Gerard Wynn, IEEFA Energy Finance Consultant
Paolo Coghe, President, Acousmatics
Arjun Flora, IEEFA Energy Finance Analyst, Europe
June 2020

Financing a Greener European Heating Sector:

A Polish Case Study

Executive Summary

When considering the alternative strategies for two coal-fired combined heat and power (CHP) plants owned by the Czech utility CEZ and based in Poland, our study finds that waste heat recovery (WHR) offers the lowest risk/return option. WHR from steel offers highly attractive financial returns, particularly in scenarios with carbon pricing where it could cost efficiently operate as baseload, substituting for coal CHP where possible, and providing a hedge against higher carbon prices. While WHR from wastewater offers lower returns, it is proven and very low risk, and we conclude it could support steel WHR in a low-carbon heating portfolio. Such a portfolio could include other renewable heating sources, such as solar thermal and geothermal, as well as renewable wind and solar power, to reduce heat pump costs and improve efficiency. Although converting to gas CHP has similar returns and value to sweating the existing coal assets for cash, gas is more profitable and has a reduced exposure to carbon pricing risk and air pollution regulation.[1] However, the profitability of both coal and gas depends in large part on support including a power price premium and capacity payments. Our analysis finds that biomass CHP is not an attractive alternative.

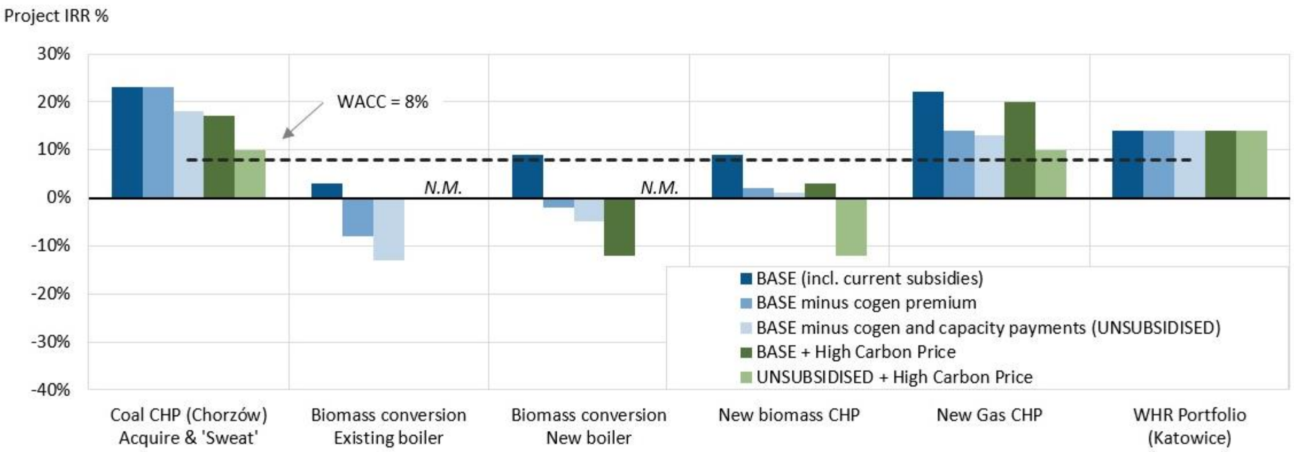
We find that present energy policies make it economically rational for operators to continue to sweat ageing coal CHP assets for the next five years, which would result in more than ten million tonnes of CO2 emissions from these two plants alone, as well as significant local air pollution. We conclude that national and local Polish leaders should be bolder in addressing the major energy transition taking place, and securing a domestic energy supply. Encouraging a switch from coal CHP to gas or biomass CHP, from one polluting combustion technology to slightly less-polluting ones, is too incremental in the context of a major energy transition. There are no dedicated policies at present to support a switch from coal CHP to WHR plants. Such support would offer better long-term value to consumers, as well as significant air quality and climate benefits. There are clear opportunities for international banks, including the European Investment Bank (EIB) and the European Bank for Reconstruction and Development (EBRD), to help reduce the cost of capital and kick-start the transition to this cleaner, low-carbon heating alternative.

Our research shows that the question of profits is really off the table: some fossil fuel and biomass combustion CHP scenarios are still profitable, but most are not (see chart below). Importantly, we find that fossil-free heating is also competitive

[1] By sweating for cash, we mean operating an ageing asset for as long as possible, avoiding investment in capital replacement

and profitable. The choice now is between two profitable options, where fossil-free heating has additional, longer-term benefits for the environment, climate and lower investment risk. It is not a question of environment and climate versus economy, where sustainability impairs profitability. Instead, a more sustainable, long-term solution also assures profitability.

IRR Performance by Technology and Subsidy Scenario



We took a case study investment approach, seeking to clarify the strategic options for a utility generating heat for district heating from a coal-fired combined heat and power (CHP) plant. We chose Poland as our case study, given its high dependence on coal that makes diversification into less-polluting options more urgent, and because of its widespread district heating networks, which should help the adoption of large-scale renewable alternatives including WHR. We selected two coal CHP plants owned by the Czech utility CEZ in the southern Polish cities of Katowice and Kraków, in the coal-mining regions of Silesia and Małopolskie. CEZ has stated that it wants to sell the two plants this year. We modelled actual output of the two existing coal CHP plants, according to heating degree days in Poland for three sample years (2010, 2016 and 2018), to compare cold versus normal and mild winters.

We investigated the following options through 2035:

1. CEZ keeps the coal CHP plants, and operates them for as long as possible.
2. CEZ sells the coal CHP plants to a new owner, who operates them for as long as possible.
3. CEZ closes the coal CHP plants, and converts them to burn 100% biomass (wood chips), either using the existing boiler or a new boiler.
4. CEZ replaces them with a new biomass CHP plant.
5. CEZ replaces them with a new gas CHP plant.

6. CEZ replaces them with a portfolio of waste heat recovery (WHR) plants, using waste heat from local wastewater treatment plants, and from local steel plants.

We modelled the various coal, gas and biomass CHP options on a single unit at the CEZ-owned CHP plants, of around 100 megawatt electrical capacity (MW). Regarding WHR, we identify portfolios of 50 megawatt thermal capacity (MWth) of local steel and wastewater plants with WHR, in each city of Katowice and Kraków.

We investigated two broad scenarios: A base scenario, with low carbon prices (rising to €30 in 2035) and assuming all subsidies available today, and a high-carbon scenario (rising to €45 in 2035) where the CHP plants fail to win some or any of these subsidies. We note that WHR receives no dedicated subsidies today in Poland. All the CHP options receive subsidies, and so are exposed to failure to compete for these, for example in capacity market auctions, or to a policy change. A cogeneration premium is available to gas and biomass CHP. Capacity payments are available to coal, gas and biomass CHP. Coal and gas CHP are also vulnerable to EU carbon prices; they have to pay for their CO_2 emissions. We also investigate a scenario where biomass CHP (presently assumed to be zero-carbon under EU rules) has to pay for its CO_2 emissions. Finally, we note that coal, gas and biomass CHP all have to apply best available technologies for reducing air pollution, under "BREF" (Best Available Technique Reference document) regulations.

Main Findings

1. CEZ keeps its two coal CHP plants, and sweats them through 2035.[2]

    a. Under our baseline low-carbon price scenario, one unit each of Chorzów and Skawina have a combined net present value (NPV) of PLN 636 million (€140 million).[3] Sweating coal assets appears to generate cash: Chorzów and Skawina have EBITDA margins of 23% and 14%, respectively, at the end of 2035.

    b. Under a high carbon price scenario, however, the EBITDA margins fall to 9% for Chorzów and turn negative for Skawina. Their combined NPV falls from PLN 636 million to PLN 397 million. If the CHP plants fail to secure capacity payments, their NPV falls further to PLN 286 million. Sweating coal CHP is a high-risk approach, because of its exposure to carbon prices and subsidies, and is a short-term strategy. Today is as good as it gets for coal CHP.

2. CEZ sells the two plants, and the new owner sweats them for as long as possible

    a. Given the risks discussed above, CEZ may prefer to sell its coal CHP, exiting the Polish heat market. If the sale price equalled our estimate for

[2] Note that under this scenario there is essentially no "engineering" risk. All other CHP scenarios involve a variety of risks typically connected to the management of large engineering projects. We do not explicitly account for these.
[3] We assume a PLN/ € exchange rate of 0.22.

their book value today, from CEZ annual reports, we estimate the buyer would see an NPV of 413 million for a single unit each at the two plants through 2035, and an internal rate of return (IRR) of 23% at its Chorzów plant, under the baseline scenario.

b. Under a high carbon price scenario, however, and if coal also failed to

win capacity payments, the IRR falls to 10%, and the combined NPV falls to PLN 62 million.[4]

3. CEZ converts coal CHP to burn 100% biomass (wood chips), either using the existing boiler or a new boiler

    a. Under our baseline scenario, biomass conversion yields only mediocre returns at best. Using a new boiler, the IRR is 9%, and NPV is PLN 25 million. Using the existing boiler (sacrificing efficiency), the IRR falls to 3% and NPV to minus PLN 194 million.

    b. Under the high-carbon scenario, where biomass conversion fails to secure a cogeneration (cogen) premium and capacity payments, and has to start paying a high carbon price, both plants have a negative IRR. Actual risks to biomass CHP are illustrated by continual revisions of the EU renewable energy directive to tighten biomass sustainability criteria.

4. CEZ replaces coal CHP with a new biomass CHP plant

    a. Under the baseline scenario, a new biomass plant achieves an IRR of 9% and NPV of PLN 69 million. It has an attractive annual EBITDA margin of 59% by 2035.

    b. This outcome is turned on its head under the high-carbon, zero subsidy scenario, resulting in a negative IRR and net income. We also note that a new biomass plant had the highest capital cost and took the most time to build of all the technologies we considered, and therefore will lose the most if our assumed lifetime is truncated.

5. CEZ replaces coal CHP with a new gas CHP plant

    a. Under the baseline scenario, a new gas CHP plant has an IRR of 22% and NPV of PLN 482 million, exceeding all biomass options, and equal to or better than sweating the coal assets.

    b. Under the high carbon, zero subsidy scenario, the gas CHP plant's IRR falls to 10%, and the NPV drops to PLN 63 million. The EBITDA margin at the end of the period falls from 46% to 28%. This outcome underscores that gas CHP also has material regulatory risk exposure.

---

[4] It should be noted that under both cases, IRR treatment depends on the opportunity cost of capital for the investor, whether private equity, developer or independent company. As a consequence, the threshold IRR would be higher if one were to take a pure equity investor perspective.

6. CEZ replaces coal CHP with a portfolio of waste heat recovery (WHR) plants

    a. Under the baseline scenario, allowing all CHP plants to secure all available subsidies, WHR portfolios in Katowice and Kraków underperform gas and coal CHP. The WHR plants have an IRR of 14% and 9% respectively, and NPVs of PLN 56 million and 14 million. However, they equal or out-perform gas CHP under our alternative high-carbon, no-subsidy scenario.

    b. Comparing the underlying assets in these WHR portfolios, steel WHR is superior to wastewater WHR, because of the higher temperature, cheaper heat source that does not require heat pumps. One 20 MWth steel WHR unit achieves an IRR of 30% versus 6% for one 10 MWth wastewater WHR unit. However, both have low running costs, with very high EBITDA margins of 95% and 56% at the end of the period.

    c. One problem for WHR is scale. We conservatively identify 50 MWth of assets in each city, which is about one-third the heat production capacity of a single coal CHP unit. Steel WHR can be challenged by a precarious global steel market. We note that the steel plant in Kraków is more efficient, fuelled by process and natural gas, not coal. On the plus side, wastewater WHR uses heat pumps which may benefit from lower wholesale power prices after the coronavirus pandemic.

Conclusions

Biomass CHP Is a Non-Starter: Even receiving all available subsidies, biomass options barely exceed our cost of capital of 8%. Without subsidies, its performance is very poor. Either way, biomass conversion or new builds underperform all our other options. We conclude that CEZ should not invest in biomass.

Coal CHP vs Gas CHP: Under our baseline scenario, gas CHP and sweating coal assets have a similar IRR and NPV. Gas is more profitable, with a higher EBITDA margin in 2035. When choosing between technologies, CEZ should carefully consider investment outlays and the timing of cash flows. Coal CHP cash flows are increasingly at risk over time, because of its carbon intensity, exposure to air pollution regulation and divestment trends, age, and loss of capacity payments. Gas is also exposed to many of these risks. We note that since 2015, CEZ has recorded large coal CHP impairments, exceeding €100 million, against Skawina (the older plant, commissioned in 1961), as can be seen in the company's annual reports. These impairments indicate that recent air quality and life extension investments at Skawina may have been poorly judged, and underscore the risks of keeping and sweating these assets, as well as the risks for any buyer aiming to do the same at the Chorzów plant. The merit for CEZ to sell its coal CHP depends entirely on sale price.

WHR: Wastewater WHR on its own has only mediocre returns, but is very low risk. Steel WHR has stellar returns, but is exposed to the global steel market. When combined in a portfolio, they perform well. In the near term, CEZ might consider steel WHR as a modular, fast-construction, low-cost option that would still allow the company to keep other options open, such as gas CHP. With very low running costs, steel WHR could operate as baseload, substituting for coal CHP where possible, and provide a hedge against higher carbon prices. Steel WHR might become the foundation for a renewables-based heating portfolio, including WHR from wastewater and other renewable heat sources, and renewable power. Placing WHR in such a portfolio would help overcome the challenges of scale. Investing in WHR might also complement the ambitions of CEZ's energy service company (ESCO) to sell efficiency services to energy-intensive industries.

Recommendations

Polish Policymakers: New-build and biomass conversion should not be subsidised, because even with subsidies, they achieve at best mediocre returns. Consumers could have better value for money with some small tailored support for WHR, such as a more dedicated approach to grants already provided on a case by case basis by the National Fund for Environmental Protection and Water Management. Polish energy policy is very much focused on securing domestic security of supply, where WHR ticks the box.

Local Government: Local authorities are responsible for clean water and air. They are best-placed to develop WHR energy sources by building relationships between local industry and water and district heating service providers. Local authorities are also well-positioned to commission analyses that identify WHR opportunities for district heating.

International Banks: WHR is characterised by high capital costs and very low running costs. International financial institutions including the EIB and EBRD might provide subsidised credit or grants towards initial construction costs, to kick-start a cleaner, low-carbon heating alternative and help carbon-intensive countries like Poland manage their transition.

CEZ: The company has said it wants to sell its coal CHP assets in Poland. Our analysis suggests that there is a better option: To invest in WHR that would allow CEZ to reduce coal consumption, carbon emissions and regulatory risk, while boosting margins.

Table of Contents

Executive Summary 1
Introduction 9
A Neglected Low-Carbon Transition 10
Closing Versus Selling Coal CHP Plants 11
Case Study Country: Poland 12
CEZ Coal CHP in Kraków and Katowice 12
The Polish Heating Market 12
A 2050 Heating Roadmap for Poland 14
Heat Supply Options 14
Coal CHP 15
Gas CHP 15
Biomass CHP 16
Waste Heat Recovery 17
Findings: Comparing Investment Returns and Financial Performance 19
Investment Returns: IRR and NPV 20
Sensitivity to CHP Subsidies 21
Financial Performance: EBITDA Margins and Net Income 23
Risk Assessment 25
Appendix 27
Annex 1: Investment Returns and Performance 27
Annex 2: Assumptions 27
Annex 3: Study Limitations 32
Annex 4: Other WHR Opportunities 32
Annex 5: Heat Pumps - Opportunities and Challenges 33
About the Authors 34

Table of Figures

IRR Performance by Technology and Subsidy Scenario 2

Figure 1: Renewables Transition: Heating Sector Has Fallen Behind, EU-27 plus UK, % of Renewables in Final Energy Consumption (ktoe) 10

Figure 2: Share of District Heating in Total Final Demand for Heating and Cooling, EU-27 plus UK, 2017 (% of ktoe) 11

Figure 3: Coal Still Dominates Polish District Heating, 2018 (% of GJ) 13

Table 1: Heat Recovery Opportunities from Steel Plants and Wastewater Treatment Plants in Our Target Regions 19

Figure 4: IRR Performance by Technology and Subsidy Scenario 20

Figure 5: NPV Performance by Technology and Subsidy Scenario 21

Table 2: Baseline Scenario - With Capacity Payment and Cogen Premium 22

Table 3: High-Risk Scenario - Without Capacity Payment or Cogen Premium, High Carbon Price 22

Figure 6: Electricity Power Price Increase Required for Threshold Cost of Capital, High Carbon Price Scenario 23

Figure 7: EBITDA Margins in 2035 by Technology and Subsidy Scenario 24

Figure 8: Net Income in 2035, by Technology and Subsidy Scenario 24

Table 4: Risk Factors for CHP vs WHR 26

Table 5: Summary of Performance Findings, by Technology 27

Table 6: Selected Financial & Operating Data for All Technologies 28

Introduction

European and global energy demand can be divided broadly among electricity, transport, and heating and cooling. In Europe, demand for heating and cooling equals electricity and transport combined. However, a low-carbon transition in the heating sector has stalled, and a renewed focus is long overdue. Electricity generation was a natural first target to drive low-cost carbon emissions reductions. Low-carbon alternatives to coal-fired electricity generation are now well understood, competitive, and include variable renewables such as onshore and offshore wind, and solar power. As a result, a low-carbon transition in electricity has forged ahead, while a clearer trajectory is emerging for low-carbon transport, with electric vehicles in the public eye.

A low-carbon transition in the heating sector has been much slower and is actually slowing down. Any shift that has occurred to date has centred largely on the burning of woody biomass, which emits air pollutants including particulates and NO_X, as well as carbon dioxide. Other cleaner, large-scale heating options are proven, such as solar thermal, geothermal, waste heat recovery, and ambient heat recovery from the ground, air and sea, but are still confined to particular countries and regions. We note that within heating and cooling, heating accounts for the largest part, and is the sole focus of this report.

We focus on district heating as a centralised source of heating used in densely populated regions and cities that can exploit efficiencies and economies of scale. Large-scale district heating also has access to large-scale renewable energy sources such as waste heat recovery and deep geothermal that are unavailable to individual buildings and households. On the downside, this focus will have less relevance for European countries without district heating networks. But we note that some analysts such as the Pan-European Thermal Atlas (PETA), an umbrella group of academics and policymakers, anticipate significant expansion of district heating in Europe in coming decades.

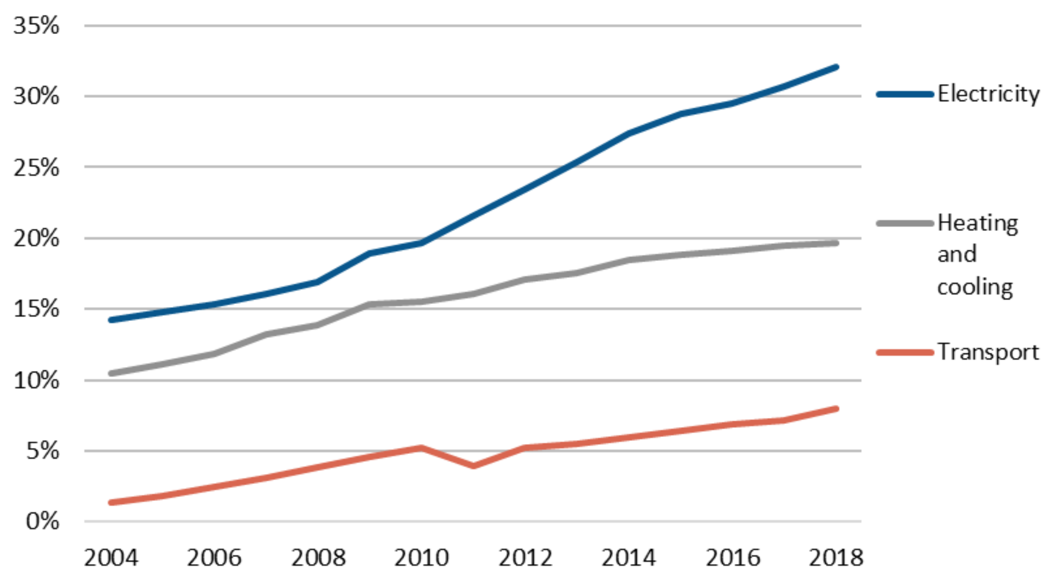
In Europe, the main heating source for district heating networks has been coal-fired combined heat and power (CHP). As a result, coal CHP accounts for a large and growing share of total coal consumption in Europe. The main approach for replacing or converting coal CHP has been to switch to alternative combustion fuels, especially natural gas or biomass. However, burning any carbon-based fuel involves carbon dioxide emissions and air pollutions. We therefore compared the economics of coal, gas and biomass CHP with a non-combustion alternative—waste heat recovery (WHR). We selected WHR as a well-established technology with large potential worldwide.

The goal of our research was to test whether it made economic sense for investors to adopt a “switch and scale” strategy by closing coal CHP plants and converting them to cleaner, non-combustion alternatives such as WHR. We took a case study approach, focusing on Poland, one of the most coal-intensive countries in Europe, with an extensive district heating network. We analysed two existing coal CHP plants in southern Poland, in Kraków and Katowice, called Skawina and Chorzów respectively, owned by the Czech utility CEZ. The utility states that it wants to sell the two plants this year. Our default scenario was for CEZ or a new owner to sweat them through 2035. We compared this investment outcome with CEZ instead replacing coal CHP with gas CHP, biomass CHP, or waste heat recovery from local steel plants and wastewater treatment plants.

A Neglected Low-Carbon Transition

EU energy demand in the heating sector is the same as that in the transport and electricity sectors combined. But electricity has led the transition to renewables. Figure 1 shows how the heating sector has lagged since 2009, when the EU adopted legally binding renewable energy targets for 2020. By 2018, renewables accounted for 32% of electricity production, compared with 20% of heating and cooling. As a result of this slow uptake of renewables in heating, the share of coal use by combined heat and power (CHP) plants rose among all large combustion energy plants from 29% in 2012 to 36% in 2018.

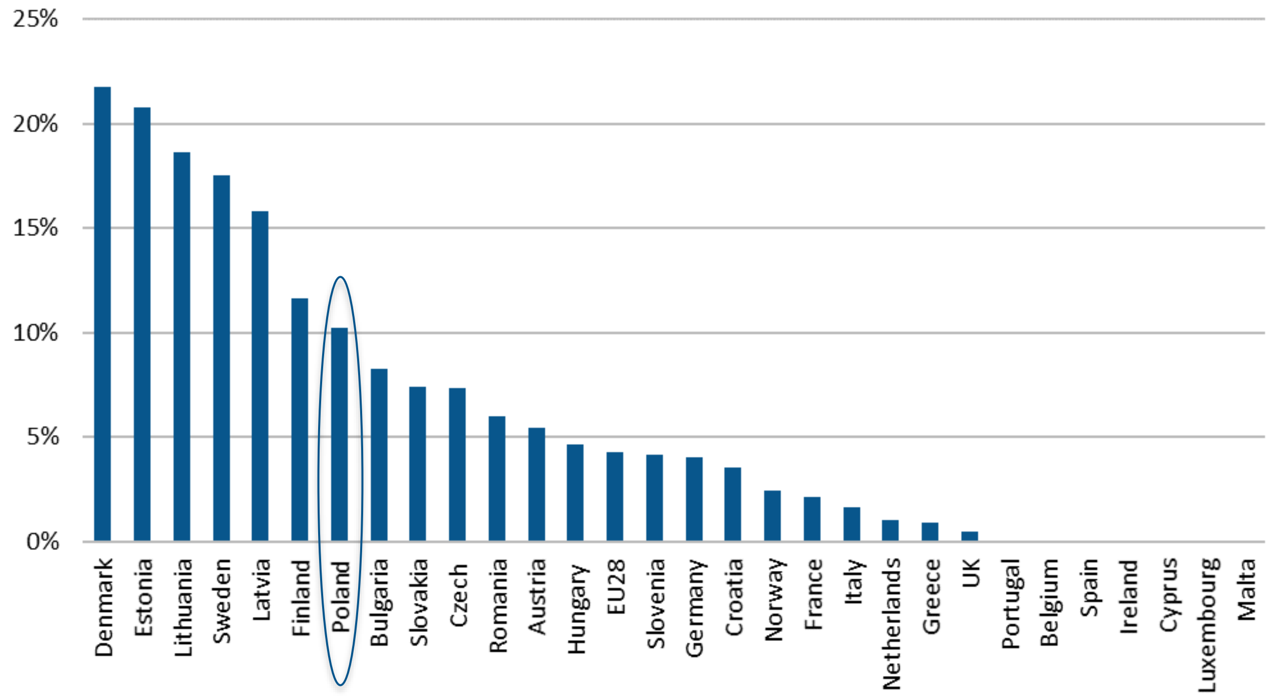
Figure 1: Renewables Transition: Heating Sector Has Fallen Behind, EU-27 plus UK, % of Renewables in Final Energy Consumption (ktoe)



Source: Eurostat.

In this report, we focus on urban district heating. Figure 2 shows the share of district heating in total national heating and cooling is dominated by Baltic states (more than 15% share), Nordic countries (more than 10%) and eastern European countries (more than 5%). Poland ranks seventh in the 27-member EU.

Figure 2: Share of District Heating in Total Final Demand for Heating and Cooling, EU-27 plus UK, 2017 (% of ktoe)



Sources: IEA, Eurostat.

Closing Versus Selling Coal CHP Plants

Coal heat and power generation—as well as mining—face multiple headwinds in the European Union, including the Paris climate agreement that would phase out its use in developed countries by 2030; declining investor interest and divestment; falling costs of renewables; rising carbon prices; and stricter EU pollution policies. As a result, many energy utilities are seeking to abandon coal by selling plants, which is faster and easier than closing, decommissioning, and remediating the sites. Closure also affects future profits because of the costs of laying off or retraining workers; selling can involve a one-off asset impairment that doesn't affect income measures such as EBITDA.

Coal plant sales may lead to a worse environmental outcome than the status quo, however. Few publicly listed utilities are interested in acquiring coal assets because of consumer and civil society opposition. As a result, sales in Europe are almost exclusively to financial buyers, such as two Czech billionaire-led companies, EPH and Seven Energy, and the U.S.-based private equity firm, Riverstone. If buyers are non-consumer-facing energy companies, and less publicly accountable, they may focus more on extracting value by prolonging coal asset life or lobbying for relaxation of environmental regulations than on reducing carbon emissions or local air pollution. Evidence for such an approach is indicated by explicit attempts to weaken environmental standards by two EPH subsidiaries in Germany that joined a legal challenge opposing tougher EU air pollution standards for large combustion plants (Best Available Technique Reference document, or “BREF”).[5]

In this report, we analyse whether existing coal CHP operators or buyers can achieve a better financial and more sustainable outcome by converting coal CHP to a low-carbon alternative, specifically WHR, rather than sweating the coal CHP plant for as long as possible or replacing it with another combustion CHP plant.

Case Study Country: Poland

CEZ Coal CHP in Kraków and Katowice

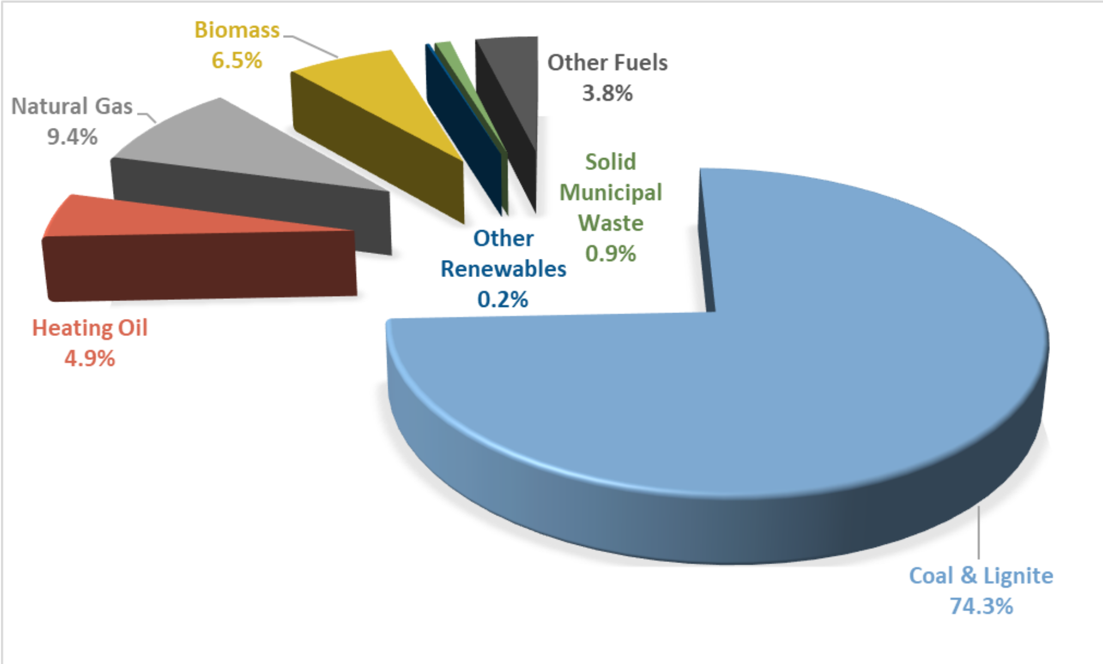
Given the site-specific nature of district heating infrastructure, we focus on actual case studies. In our case study selection, we sought to account for data availability and wider relevance in Europe’s effort to transition away from high-carbon energy. We selected two CHP units owned by the Czech energy company CEZ, both located in coal mining regions in southern Poland. As a high-carbon economy, a transition to cleaner heat in Poland is especially urgent to reduce local air pollutants and carbon emissions, as well as stranded asset exposure. The two CEZ coal units are the Skawina and Chorzów CHP plants, serving large-scale DH networks centred around the cities of Kraków and Katowice. The Kraków network connects the city of Kraków with Skawina, the site of the CEZ Skawina CHP plant.[6] Heat is supplied principally by three energy companies: PGE Energia Ciepła SA (72% share), CEZ Skawina SA (25%) and ZTPO (3%). In Katowice, the district heating network connects an area including Katowice, Chorzów, Siemianowice and Świętochłowice.

The Polish Heating Market

In Poland, the heating and cooling sector accounts for an even greater share of total final energy demand than in the rest of Europe, at 56% compared with around 50% in the EU as a whole.[7] Hard coal is the dominant fuel in district heating in Poland, with brown coal (lignite) making a small contribution (see Figure 3).[8] Natural gas is the second most common. Fossil fuels account for nearly 90% of district heating sources, followed by biomass; the contribution of other renewables, such as geothermal, is almost non-existent. Licenced heat producers were responsible for 37 million tonnes of carbon dioxide emissions in 2018, a 5% decrease from the previous year.

[5] Official Journal of the European Union. *Action brought on Nov 7 2017 – Euracoal and Others vs European Commission*. 2018.
[6] Cieplo dla Krakowa. District heating network.
[7] Aalborg Universitet. Heat Roadmap Poland. 2018.
[8] Energy Regulatory Office. Thermal energy report in numbers – 2018. September 6, 2019.

Figure 3: Coal Still Dominates Polish District Heating, 2018 (% of GJ)



Source: ERO.

Poland's heat market is local, with monopoly characteristics. Energy companies independently set tariffs based on the cost of heat generation and present them to the Energy Regulatory Office for approval. As a result, tariffs for heat production will reflect costs of heat generation the previous calendar year. This delay may mean there is a mismatch between sale prices and rising costs of fuel or carbon. Regarding carbon costs, the heat reference price is partly based on heat units outside the EU emissions trading scheme—below 20MW capacity—which means that carbon prices are not fully reflected. As a result, heat producers don't fully recoup carbon price rises. In 2018, rising coal and carbon prices pushed the average price of heat sold via district heating networks to 40 PLN/GJ (gigajoule), a 3% increase from 2017. Even so, heat generated from burning coal was still cheaper than natural gas and biomass.

In Poland, there has been a legacy of support for CHP plants, as a more efficient alternative to power plants that only generate electricity. They are also viewed as cleaner alternatives than burning wood and coal in the home. A new subsidy regime was recently introduced, replacing a former "certificates of origin" scheme, with a new "cogeneration premium." The scheme has an annual budget of €500 million. It is available to gas and biomass CHP plants, but not to coal CHP, except as a last resort. The scheme provides a premium on top of the wholesale power price to bridge any gap between electricity generation cost and the market price. It is only available when CHP plants are producing both heat and power; premiums are not available during the summer when plants are only producing electricity. The premium is calculated as the difference between costs and heat and power sales and allows an 8% return. We note that we also apply a weighted average cost of capital

(WACC) of 8%. There are three tiers of support: New, substantially refurbished, refurbished and existing (the latter applies to gas CHP only).

As its name implies, the cogeneration premium is exclusively available to CHP plants. There is no equivalent scheme to support non-combustion heat production such as waste heat recovery. Extraction CHP plants are also eligible to participate in Poland's capacity market, where power plants and CHP bid to provide electricity generating capacity under single- and multi-year contracts, with the goal of assuring a secure supply. CHP plants are not allowed to claim capacity payments when they are earning the cogen premium, i.e., when they are producing both heat and power.

A 2050 Heating Roadmap for Poland

"Heat Roadmap Europe" is an EU-funded project that has attempted to provide guidance for policymakers and investors by mapping the low-carbon heating and cooling prospects of EU member states over the next three decades.[9] The initiative found that district heating could be a key to increasing the share of renewables in high-density areas. In Poland, it recommended a roughly 10 percentage point increase in the share of residential heat demand supplied by district heating, to around a 37% share.[10] The study found that large-scale heat pumps would be a key technology to aggregate renewable sources, and account for more than a quarter of district heating supply in 2050 (compared with almost none today). The study found that waste heat recovery was one of the biggest renewable energy opportunities, both directly and via heat pumps. It concluded that the main heat sources in 2050 in Poland would be non-fossil fuel CHP plants, large-scale heat pumps, and waste heat recovery.

Heat Supply Options

The main source for district heating supply in Poland today is coal-fired combined heat and power (CHP). We compare the economics of coal with two alternative combustion fuels, gas and biomass. We assume these CHP plants are all extraction plants, which burn fuels to drive a steam turbine that produces electricity, and then extract some of the steam for heating. Extraction plants can operate flexibly between summer and winter, between power and heat production. We modelled the gas and biomass CHP options on the heat and power production profile of the existing Chorzów coal CHP plant in Katowice, as the newer, more productive and more profitable of the two CEZ coal CHP plants. We compare the economics of coal, gas and biomass CHP with waste heat recovery using heat pumps or heat exchangers. We based our WHR options on actual steel plants and wastewater treatment plants in Katowice and Kraków, estimating a combined 50MWth available in each city. We describe these technologies in more detail in the following sections.

[9] Heat Roadmap Europe. About HRE4. May 26, 2020.
[10] Aalborg University. Heat Roadmap Poland: Quantifying the Impact of Low-Carbon Heating and Cooling Roadmaps. 2018.

Coal CHP

We modelled existing coal CHP on a single unit each at the CEZ-owned Chorzów and Skawina plants in Katowice and Kraków. The Skawina CHP plant was commissioned in 1961. The plant has long supplied the local Skawina district heating network, and the Kraków network since 1986.[11] We estimate that each of Skawina's three units has a maximum net electrical capacity of 73 MW, and a thermal capacity of 146 MWth. The plant has seen various upgrades to reduce toxic emissions of sulphur dioxide and NOx. The plant emitted more than 1 million tonnes of carbon dioxide in 2019, far exceeding its free allocation of 0.05 million tonnes, implying a significant carbon cost.[12] We note that in its annual reports, CEZ is making larger and more frequent coal CHP impairments, especially against its older Skawina plant.[13] These impairments indicate that recent air quality and life extension investments at Skawina may have been poorly judged, and underscore the risks of keeping and sweating these assets, as well as the risks for any buyer aiming to do the same at the Chorzów plant.

The Chorzów CHP plant was commissioned in 2003 to replace an older, co-located plant. The CHP plant consists of two condensing power units, each with a maximum net electrical power of 100 MW, and a thermal power of 180 MWth at full cogeneration.[14] In addition, CEZ Chorzów has two peak heat exchangers that enable it to achieve a total thermal power of 500 MWth. Since 2008, the plant has co-fired biomass with coal. It presently burns a mixture of 84% coal and 16% biomass. The plant emitted some 1.3 million tonnes of carbon dioxide in 2019, far exceeding free allowances of 0.06 million tonnes, implying a significant carbon cost.[15]

Gas CHP

We model a 100 MW new-build combined-cycle extraction gas CHP plant, based on the production profile of the Chorzów coal CHP plant. We derived cost data, including capex, fixed and non-fuel variable costs, from Poland's cogen premium state aid approval application to the European Commission. We supplement and cross-check these data with the Danish Energy Agency's "Technology Data" catalogue, including their energy efficiency assumptions. We assume that adequate gas pipeline infrastructure is already or will be located in Katowice and Kraków. We note there is significant gas pipeline investment in the region to boost Europe's North-South Gas Corridor. The goal of this investment is to improve the diversity and stability of gas supplies in central-eastern and south-eastern Europe, including links with LNG terminals and gas resources in the Baltic and North Sea in the north, and with LNG terminals in the south. In addition, there is investment to improve gas pipeline interconnections between southern Poland, Slovakia and the Czech Republic.

---

[11] CEZ Poland. CEZ Skawina SA. 2020.
[12] European Union. Union Registry, Phase III (2013-2020). 2020.
[13] These recent Skawina impairments include: €5m in 2014; €44m in 2015; €11m in 2018; and €54m in 2019
[14] CEZ Polska. Profile: CEZ Chorzów. May 28, 2020.
[15] European Union. Union Registry, Phase III (2013-2020). 2020.

Gas CHP is gaining support across Europe as an alternative to coal CHP, targeting a reduction in CO_2 emissions and higher efficiencies as well as fewer particulates. Operational similarities to coal CHP mean much existing infrastructure can be used. However, natural gas is still a fossil fuel and not a solution for "greening" district heating. In addition, there are greenhouse gas risks from methane leaks. Although it is a relevant part of the energy transition, we highlight the risk that gas becomes a de facto choice, particularly when supported by subsidies, at the expense of lower carbon, lower risk, longer term options (such as WHR explored in this report).

Biomass CHP

As for gas, we modelled biomass CHP using the production profile of a single, 100 MW unit at the Chorzów CEZ coal CHP plant. We derive data both from the Danish Energy Agency's data catalogue, and the EU state aid approval document for Poland's cogen premium.[16] We analyse three options for replacing coal CHP with 100% biomass (wood chips):

1. To build a brand-new biomass CHP unit;
2. To convert the existing coal plant, using the existing boiler; and
3. To convert the existing coal plant, using a new boiler.

Biomass plants can burn a variety of wood, including chips and more expensive pellets. We assumed the fuel in southern Poland would consist of local wood chips. This assumption was based on a review of local biomass availability; the distance to imported sources for wood pellets via the Baltic Sea; and the biomass fuel burned in actual CHP plants in Poland today. Two of the largest biomass plants in Poland, at Szczecin in the north and Polaniec in the south, both burn biomass consisting mostly of wood chips.

Biomass CHP receives some of the most generous heat production subsidies in Poland and is considered relatively low carbon from a regulatory perspective, benefitting from remaining outside the EU emissions trading scheme (ETS). However, questions remain over the sustainability of the biomass supply chain and the significant pollutants emitted during combustion. Risks to biomass CHP are illustrated by the continuing revisions of the EU renewable energy directive that aim to tighten biomass sustainability criteria.[17] For example, the recent 2018 update of the directive ruled out wood chips transported over distances greater than 2,500km. Further guidance is due later this year and next on these criteria.[18] We used an open-source, EU-funded resource called Hotmaps to determine the local

---

[16] European Commission. State Aid SA.51192 (2019/N)—Poland—CHP support and State aid. SA.52530 (2019/N)—Poland—Reductions from CHP charges for Energy Intensive Users. April 15, 2019, p. 13.
[17] European Union. Official Journal of the European Union, Directive 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources. December 21, 2018.
[18] European Commission. Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee and The Committee of the Regions, EU Biodiversity Strategy for 2030. May 20, 2020.

availability of forest and agricultural "residues," i.e. biomass that was not required for other uses, such as processing waste. We calculate that the most efficient new-build 100 MW biomass unit modelled in this report would consume around 2,700 GWh of biomass annually. Hotmaps data suggest that this amount of biomass was equivalent to available forest and agricultural residues in an area of about 25,000 square kilometres surrounding either Katowice or Kraków (8% of the area of Poland), indicating the challenge of sourcing local sustainable biomass.

Waste Heat Recovery

We investigated waste heat recovery opportunities at actual sites in our two target cities, focusing on wastewater treatment plants and steelmaking. These two heat sources differ fundamentally by temperature. Steel plants generate heat above 100°C, which can be simply and cheaply recovered by passing excess heat directly to the district heating network via a heat exchanger. Wastewater treatment plants generate waste heat below 20°C. Large-scale compressor heat pumps are used to increase the water temperature for use in direct heating. We discuss heat pump opportunities and challenges in more detail in the Appendix Annex 5. A range of other renewable heat sources exist can feed into district heating network via heat pumps or directly, including data centre heat recovery, solar thermal, geothermal and "heat mining." These are briefly summarised in the Appendix Annex 4.

To estimate the WHR opportunities in Kraków and Katowice, we used two publicly available data sources: Hotmaps and the Pan-European Thermal Atlas (PETA). Each provides local estimates for waste heat recovery potential, using slightly different methods.[19] In the case of steel plants, we use a conservative estimate by Hotmaps. In the case of wastewater treatment, we use our own estimate for the actual WHR opportunity, based on flow rate, assumed wastewater temperature and additional source pump power demand. We found our estimate was more conservative than both PETA and Hotmaps. We briefly describe our approach.

Steelmaking

ArcelorMittal has significant steelmaking operations in both Kraków and Katowice. Hotmaps uses published CO_2 emissions to estimate local steel output and standard references for waste heat per tonne to calculate the total waste heat potential. In Katowice, Hotmaps identifies a significant waste heat potential at the Dąbrowa Górnicza steel plant, totalling 447 GWh annually, equivalent to about 85 MWth (megawatt thermal) capacity, if we assume a 60% capacity factor. We assume that the main heat source is sinter cooling, as used by ArcelorMittal for district heating at a similar steel plant in Dunkirk, where heat is captured using an overhead extractor hood. The Dunkirk steel plant WHR unit was commissioned in 1986 and expanded in 2008. It now has a thermal capacity of 36 MWth and supplies more than 110 GWh

[19] The Hotmaps Project aims to help public authorities identify local resources to meet their thermal energy needs in a sustainable, cost-effective way. It is an EU-funded research and innovation programme, led by public authorities across Europe, alongside universities and think-tanks. PETA is a similar, EU-funded initiative under the Heat Roadmap Europe project, also led by various public and private authorities and think-tanks, which aims to help remove market barriers to the uptake of efficient heating and cooling solutions.

of heat annually to the local district heating network, indicating a well-established technology that works at scale. In Kraków, Hotmaps identifies a smaller, 95 GWh waste heat source (about 20 MWth capacity). In summary, we conservatively estimate a 20 MWth resource in Katowice and a 10 MWth resource in Kraków (see Table 2 below), estimates that we reached partly as a result of correspondence with a WHR expert at the consulting firm, Ramboll.

We note the exposure of steel plant WHR to the global steel market is a significant economic risk. ArcelorMittal has recently idled its Kraków steel plant for several months due to poor global steel market conditions, extended by the coronavirus pandemic.[20] Under such circumstances, we assume the dedicated CHP plant supplying heat and power to the steel plants would instead directly supply the local district heating networks. We note also valid concerns about the contribution of steel WHR to local pollution and carbon emissions, especially if WHR adds to the business case for steel and supports or prolongs its operation. The Kraków ArcelorMittal steel plant recently updated its energy source, reducing local pollution with a 75 MWe CHP plant ("Generation Plant Kraków") that the owner recently converted from coal to burn a combination of natural and process gases from the steel plant.[21] The ArcelorMittal factory at Katowice (Dąbrowa Górnicza) is powered by a 180 MWe Tameh CHP plant called "Generation Plant Nowa" that burns coal, natural gas and process gas. We note that there is growing ambition among the most progressive EU countries to develop "green hydrogen," such as Denmark's use of offshore wind, whose use could entirely decarbonise the steel sector, as a new, non-fossil fuel source of industrial heat.[22] Applying WHR could be a first step towards such radical decarbonisation.

Wastewater Treatment

Regarding wastewater treatment, we used Hotmaps and PETA to identify local wastewater treatment plants. In the Katowice district heating system, these were the Gigablok, Dąbrówka-Mała Centrum and Radocha II plants. [23,24] In the Kraków-Skawina system, we identified one large plant at Kraków-Płaszów.[25] We calculated waste heat potential based on local treatment plant flow rate data. We then allocated heat pumps to this waste heat, in multiples of 5 MWth and 10 MWth capacity, based on Danish catalogue cost data. In this way, we derived a total 30 MWth installed heat pump capacity in Katowice and 40 MWth in Kraków. We note that WHR from wastewater treatment plants is a well-established technology in Europe. Perhaps the largest example is Gothenburg, where heat pumps commissioned in 1985 have a combined capacity of 160 MWth, supplying more than 440 GWh of heat annually to the local district heating network. Another example is in Sandvika, Norway, where heat pumps commissioned in 1988 and expanded in

---

[20] Argus Media. Coronavirus postpones AM Kraków furnace restart. March 17, 2020.
[21] Tauron ArcelorMittal Energy Holding. Modernization of boiler no. 8 completed. March 2018.
[22] Maersk. Leading Danish companies join forces on an ambitious sustainable fuel project. May 26, 2020.
[23] Katowickie Wodociągi SA. Treatment Plants. May 28, 2020.
[24] Sosnowieckie Wodociągi SA. Radocha II sewage treatment plant. May 28, 2020.
[25] Wodociągi Miasta Krakowa. Płaszów Wastewater Treatment Plant. May 28, 2020.

2008 have a combined capacity of 23 MWth and supply more than 50 GWh heat annually for district heating.

Table 1 summarises our findings for the potential WHR-installed thermal capacity from steel and wastewater in Kraków and Katowice, and compares the figures with the actual heat capacity of a single generation unit at the local coal CHP. Our estimated WHR potential is equivalent to about one-third of the installed thermal capacity of a single existing coal CHP unit.

Table 1: Heat Recovery Opportunities from Steel Plants and Wastewater Treatment Plants in Our Target Regions

DH Network	Fuel Source	Operator	Data Source	Heat Capacity, MWth
Katowice	Coal CHP	CEZ Chorzów (1 unit)	CEZ	180
	WHR - steel plant	ArcelorMittal	Ramboll and Hotmaps	20
	WHR - wastewater treatment	Various	IEEFA estimate	30
Kraków	Coal CHP	CEZ Skawina (1 unit)	CEZ	146
	WHR - steel plant	ArcelorMittal	Ramboll and Hotmaps	10
	WHR - wastewater treatment	Various	IEEFA estimate	40

Sources: As Shown.

Findings: Comparing Investment Returns and Financial Performance

We investigated the following options through 2035:

1. CEZ keeps the existing coal CHP plants and sweats them for as long as possible.

2. CEZ sells the coal CHP plants to a new owner, who sweats them for as long as possible.

3. CEZ closes the coal CHP plants and converts them to burn 100% biomass (wood chips) instead, either using the existing boiler or a new boiler.

4. CEZ replaces the coal CHP with a new biomass CHP plant.

5. CEZ replaces the coal CHP with a new gas CHP plant.

6. CEZ replaces the coal CHP with a portfolio of waste heat recovery (WHR) plants, using waste heat from local wastewater treatment plants, and local steel plants.

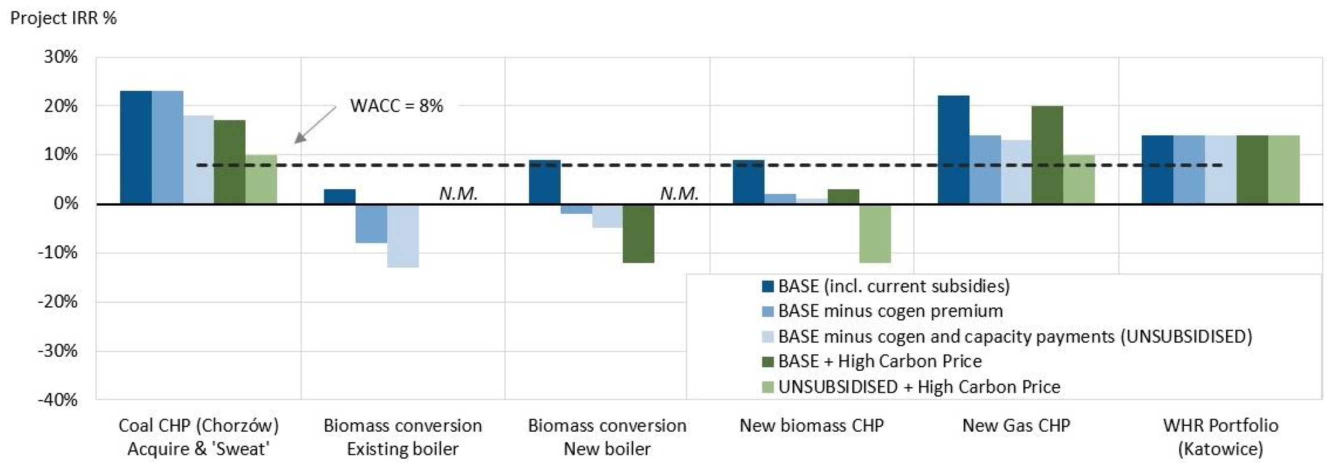
We investigated two broad scenarios: A base scenario, with low carbon prices (rising to €30 in 2035) and assuming all subsidies available today, and a high-carbon scenario (rising to €45 in 2035) where the CHP plants fail to win some or any of these subsidies. We note that WHR receives no dedicated subsidies today in

Poland. All the CHP options receive subsidies, and so are exposed to failure to compete for these, for example in capacity market auctions, or to a policy change. A cogeneration premium is available to gas and biomass CHP. Capacity payments are available to coal, gas and biomass CHP. Coal and gas CHP are also vulnerable to EU carbon prices; they have to pay for their CO_2 emissions. We also investigate a scenario where biomass CHP (presently assumed to be zero-carbon under EU rules) has to pay for its CO_2 emissions, a hypothetical situation. Finally, we note that coal, gas and biomass CHP all have to apply best available technologies for reducing air pollution, under "BREF" (Best Available Technique Reference document) regulations.

Investment Returns: IRR and NPV

Figures 4 and 5 below summarise the investment performance of the above options two to six. We leave out the first option since it does not require an initial investment outlay.

Figure 4: IRR Performance by Technology and Subsidy Scenario

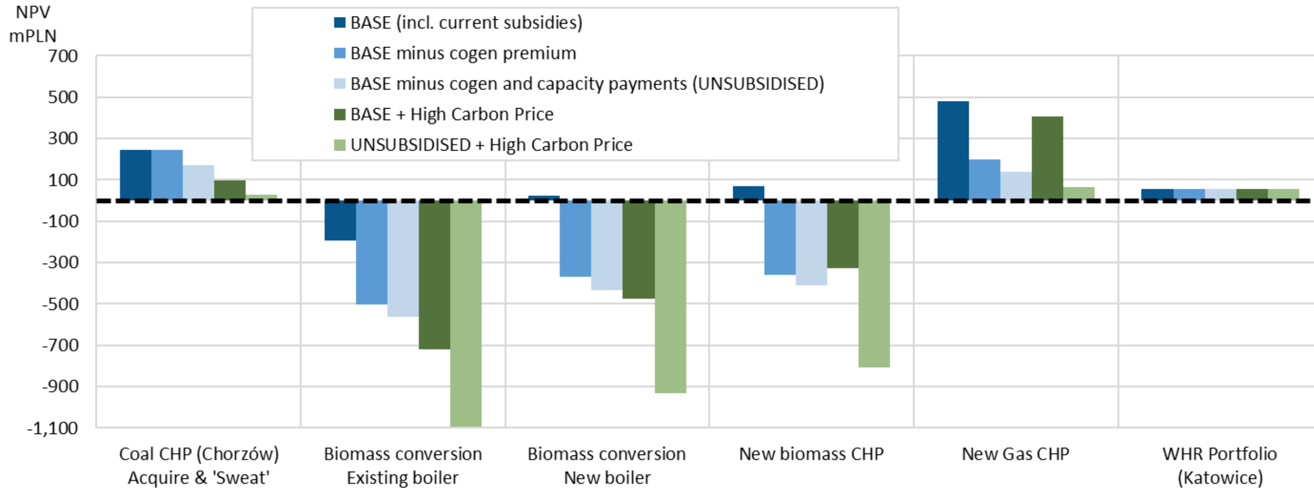


We can see clearly from Figure 4 that biomass does not meet the grade. Biomass at best only just exceeds our assumed cost of capital, even after accounting for "price adders" such as capacity payments and a cogen premium. As these adders are removed and a higher carbon price is introduced, cash flows over the investment period eventually become entirely negative for the biomass conversion options, making the IRR result not meaningful ("N.M.", in Figure 4 above). We note that biomass at present does not have to pay a carbon price, in the EU ETS. Adding a carbon price was intended to illustrate the economic impact of that exemption.

New gas CHP and old existing coal CHP fare better, but are vulnerable to changes in carbon prices. Because it is more exposed than gas, coal is slightly outperformed by gas in our high carbon price scenario.

WHR performs well, exceeding the cost of capital and returning the same 14% across all scenarios since it does not currently receive subsidies and is not exposed to carbon price risk.

Figure 5: NPV Performance by Technology and Subsidy Scenario



The same trends are more apparent in Figure 5. Even with existing subsidies, biomass can provide, at best, only a very small positive NPV. Without subsidies, all biomass options go heavily negative. Gas CHP only outperforms coal CHP when subsidised, or under a high carbon price scenario. WHR produces a positive NPV in all cases and outperforms all the others in the high-carbon, no subsidies scenario. We note that WHR has a smaller NPV partly because it is physically smaller; it has only one-third of the heat generating capacity of CHP.

Finally, we find that the financial performance of CHP technologies is significantly affected by the severity of winter, which can reduce IRR by around 3 to 5 percentage points (based on a comparison of 2018 with 2010, where the former had 20% fewer "heating degree days", HDD, over the year). This is sufficient to make marginal projects, such as new-build biomass CHP, significantly less attractive. As a low operating cost technology, we might expect WHR to operate at baseload, making CHP more susceptible to increasingly infrequent winter heating demand peaks.

Sensitivity to CHP Subsidies

The most generous CHP support schemes in Poland are the cogen premium and capacity market. In this section, we inspect the performance of our various CHP options with this support, and consider further support that biomass requires to meet our investment hurdles. For each technology, we have computed the minimum electricity price inflation necessary to reach a cost of capital of 8%.

Table 2 below shows the situation in our baseline scenario, with all available subsidies. Table 3 shows the opposite situation, where we remove both supports and also apply a high carbon price, in this case of €40 in 2025, to coal and gas CHP only, since at present biomass does not pay for its carbon emissions. This is higher than the €35 in 2025 under our high-carbon scenario, because we aimed to find what level of carbon price in 2025 would cause coal to fail to reach our 8% cost of capital threshold. Table 2 shows that with generous subsidies, a new biomass CHP plant and a biomass conversion with a new boiler both meet our target 8%

enterprise IRR (which is based on a 12% cost of equity), while converting to biomass but keeping the existing boiler does not make the grade and would need higher electricity prices just to break even. Table 3 shows how far biomass is out of the money without the subsidies already available today.

Table 2: Baseline Scenario - With Capacity Payment and Cogen Premium

Technology Option	Electricity Market Price PLN/MWh [a]	Capacity Payment PLN/MWh [b]	COGEN Premium PLN/MWh [c]	BREAKEVEN ADDER PLN/MWh [d]	Electricity Market Price Shortfall % [e] = [d] / ([a] + [b] + [c])
New Biomass CHP	246.5	259.9	286.8	0.0	none
Conv. New Boiler	246.5	259.9	201.4	0.0	none
Conv. Existing Boiler	246.5	259.9	158.2	53.0	8%
GAS CHP	246.5	259.9	150.7	0.0	none
Existing COAL CHPs	246.5	259.9	0.0	0.0	none
WHR Katowice	246.5	0.0	0.0	0.0	none

Note: the breakeven adder is the increase in electricity market prices that would be needed for the specific technology to reach the target IRR (8%) and achieve 0 NPV. If the adder is = 0 it means that the specific technology already reaches the target IRR (8%) and achieves 0 NPV at current prices.

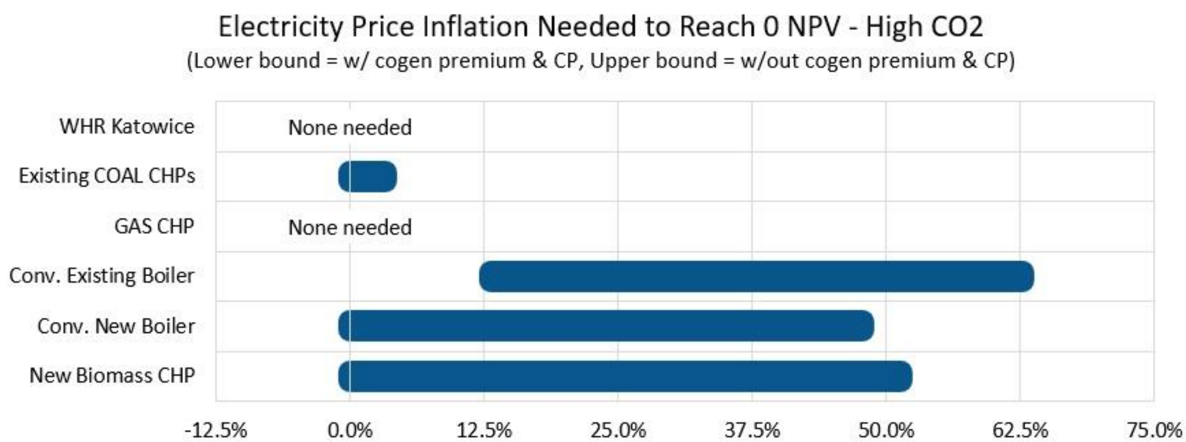
Table 3: High-Risk Scenario - Without Capacity Payment or Cogen Premium, High Carbon Price

Technology	Electricity Market Price PLN/MWh [a]	Capacity Payment PLN/MWh [b]	COGEN Premium PLN/MWh [c]	BREAKEVEN ADDER PLN/MWh [d]	Electricity Market Price Shortfall % [e] = [d] / ([a] + [b] + [c])
New Biomass CHP	246.5	0.0	0.0	126.5	51%
Conv. New Boiler	246.5	0.0	0.0	117.9	48%
Conv. Existing Boiler	246.5	0.0	0.0	154.5	63%
GAS CHP	246.5	0.0	0.0	0.0	none
Existing COAL CHPs	246.5	0.0	0.0	8.0	3%
WHR Katowice	246.5	0.0	0.0	0.0	none

Note: the breakeven adder is the increase in electricity market prices that would be needed for the specific technology to reach the target IRR (8%) and achieve 0 NPV. If the adder is = 0 it means that the specific technology already reaches the target IRR (8%) and achieves 0 NPV at current prices.

Figure 6 illustrates these findings in a chart, where we explore sensitivity to the cogen premium and capacity payments, given by the horizontal position of the bar in the chart. The further the bar is to the right, the higher the electricity price (in addition to the subsidy) required to reach the target IRR, and therefore the more regulatory risk for investors. If a bar does not reach 0 in the horizontal axis (e.g., biomass), then the technology will not break even, even with the help of capacity payments and cogen premium. Without these subsidies, we see a shortfall of around 50% in today's power price for biomass CHP options.

Figure 6: Electricity Power Price Increase Required for Threshold Cost of Capital, High Carbon Price Scenario



Financial Performance: EBITDA Margins and Net Income

Figures 7 and 8 show the projected financial performance of the various technology options in 2035, under our five subsidy scenarios. Coal CHP performance is unaffected by existing subsidies, as capacity payments for coal end in 2025. We see that coal is exceptionally vulnerable to higher carbon prices. Its performance underscores the near-term nature of the strategy to sweat such assets. Conversion to biomass is shown to be unprofitable on a net income basis (Figure 8) without full subsidy support. New-build biomass and gas CHP perform better, with generally positive income. Gas CHP is less exposed to subsidy risks than biomass, generating ~30-50% EBITDA margins vs ~10-60% for biomass. The low operating cost of WHR shows in a margin of more than 70%, but the lack of scale is apparent in lower net income, e.g., PLN 23 million vs PLN 55 million for gas CHP in our high-carbon scenario.

Figure 7: EBITDA Margins in 2035 by Technology and Subsidy Scenario

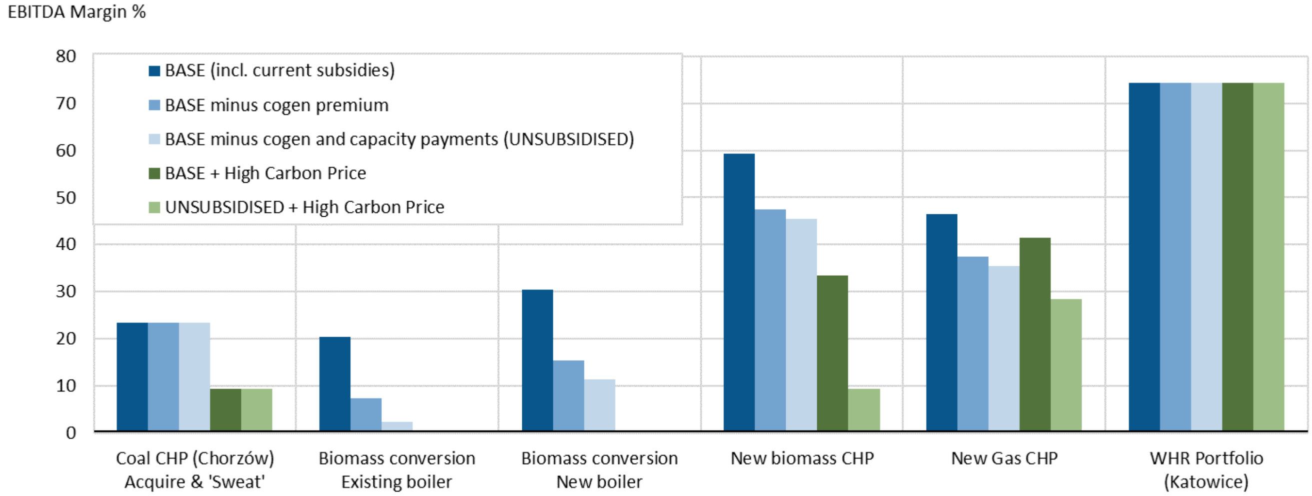
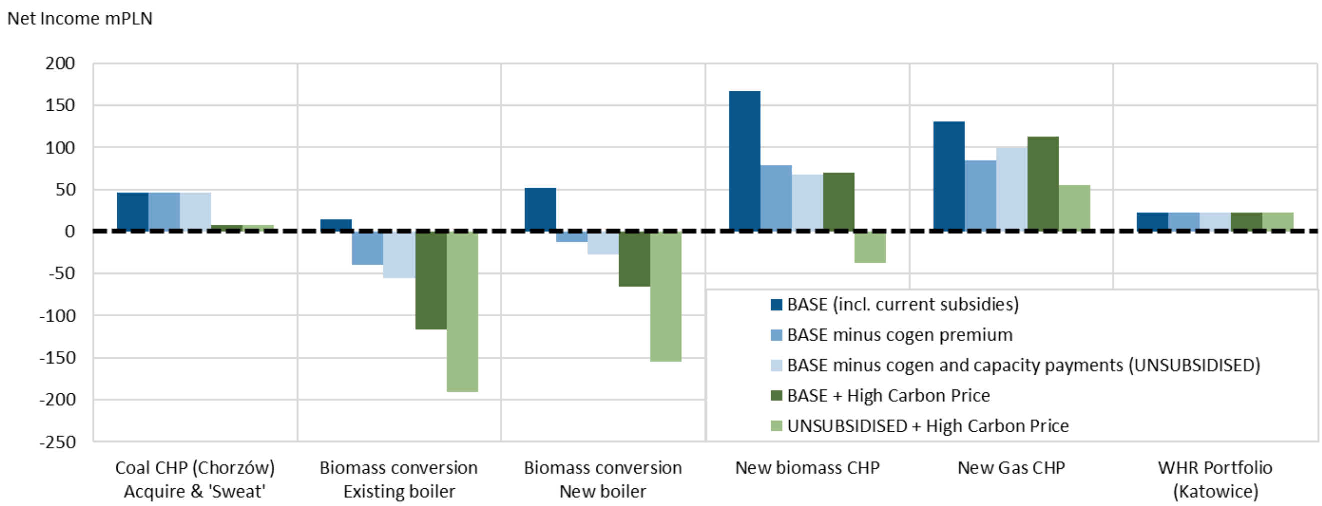


Figure 8: Net Income in 2035, by Technology and Subsidy Scenario



A more detailed assessment of WHR potential would be required to determine exactly how much annual heat could be produced. We note the variance in both profitability and risk between WHR from steel plants and from wastewater. Nevertheless, this analysis shows there is good reason to explore this option in more detail—not just in this particular region, but also more broadly across Poland, where district heating networks would benefit from a secure, low-carbon, domestic supply source. More detailed results of all technologies and scenarios are shown in the Appendix.

Risk Assessment

Energy Demand and Cost of Capital

All investors want to be compensated for risk, and different investors have different risk appetites. For all investors in CHP projects, a solid investment case is built on stable cash flows, as well as an assumption of rising power demand and stable heat demand. Both of these assumptions may be flawed.

There is a general trend in Europe for a decoupling of energy demand and economic growth, as a result of advances in energy efficiency, growth in the less energy-intensive service economy, and growth in renewable energy. In addition, demand reductions from consumer changes in behaviour related to the COVID-19 pandemic may create revenue shortfalls for utilities. The pandemic's effects on demand will be exacerbated for producers selling power to commercial and industrial customers.

When it comes to heat demand, our modelling shows that NPV values are very susceptible to the number of heating degree days. For example, new-build biomass, the highest capital cost project we considered, has an NPV (discounted at our WACC of 8%) for a cold winter (i.e., 2010) equal to PLN 108 million. The same project would incur a loss of PLN 86 million on its NPV for a mild winter (2018). For a new gas CHP plant, the most profitable project (highest NPV under our low-carbon scenario) among the ones we considered, the NPV was about 30% lower in a mild winter (PLN 380 million vs PLN 541 million for a cold winter). The unstable cash flows caused by the swing in such values are more problematic for investors than the possibility of an occasional warm winter – the more so for higher opportunity cost of capital. It's also worth noting that eight of the 10 warmest years in Poland since 1975 have occurred since 2000.[26]

Preliminary analyses of the impact of COVID-19 also demonstrate the cost of capital for utilities has been affected. In the U.S., the cost of capital for utilities is increasing because of increases in the spread between utility and government bonds, increases in overall volatility, and increased utility business risk.[27] We note that there has been increasing reluctance among banks to lend to coal projects, and even to lend to gas projects. A decreased ability to borrow capital would impact the cost of capital in a negative way. For example, a 40-60 capital structure (vs a 50% debt and 50% equity as we modelled) would entail a decrease of 52 PLNm (-11%) in NPV terms for a new gas CHP plant. For the most capital intensive of the biomass CHP options we modelled (the new plant), the change in capital structure would almost wipe out NPV, from a PLN 69 million return in NPV terms to PLN 9 million.

Finally, it should be noted that all the projects we modelled are not created equal, in terms of risk. Some of the projects we modelled (notably existing coal) only have a downside from the current status if tougher air pollution regulations prevail, a coal phaseout is implemented or lenders stop financing fossil fuel generation projects.

---

[26] Eurostat. Cooling and heating degree days by country—annual data. February 24, 2020.
[27] The Brattle Group. Brattle Economists Publish Assessment on COVID-19 Impacts on Energy Industry. May 12, 2020.

Such risks are not mutually exclusive, and will increase a project's cost of capital.

Other Risks

Table 4 below shows a qualitative assessment of other risk factors by technology.

Table 4: Risk Factors for CHP vs WHR

Risk Factors	CHP			WHR	
	Coal	Gas	Biomass	Sewage	Steel
Environmental policy and regulatory risks: – Coal and gas are exposed to increases in CO2 certificate prices – All CHPs are exposed to regulatory and environment-related risks that could jeopardise cash flows further. – Air pollution regulation (e.g. BREF) forcing additional 'maintenance' (vs growth) CAPEX and foregone revenues. – Given that "cogen premium" and "capacity payments" represent the status quo, projects that rely on these subsidies to supplement cash flows stand to lose out if the subsidies are removed or diminished.	High	Medium	High	Low	Low
Fuel price and supply risks	Medium	Medium	Medium	Low	Low
Volume risk, e.g. closure of steel plants or downtime due to economic factors	Low	Low	Low	Low	High
Project execution risks: – All new build CHPs contain construction risk – WHR carries risk from being a newer, smaller in scale and less widely implemented technology, with lack of applicable best practices and greater bespoke design required	Low	Medium	Medium	Medium	Low
Electricity price impact: – WHR from sewage/wastewater requires electricity to run heat pumps. Where this can be sourced from on-site generation, risk is low, but where it must be imported from the Grid there is significant exposure	Positive	Positive	Positive	Negative	N/A

Appendix

Annex 1: Investment Returns and Performance

We summarise our IRR, NPV, EBITDA margin and net income findings in Table 5 below.

Table 5: Summary of Performance Findings, by Technology

		Sweated coal		Acquired & Sweated coal		Biomass Conversion		New-Build						
		Chorzów	Skawina	Chorzów	Skawina	Existing Boiler	New Boiler	Biomass CHP	Gas CHP	WHR portoflio	WHR Katowice	WHR Krakow	WHR water	WHR steel
WITH SUBSIDIES														
Project IRR (WACC: 8%)	%	N/A	N/A	23.1	N/A	3	9	9	22	9-14	14	9	6	30
NPV (@8% discount rate)	PLN mln	464	172	243	170	-194	25	69	482	14-56	56	14	-4	77
EBITDA margin, end of period	%	23	14	23	14	20	30	59	46	66-74	74	66	56	95
NET INCOME, end of period	PLN mln	62	20	46	20	15	52	167	131	18-23	23	18	3	16
WITHOUT COGEN														
Project IRR (WACC: 8%)	%	N/A	N/A	23	N/A	-8	-2	2	14	9-14	14	9	6	30
NPV (@8% discount rate)	PLN mln	464	172	243	170	-505	-371	-361	198	14-56	56	14	-4	77
EBITDA margin, end of period	%	23	14	23	14	7	15	47	37	66-74	74	66	56	95
NET INCOME, end of period	PLN mln	62	20	46	20	-40	-12	79	85	18-23	23	18	3	16
W/O COGEN, NO CAPACITY PAYMENTS														
Project IRR (WACC: 8%)	%	N/A	N/A	18	N/A	-13	-5	1	13	9-14	14	9	6	30
NPV (@8% discount rate)	PLN mln	392	132	172	130	-565	-432	-411	137	14-56	56	14	-4	77
EBITDA margin, end of period	%	23	14	23	14	2	11	45	35	66-74	74	66	56	95
NET INCOME, end of period	PLN mln	62	20	46	20	-55	-27	68	99	18-23	23	18	3	16
HIGH CARBON (including biomass)														
Project IRR (WACC: 8%)	%	N/A	N/A	17	N/A	negative	-12	3	20	9-14	14	9	6	30
NPV (@8% discount rate)	PLN mln	320	77	99	74	-720	-476	-326	407	14-56	56	14	-4	77
EBITDA margin, end of period	%	9	negative	9	negative	negative	negative	33	41	66-74	74	66	56	95
NET INCOME, end of period	PLN mln	23	-7	8	-7	-116	-65	70	113	18-23	23	18	3	16
HIGH CARBON, W/O COGEN, NO CP														
Project IRR (WACC: 8%)	%	N/A	N/A	10	N/A	negative	negative	-12	10	9-14	14	9	6	30
NPV (@8% discount rate)	PLN mln	249	37	28	34	-1093	-933	-807	63	14-56	56	14	-4	77
EBITDA margin, end of period	%	9	negative	9	negative	negative	negative	9	28	66-74	74	66	56	95
NET INCOME, end of period	PLN mln	23	-7	8	-7	-191	-155	-37	55	18-23	23	18	3	16

Annex 2: Assumptions

Our analysis period spans 15 years, from 2020 to 2035. We took this medium-term view to account for the performance of new-build heat production assets, which typically last 25 years or more. We do not include any residual value in 2035 in our estimate of net present value (NPV), thus disadvantaging longer-lived new-build assets, such as gas CHP and WHR versus coal CHP and biomass conversion. We did not account for residual value on the basis of great uncertainty in commodity prices and energy markets generally so far ahead. We phase capex over one to four years, depending on the build time of the asset. Table 6 shows an overview of our financial and operational assumptions.

Table 6: Selected Financial & Operating Data for All Technologies

	Variable	Installed Capacity	Capex	Fixed O&M	Variable O&M (Excl. Carbon and Fuel)	Electrical Efficiency	Carbon Intensity (EU ETS)	Carbon Intensity (EU ETS Plus Biomass)	Capacity Payment (2024 Price)	Cogen Premium (2020 Price)
	Units	MWe (WHR - MWth)	PLN mln/ MW	PLN/ MW/ year	PLN/ MWh	%	CO2/ MWh Electrical	CO2/ MWh Electrical	PLN/ kW/ yr	PLN/ MWh
Existing	Coal CHP - Chorzów	100	2.62	250,000	10.0	25%	0.92	0.92	259.87	0
	Coal CHP - Skawina	73	0.04	250,000	10.0	24%	1.09	1.09	259.87	0
Conversion	Biomass CHP - new boiler	100	7.27	334,978	12.5	23%	0.00	1.54	259.87	201.35
	Biomass CHP - old boiler	100	7.27	362,500	14.5	21%	0.00	1.69	259.87	158.2
New-build	Gas CHP	100	4.50	225,000	5.0	54%	0.43	0.43	259.87	150.65
	Biomass CHP	100	11.36	313,404	11.8	43%	0.00	0.82	259.87	286.78
	WHR water - small	5	3.91	9,084	9.95	2.9 (COP)	0	0	0	0
	WHR water - large	10	3.04	9,084	7.68	2.9 (COP)	0	0	0	0
	WHR steel - small	10	3.18	0	9.08	N/A	0	0	0	0
	WHR steel - large	20	2.27	0	9.08	N/A	0	0	0	0

Commodity Markets

Carbon Prices

The EU emissions trading scheme requires all large industrial polluters above 20 MW, including CHP plants, to acquire an EU allowance (EUA) for every tonne of carbon dioxide emissions. CHP plants get a certain portion of their EUAs for free. However, this allocation has fallen significantly. Our two CEZ coal CHP plants received less than 5% of their CO_2 emissions as free allowances in 2019. As a result, we disregard free allowances in our analysis. Regarding the level of carbon prices, we have two carbon price scenarios. In our baseline scenario, prices rise by inflation from €23 at the end of the forward market in 2024 (at the time of writing), to €30 in 2035. In our high carbon price scenario, carbon prices jump to €35 in 2025, and then rise to €45 in 2035.

Fuel Prices

We take coal prices from the futures market as published by the Intercontinental Exchange (ICE) for 2021 and 2022, and thereafter index to inflation through 2035.[28] We take gas prices from forward contracts for 2021 and 2022 in Poland, as published by the Polish Power Exchange, TGE, and then apply inflation.[29] We take Polish national biomass prices for all heat sources in 2018 as published by Poland's Energy Regulatory Office, and then index to inflation.[30] To derive CHP fuel costs, we convert the prices into price per megawatt hour (MWh) and then divide by the electrical efficiency of the CHP asset.

[28] Intercontinental Exchange. API2 Rotterdam Coal Futures. May 27, 2020.
[29] TGE. About the market – gas. May 28, 2020.
[30] Energy Regulatory Office. Thermal energy in numbers – 2018. September 6, 2019.

Financial

Cost of Capital, Interest and Taxes

We assume a cost of debt of 5%, a cost of equity of 12%, and a 50-50 capital structure equally balanced between debt and equity, resulting in a weighted average cost of capital (WACC) of 8%. We use this WACC also as our discount rate when calculating net present value. We use an inflation rate of 2.5%, in line with expectations of PGE, Poland's biggest energy company. We allocate capex debt interest payments as incurred by individual technologies and pay for interest payments using debt and equity. We use Poland's corporate tax rate of 19%. We use a PLN/ Euro exchange rate of 0.22.

Capex, and Fixed and Variable Operating and Maintenance (O&M) Costs

Existing Coal CHP: We estimate existing coal capex as the fee paid by a hypothetical buyer of the coal assets from the present owner, CEZ. We calculate this purchase price as the price paid by CEZ in 2006, minus subsequent impairments and depreciation, arriving at a total of PLN 582 million, for the entire CHP plants, based on our interpretation of the utility's historical financial reports. We derive fixed and variable O&M costs from Polish government assumptions published in its EU state aid approval application for a cogeneration premium. We derive efficiency and carbon intensity from data published by CEZ for actual power and heat generation, fuel consumption and carbon emissions.

New-build Gas CHP: We obtained capex, fixed and variable O&M costs from the EU state aid approval application. We assume the same carbon intensity of electricity generation as PGE's existing gas CHP plant, Zielona Gora. We estimate a back-pressure electrical efficiency using Danish catalogue data for efficiency in condensing mode, and construction time.

New-build Biomass CHP: We derive capex and fixed and variable O&M cost from the EU state aid application. We use Danish catalogue data for electrical efficiency and construction time. We assume a base case carbon intensity of zero, in line with EU carbon market rules. We also calculate actual carbon emissions, using data for the carbon content per MWh of woodchips, dividing this by the electrical efficiency of the CHP plant, and multiplying by power generation in MWh.

Conversion Biomass CHP: We use Danish catalogue data for capex, fixed and variable O&M costs, and for construction time. We assume that efficiency is a discount on the existing coal CHP electrical efficiency, of minus 2% for biomass conversion using a new boiler, and minus 4% for using the existing boiler, in line with Danish catalogue data. We note that because of the low electrical efficiency of the existing coal CHP, this is a severe penalty. We treat carbon intensity in the same way as new-build biomass.

WHR from Steel Plants: A Ramboll expert provided data for capex and O&M costs. We assume that the energy company, in this case CEZ, pays the full WHR capex and operating costs. We assume that the operating costs include a fee paid to the steel plant owner, ArcelorMittal in this case, for use of the waste heat.

WHR from Wastewater Treatment Plants: We use Danish catalogue data for construction time, and for capex and fixed and variable O&M costs, for both a larger, 10 MWth, and smaller, 5 MWth, heat pump with WHR. As for Steel Plant WHR, we assume that the energy company makes all the required investments. We assume that the wastewater plant owner provides the waste heat for free.

"BREF"

Large combustion plants including CHP in the European Union are required to apply best available technology for reducing emissions of dangerous air pollutants under the EU industrial emissions directive, using a regularly updated Best Available Technology Reference document. We assume that our coal, gas and biomass CHP plants will meet the next BREF implementation deadline of 2021. We also assume that new-build gas will meet the following deadline, which we expect around 2028, as a clean combustion technology. We assume that existing coal and newbuild or conversion biomass will have to upgrade their entire capacity to the latest abatement technology, and apply a conservative, index-linked abatement cost of PLN 0.13 million per installed megawatt in 2020, depreciated over 10 years. This cost is based on the actual cost of abatement as reported by PGE, for the present BREF due 2021, of PLN 2 billion across the company's entire installed fossil fuel generating capacity of 15 GW. We assume that these BREF upgrades take 12 months and are carried out over three years from 2026-2028, i.e., that 33% of coal and biomass capacity is unavailable annually in these years.

Subsidies

Poland awards CHP plants various non-energy market payments and subsidies. The main two such payments are the capacity market and the recently introduced cogeneration premium. We are unaware of any dedicated support scheme available for WHR. Regarding capacity payments, we took actual auction results through 2024, and then indexed to inflation through 2035 for gas and biomass, and to 2025 for coal, which is banned from capacity markets after 2025 under EU rules. We only allowed CHP plants to benefit from capacity payments when they were not receiving the cogeneration premium. We used the 15-year cogeneration premium contracts awarded to CHP plants last year, which guaranteed a certain premium above the power price for electricity sold by new-build gas (PLN 151/ MWh) and new-build, extensively refurbished and refurbished biomass (PLN 287, PLN 201 and PLN 158 respectively). We limit these payments to periods when CHP plants produce both heat and power, i.e., not in summer.

Operational

We apply a 0.15% annual degradation rate for energy output by all technologies.

Thermal CHP

Capacity: We analysed one unit each at the two CEZ-owned coal CHP plants that have a net electrical capacity of 73MW for Skawina and 100MW for Chorzów. We modelled the new-build gas and new-build and conversion biomass CHP on the Chorzów coal CHP plant, as the newer and more profitable of the two, i.e., with 100MW net capacity.

Capacity factor: We modelled heat and power output according to published output and heating degree days in a cold winter (based on 2010), our base year (2016), and a mild winter (2018). In our base year, this modelling indicated electrical and thermal capacity factors at Chorzów of 81% and 28% respectively, and 62% and 19% at Skawina.

Lifetime: For simplicity, we assume that both existing coal CHP plants are available for the full 15 years of our analysis through 2035, even though Skawina is already 59 years old and Chorzów is already 17 years old. In line with Danish catalogue data, we assign a lifetime of 15 years to biomass CHP conversion, and a lifetime of 25 years to new-build CHP.

WHR

Capacity: We identified 50MWth (net installed thermal capacity) each in Kraków and Katowice. Regarding steel thermal capacity, we took Hotmaps estimates and conservatively reduced these to derive actual available thermal capacity. Regarding wastewater treatment, we calculated available potential using published flow rates and an assumed temperature difference across the heat pump exchanger, and a relatively conservative estimate for the heat pump coefficient of performance (COP) of 2.9. We calculated the required heat pump thermal capacity based on this thermal potential.

Capacity factor: For wastewater treatment, we apply a 43% capacity factor, based on an unweighted average capacity factor at four large-scale, European WHR projects using heat pumps (at data centres, wastewater treatment and steel plants). For steel, we apply a 57% capacity factor, based on correspondence with a WHR expert at Ramboll. A higher steel WHR capacity factor is rational, given exceptionally low operating costs.

Heat pump efficiency: We assumed a coefficient of performance (COP) of 2.9, based on data published according to assumed sink and source temperature. The COP multiple includes mechanical and thermal losses. The COP is a key factor driving economics and depends on the efficiency of the heat pump, the temperature of the heat source (the higher the better), and the temperature difference between heat source and sink (the smaller the better).[31] We based our assumed heat pump evaporator temperature of 6.5°C on correspondence with heat pump experts.[32] We

[31] Arpagaus, C.: Hochtemperatur-Wärmepumpen für industrielle Anwendungen. Presentation at Internationaler Grosswärmepumpen Kongress, 8. Mai 2019, Zürich
32 Illner, M. Waste-water heat recovery in the NeckarPark district in Stuttgart, Germany. Fraunhofer-Institut für Bauphysik, Stuttgart, D, 2020. (unpublished).

assume an additional power consumption by the wastewater source pump, as a result of the WHR system, equivalent to 13.5% of the heat pump power demand.[33]

Lifetime: Large-scale WHR projects for district heating that were built in the 1980s are still operating today, both at wastewater treatment plants (e.g., at Sandvika and Gothenburg) and at steel plants (e.g., at Dunkirk). As a result, we conservatively assume a 25-year lifetime.

Annex 3: Study Limitations

We focus exclusively on the supply side of heat provision, through district heating networks. We do not consider energy efficiency, which is a key component of any low-carbon transition in the heating sector, including district heating. It is beyond the scope of this report to study the specific technology limitations posed by Poland's district heating networks. Another relevant factor is network temperature. We note that heat pumps work best with lower temperature heat networks, because a key factor in their efficiency is determined by the temperature difference between heat source and heat sink. District heating networks in Poland generally operate at a high temperature, but specific data were not immediately available. Regarding methodological limitations, ours is not an hourly heat and power despatch model. We do not account for the impact of the cost of electricity generation on despatch to the grid. Instead, we use fixed heat and power capacity factors, based on the operation of the two existing CEZ-owned coal CHPs. We do not account for dynamic interactions between commodity prices, instead effectively locking in the current cross-commodity price relationships, with the exception of a low and high carbon price scenario.

Annex 4: Other WHR Opportunities

Besides wastewater and steel plants, a range of other potential renewable heat sources exist that can feed into district heating network via heat pumps or directly, including data centre heat recovery, solar thermal, geothermal and "heat mining." We decided not to include these in this report, for reasons briefly summarised:

1. Data Centre Waste Heat Recovery: There is ample precedent for large-scale waste heat recovery from data centres, a rapid growth market. Poland has a widespread district heating grid, which is an important advantage for data centres seeking to recycle waste heat. However, data centres will also prioritise countries with a low-carbon electric grid, where Poland presently ranks low.

2. Solar thermal: A seasonal mismatch between the peak availability of solar energy and of peak demand for heating may pose a problem when considered on the very large scale. However, we recognise that thermal storage can help overcome this problem, and that solar thermal can contribute significantly.

[33] Hubacher, P., Bernal, C., Ehrbar, M.: Feldmonitoring und Analysen an Grosswärmepumpen Phase 2. Bundesamt für Energie BFE. Bern, CH, 2010

3. Deep geothermal: Geothermal heat can be extracted from hot sedimentary rocks or deep aquifers. Its use is still an emerging technology across Europe, including in Poland. One challenge is financing exploratory wells, which have no guarantee of an economic prospect. Another is the high capital cost of boreholes. A third difficulty in Poland is the high mineralization of subterranean water, including dissolved chemicals that can be corrosive to the metal elements used in a heating system, including pipelines and boreholes. The best geothermal resources in Poland are outside our two target cities.[34]

4. Flooded, underground mine shafts ("heat mining"): Heat mining refers to using heat pumps to exploit warm water at the base of disused mine shafts. There is no shortage of disused mines locally in our target regions. One local study identified three disused mines with a water temperature of 24-26°C at depths of 300-450 metres, and a potential, combined thermal power of 8 MWth, based on an assumed heat pump COP of 4.[35] However, heat mining is presently at demonstration stage, and therefore not useful for this study.

Annex 5: Heat Pumps - Opportunities and Challenges

Heat pumps use a refrigerant to draw heat at the heat source, through evaporation under low pressure, and then raise the temperature of the refrigerant by compression, before releasing this heat to the sink by condensation. A heat pump might typically reduce the temperature of the heat source by 3-5°C and raise the heat sink temperature by 30°C or more. The practical heat output is usually 3 to 5 times the input electricity required to drive the pump, i.e., achieving an efficiency exceeding 300%. Heat pumps have some emerging advantages in district heating. Such advantages include enabling and aggregating a wide range of low-temperature renewable heat sources, such as geothermal, solar thermal and waste heat recovery.[36] Due to continuing building efficiency upgrades, we would expect the required supply temperature in district heating networks to fall over time. This will have a beneficial effect for the use of heat pumps, by allowing the integration of more, lower temperature renewable and waste heat resources, and of increasing overall system efficiency. In addition, compressor heat pumps may help integrate variable renewables by providing a flexible demand source to align with peak electricity supply. By combining heating and cooling functions, in the heat sink and heat source respectively, heat pumps can provide both cooling and heating functions. Heat pumps also face certain challenges. For example, they function best at lower temperatures, which may mean lower efficiencies in the case of Poland's high-temperature district heating networks.

---

[34] These conclusions are made from direct email correspondence with Michal Wilczynski, and from his published reports.
[35] Low Carbon After Life. LoCAL Deliverable 1.7: Report on Bytom predictive modelling. Undated.
[36] There are two types of heat pump: compressor and absorption. Absorption heat pumps require both a high temperature and lower temperature heat source. Because our energy source is low-grade, waste heat, we have focused on compressor pumps.

About IEEFA

The Institute for Energy Economics and Financial Analysis (IEEFA) examines issues related to energy markets, trends and policies. The Institute's mission is to accelerate the transition to a diverse, sustainable and profitable energy economy. www.ieefa.org

About the Authors

Gerard Wynn

Gerard Wynn is an energy finance consultant at IEEFA, specialising in the economics and finance of renewables and fossil fuel generation. He has previously worked as an analyst, editor and writer, in the energy and environment sectors. He worked for a decade as a reporter and columnist at Reuters News Agency, covering energy and climate change. He started his career with a Ph.D. in agricultural economics.

Paolo Coghe

Paolo Coghe is an international financial economist with over 20 years of experience focused on energy markets and commodities research, analysis and strategy. Before founding energy consultancy Acousmatics, he held positions with the Brattle Group, Centrica, Koch Supply and Trading, and Société Générale. He has conducted research on European energy markets for publication by IEEFA since 2016. Paolo holds degrees in Business Economics from the McCallum Graduate School of Business at Bentley University, and in Economics from the University of Cagliari.

Arjun Flora

Arjun Flora is an energy finance analyst at IEEFA, with a particular focus on the new energy technology sector. He previously spent five years working on M&A and capital-raising transactions at Alexa Capital. He started his career in technology investment banking at Jefferies and holds a M.Eng. from the University of Cambridge.

Acknowledgements

We acknowledge the contribution of Ramboll's Martin Brunner, in supplying cost estimations for WHR from steel plants. And we acknowledge the contribution of Micha Illner, at Germany's Fraunhofer Institute for Building Physics, for our assumptions around heat pump operation including evaporator temperature, COP and auxiliary source pump power demand.