020-21 was around 20Bcm but is expected to fall to around 19Bcm in 2022.

42 Biogas production in Poland—Current state, potential and perspectives, 2015 (link)

43 Assuming total gas fleet in Poland of 8-15GW with annual capacity factors of 20-50%, as gas power plants take on the role of back-up generators.

LNG infrastructure, such as the Gdansk Floating Storage and Regasification Unit (FSRU), progresses as planned. Should all new LNG infrastructure get completed on time, Poland will have enough gas to export to neighboring countries.

Expanding the 5Bcm Swinoujscie LNG terminal by an additional 3Bcm/year will be critical.[44] Qatar is expected to boost exports starting 2026, which should ease pressure on prices. With global LNG production rising and its plans for new LNG terminals, Poland should be able to source the gas it needs for its power sector by 2030.

Getting the gas to Belchatow

While the overall volume of conventional natural gas supply in Poland could match overall demand by the end of this decade, it is far from clear that Belchatow specifically would have sufficient access to gas to justify a gas-fired plant, given the lack of pipeline infrastructure in the region. To date, the gas transmission grid operator Gaz-System has made little effort to investigate the potential for expanding the gas grid to the site of the current Belchatow power plant.

There is today a local gas distribution grid in Belchatow, but it does not have high enough flow or pressure to support a gas-fired power plant. Polish gas distribution company Polska Spolka Gazownictwa (PS Gaz) offers gas connections for industrial customers in Poland, and is evaluating a potential 500-diameter (20-inch) pipeline through the town of Belchatow.[45] However, this would not provide enough gas for a local 100MW CHP plant, according to a PS Gaz spokesperson.

Typical costs for a new gas pipeline range from 0.9-2 million euros per kilometer. The upper range of this is for pipelines that are ready to transport 100% hydrogen. Compressors maintaining sufficient pressure and flow would add approximately 15% to the total cost. Belchatow could be connected to different points of the gas transmission network, depending on the required gas pressure, technical feasibility and potential future plans of green hydrogen transportation, in line with Poland's hydrogen strategy.[46]

A pipeline that would potentially connect a gas-fired power plant at Belchatow to the gas transmission grid could be as short as 20km or as long as 200km, depending on which connection point can provide sufficient pressure and gas flow. Such a line could cost as little as 30 million euros or as much as 400 million.[47] The low end of this range is unlikely as the section of the transmission grid closest to Belchatow would have insufficient gas supply even for a 100MW gas power plant. Because of this, a pipeline of some 100km is more likely, costing at least 30% of the typical capex of 360 million euros for a 500MW combined-cycle gas turbine. A detailed study by Gaz System is needed to obtain the exact cost of building out the gas grid.

In terms of alternative sources of gas relying less on a national pipeline network, bio-methane or green hydrogen could in theory be produced locally or nearby. But these sources would almost certainly be insufficient to ensure steady generation at a 100MW or larger plant.

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[44] The assumed inflow of LNG is not the same as a terminal's rated capacity, as LNG terminals cannot reach 100% utilization rates, because of maintenance needs and the logistics around LNG cargos.

[45] Construction of a high-pressure gas pipeline MOP 6.3 MPa DN500 from Kalisz - Sieradz - Piotrków Trybunalski (link)

[46] Polish Hydrogen Strategy Until 2030 With An Outlook Until 2040 (pdf link).

[47] This figure does not account for potential changes needed to the transmission grid beyond building a connection pipeline to Belchatow.

Securing investment for a gas transmission pipeline to Belchatow might prove challenging, but the case for investment might be stronger if the pipeline route can be optimized for future flows of green hydrogen. We examined this more closely in section *3.6 Options post-2030.*

Transition risks for a new gas-fired power plan

Even if the challenges of connecting to the grid can be overcome, a new gas-fired power plant runs the risk of becoming a stranded asset given the EU's goal of achieving net-zero emissions target by 2050. The typical lifetime of a gas-fired power plant is up to 30 years.

Stranded asset risk could potentially be mitigated should the plant seek to run on some form of zero-emissions fuel and blending conventional natural gas with green hydrogen or biomethane could cut emissions. New gas turbines are currently estimated to be able to handle hydrogen blend rates of up to 50%, with the share expected to rise to 70-100% by 2030. To date, however, no turbine that can run on 100% hydrogen is in commercial use.

Ultimately, a gas-fired power plant might not be needed at Belchatow, if enough renewable capacity along with a district heating system powered by waste-to energy, biomass or an industrial-scale heat pump. Should the grid operator determine the site needs more firm capacity, hydrogen-ready gas power plants to produce district heat and provide flexibility would likely be preferable. This could be, for example, a 70-100MW CHP unit and a 50-200MW flexible peaking gas unit, which can act as back-up when local renewable energy output is low. Peaking power plants tend to be optimal for lower capacity factors because of lower capex, but higher running costs. Determining the optimal size of the plants will depend on renewable energy build onsite, as well as detailed evaluations of the cost of connecting the site to the gas grid. Any pipeline investments should also be hydrogen-ready.

Energy-from-waste or biomass

This section briefly examines key considerations for building a power plant burning solid fuels such as municipal solid waste[48] or biomass at Belchatow. Each has potentially limited impact in replacing local lignite power generation as biomass plants tend to be small in scale and optimized for district heat production. As of year-end 2021, Poland's installed biomass capacity totaled approximately 1.5GW while energy-from-waste (EfW) capacity was 70MW.

Bioenergy would potentially be most useful as a CHP plant to serve as a baseload source, rather than as a "peaker" to pick up the slack when renewables output drops. Plants burning solid fuels typically have slower start-up times than gas power plants and thus provide limited flexibility to the grid.

EfW facilities are typically small, and often better optimized to produce heat rather than electricity, because of the relatively low energy density of waste (typically below 2000kcal/kg) and limited feedstock supplies. Most biomass and EfW plants in Poland are smaller than 30MW. EfW capacity is now set to grow, with three projects totaling 40MW in the pipeline. In addition, the city of Lodz, located near Belchatow, plans to construct an EFW facility though environmentalists have objected. In June 2022, PGE abandoned plans for a 23MWe (megawatt electric) EfW plant. The plant was planned to burn some 180,000 tons of waste per year.

[48] Municipal solid waste can be utilized for energy production by directly combusting the fuel or by producing biogas through anaerobic digestion. The section ***Error! Reference source not found.*** describes the production of biogas using anaerobic digestion. Energy-from-waste in this section refers to direct combustion of municipal solid waste. It is possible to co-fire biomass with municipal solid waste.

Finland, Sweden and Denmark have successfully replaced coal-fired district heating with energy-from-waste over the past 20 years. Many of these EfW plants connected to district heat networks have been commercially successful without relying on subsidies. However, because EfW is a capital-intensive technology many plants rely on government grants to provide investment support for construction.

Moreover, EfW appears unlikely to be a key technology in Europe's broader energy transition. EU circular economy targets and the European Green Deal do not envision energy-from-waste to play a large role in Europe's path towards cleaner energy. In fact, several EU funds specifically exclude energy-from-waste from funding. The Just Transition Fund is unlikely to support EfW facilities, and EfW is not included in the EU taxonomy for sustainable activities.[49] All that said, EfW is fully allowed in the EU, even if not supported by EU funds. Cases in the Nordics show that the technology can be successful without subsidies.

Energy-from-waste for district heating in Vantaa, Finland

Finland's largest EfW plant was constructed over 2011-2014 and is located in Vantaa, just outside the capital city Helsinki. As of 2021, it had capacity of 78MWe and 120MWth, and burned around 340,000 tons of municipal waste per year. The waste is sourced from a population of 1.5 million residents in the Helsinki metropolitan area. The plant cost some 300 million euros to build and received investment support from the Finnish government of some 1.5 million euros in 2011. The support was for using innovative technology, bringing the plants efficiency to 95%.[50]

The EfW plant covers about half of Vantaa's heating needs. The city has a population of around 240,000 people, of which 80% live in buildings served by district heat. As of 2022, the cost of district heat in Vantaa is significantly cheaper than in the neighboring Helsinki. In Vantaa, the heating cost for apartment blocks is 76 euros/MWh compared to 125 euros/MWh in Helsinki. That is because Helsinki has been much more impacted by the energy crisis of 2022. Helsinki still relies on hard coal for district heating and has recently paid record prices for the fuel[51] while also covering the associated carbon emissions costs. In 2022, the Vantaa EfW plant is being expanded to provide greater supply to Helsinki, as the capital city prepares to close most its coal plants by 2025, ahead of the nationwide 2029 coal phase out.

Electricity from biomass is often on the more expensive side, with LCOEs ranging from 140-470 euros/MWh across European countries. This means that biomass typically relies on subsidies to operate. Poland has granted investment support to CHP using biomass in 2020, using EU funds. This support was approved by the European Commission,[52] suggesting it could be possible to secure funding for a biomass-fueled CHP plant at Belchatow.

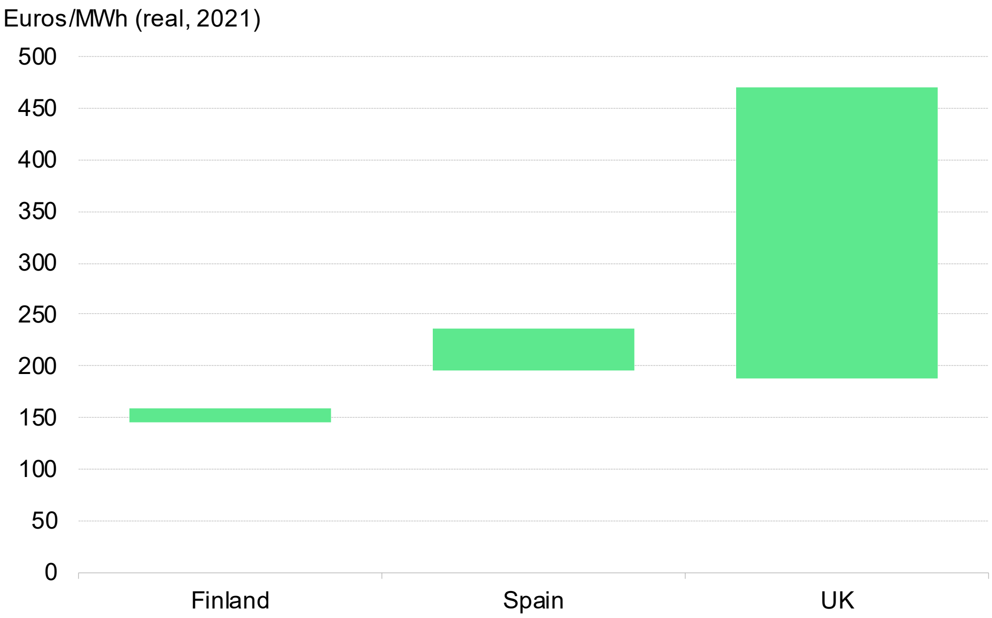
49 EU taxonomy for sustainable activities (link)

50 Afry: Groundbreaking energy-from-waste plant, Vantaa Energy, Finland (link)

51 Hard coal prices in Europe increased by around 300% from 2018 to September 2022

52 Commission approves €23 million investment aid to support high efficiency cogeneration fuelled by biomass in Poland (link)

Figure 24: Biomass levelized cost of energy (LCOE) ranges for select European countries



Source: BloombergNEF. Note: Higher number of biomass projects tracked in the UK, resulting in a wider range of LCOEs.

The challenge of sourcing sufficiently large amounts of sustainable biomass feedstock has the potential to limit the size of any new Belchatow biomass plant. Poland met as much as 80% of its feedstock needs with imports in 2020 and imports have averaged 50% since 2013.[53] Belarus has been the primary supplier and when it ceased exports in 2021, Polish plants' output fell. Poland also exports some domestically-produced biomass pellets,[54] but their high cost could make them less useful domestically. In 2022, the price of wood pellets has doubled or even tripled across many European countries from around 150 to 260-400 euros/ton. Beyond the financial costs, environmental groups have long challenged the sustainability of wood pellets or briquettes, arguing that they contribute to deforestation and have substantial carbon footprints when imported long distances.

Poland could potentially make better use of biomass from waste streams, which would be more in line with proposed EU rules that strictly define sustainable biomass. These include agricultural waste products and dust from sawmills. One possibility is straw, which has an energy density similar to lignite. However, straw resources are scattered across Poland and would require significant organization to collect and process into straw pellets. When Poland cut subsidies for biomass power generation in 2015, demand for straw pellets dropped. Reinstating those supports or other forms of public support could potentially reinvigorate the market.

[53] Biomass in the fuel mix of the Polish energy and heating sector (link)

[54] Poland exported 1 million tons of wood pellets to Germany in 2020, according to the study *Wood Biomass Resources in Poland Depending on Forest Structure and Industrial Processing of Wood Raw Material*, 2022 (link)

Biomass with carbon capture and storage

Biomass with carbon capture and storage (BECCS) could be an innovative technology to be tried at Belchatow. While such a plant is unlikely to get built purely on economic grounds it could potentially secure innovation grant funding. Belchatow planned a carbon capture and storage pilot project in 2012 with the captured carbon to be piped 100-150km to suitable underground caverns for storage. However, the project was cancelled due to lack of funding.

Carbon capture from fossil fuels usually has residual carbon emissions, whereas BECCS is carbon negative. For BECCS to truly reduce emissions, biomass must come from sustainable sources.

3.6 Options post-2030

While the energy transition in and around Belchatow is already underway, there are technologies poised to mature only after 2030 that could help the region move successfully toward lower-carbon energy. This section discusses four possibles for deployment in the region: green hydrogen, small modular nuclear reactors (SMRs), floating solar and pumped hydro storage.

Green hydrogen production

Green hydrogen can be produced by electrolysis, using renewable electricity to split water molecules. While there are several mature electrolysis technologies available today, none has scaled sufficiently to produce economies of scale and low-cost equipment. Direct demand for green hydrogen is limited today, but that is poised to change dramatically by 2030.

Poland's own stated hydrogen strategy aims to have green hydrogen used in both industry and transport. The strategy sets a specific target of 2GW of electrolyzes installed before 2030. Belchatow could become part of an emerging Polish green hydrogen economy towards the end of the 2020s, but this depends on scaling production, developing compatible infrastructure, and creating certainty that the hydrogen produced has a reliable, creditworthy potential buyer.

Production will only be viable if there are clear use cases for the fuel and if the necessary transport, storage and end-use infrastructure is in place. Industry, in particularly, is set to become a large consumer. The Council of the European Union and energy ministers representing EU member states[55] have set a target of replacing half of all gray hydrogen used today in industry with non-biological renewable fuels, such as green hydrogen by 2035. In the Belchatow region, the large steel mill near Czestochowa could be an attractive industrial offtaker for such hydrogen.

Electrolyzers powered by local renewables or through grid connection

Locating hydrogen production in so-called "brownfield" sites such as Belchatow can offer many benefits. Belchatow's large grid connection could be utilized to power electrolyzers, which could be fully or partially powered by the 5GW of solar and 5.7GW of wind suggested as optimal in chapter *3.4 Variable renewables*.

Green hydrogen also produced near Belchatow would also make it possible to add more local renewable energy capacity. A 500MW electrolyzer that produced zero-carbon hydrogen operating

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55 *"Fit for 55": Council agrees on higher targets for renewables and energy efficiency (link).*
The EU is likely to adopt the proposed targets and support mechanisms for green hydrogen production. For more, see *2H 2022 Hydrogen Market Outlook: Policy Finally Arrives* is available for BloombergNEF and Bloomberg Anywhere clients (web | terminal)

at 70% utilization would require around 1.1GW of onshore wind and 770MW of solar PV capacity to operate. Adding this could bring total renewable capacity installed at Belchatow to 6.8GW wind and 5.8GW PV. BNEF estimates that the available land around Belchatow could accommodate some 5-15GW of onshore wind and approximately 5-6GW of solar PV.

Hydrogen production in Belchatow would benefit from aligning with standards for renewable energy in the process of being set by the Commission.[56] This way, the green hydrogen could formally contribute towards Poland's renewable energy targets. The Commission's draft delegated act defines renewable hydrogen as being produced from directly connected renewables off-grid or through power purchase agreements (PPAs) with grid assets in the same power market bidding zone. It also stipulates that hydrogen production would need to be matched to renewable energy generation on an hourly basis, even when connected to the grid.

Both options are feasible in Belchatow as the existing 5GW grid connection could be used to power electrolyzers. Using PPAs could have advantages because electricity can be procured from more distant sites at lower cost and higher capacity factors than onsite generation. Hydrogen producers could, for example, buy from offshore wind projects, albeit likely at a higher electricity cost than from onshore sites.[57] It would still be advantageous to supply electrolyzers at least partially by locally-produced renewable energy, both on the basis of cost and minimizing strain on the grid.

Hydrogen use-cases

Green hydrogen can be used to decarbonize a range of sectors, from heavy industry, to power generation and transport. BloombergNEF expects green hydrogen applications to be most promising where hydrogen is already used as a chemical feedstock today or direct electrification is not feasible.

Existing industry could become the initial offtaker for green hydrogen at Belchatow. Poland already uses 1.3 million tons of hydrogen from natural gas for industries such as oil refining and fertilizer production, according to the country's hydrogen strategy.[58] This makes Polish industry the third largest consumer of hydrogen in Europe. This demand could be partly met by green hydrogen production in Belchatow. For example, a 500MW electrolyzer operating at 70% utilization could produce 52,000 tons of green hydrogen and meet around 5% of current Polish hydrogen demand.

Green steel production could also be a source of new hydrogen demand. Poland is currently the fifth largest steel producer[59] in the European Union, accounting for 8.5 million tons of crude steel made in 2021. BloombergNEF expects hydrogen-based direct reduction to be the cheapest way to produce net-zero steel by 2050.[60] Producers such as Liberty Steel have announced the production of hydrogen-based green steel at its Czestochowa plant, just 70km from Belchatow

56 The European Commission published two draft delegated acts to define criteria for renewable hydrogen production based on additionality requirements and assessment methodology for greenhouse gas emissions.

57 For more hydrogen research, BloomberNEF and Bloomberg Anywhere clients can *read Hydrogen From Offshore Wind: Economics* (web | terminal).

58 *Polish hydrogen strategy* (link)

59 European steel in figures (link)

60 See *Decarbonizing Steel: A Net-Zero Pathway* (web | terminal).

power station. Its current capacity of 0.7 million tons of steel per annum could create a potential hydrogen demand of 51,100 tons of hydrogen per year.[61]

Policy in the form of a price on carbon is likely to influence deployment of hydrogen in Poland's power sector. Clean hydrogen has the potential to replace natural gas for power generation in new and existing turbines. But for hydrogen to compete directly with the cost of natural gas power generation, a carbon price will generally be required. At natural gas prices of around 11 euros per million British Thermal Units (110 euros/MWh) and green hydrogen prices of 1.90 euros/kg, the carbon price required to make hydrogen-based power generation cheaper than natural gas would be around 100 euros per ton carbon dioxide (tCO_2). BloombergNEF expects EU carbon prices reach 136 euros/tCO2 in 2030, and for industries to face higher direct exposure to carbon pricing as free allocation is planned to be phased out.

Road transport is unlikely be a major hydrogen demand driver due to economics alone. For buses and heavy-duty commercial vehicles, fuel cell drivetrains can become competitive against diesel for long-haul routes by 2030 in markets where hydrogen fuel is priced competitively against diesel. Here again, fuel cell drivetrains will not be more economic than battery electric vehicle drivetrains under most circumstances. They are also unlikely to become a large source of hydrogen demand. For example, the Polish hydrogen strategy targets deployment of 1,000 fuel cell buses by 2030. Refueling these vehicles likely only requires around 5,800 tons of hydrogen per year.[62] This amounts to just 11% of annual demand for the Liberty steel plant in Czestochowa.

Technology feasibility and cost

A range of project designs are feasible for green hydrogen production at the Belchatow site. BloombergNEF assessed the hourly dispatch profile of solar PV and onshore wind at the site to derive the potential project designs below. The different designs represent a trade-off between maximizing stable hydrogen output and lowest cost of production.

Pairing an electrolyzer with local renewables could produce low-cost green hydrogen in Belchatow. By 2030, green hydrogen could be produced for 1.20-1.95 euros/kg (real 2021) using onshore wind and solar PV at the current site of the Belchatow power station (Figure 25). This would likely be cheaper than the fossil fuel hydrogen produced in Poland today, which is estimated to cost between 1.35-2 euros/kg depending on the gas price. However, once electrolyzer costs fall, the cheapest hydrogen can be achieved with an electrolyzer utilization rate of just 30%. Lower utilization would mean less accompanying wind and solar capacity would be required to power the plant. Whether a plant operating at just 30% is sufficient will be contingent on the nature of the demand for hydrogen.

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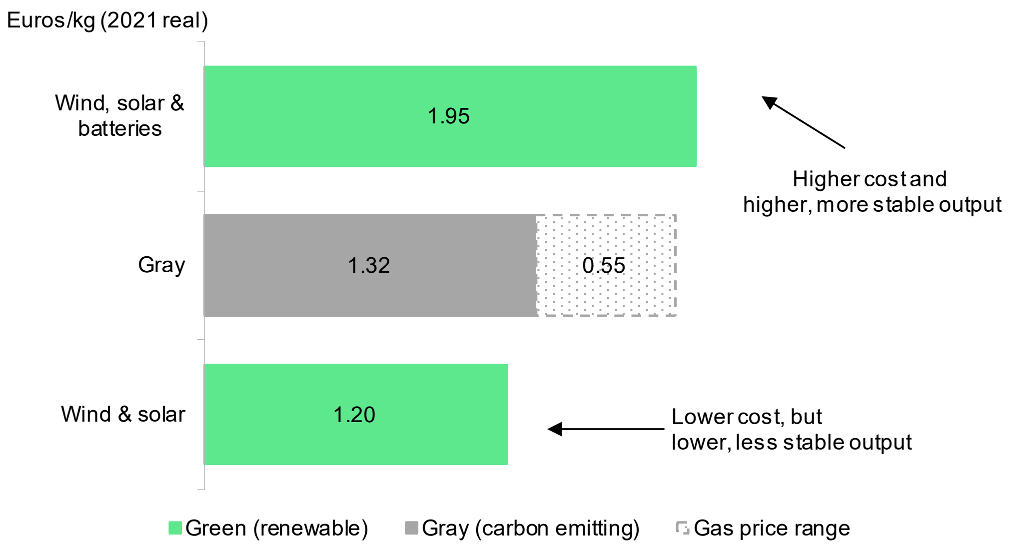
61 We assume 73 kilogram of hydrogen is needed to produce each ton of steel

62 Based on a fuel efficiency of 12.1 kilometers per kilogram of hydrogen and an annual mileage of 70,000km per vehicle.

Figure 25: Levelized cost of hydrogen production in Belchatow, 2030



Source: BloombergNEF. Note: Green hydrogen cost based on alkaline electrolyzer capex in 2030, onshore wind capacity factor of 34.5% and solar capacity of 12.9%. Renewables capacity set to reach a 80% electrolyzer utilization in 'oversized wind and solar'. Low-end gray hydrogen cost assumes a gas price of 66 euros/MWh while high-end assumes EUR106/MWh.

Most industrial players using hydrogen would require a steady flow of production. This would ideally mean electrolyzer utilization rates of around 70-90%. By 2030, the capex of an electrolyzer is expected to fall by 55% from today[63] making the electricity price the most important component of the hydrogen cost. Oversizing wind and solar PV and pairing them with a battery would enable the electrolyzer to produce hydrogen at full capacity for 80% of the time but would lead to a higher cost 1.92 euros/kg in 2030, or 60% higher than with a 30% electrolyzer utilization (Figure 25).. However, this assumes that 22% of electricity is overproduction that cannot be used. In Belchatow, some of this excess power could be sold to the grid, reducing the cost of hydrogen production.

Adding hydrogen storage to allow for lower capacity factors might be challenging at Belchatow. There are no naturally occurring caverns suitable for hydrogen storage nearby to BNEF's knowledge. The nearest salt-cavern potentially suitable is in Moglino, some 180km away. Storing hydrogen will always be more expensive than natural gas because of hydrogen's physical properties. It takes up three to four times as much space as natural gas to store the equivalent amount of energy, and it takes more energy to liquefy. Storage in pressurized containers is likely to add between 0.17-1.00 euros/kg to the price of green hydrogen if the storage is emptied and refilled daily, or 1.20-7.00 euros/kg if the storage is filled and emptied weekly.

Transporting hydrogen

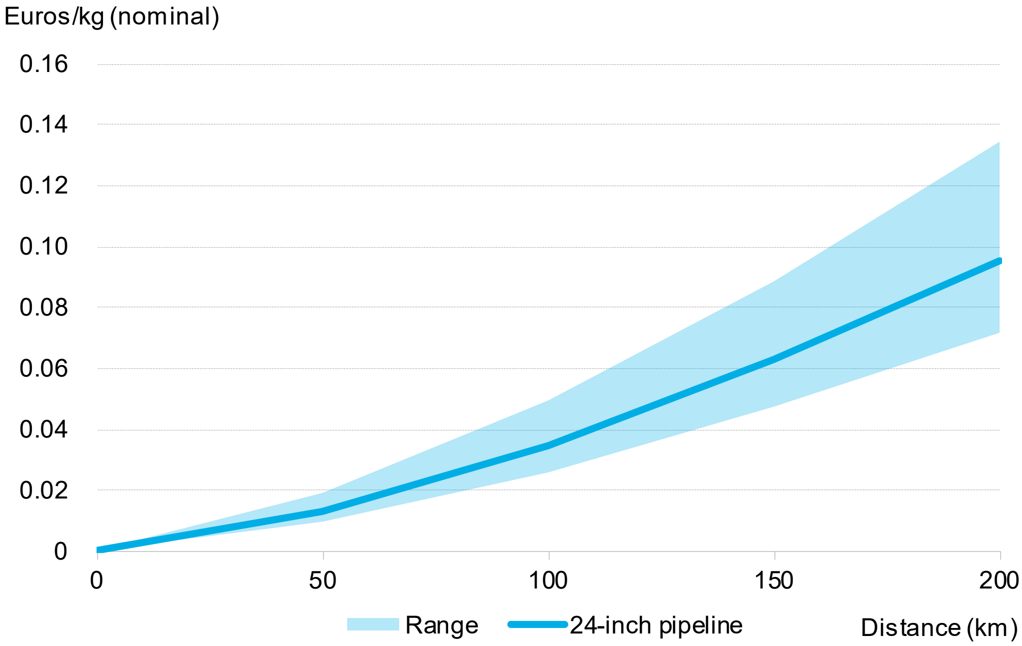
To meet demand for hydrogen in industrial clusters close to Belchatow, hydrogen produced would need to be transported, potentially via a newly built transmission pipeline or series of pipelines as BNEF regards pipelines as the cheapest way to transport large volumes of hydrogen over long

[63] For more on electrolyzer costs and technologies, see *1H 2022 Hydrogen Levelized Cost Update,* available for BloombergNEF and Bloomberg Anywhere clients (web | terminal)

distances.[64] As mentioned in section *4.5 Risks to natural gas*, no existing gas transmission pipeline exists in Belchatow to be converted to deliver hydrogen. As a result, a new pipeline would need to be constructed if local hydrogen were to get delivered to elsewhere in the country. Transporting hydrogen using a newly built 20 to 28-inch transmission pipeline over 200km would add 0.07-0.13 euros/kg to the cost of hydrogen production in Belchatow. It would also provide enough transmission capacity for the output of 1.7-4GW electrolyzer capacity running at 100% utilization.

Less infrastructure at lower cost would be needed to serve demand closer to hydrogen production. BNEF estimates hydrogen transport over 50km in a new 12-inch distribution pipeline to add 0.23 euros/kg or about 10% to stable hydrogen production cost in Belchatow using wind, and solar.

Figure 26: Levelized cost of hydrogen transport in newly built 20-28 inch transmission pipelines, 2022



Source: BloombergNEF. Note: Assumes pipeline transport of hydrogen between 30 and 50 bar. Costs are based on flat terrain and low population density.

Nuclear power

Due to uncertainties around construction costs and timing, financing, and technology development, BNEF does not regard nuclear to be the best technology choice for replacing lignite generation at Belchatow. Recent European large-scale nuclear projects have seen severe delays and are ill suited for co-location with wind and solar, assuming renewables are built locally before 2030. Emerging small modular reactors (SMRs) could be more suitable for co-location with renewables but SMR feasibility will depend on whether projects currently under development in other countries prove successful.

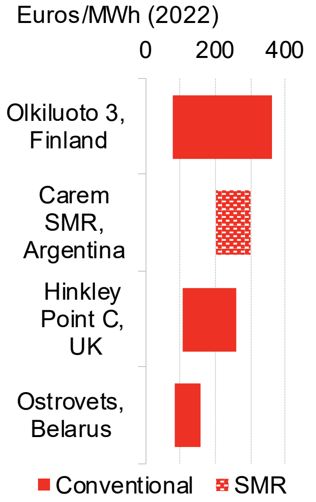
64 *BloombergNEF Hydrogen: The Economics of Pipeline Transport. Full report available only for BNEF clients.*

Poland's national strategy[65] envisions 6-9GW nuclear to be built before 2043, but only one reactor is under development so far. In December 2021, the Polish government confirmed the site in northern Poland for what would be the country's first nuclear plant, a 1-1.6GW reactor estimated to cost around 32 billion euros (PLN 150 billion). Considering this decision, it is highly unlikely that a second large nuclear investment would be made elsewhere in Poland, at least until that first project makes substantial progress.

This marks the second time in recent years that Poland has stated publicly a plan to add nuclear generating capacity. In 2014, the government said it sought to have the country's first plant online by 2024. To date, however, Poland has yet to complete or even start construction on a reactor.

For existing, large-scale nuclear designs the key risks are construction delays and cost overruns. The Olkiluoto 3 and Sizewell C projects in Finland and the UK respectively, are two examples of the risks around delays and expanding budgets. Even nuclear projects that are considered more successful often need at least 10 years between a construction contract being awarded and a nuclear unit starting commercial power generation. Long construction times together with high capital requirements lead to expensive financing costs, contributing to overrunning costs.

Figure 27: LCOE ranges of recently completed nuclear power projects



Source: BloombergNEF.

SMRs are essentially power plants consisting of smaller reactor units (<300MW) producing steam that is used in a turbine to generate electricity. The relatively small size of SMRs make them potentially easier to integrate in a high renewables power system, and the reactors are typically designed for enhanced abilities to ramp generation up and down. SMRs paired with innovative energy storage solutions or batteries could complement renewable energy sources even better by providing rapid changes in output, but this is still an emerging technology. Assuming that solar and wind replace the older units due to close by 2035, it is advantageous to choose a nuclear technology which would complement rather than compete with renewables.

Only a few SMR projects are under construction globally, making it difficult to estate the potential costs associated with the technology. BNEF estimates the capex for the 25MW Carem SMR in Argentina at 21-24 million euros/MW compared to the 15.3 million initially budgeted. In practice, the power plant might achieve an LCOE of 305 euros/MWh assuming a 55% capacity factor, and 206 euros/MWh assuming day-in day-out operation. A 345MW SMR demonstration project in Wyoming in the US could serve as an interesting example for the Belchatow region if completed successfully.

One potential advantage of an SMR compared to a large-scale reactor is lower financing costs. Large-scale reactors can face high interest costs due to the risk of project delays. A smaller reactor is less capital intensive, which could mean lower financing costs. However, SMR technology remains unproven and today requires early stage, highly risk-tolerant and quite expensive capital to finance. A potential SMR in Belchatow should be entirely contingent on the level of success SMR projects elsewhere achieve over the next five years. Another key determinant should be whether public financing is available to reduce the risk for private investors.

Case study: TerraPower Natrium Next Generation Nuclear project

SMR technology and project developer TerraPower is looking to build its 345MW Natrium reactor in the US state of Wyoming. The plant would replace local, existing coal-fired generation and is expected to be operational by 2030. The company said it expects to apply for a license for the plant in the second half of 2023 but significant uncertainties remain.

[65] Polish Nuclear Power Program (link)

Budget: $4 billion
Capex: $2,800-$3,000/kW
Funding: 50% by the US federal government, 50% by Bill Gates-owned TerraPower
Installed capacity: 345MW, with 500MW peak output due to inbuilt thermal storage
Innovative technology: Sodium-cooled fast reactor with molten salt energy storage. The inbuilt storage helps integration of renewable energy, as power output can be varied. The Natrium design is potentially simpler than previously proposed reactors. Its smaller physical footprint will theoretically make it less expensive to build and faster to license.

Floating solar

While a floating solar PV project is currently not viable at Belchatow, the technology could become a realistic option once the existing lignite mines get flooded after closure. At first, the deepest parts of the lignite mine will not be suitable for solar panel installations due to shade from the mine edges. However, as the water level rises, the shade will recede making a floating PV system a possibility.

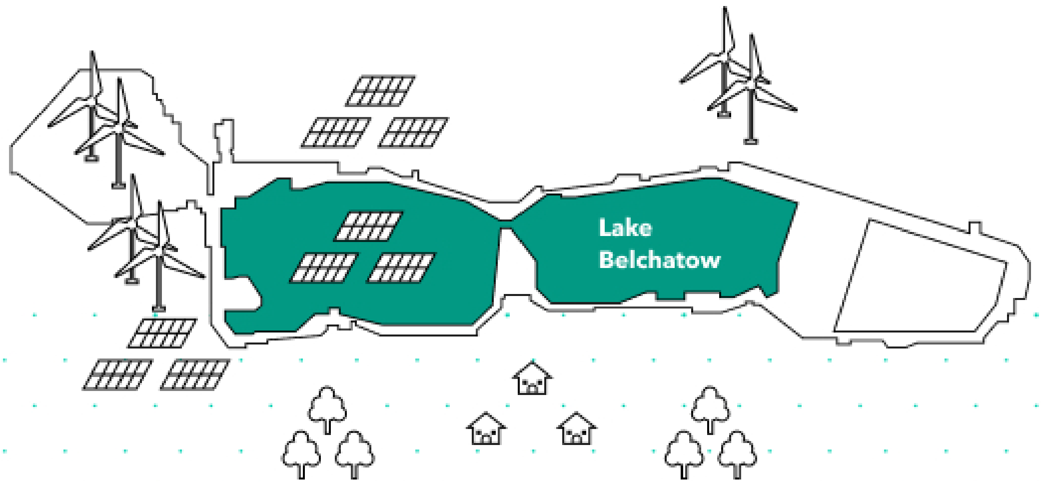
Floating solar projects are rare today compared to ground-mounted or rooftop solar. Floating solar totals 4GW globally compared to over 600GW of onshore, utility-scale PV as of mid-2022. Capex for floating solar is typically around 10-20% higher than for ground-mounted projects. Floating solar tends to get built near existing grid connections so that the higher capex is offset by grid connection savings. Solar panels installed above cool water also have higher efficiency, improving the output from floating solar.

In Portugal, floating solar is being built on hydro dams. The country awarded 103MW of floating PV capacity with contract-for-difference subsidies via an auction held in April 2022.[66] The auction also awarded grid connection permits that make use of the existing grid connections of dam hydro power plants. Hydropower is unlikely to generate while solar output is high. In Germany, a subsidy-free floating solar project of 3MW has begun generating on an artificial lake previously used as a quarry. This relatively small project covers 1.8 hectares, or just 2.3% of the lake's surface.

By 2050, two lakes in the Belchatow mining area could cover an area totaling 35-40km^2. The lakes on the sites of the former lignite mines are estimated to reach their full size only in 20-25 years after mining and shoreline landscaping ends. Some floating solar can accommodate rising water levels, so the project could be installed even before the lake has reached its final water level. If a quarter of the lake area were used for floating solar, installed capacity could reach some 1.5GW.

[66] For more, see *Fast Permitting and Floating Solar in Iberia*, available for BloombergNEF and Bloomberg Anywhere clients (web | terminal)

Figure 28: Illustration of floating solar PV on post-mining lakes in Belchatow



Source: BloombergNEF

Innovative pumped hydro

Pumped hydro is a technology that typically involves pumping water up to higher elevations at times when electricity on the grid is plentiful and low-priced, then discharging it to spin a turbine and generate power when supply is scarce and prices are higher. Pumped hydro, however, is not a technology poised to fill any gaps left by lignite generation at Belchatow. This is because the timeline of when lignite generation ends does not match with the earliest date that pumped hydro could start operating.

Nevertheless, should the ongoing Antantis research project[67] conclude that pumped hydro is feasible it could be considered for grid services and renewable energy balancing as Poland nears the suggested coal phase out by 2050. See chapter *3.5 Energy storage Firm and flexible capacity alternatives* above for analysis on energy storage technologies which could be implemented earlier.

It is expected to take some 20 years after lignite mining ceases at Belchatow before the opencast mines sufficiently fill with water. It would therefore likely only be around 2050 when water levels in the two artificial lakes in Belchatow could be used for pumped hydro. As pumped hydro is an energy storage not energy-generating technology it is best suited for pairing with variable renewable energy and providing grid services.

Poland has some 1.4GW of installed pumped hydro capacity as of early 2022, and more projects are being planned. Pumped hydro storage is an established technology for long duration energy storage. It often offers a duration of around 10 hours, compared to lithium-ion batteries that tend to offer just four hours. Batteries and pumped hydro can fulfil different roles in the power system and do not necessarily compete. Most existing pumped hydro tends to be financially competitive against other forms of long-duration storage, such as green hydrogen.

[67] This report does not assess the technical feasibility of installing pumped hydro in Belchatow, as the EU-funded Antlantis project by the Central Mining Institute (GIG: Główny Instytut Górnictwais) and GFZ German Research Centre for Geosciences is already assessing this. This study is expected to be completed in August 2024.

The idea of converting former mines to pumped hydro facilities has been proposed at other mines around the world, but BNEF is not aware of any projects brought to completion. The concept has been proposed both for opencast lignite mines as well as underground hard coal mines. In Scotland, the former Glenmuckloch opencast mine received permission to be converted into a pumped hydro storage facility in 2016. The potential 200-400MW plant is remains in early-stage development after receiving a five-year extension of its planning permit in June 2022.

Section 4. Supporting Belchatow’s transition

Strong governance and engagement across stakeholders will be crucial to developing a new energy production cluster at Belchatow ready to come online before lignite mining and generation come to an end. This section highlights key actions local authorities, national government ministries, the grid operator and the current plant owner could take to ensure a smooth transition. Potential options detailed here build on examples of effective programs implemented elsewhere, including Spain, Germany and Australia.

There are multiple possibilities for what comes next at Belchatow. None, however, can be achieved without good governance, robust procedures and strong coordination between key stakeholders. This includes regional authorities, current Belchatow power plant owner PGE, the Polish Ministry of State Assets which could become future owner the new National Energy Security Agency (NABE), local environmental groups and, most critically, local workers.[68] While there is always a degree of uncertainty around political decisions, this section highlights best practices that can:

1. Ensure stable operation of the Polish electricity system
2. Enable installation of new energy generation technologies in the local area
3. Support the local and regional economy

Good governance for grid stability

The earlier Poland transmission grid operator PSE can anticipate upcoming changes in generation at Belchatow, the easier it will be to plan accordingly to maintain stable grid operations. Current power plant owner PGE should therefore complete issuing the closure plans it announced in 2021 and inform grid operator that Belchatow’s oldest units are to be shut in 2030 or before.

Grid operator PSE should clearly communicate conditions under which it will grant permission for units at Belchatow to close. PSE must communicate these to PGE, local authorities, and the Ministry of State Assets which is planning the set-up of NABE. Ultimately, the units cannot be shut if doing so endangers the stability of Poland’s power grid. The public is also entitled to transparency on these issues.

Current plant owner PGE would be best served not waiting for ownership to shift to NABE and instead formalize a shut-down schedule for the units that are slated to close first. PGE needs to communicate with PSE to ensure the grid operator is in agreement. PGE must make a detailed assessment of how many units can be mothballed or closed by 2030. As discussed above, BNEF expects economics will push at least 1.5GW of Belchatow’s capacity to retire before 2032.

PGE’s formal closure notice would allow PSE to auction freed-up grid capacity to new sources of generation, including renewables. The sooner such a notice is issued, the more time energy project developers will have to start planning projects. As planning and constructing a new wind or solar project typically takes several years, failing to kick the process off soon will make it difficult

[68] Consultations with the European Commission and the results of Polish parliamentary elections to be held in autumn of 2023 could influence details around how NABE is created and managed.

to bring renewables or battery capacity online by 2029 when lignite generation becomes uneconomic. Ultimately, delaying formal closure notification of the lignite units has the potential to put Polish energy security at risk.

Enabling local renewables build

This report illustrates the substantial opportunities that exist for developing wind and solar capacity at Belchatow to follow the closure of the lignite units. Such projects have the potential to maintain Polish energy security while at the same time reducing consumer energy prices. However, there are two key barriers to such development today:

1. Lack of clarity on grid connection availability
2. Minimum-distance rules for onshore wind

Freeing grid capacity. As discussed above, clean energy developers are waiting on PGE to give formal notice of which Belchatow it plans to close first. Closing four to five of the oldest units in 2029-2030 would allow up to 3-4GW of renewables to connect at the Rogowiec substation. To achieve this, the Lodz Marshal's office and the relevant national ministries could work together with PGE and PSE to determine optimal closure dates.

The potentially vacant grid capacity could be auctioned to new energy project developers well before it becomes available for use. While a somewhat similar approach has been tried in Spain's Andorra Teruel region, Polish policymakers would be wise to take lessons from what has – and has not – worked there. In Teruel, plans to commission clean replacement capacity are in motion, the process has not moved swiftly. Belchatow can learn from this and make the grid connection available for applications ahead of time before lignite closures start.

Lessons learned: Andorra Teruel region, Spain

Utility Enel Endesa formally asked Spain's grid operator permission to close the 1,050MW Teruel power plant in December 2018. Two years later, it ceased operations.

The plant had run on black lignite (sub-bituminous coal) from the nearby Estercuel opencast mine and other mines in the Teruel region. The mine is owned by a different company than the power plant, but the plant's closure directly hurt Estercuel, one of the few Spanish coal mines that had opted to forego Just Transition Funding by continuing to operate. Once it became clear there would be no further major buyers of the mine's coal, Estercuel changed course and took the Just Transition deal.

The national government enacted a special law to support renewable energy development in the area to support the region's transition. It allowed access to Teruel's 1,200MW grid connection to be auctioned to renewable energy providers, with economic, social and environmental criteria to be used in determining winners. Endesa, which surrendered rights to the grid connection when its plant closed, is now looking to build renewable energy projects that will win contracts under tender. Hydrogen projects can also take part.

Policymakers have prioritized worker retraining in the region where the plant operated. Spain's approximately 14% unemployment rate is among the highest in Europe. For the tender, demonstrating social impact is one criteria on which projects are being judged. This has proven challenging to developers typically focused more on delivering value and low price than other considerations.

Overall progress has been slower than clean energy developers would have liked. Only after the coal plant had been closed for five months was the auction announced in May 2021. In response, 11 projects submitted bids to the tender in January 2022. [69] Nine months later on October 11, 2022, Endesa reported provisionally securing 953MW out of the 1202MW grid connection capacity on offer. [70]

Ensuring land availability for renewable build. Land-use restrictions in Poland concern mainly onshore wind plants, but can also be an issue for PV projects. The region is waiting for the Polish Sejm (parliament) to approve the new 500m minimum distance rule, which would replace the existing "10-H" rule that often bars wind turbines closer than 2km radius from residential buildings. The local municipalities (gminas) and the Lodz region can show their support for this change by actively engaging with members of parliament who might be skeptical of the new rules.

Municipalities close to Belchatow can then work coordinate on integrating the 500m rule into local land-use plans. The Lodz region's (Vovoidship) Marshal's office could support these efforts in various ways, such as hosting workshops and providing access to experts. Workshops could highlight the potential benefits of hosting renewable energy plants, including higher tax revenues.

Neighboring municipalities could collaborate to establish dedicated areas to speed wind and solar development. Such "renewable energy zones" have been trialed already in Germany, Spain, Finland and Sweden.[71] The EU's REPower EU plan to reduce reliance on Russian natural gas also proposes creating such "go-to" areas for renewables and recommends using EU funding to aid the process.

Fostering renewables and lignite co-existence. Clean energy and lignite can clearly co-exist in the Belchatow region, as proven already by the small wind farm already operating on Kamiensk Hill. Utility PGE owns the land around the Belchatow power plant and could be proactive in enabling local renewable development there.

Similar examples of renewable energy projects operating in an area with closing lignite mines and power plants can be found in Germany's North Rhine-Westphalia lignite region. Utility RWE is working on several new energy projects there despite some lignite unit closures not planned for closure sooner than 2038.[72]

Lessons learned: North Rhine-Westphalia, Germany

Neurath was historically Europe's the second-largest lignite power plant at 4.2GW capacity. Since the start of 2021, however, two of the plant's 312MW units have been taken out of operation.

Like Belchatow, Neurath has relatively new units commissioned in 2012 which are expected to generate until 2030-2038, when they are shut down by Germany's coal phase-out policies.

Neurath relies on lignite from the nearby Garzweiler and Hambach opencast mines. A smaller lignite mine, Inden, which supplies the Weisweiler power plant is also located in the same area.

Neurath owner RWE and the adjacent mines published an investment plan for the area in February 2022[73] and have launched several projects to build renewable energy projects at the

[69] *Seven brides for 1,200 MW: this is the fight for the connection point of the thermal power plant in Andorra* (link in Spanish)

[70] Endesa is provisionally awarded 953 MW of the just transition tender in Andorra (link)

[71] See for example, *The scope of municipal energy plans in a Swedish region* (link)

[72] The German government has proposed a 2030 coal phase-out but the coal-phase out law has not been updated, which means that the legal phase-out date remains 2038.

[73] RWE: Our plan for North Rhine-Westphalia (link)

mine sites. The 67MW Hohe wind farm is already generating next to Garzweiler. The 30MW Bedburg A44n wind project, co-owned by RWE and the local city, was commissioned in 2022. The project employs 164-meter 5.7MW turbines, spaced some 200-350 meters apart and occupy an area equivalent to around half of mining site.

RWE is also commissioning a 14.4MW solar park with 9.6MWh battery storage, at the recultivated edge of the Inden opencast mine. Finally, RWE is exploring thermal generation technologies including plants burning sewage sludge and hydrogen-ready gas power plants.[66] The utility is seeking to develop a mix of multiple technologies to replace the generation the large-scale lignite plants provide.

Supporting a smooth transition process for local communities

Municipalities around Belchatow, along with the Lodz region's Marshal's office, can anticipate a future in which lignite generation declines 2025-27 and gas markets and renewables growth dictate the pace of change. Strong local initiatives can be necessary catalysts as cities and regions have demonstrated.[74] However, the national government has a critical role to play in ensuring a smooth transition. Relevant ministries in the Polish government can recognize the risks today facing Belchatow, namely that lower future generation will mean lower lignite demand and fewer jobs. This will be the case regardless of what strategic reserves[75] measures the government seeks to implement.

Make detailed transition plans many years in advance. The energy transition is well underway globally and the Belchatow region should plan now for how it will manifest locally. While there are several examples of poorly managed transitions of former coal or lignite areas, there are success stories as well. Effective transitions range across years and must therefore be prepared for well in advance. Some 7,500 are employed directly at Belchatow either in mining or at the power plant. The complex supports even more indirect jobs given the number of businesses that provide services to workers. If left unmanaged, a sharp reduction in lignite generation could produce widespread layoffs at Belchatow.

Anticipate closures and learn from others. Economics are driving mine and coal plant closures in many other parts of the globe today. In other cases, governments are mandating coal closures. In still others, they have simply decided to stop subsidizing unprofitable coal mines. Spain, Greece, Germany, Sweden, the UK and Australia all offer potentially useful examples. The state of Victoria in Australia, in particular, has taken a deliberative approach which could offer Polish policymakers could seek to emulate[76].

[74] For examples of city-led energy transitions, see *Building on Cities to Deliver a Green and Just Recovery* (link) by BloombergNEF and C40

[75] Strategic reserves are a temporary policy mechanism to keep certain generation capacities outside the electricity market for operation only in emergencies. This means that lignite units would not be formally retired, but they would not operate unless there was a short-term shortage of supply.

[76] Victoria State Government: Latrobe Valley Mine Rehabilitation Advisory Committee (link)

Lessons learned: the Latrobe Valley Lignite Area in Victoria, Australia

The Latrobe Valley is home to large brown coal reserves and has been the main source of power generation for Victoria and south-eastern Australia for more than 130 years.

In November 2016, Engie announced the closure of the Hazelwood Power Station and Mine, impacting approximately 1,000 direct and indirect jobs. The 1.5GW Yallourn coal plant, which provided 22% of Victoria's electricity consumption in 2021, is scheduled to close over 2028-2032. Because of this, the transition plans for the region must also consider energy security.

In response, the Victoria state government established a Mine Land Rehabilitation Authority. To ensure all stakeholders were involved in planning a strategy for former mining areas, the government also formed an Advisory Committee. Together, the authority and committee oversee a Regional Rehabilitation strategy that includes a four-year $184 million commitment to support local workers, businesses and communities.

The funds have already gone to a variety of new green energy business ventures, including the Gippsland Climate Change Network developing a floating solar demonstration project with a small grant. Installation of solar and battery systems was also supported with some $288,000, and funds have gone to one energy optimization demonstration project and two energy storage projects. Construction has begun on the region's first wind farm, providing some 186 jobs to install 200MW of wind next to the former coal plant. At least 70MW of PV is also under construction, providing an estimated 150 jobs.

Partner to train up a local clean energy workforce. Local authorities can facilitate training opportunities for lignite miners and plant operators with an interest in renewables. Such programs could be realized in collaboration with PGE or other Polish energy companies. It takes about two years to become a solar panel or wind turbine technician. If local residents are not trained ahead of time, workers from elsewhere will compete for the jobs. The EU Just Transition fund could underwrite such programs. Nearby Lodz university and the Belchatow industrial education centers[77] can also play an active role in any reskilling efforts.

Building renewable energy projects gradually, in concert with planned lignite closures has the potential to provide construction jobs for years. Conversely, a multi-gigawatt simultaneous solar and wind build-out would require a vast but only temporary imported workforce.

Stimulate innovation by making use of national and EU funding. Local authorities, including the Lodz region and municipalities, could take initiative to stimulate innovation in the energy industry. This can include stakeholder engagement to explore local and regional use-cases for green hydrogen. National or EU funds could be used to fund local demonstration projects in green hydrogen production or energy storage solutions. Utility PGE could benefit from bringing forward these initiatives but other energy industry actors should also be encouraged to become part of a new energy cluster in the Belchatow region. Local innovation tenders could be held by the Lodz Marshal's office to distribute funds for innovative projects.

[77] "Branzowa szkola II stopnia" in Polish

Appendix A. Poland power sector scenarios and commodity price assumptions

A.1. Commodity price assumptions

The projected commodity price developments shown below have been used in BNEF's future energy scenario modelling and inform our view on when lignite generation in Poland is likely to drop.

Table 3: Coal, gas, lignite and carbon price assumptions (real 2021 values)

		2015	2021	2025	2030
Hard coal	€/ton 6000kcal	64	78	69	48
Natural gas €/mmbtu	Base-case	7	13	19	7
	50% higher	7	13	28	10
Lignite	€/ton of 3000kcal	20	20	20	20
Carbon, €/ton CO2	Base-case	8	54	99	132
	20% lower	8	54	79	105

Source: BloombergNEF. Note: All prices in real 2021 values, and model inputs in USD have been converted to euros (€) using the 2021 average exchange rate of 0.85. Mmbtu stands for million British thermal units.

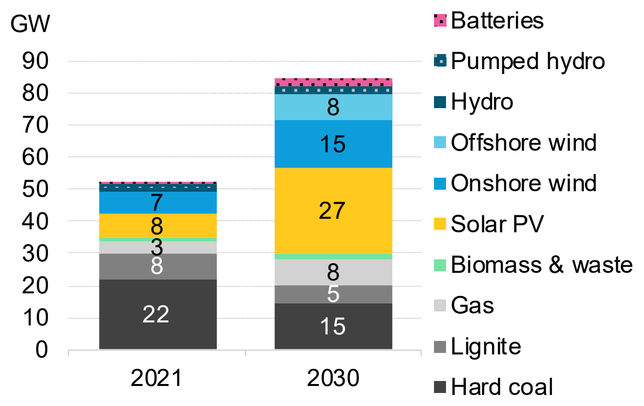
A.2. Modelled future energy scenarios

Two future energy scenarios for the Polish power sector were modelled specifically for this report: the "Base-case" and "High Gas/Low CO2 Prices". BNEF's proprietary NEFM2 model was used to determine the least-cost power mix that can reliably meet power demand for every hour of the year. This model is also used to create the New Energy Outlook (NEO) (web | terminal), BNEF's annual long-term scenario analysis on the global future of the energy economy covering electricity, industry, buildings and transport and the key drivers shaping these sectors until 2050.

The base-case scenario builds on modelling done for BloombergNEF's *European Energy Transition Outlook 2022* (available for BloombergNEF and Bloomberg Anywhere clients on web | terminal). The changes between the scenario presented in the European Energy Transition Outlook and this base-case scenario reflects changes in fuel prices and stricter limits for onshore wind build until 2030, reflecting restrictions in land-use. Gas capacity build was also restricted to 8GW cumulatively until 2027, to reflect limitations in gas supply over the next five years if Europe is cut off from Russian natural gas.

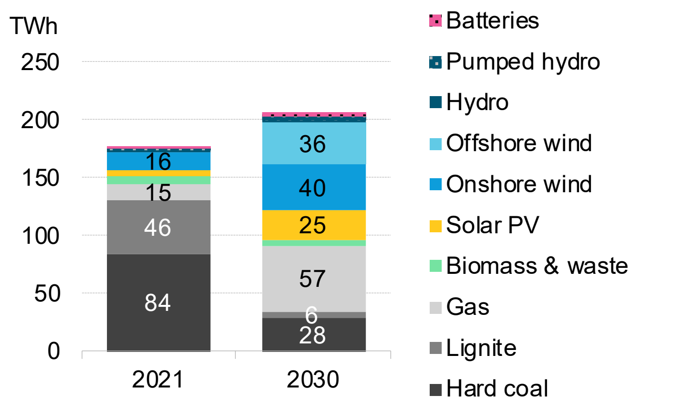
Both scenarios see offshore wind capacity slightly above the current pipeline of 5.9GW. The model builds least-cost capacity within given restrictions, and as onshore wind is restricted offshore wind is built. Offshore wind build above the current pipeline is realistic, as projects are already in pre-development with the intention of taking part in offshore wind auctions in 2025 or 2027. The model includes a requirement for some firm back-up capacity, which explains why the model retains coal and lignite units that do not generate.

Figure 29: Base-case scenario: installed capacity in 2021 vs. 2030



Source: BloombergNEF

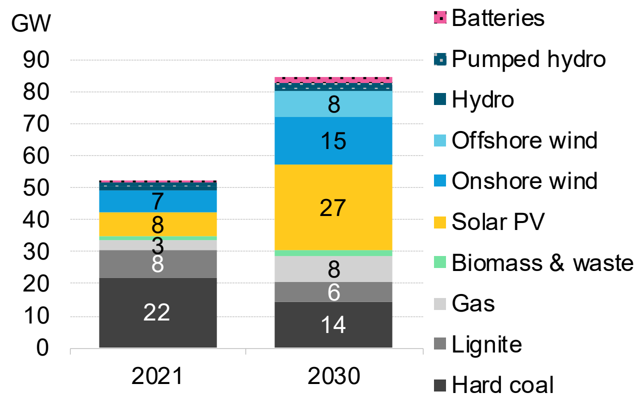
Figure 30: Base-case scenario: generation in 2021 vs. 2030



Source: BloombergNEF

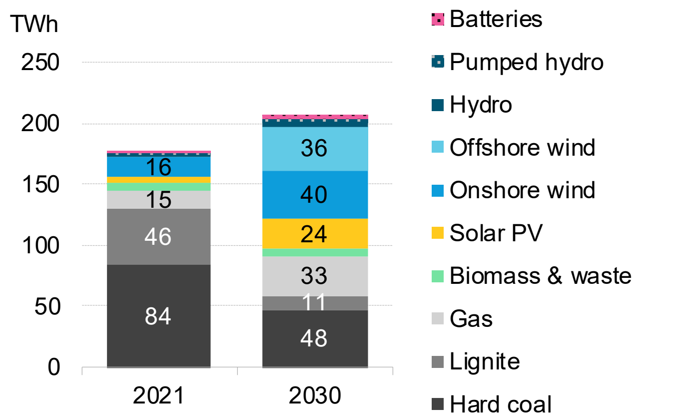
The High Gas/Low CO2 Prices Scenario reflects sensitivity analysis around gas and CO2 prices, as these are important cost components for the Polish power system. The scenario assumes gas prices remain 50% above BNEF's base-case gas price outlook until 2035. Prices are still expected to come down from the global records of 2022 but would remain slightly above the pre-pandemic levels seen 2015-2019 in Poland. Under these prices, Poland could likely be competitive in procuring LNG from global spot markets. The CO2 price in this scenario is assumed to stay at 20% below BNEF's 2022 base-case outlook for carbon prices. BNEF analysis found that a scenario with 20% lower carbon prices but base-case gas prices would not significantly change lignite running hours or retirements. The combination of high gas prices and low CO2 prices can be seen as a best-case scenario for Polish lignite generation.

Figure 31: High Gas/Low CO2 Prices Scenario: installed capacity in 2021 vs. 2030



Source: BloombergNEF

Figure 32: High Gas/Low CO2 Prices Scenario: generation in 2021 vs. 2030



Source: BloombergNEF

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Our mission is to initiate dialogue, propose knowledge-based solutions, and inspire action for a just and effective energy transition leading to climate neutrality. We achieve this through analysis, opinions, and dialogue on the decarbonization of key areas of the economy.

Other contributions

Many senior officials and experts provided input and comments of great value to this research. They include: Monika Morawiecka (Regulatory Assistance Project, RAP), local authorities from the Lodz region and other stakeholders of the Polish and European energy sectors.

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