WÄRTSILÄ

Powering Poland's future:

Optimising the power system and district heating for the next decade

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Executive summary

Increasing energy production from renewable sources is foundational to the global shift to net zero. For Poland's coal dominated power system and district heating (DH) networks, this transition poses both challenges and immense opportunities. In this study, Wärtsilä uses advanced modelling by PLEXOS® to explore opportunities to co-optimise these sectors over the next decade. The results offer a pragmatic and cost-effective strategy to implement Poland's coal retirement and renewable expansion plans, while enhancing sustainability, flexibility and affordability within its power and heating systems.

The modelling shows that coupling Poland's power and DH systems brings substantial benefits. Notably, this strategy facilitates a harmonious shift from coal-dominated to majority renewable power and heating systems. This approach produces significant cost and emission benefits, saving a cumulative 3.8 billion euros (BEUR) and a 57% reduction in annual carbon dioxide (CO_2) emissions by 2032. Remarkably, these arise despite the expected growth in electricity demand. This pathway not only propels Poland towards achieving its emission reduction goals, but also delivers future-proofed infrastructure and secure and affordable energy supply. The modelling shows that the co-optimised dispatch of the power and heating sectors enables the increased utilisation of renewable energy (RE) and heat pumps to replace planned coal retirements.

One key takeaway is the importance of establishing flexible generating assets within DH systems. Specifically, the deployment of heat pumps and Combined Heat and Power (CHP) gas engines is critical for efficiently integrating RE. These flexible DH technologies play a pivotal role in balancing intermittent RE generation while ensuring a reliable and resilient electricity and heat supply.

The study addresses Poland's specific challenges related to the decarbonisation of its aged and inefficient coal-powered DH systems. The co-optimisation approach not only guarantees a more sustainable and efficient energy mix, but also presents the most cost-effective transition pathway to achieve this.

Optimising Poland's clean energy future

- Renewables provide cheap energy and help decarbonise power and heating.
- Heat pumps, CHP engines and heat storage ensure a balanced power system while supplying heat.
- Co-optimising the power and heating is the least cost option, leading to 3.8 BEUR cumulative savings and a 57% reduction of annual CO_2 emissions by 2032.

Introduction

Wärtsilä's modelling experience

Wärtsilä is the global leader in solutions that enable the transition to more sustainable societies. With the mission to accelerate the shift towards 100% renewable future, Wärtsilä has accumulated extensive capabilities in energy system modelling. Using PLEXOS® software, Wärtsilä has completed analysis of nearly 200 country and system studies globally to identify the optimal system designs to support the integration of renewables and reduce the system operational cost and emissions.

Europe's energy landscape is undergoing a profound transformation, characterised by a significant shift towards renewable energy sources and greenhouse gas emissions reduction.

Poland finds itself in a unique position within this evolving energy landscape. Coal plays a central role accounting for 61% of power and 80% of heat production in Poland. Coal's dominance within the economy, therefore, presents a difficult starting point for efforts over the next decade. Moreover, Poland's current coal phase-out target date is later than the 2030 goal set by most other EU member states.

Nonetheless, Poland has had notable success in pushing for the energy transition. Attractive investment conditions for solar photovoltaics (PV) have made the country one of the fastest-growing PV markets in the EU.

A comprehensive offshore wind strategy has also contributed to deals for 5.9 gigawatt (GW) of capacity to come online by 2027 (Poland 2022 Energy-Policy Review, IEA).

Despite this initial progress, a distinct set of challenges remains for Poland's long journey to net zero. The gradual decarbonisation must be achieved amidst rising electricity demand. Furthermore, the country's infrastructure is ageing and inefficient, posing obstacles to the integration of RE sources. Most notably, however, Poland's challenge lies within the transition of its DH systems away from coal. While there is broad consensus for the decarbonisation strategy for the power system, via integrating the new wave of solar and wind generation, there is marked uncertainty among stakeholders regarding the equivalent pathway for DH.

The challenges stem from a number of conditions. Firstly, the DH systems are characterised by inefficiency and high emissions resulting from coal-based heat production, outdated infrastructure and suboptimal operations. The second refers to scale, with the country having the largest DH system in terms of pipelines within the EU. The current system is also financially burdensome, in terms of driving energy poverty and being subject to rising costs due to non-compliance with EU CO_2 emission allowances.

Addressing these challenges in a data-driven and strategic way can bring significant opportunities for Poland. Seizing these opportunities means that the prospect of secure, affordable, and sustainable energy is well within reach.

Wärtsilä's PLEXOS® modelling illustrates the optimised pathway for Poland to capitalise on the benefits of coupling power and DH. This approach promises to deliver significant environmental, economic and societal benefits, laying the foundation for a fully decarbonised future.

Poland’s clean energy future

Modelling results

Poland’s optimised mix

Poland’s decarbonisation journey is already well underway. However, there are plentiful opportunities to optimise this transition. Using existing and planned capacities and selecting new capacity opportunities, PLEXOS® charts the optimised mix for supporting renewable integration and replacing retiring coal capacity in power and heat over the next ten years. Through sector coupling, excess RE generation can be harnessed for DH. Flexible DH technologies provide additional balancing, creating a symbiotic and efficient mix.

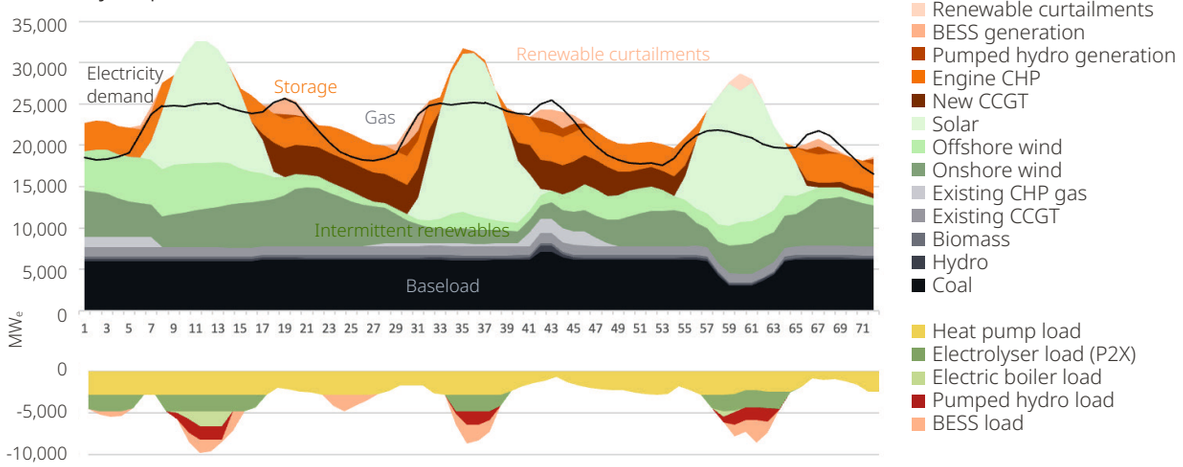
PLEXOS® energy simulation software

PLEXOS® by Energy Exemplar is a proven energy simulation software used by 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 designed to find the most cost-optimal solution for each scenario based on the applied constraints. It can, therefore, provide valuable insights into the operation, expansion, and optimisation of power systems to find the most efficient and flexible solutions.

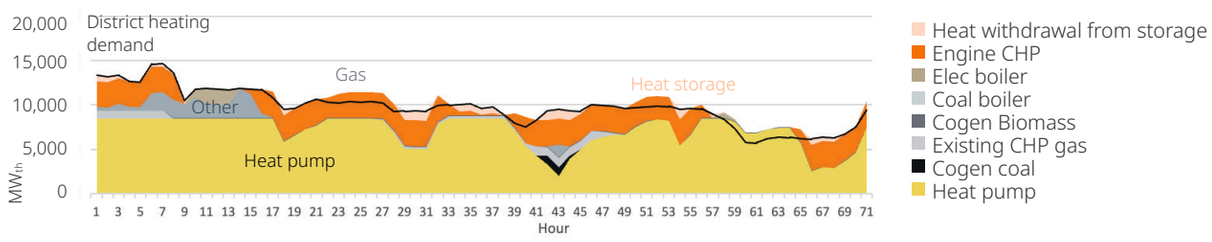
Snapshot of co-optimised dispatch during three days in March 2030

PLEXOS® simulates the 10-year modelling horizon hour-by-hour and finds the cost-optimal mix for power and district heating sectors

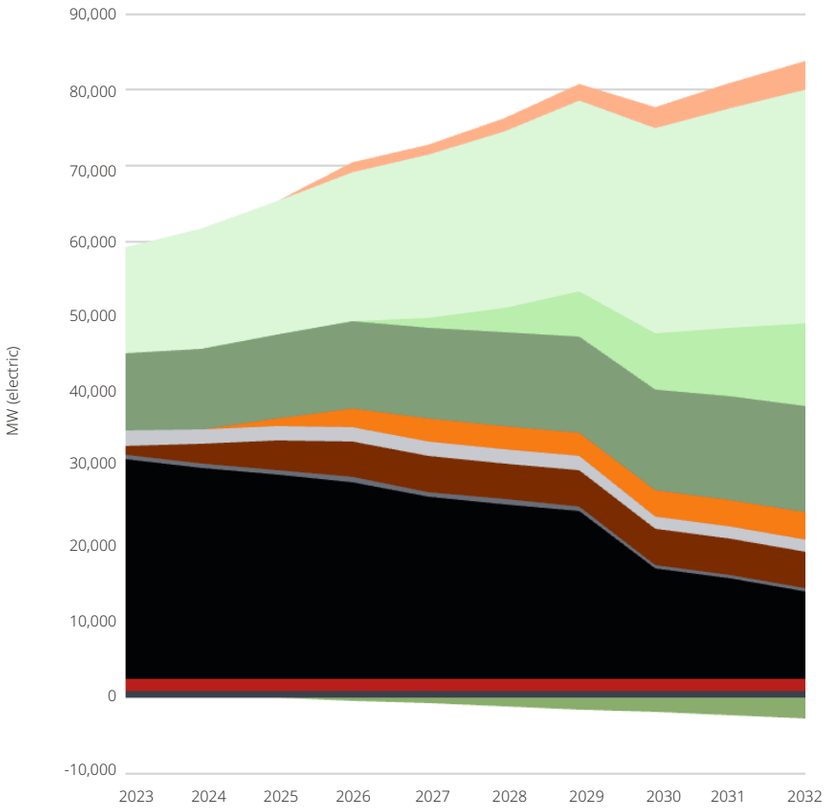
Electricity dispatch



Heat dispatch



Optimised power mix



BESS
3.9 GW by 2032 (optimized)

As per expert consensus forecast

Solar
Offshore wind
Onshore wind

CHP gas engines
3.6 GW by 2032 (optimised)

Existing CHP gas

CCGT
Announced projects only, otherwise CCGT not built by PLEXOS®

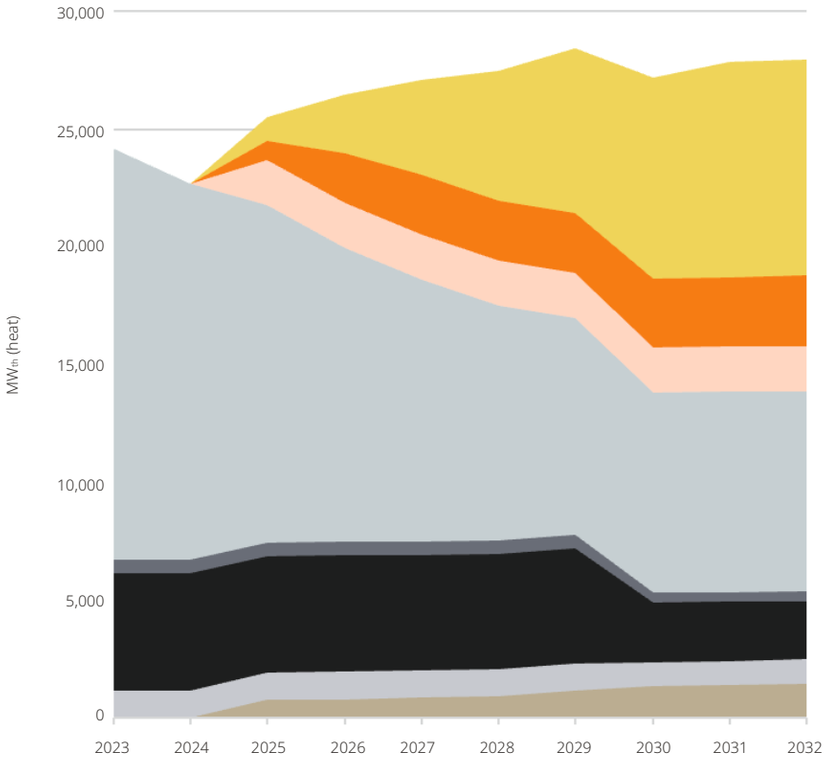
Biomass

Coal
Retirement and mothballing as per companies' plans

As per TSO plan

Pumped hydro
Hydro
Electrolyser

Optimised district heating mix



Heat pump
9.1 GW_{th} by 2032

CHP engines
3.1 GW_{th} by 2032

Electric boilers
1.9 GW_{th} by 2032

Existing coal boilers

Existing biomass CHP

Existing coal CHP

Existing gas CHP

Heat storage
1.5 GW_{th} (24-hour duration) by 2032

Benefits of co-optimisation

By co-optimising power and DH, the PLEXOS® modelling results show that Poland can reach a number of economic and energy milestones over the next decade.

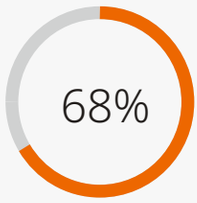
Significant advancement in renewable integration
With co-optimisation, the share of renewable energy increases from 29% in 2023 to 68% in 2032, making it the primary and most accessible source by this date. Correspondingly, coal consumption is projected to decline from 61% to 26% in power production and from 80% to 8% in heat production. Wind energy plays a primary role in displacing coal in the power sector, while renewable powered heat pumps are the primary displacers in the heating sector.

This renewable trajectory also aligns closely with plans set by official bodies, including the Transmission System Operator (TSO) and think tanks. Therefore, the PLEXOS® results demonstrate the feasibility of implementing this transition pathway alongside offering valuable optimisation opportunities as identified by the modelling.

Substantial reduction of fuel consumption and emissions
By doubling down on RE deployment alongside sector coupling, the modelling also identifies significant potential reductions in CO_2 emissions and fuel consumption by 2032 as lower-emission technologies steadily displace coal. In ten years' time, annual CO_2 emissions can fall by 57%, from 42 megaton (Mton) CO_2 in 2023 to 18 Mton CO_2 in 2032. Notably, this reduction occurs despite a rise in electricity consumption over the same period.

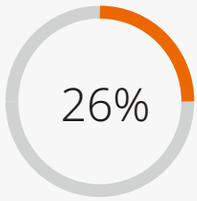
The fall in fuel consumption can be attributed to the increased utilisation of renewables alongside the building of highly efficient CHP plants. In addition, the widespread adoption of efficient heat pumps – which, on average, produce several times more heat than they consume in electricity – makes them an integral part of the drive toward considerable emission and fuel reductions.

↑ Renewable

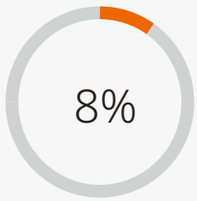


Renewable powered by 2032

↓ Coal



Share in the power sector
61% to 26 %



Share in the district heating
80% to 8 %

CHP engines vs. CCGTs

About 3.5 GW of new power-only Combined Cycle Gas Turbine (CCGT) power plants have been planned to support the Polish grid. They are supposed to operate in a base load or a flexible base load mode. CCGTs can achieve 60% of electrical efficiency at optimal load but cannot sustain high efficiency at part load and are not suitable for cycling operations typically required in high-RE systems. Many of the planned projects are located at the sites of large existing coal plants, away from cities, where there is no or very little district heating demand. On the contrary, CHP engines fit well the vast majority of district heating networks in Poland. They can simultaneously produce electricity and useful heat, achieving total efficiency 90%. CHP engines offer exceptional flexibility, providing fast response to balance variable renewable output and quickly reacting to price changes in the electricity market, thus profitably stabilizing the grid.

System cost savings and affordable energy

The study highlights the opportunity for significant cost savings through the co-optimisation of power and DH sectors. By 2032, this results in cumulative savings of 3.8 BEUR vs. without co-optimisation. Notably, the study identifies that Poland's planned 3.5 GWe CCGT plants are not cost-optimal – excluding these could unlock an additional 1.8 BEUR in total system cost savings. Furthermore, optimised and majority renewable-powered systems can ultimately lead to lower power and heating prices for consumers over the long term.

Enhanced energy efficiency and security

This study shows that a co-optimisation strategy in Poland, grounded in a dynamic and sustainable fuel mix, can ensure a secure and reliable power and heat supply even during periods of low renewable energy output. System flexibility, achieved through a combination of district heating power sinks and CHP capacity, maximises renewable integration while minimising curtailments.

This results in exceptional system efficiencies. Furthermore, increasing the domestic generation of clean RE enhances energy independence, paramount to safeguarding nations from global energy market volatility.

Key findings

Flexibility plays a critical role in decarbonising district heating
During co-optimisation, flexibility assumes a pivotal role in decarbonising Poland's DH systems. Investments channelled into a diverse range of flexible technologies are therefore paramount to achieving the cost-optimal outcome. Within this context, these complementary technologies include CHP engines, heat pumps, electric boilers, heat storage and BESS.

By embracing flexibility solutions at scale, Poland can maximise returns on its RE investments by harnessing wind and solar power variability. Furthermore, flexibility facilitates the introduction of new technologies, such as green hydrogen production through the electrolysis with RE. This hydrogen production can be scaled up and redeployed as a balancing solution while hydrogen or its derivatives can fuel CHP engines, providing additional decarbonised power supply support to meet future demand needs.

Engines and heat pumps enable the most efficient renewable integration
In the modelling, CHP engines and heat pumps emerge as the key facilitators for efficiently integrating Poland's expanding solar PV and wind capacity. These flexible CHP engines offer a minor but powerful role in balancing the variability of RE generation across power and heat systems. Simultaneously, heat pumps serve as invaluable assets by absorbing excess RE during periods of abundance, thereby minimising curtailments and enhancing efficiencies. This synergy between renewables, CHP engines and heat pumps, therefore, facilitates the widespread incorporation of RE into heat production. This guarantees a reliable and more affordable system, as RE steadily replaces coal.

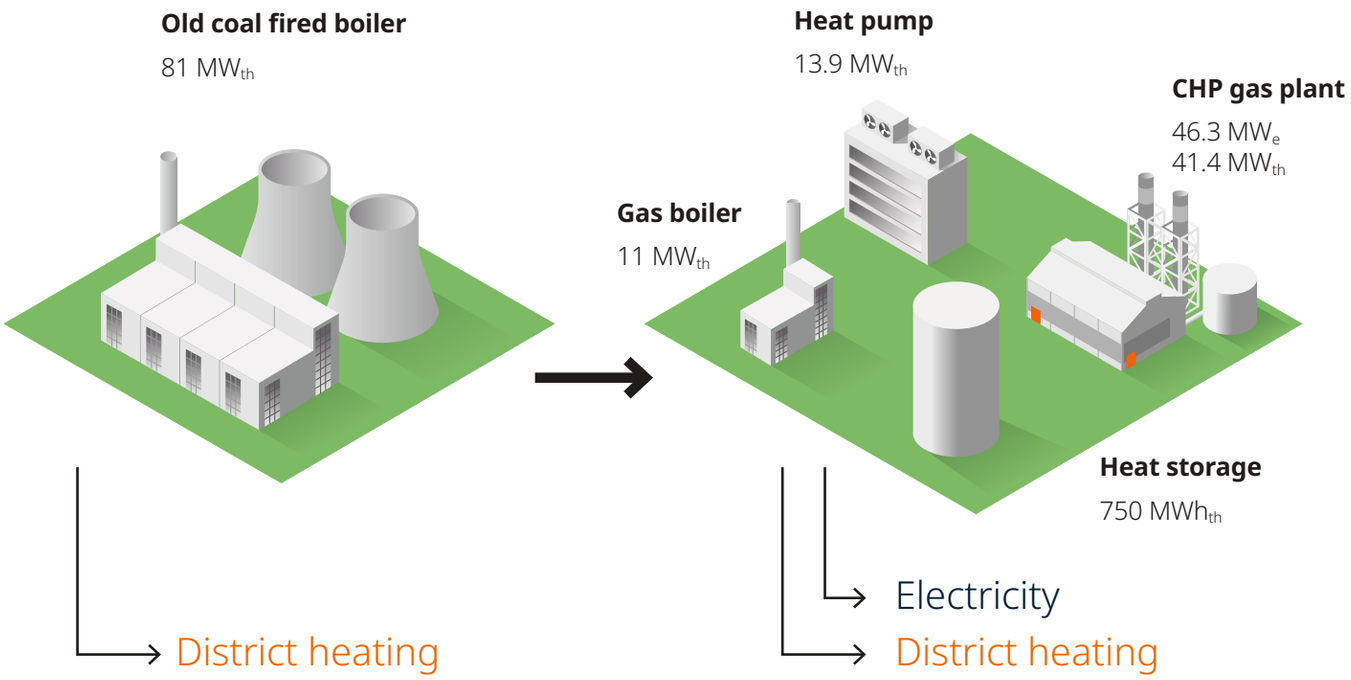
> "By embracing flexibility solutions at scale, Poland can maximise returns on its RE investments by harnessing wind and solar power variability.

Optimising individual district heat systems: OPEC Grudziądz

As DH systems are pivotal for Poland's energy trajectory, Wärtsilä additionally assessed the investment feasibility across multiple individual systems using high-resolution short-term modelling in PLEXOS®. This approach allows for a more granular analysis of local heating systems to uncover the cost-optimal technology mix to meet the heat demand of an individual system.

Short-term modelling minimises costs, maximises profits and also allows for system-specific constraints. These can include the availability of heat sources for water-to-water heat pumps, a specific mix of existing assets, and even company-level decarbonisation targets.

Here, the results for optimising the heating system for the company OPEC Grudziądz illustrate one such cost-optimal mix to decarbonise one of Poland's DH systems.



Key findings

For the existing coal-based baseline scenario, the modelling found that the required heat tariff to fully cover operational expenditures was 51.5 EUR per megawatt-hour of thermal energy (MWhth). However, an optimised system – characterised by a diversified mix of flexible technologies – results in a lower required heat tariff with all the simulated day-ahead (DA) electricity and gas price combinations. In all optimised scenarios, the required heat tariff to cover both operational expenses and capital expenses with a 10%Internal Rate of Return (IRR) was notably lower when compared to coal-based baseline.

In almost all the optimised scenarios for OPEC Grudziądz, PLEXOS® builds 60 to 80 MW_e of new CHP engines, equivalent to 5 to 7 units, together with 360 MWhth of heat storage and 11 to 17 MW_{th} of gas boilers. The addition of heat pumps and electric boilers makes economic sense when the DA electricity price is low, and the gas price is high. As evident in the neighbouring markets of Germany and Denmark, the growing shares of RE lead to high volatility of electricity price and enable feasible heat pump investments. The DA price in Poland has already started demonstrating volatility with the price hitting zero several times per week.

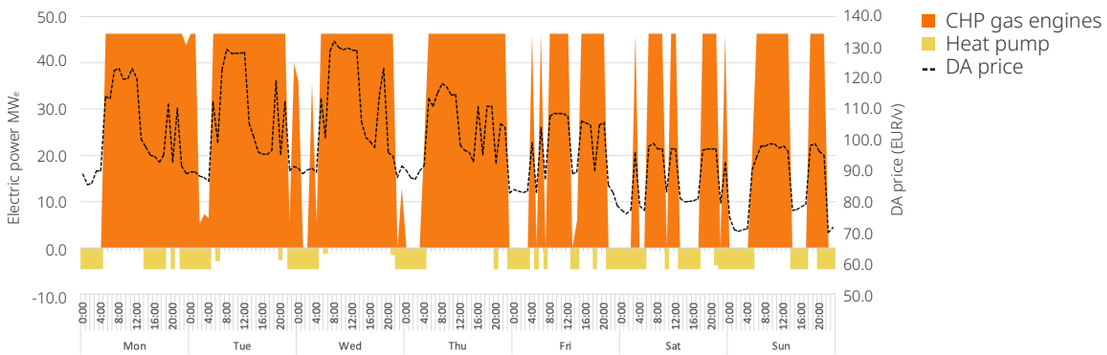
Furthermore, optimised DH systems, especially those with CHP plants, demonstrate the potential to generate extra revenue by participating in ancillary services markets.

Heat pump

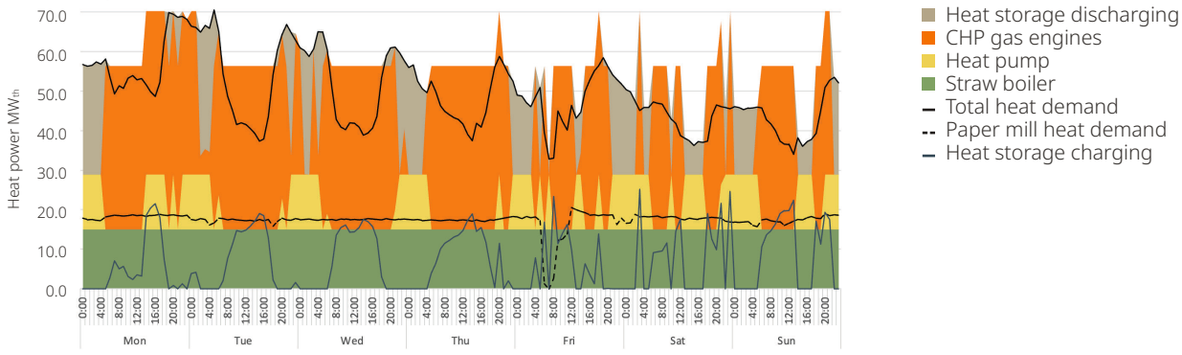
A heat pump extracts heat from a source, such as the surrounding air, geothermal energy stored in the ground, or industrial waste, and then amplifies the heat. Heat pumps are far more efficient than conventional heating technologies such as boilers or electric heaters. The output of energy in the form of heat is normally several times greater than that required to power the heat pump. Integrating heat pumps can result in significant cost savings while facilitating the transition from fossil fuels.

Cost-optimised configuration by PLEXOS®
@ Gas price 54 EUR/MWh, av. day-ahead price 97.5 EUR/MWh

Power dispatch (MW_e) - week 16



Heat dispatch (MW_{th}) - week 16



Modelling of individual DH systems

Summary
Through modelling individual DH system scenarios, Wärtsilä was able to verify the technical and economic feasibility of Poland's overarching co-optimised strategy for power and heat. PLEXOS® findings underscore that investing in dynamic DH systems is not only profitable, but simultaneously reduces the heat tariff for consumers.

Depending on the day-ahead (DA) electricity and gas price scenarios, PLEXOS® identified different CHP engine, heat storage and gas boiler configurations complemented by heat pumps and electric boilers. This diversification of DH system technologies provides unparalleled flexibility and efficiency compared to the legacy coal-based system.

These insights into the optimisation of DH systems emphasise their role in achieving sustainability and cost-effectiveness while decarbonising local heating networks. The exploration of optimised scenarios at both country-wide and system-level scales cements the validity of its benefits shown to address Poland's complex energy system challenges.

Conclusion

The transition from coal-dominated to majority renewable electricity and heating systems represents a profound transformation. Yet, this study demonstrates how Poland can achieve this over the next decade – while unlocking substantial system cost savings and emissions reductions across both sectors.

Co-optimising power and DH would allow Poland to maximise the substantial opportunities available along its coal phase-out pathway. The results highlight that this strategy is pivotal to integrating Poland's incoming RE generation most effectively and efficiently, while identifying additional capacity opportunities.

Notably, adding flexibility into DH allows for the seamless integration of RE, offering the optimised solution to address this pressing challenge. Alongside efficient heat pumps, this approach delivers modernised systems while facilitating synergised and decarbonised power and heating sectors. Moreover, this strategy is financially advantageous. By 2032, this facilitates a cumulative 3.8 BEUR savings alongside a 57% reduction in annual CO_2 emissions across the sectors.

A co-optimisation strategy, therefore, grounded in a more sustainable and dynamic fuel mix, maximises efficiencies and ensures system security. The result is the provision of more consistent and affordable energy across the country while advancing progress towards meeting EU climate goals.

Ultimately, and despite inherent challenges, the future is bright for Poland's power and DH systems. This study shows that the knowledge and technology for optimising these sectors exist, offering myriad socio-economic opportunities along the way. Taking proactive measures today will serve as the cornerstone of Poland's energy transition, cultivating the long-term benefits of a more affordable, secure and sustainable future.

> "Through co-optimisation, district heating will absorb excess RE and balance the grid while producing cheaper heat.

Methodology

Country-level modelling

The objective of this study was to explore opportunities to co-optimise power and DH within Poland's planned RE developments and coal retirements. Using PLEXOS® energy simulation software, Wärtsilä modelled scenarios to minimise the total system cost within planned developments while selecting optimal additional capacities to meet the country-level power and DH demand.

The approach accounted for planned developments and trends in Poland's energy sector over the next ten years. This included the annual expansion of renewable generation, power plant projects under construction including the planned 3.5 GWe Combined Cycle Gas Turbines (CCGTs), coal retirements and anticipated growth in electricity demand. This was in addition to accommodating Poland's existing generating fleet, plant performance, operational and capital expenditures, and current and future carbon and fuel pricing. This input data was drawn from official sources, including the Polish Transmission System Operator (PSE), Instrat, Bloomberg, S&P Global and the European Network of Transmission System Operators for Electricity (ENTSO-E).

To model scenarios, PLEXOS® co-optimised generation cost in power and DH on an hourly basis by simulating the economic dispatch covering demand curves over a 10-year horizon, with adjustments for assumed change. The study did not impose CO_2 limits, but factored in emissions penalties through the EU Emissions Trading System (ETS) carbon price, which increases fuel costs based on emission rates.

The modelling, therefore, considered the complex environmental and financial aspects for integrating planned and new RE and other technologies into power and DH. Simultaneously, it captured the complex dynamics between the sectors to present the co-optimised dispatch pathway through to 2032.

Individual system modelling

PLEXOS® used a 1-hour resolution model to analyse different 1-year scenarios of the individual heating systems. In the above described OPEC Grudziądz case, the baseline scenario included optimally dispatching a system comprised of coal and straw boilers to meet demand. The various optimised scenarios comprised straw boilers and a mix of new components, including CHP engines, heat pumps, heat storage, and electric and gas boilers.

The modelling considered a variety of sensitivities with different gas price and day-ahead (DA) electricity price profile combinations. These were created by using historical DA price curve in Poland in 2019, increasing its volatility and adjusting the average price level. Additional inputs based on market and economic variables included CHP bonus, taxes and surcharges for electricity purchased from the grid, and the EU ETS carbon price. This methodology allowed for a comprehensive understanding of heat dispatch and DA market participation to efficiently meet individual heating system demand with relevant market and economic variables considered.

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Wärtsilä leads the transition towards a 100% renewable energy future. With offices in 79 countries and more than 240 locations, we help our customers unlock the value of the energy transition by optimising their energy systems and future-proofing their assets. Our offering comprises flexible power plants, energy management systems, and storage, as well as lifecycle services that ensure increased efficiency and guaranteed performance.