OPTIMISING YOUR RESPONSE TO THE GERMAN COMBINED HEAT AND POWER ACT

Why innovative CHP systems are good for the climate – and your business

Wärtsilä carried out a study to identify the optimal way for providers in Germany to respond to the incentives offered by the updated Combined Heat and Power (CHP) Act. The results of the study show that internal combustion engine CHP plants combined with renewable energy source (RES)-based heat represent an excellent business case. The case can be further strengthened by replacing a coal-fired CHP plant.

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In 2020 the German parliament adopted the coal exit law, which sets out the roadmap for shutting down Germany's remaining coal power capacity by 2038. In 2020 the Kraft-Wärme-Kopplungsgesetz (KWKG), or CHP Act, was amended. In addition to the financial bonus for both new and modernised CHP plants, there is an amended section focusing on a bonus for CHP plants that utilise "innovative renewable heat" based on technology such as heat pumps. The CHP Act also provides a revamped one-time bonus for providers that switch away from coal-fired CHP plants. In order to determine the optimal percentage of RES-based heat for each individual plant, three key questions must first be answered:

1. What is the realistic share of RES-based heat that can be achieved based on the available ambient heat sources the plant can utilise?
2. What is the optimal share of RES-based heat that should be achieved? This is key as a higher share of RES-based heat means a smaller CHP plant, which forces providers into a tender scheme instead of receiving a fixed bonus. The cost of utilising ambient heat also needs to be taken into account. "Ambient heat" refers to heat that is present in layers of air close to the ground, in surface bodies of water and in the ground a few metres below the surface, primarily through the storage of solar energy.
3. Can the business case be further enhanced by replacing a coal-fired CHP plant? If there is a coal-fired CHP plant eligible for coal-replacement bonus, the timing of the switch must be evaluated to ensure a smooth transition.

These questions need to be answered on a case-by-case basis in order to determine the exact level of RES-based heat to invest in, but overall there is a strong case for increasing the use of RES-based heat in Germany as a whole.

To answer these questions, Wärtsilä invites CHP plant owners to discuss their individual needs. Wärtsilä can model each case individually in order to determine the optimal way to leverage the opportunities presented by the CHP Act.

II. MARKET BACKGROUND

The coal exit law adopted in 2020 sets out a roadmap for shutting down Germany's remaining coal power capacity by 2038. The reduction in electricity generation from coal-fired power plants is to be offset through investments in renewable energy sources, among other measures.

Germany is also committed to the "Energiewende" (energy transition), and the country has already made progress in reaching its decarbonisation targets. The COVID-19 pandemic has proven to be a real stress-test for the German power system and has provided some important insights. For example, due to the lockdown measures adopted by the German government in order to tackle the spread of the virus, energy consumption fell while the amount of energy generated from renewable sources remained unchanged, leading to a higher share of renewable energy in the production mix.

There have been missed opportunities in Germany in the form of periods of time during which the country could have theoretically met 100% of its energy demand with renewable energy sources. For example, on April 21 2020 between 12:00 and 13:00, the total national electricity demand was 59,357 MWh and the total renewable generation capacity – including solar, wind, hydro and biomass – was 61,169 MWh. However, during that same hour inflexible coal and nuclear power plants, which could not be shut down, generated 10,489 MWh, thereby pushing the CO_2 intensity of power generation from zero to 79 CO_2g/kWh.

This inflexibility resulted in Germany paying a steep price, as neighbouring countries with more flexible generation systems – namely Switzerland, Austria, the Czech Republic, France, Poland, the Netherlands, Denmark and Sweden – were able and willing to adjust their generation accordingly. They accepted Germany's excess electricity, leading to the day-ahead price in Germany dropping to -83.94 EUR/MWh and meaning that Germany paid these countries EUR 880,000 to accept its excess energy.

This example shows that structural obstacles – primarily a lack of flexible capacity – still exist and are actively hindering full decarbonisation in Germany.

New CHP Act offers a coal-replacement bonus for modern plants

CHP plants have a special role to play in both the phase-out of coal and in terms of introducing greater flexibility into the network. The recently amended Kraft-Wärme-Kopplungsgesetz (KWKG), also known as the CHP Act, is to be continued until 2026 and encourages the replacement of coal-fired power plants with CHP facilities, offering a one-time coal-replacement bonus for new plants.

Many of the details are the same as older versions of the CHP Act. Both new and modernised CHP plants are eligible for the bonus if their commercial operation date is before the end of 2026. For CHP plants of 1 to 50 MW, the bonus is tendered, while for CHP plants over 50 MW the bonus is fixed. The bonuses are shown in the following table:

	EUR/MWh_e
<50 kW	80
50 kW – 100 kW	60
100 kW – 250 kW	50
250 kW – 2 MW	44
>2 MW	34

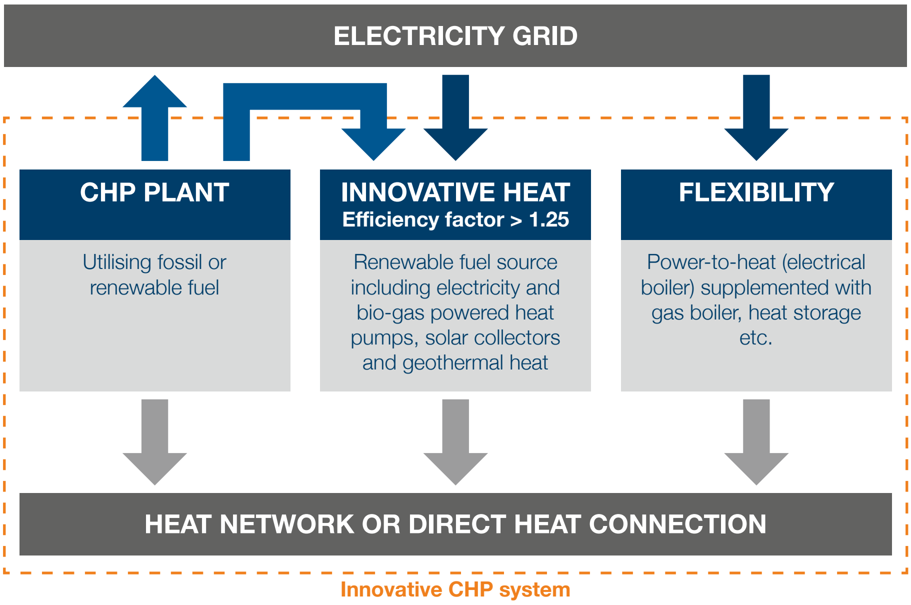
The bonus is paid for 30,000 full load hours. Restricting the full load hours per year for which CHP plants are eligible to receive a bonus will put more focus on how these plants are operated. Ideally the CHP plants should only run when power prices are high, as that gives the best profit margin – in other words, this is an incentive for more flexible operation. The maximum full load hours are restricted by year as shown below:

	Maximum fulll load hours pre year
2021–	5,000
2023–	4,000
2025–	3,500

Encouraging greater use of innovative renewable heat

In addition to the above, in line with Section 7a of the CHP Act utilities are eligible for a financial bonus if they use RES-based heat (for example from heat pumps) to take heat from ambient surroundings and supply it to district heating systems. The goal of this section of the act is to encourage greater use of RES in the supply of district heat. To qualify for the bonus a CHP system must contain:

- a CHP plant using fossil or renewable fuel
- an innovative heat-generation asset (such as a heat pump) with an efficiency factor greater than 1.25
- a flexibility asset (such as heat storage)



If innovative renewable heat generation technologies are utilised, the CHP bonus amount is increased according to table below:

Annual share of innovative renewable generation based on reference heat	CHP bonus increase ($€/MWh_e$)
5%	4
10%	8
15%	12
20%	18
25%	23
30%	30
35%	38
40%	47
45%	57
50%	70

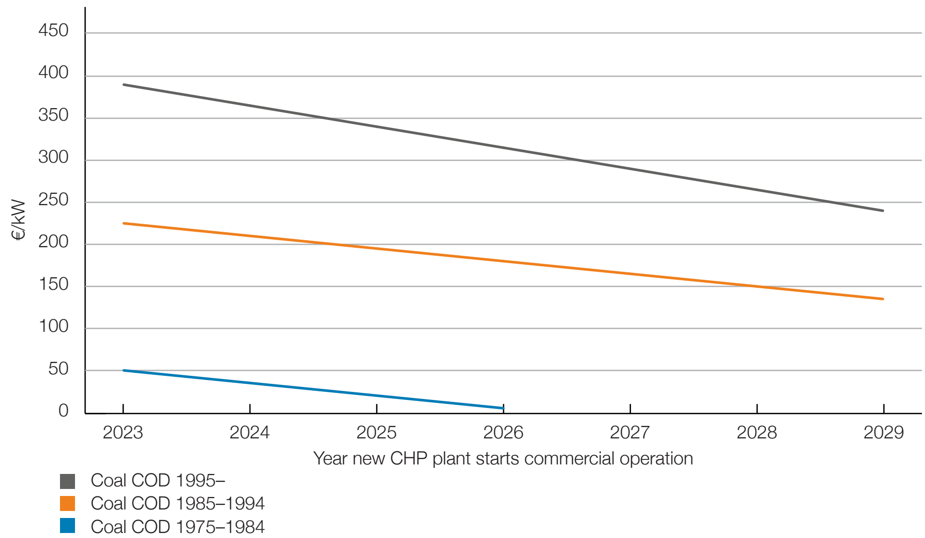
Note: Reference heat is the sum of heat generation from the CHP plant with 3,000 full load hours and innovative renewable heat generation. Utilisation of a heat pump to increase plant efficiency is not applicable under section 7a of the act.

Coal-replacement bonus

The goal of section 7c of the CHP Act is to encourage the replacement of hard coal and lignite-based generating plants. Any new CHP plant that replaces a coal-fired CHP plant must feed into the same heating network but doesn't have to be located on the same site. The old plant must be shut down when the new one is taken into continuous operation.

The coal-replacement bonus is paid as a lump sum once the existing coal CHP plant has been shut down. The bonus is based on the electrical output of the new plant, meaning the plant size can be freely chosen (however it cannot be bigger than the coal plant to be replaced). The bonus amount corresponds to the electrical capacity of the new CHP plant and is calculated as a function of the age of the coal plant and the year when the new CHP plant is taken into commercial operation, as shown below.

Figure 1. Coal-replacement bonus



III. DETERMINING THE OPTIMAL PATH FORWARD

ABOUT PLEXOS ENERGY SIMULATION SOFTWARE

PLEXOS by Energy Exemplar is a proven energy simulation software used by the world's leading system operators, regulators and planners as well as utilities, traders, consultants and manufacturers. Wärtsilä uses PLEXOS globally for power system modelling, both in long-term capacity development optimisation and short-term dispatch optimisation. PLEXOS is built to find the most cost optimal solution for each scenario based on the applied constraints.

The bonuses offered by the updates to the CHP Act will obviously be beneficial to CHP plant owners and CHP providers in Germany. However, exactly how best to take advantage of the act remains unclear. This lack of clarity is what led Wärtsilä to decide to conduct a modelling exercise to determine the optimal capacity mix depending on the CHP plant technology used and the different share of renewable heat production. The modelling was conducted using PLEXOS energy simulation software.

The model included a CHP plant plus a predefined share of innovative renewable heat as per the CHP Act, ranging from 0 to 50% of total annual reference heat. For each level of share of innovative heat, PLEXOS ran three scenarios with three different CHP plant technologies: internal combustion engines (ICE), combined cycle gas turbines (CCGT) and open cycle gas turbines (OCGT). PLEXOS was given the flexibility to decide the capacity of the CHP plant and to build additional capacity (heat pump, heat storage, electric boiler, gas boiler) for the system to meet the heat demand and take full advantage of the potential bonuses. In the model, the whole system is connected with a day-ahead electricity market where it could either buy or sell electricity at 15-minute intervals.

The model used the following parameters:

- 100 MW peak heat demand
- Options for new capacity in the model: CHP plant, heat pump, heat storage, electric boiler, gas boiler
- 11 levels of innovative renewable heat (ranging from 0 to 50%)
- 15-minute time resolution model
- CHP plant trading on day-ahead market

Scenario planning and short-term dispatch modelling were performed with PLEXOS.

IV. THE MODELLING RESULTS

In addition to the CHP plant, the model also built a certain capacity of heat pump and heat storage; the exact capacity varies between scenarios depending on the CHP plant technology and the share of renewable heat in the system. In general, the modelling produced the following results:

1. There is a linear correlation between CHP plant capacity and heat pump capacity.

As expected, to reach a higher share of renewable heat increased heat pump capacity is required in the system. Consequently, the greater the heat pump capacity the lower the capacity of the CHP plant needed. Heat storage capacity is fairly constant.

The model takes into account all taxes and surcharges for selling and purchasing electricity on the market as well as the obligation to pay a reduced Renewable Energy Surcharge (EEG Umlage) for self-generated electricity. Due to the surcharges, the heat pump runs almost exclusively on self-generated electricity from the CHP plant.

Figure 2. CHP plant capacity

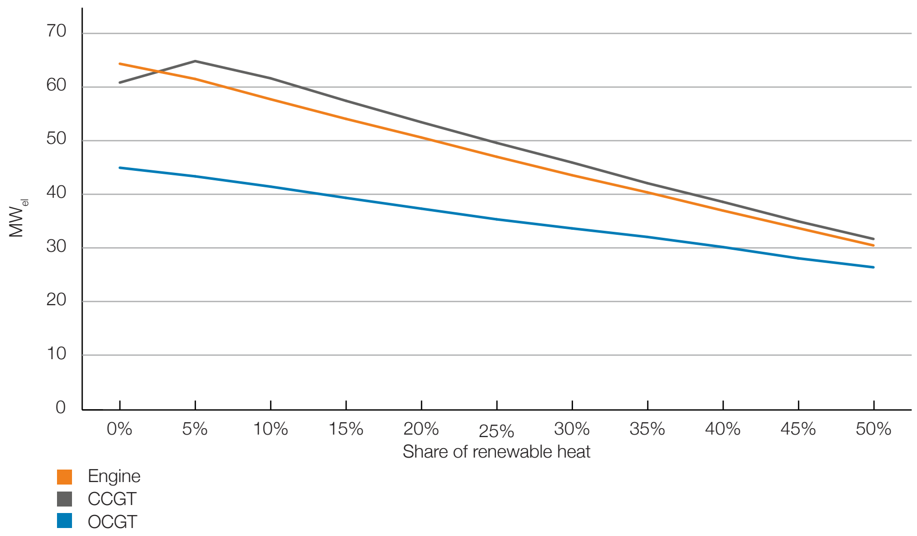


Figure 3. Heat pump capacity

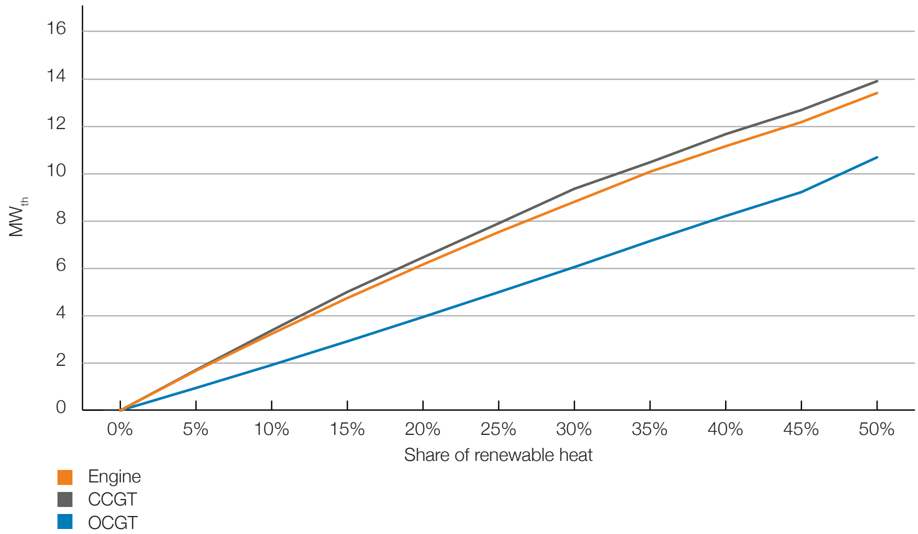
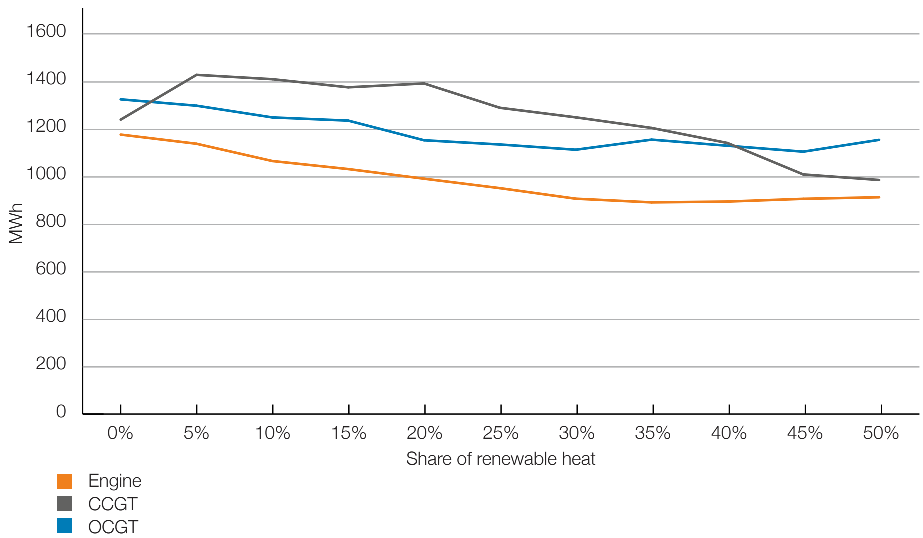


Figure 4. Heat storage capacity



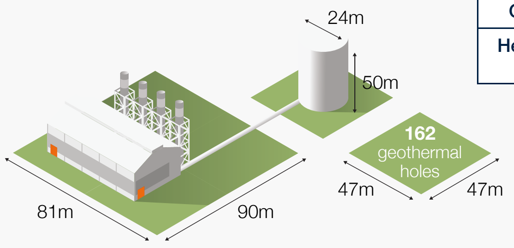
2. The footprint of the RES-based heat source is important in determining the optimal level of investment.
This means the precise business case for a given provider varies based on their location and assets. For example, is there a river nearby, or will geothermal heat need to be used exclusively?

The issue of space is illustrated below in a comparison between a 5 and 50% renewable heat solution. At 5% RES-based heat, 162 drill holes (approximately 200 m in depth) across an area of 2,209 m^2 are needed for geothermal heat production, while at 50% the number rises to 1,523 drill holes across an area of 46,200 m^2, which is obviously impractical. This example illustrates the necessity to strike a balance between the optimal RES-based heat percentage and the available space for drilling activities in any given location.

Figure 5. Space requirement, 100 MW peak heat demand

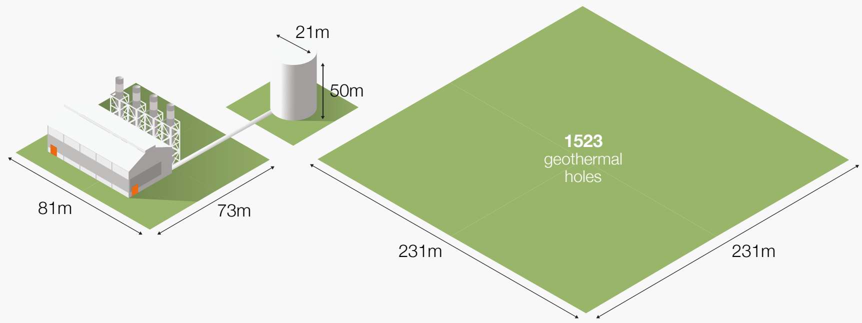
5%
RENEWABLE HEAT PRODUCTION

Unit	Installed capacity
CHP plant	61.5 MW_e
Heat pump	1.68 MW_{th}
Electric boiler	0 MW_{th}
Gas boiler	100 MWth
Heat storage	1,138 MWh 22,760 m^3



50%
RENEWABLE HEAT PRODUCTION

Unit	Installed capacity
CHP plant	30.5 MW_e
Heat pump	13.4 MW_{th}
Electric boiler	0 MW_{th}
Gas boiler	100 MWth
Heat storage	911 MWh 18,220 m^3



3. Flexible engines offer the lowest heat-generation prices.

This study shows the benefit of flexibility. Engine flexibility enables the operator to dispatch the plant according to market prices, meaning it is possible to start the plant for a short period of time to catch price spikes and, conversely, to shut down the plant to avoid price troughs. This flexibility enables the engine plant to achieve a higher average sales price for the electricity it produces. As shown in Figure 6 below, in all cases the engine plant is able to sell its electricity at a price which is 5–10% higher than the CCGT and OCGT alternatives. This behaviour becomes very clear when considering the number of starts for the plants. The engine plant starts around 3,000 times per year while the number of starts for the turbine-based plants is measured in the low hundreds.

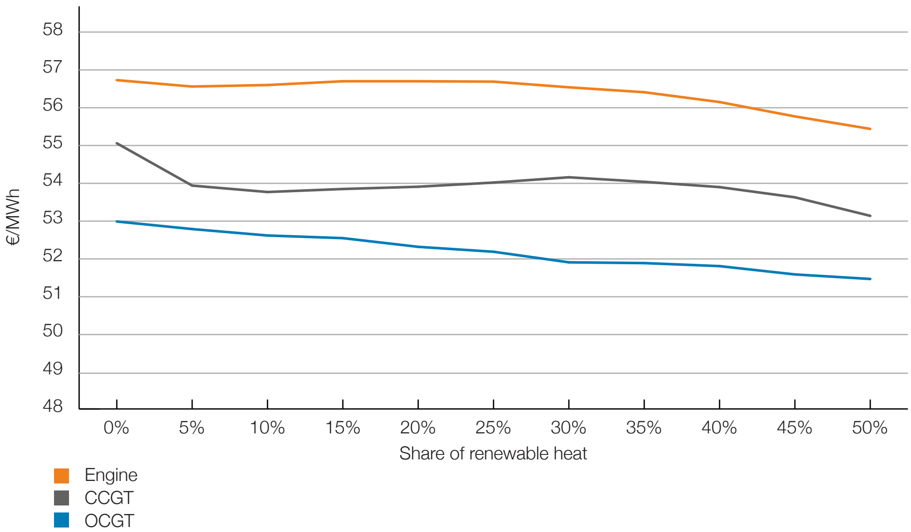


Figure 6. Electricity market average sales price

The flexibility to choose the best operating mode, together with a high power-to-heat ratio, gives an advantage to the engine CHP plant and it results in heat generation prices that are 10–15% lower than for turbine-based alternatives throughout the range.

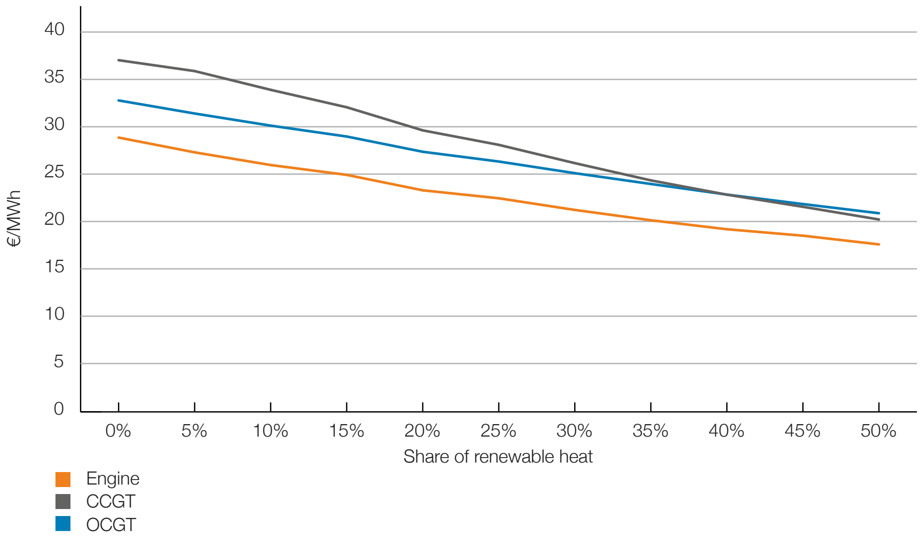
As shown in Figure 7, the average required heat price is reduced with the increasing share of renewable heat production. In other words, the higher the share of renewable heat generation, the better the business case.

However, it must be pointed out that the cost of utilising ambient heat is not included in the calculation as this is highly dependent on site conditions and available heat sources. Therefore, the question of an available heat source and the cost of utilising that heat must be carefully considered in each case. For the same reasons, we predict that there is a case-specific optimal point where the cost of exploiting more ambient heat is more expensive than the benefit of a further increase in the CHP bonus.

In this specific example, in the engine alternative the investment costs for the 50% share of renewable heat can be approximately 6 MEUR higher and still be on par with the 45% share of renewable heat case.

Figure 7. Average required heat price over lifetime

Assumptions	
Peak heat demand	$100MW_{th}$
Economical lifetime	15 years
Equity/debt	25% / 75%
RoE	5%
Interest rate	2%
Target IRR	10%



These results do not account for the coal switch bonus. When the bonus is included the heat generation price is reduced.

As expected, the CO_2 intensity drops when more heating comes from renewable sources. The graph below depicts CO_2 intensity based on useful energy (electricity sold to market plus district heating). All scenarios (engines, CCGT and OCGT) show the same trend; however, the lower power-to-heat ratio of the OCGT causes the CO_2 intensity to drop to even out when reaching high shares of renewable heat.

At high shares of renewable heat, electrical efficiency becomes more important as electricity is a “raw material” for the heat pump.

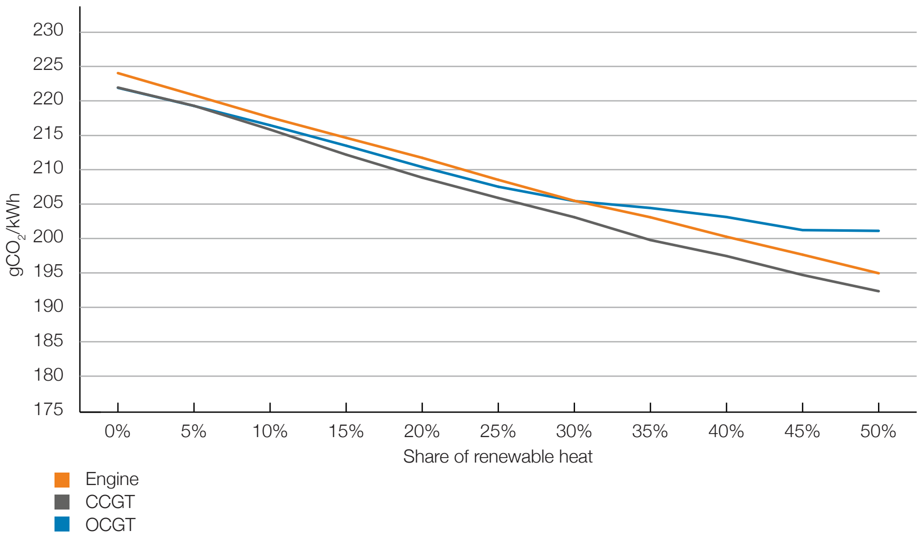


Figure 8. CO_2 intensity per useful energy

V. HOW TO HARNESS THE BENEFITS OF THE CHP ACT IN GERMANY

Based on the modelling results, investing in renewable heat makes sound financial sense for German CHP providers. Including renewable heat generation will significantly improve the business case of a new CHP plant – indeed, the more renewable heat used, the better the business case becomes. Engine CHP plants lead to the most cost-efficient outcome. Their combination of high single-cycle efficiency and flexibility results in heat generation prices that are 10–15% lower than for turbine-based alternatives.

However, there are three key points to consider for each case before a concrete RES heat investment level can be given:

1) What is the realistic share of renewable heat that can be achieved?
In order to answer this, one needs to look at what ambient heat sources can be utilised and potentially how much heat can be sourced. This answers the question of the cost of utilising ambient heat as well and needs to be determined on a case by case basis.

2) What is the optimal share of renewable heat that should be achieved?
A higher share of RES-based heat means a smaller CHP plant, which forces providers into a tender scheme if plant output falls below 50 MW. The cost of utilising ambient heat also plays a role here. Reaching high shares of renewable heat might require significant infrastructure investment.

3) Can the business case be further enhanced by replacing a coal-fired CHP plant?
Earlier closure of a coal-fired CHP will lead to greater financial rewards in the form of bonuses. This is a key factor in determining the optimal time to invest.

Wärtsilä invites CHP plant owners to discuss their individual needs with us – we can model each case individually in order to determine the optimal way to leverage the opportunities presented by the CHP Act.

Benefits

- While all CHP plant options (engine, CCGT, OCGT) result in lower heat-generation prices, engines lead to the most cost-efficient outcome, with heat generation prices that are 10–15% lower than for turbine-based alternatives.
- Switching away from coal, and increasing the share of RES-based heat, reduces emissions.
- In the future, when using engine CHP plants, emissions can be reduced even further with the possibility to use synthetic or biofuels.
- Engines can be quickly ramped up or stopped, offering more flexible operation. This enables the plant to closely follow the price signals from the electricity market, resulting in higher average prices for electricity sold.

VI. CONCLUSION

Germany is phasing out coal, and the recently amended CHP Act provides financial incentives for providers to invest in innovative renewable heat. Based on the results of PLEXOS modelling conducted by Wärtsilä, there is a compelling business case for CHP providers to include RES-based heat. This business case is further enhanced if a coal-fired plant is replaced with a non-coal-fired CHP. The exact percentage of RES-based heat to include in the generation mix needs to be determined on a case-by-case basis according to the unique parameters for a given provider. Wärtsilä can model each case individually in order to determine the optimal way for customers to leverage the opportunities presented by the CHP Act.

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WÄRTSILÄ ENERGY IN BRIEF

Wärtsilä Energy leads the transition towards a 100% renewable energy future. We help our customers in decarbonisation by developing market-leading technologies. These cover future-fuel enabled balancing power plants, hybrid solutions, energy storage and optimisation technology, including the GEMS energy management platform. Wärtsilä Energy's lifecycle services are designed to increase efficiency, promote reliability and guarantee operational performance. Our track record comprises 74 GW of power plant capacity and more than 80 energy storage systems delivered to 180 countries around the world.

https://www.wartsila.com/energy
jan.andersson@wartsila.com