

Master's Programme in Advanced Energy Solutions

Long-term optimization of district heating networks using thermal energy storage

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Abstract

District heating is used to transfer heat from power plants that produce combined heat and power or from heat pumps. This thesis addresses the problem of modeling a district heating network and investigates alternative scenarios for the network to aid in planning. This thesis proposes an energy optimization model for a specific case of a district heating system which has access to thermal storage. The model is built using SpineOpt modelling framework and the study discovers that significant operational and investment costs in heat pumps are incurred in a scenario where combined heat and power plants are decommissioned.

Keywords district heating, optimization, model, energy, scenario, planning

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Preface and acknowledgements

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Otaniemi, 20 January 2025
Tanjim Efaz

1 Introduction

The global transition towards green energy systems has propelled the integration of renewable energy sources into energy grids. Thus, energy system operators face an ever-growing challenge of aligning variable, intermittent renewable energy generation with fluctuating demand. New energy sources are being considered as the sustainability of some sources of energy are called into question. Large power plants burning fossil fuels or even biomass are under consideration for being phased out due to the lack of sustainability of these sources of energy or for not adhering to climate goals.

This thesis explores the task of optimizing a district heating grid with access to thermal energy storage in a case study centred around the municipality of Høje-Taastrup in the Capital Region of Denmark. The municipality has a Pit Thermal Energy Storage (PTES) that came into operation in 2023 and can hold a volume of 70 000 m³ of water that represents a storage capacity of 3300 MWh of heat energy. The PTES stores heat supplied by the transmission system operated by the transmission company VEKS, and the storage is intended for providing flexibility in load dispatch of large CHP plants and increasing utilization of heat from waste-incineration plants [1]. This thesis develops an optimization model of district heating in the Høje-Taastrup region and the VEKS transmission system.

The optimisation model is developed using open-source energy modelling tools Spine Toolbox and SpineOpt.jl. The price of electricity is included in the model since cogeneration of heat and electricity is a major component of Danish district heating system. Prices of fuels like biomass, which is a major source of energy in the Danish energy system, are also included. The thesis studies scenarios where large biomass fuelled CHP plants are decommissioned and replaced by alternative heat sources like heat pumps.

1.1 Research Questions

The thesis will address the following research questions:

- How can we develop a model of a district heating network?
- How can we model different combinations of heat production like CHP and heat pumps?
- What are the optimal investments in heat technology in scenarios where biomass fuelled CHP is reduced or phased out?

2 Literature review

2.1 Overview of District Heating

A district heating (DH) network is a system for distributing heat generated in a centralized location through a network of insulated pipes to provide heating for residential and commercial buildings. This heat can be used for space heating and water heating.

The heat is often produced at a central plant using various energy sources such as fossil fuels, biomass, geothermal energy, heat pumps, or waste heat from industrial processes. The centralized production allows for higher efficiency and better pollution control compared to individual heating systems.

District heating systems can serve a wide range of buildings, from residential apartments to commercial complexes and industrial facilities. They are particularly common in urban areas and can be scaled to meet the needs of growing communities.

District heating has evolved through four distinct generations, each characterized by advancements in technology and efficiency [2]. First generation DH used steam to transport heat at temperatures up to 200°C. It was primarily used in urban industries and large buildings. The high heat content and low mass flows were key features. Second generation DH transitioned to using pressurized superheated water above 100°C. It enabled the efficient use of waste heat from power plants, reducing fossil fuel consumption significantly. This generation also improved operational safety and efficiency. Third generation DH transitioned to using pressurized superheated water above 100°C. It enabled the efficient use of waste heat from power plants, reducing fossil fuel consumption significantly. This generation also improved operational safety and efficiency. The latest generation, or 4th generation, of DH emphasizes sustainability and the integration of renewable energy sources. It operates at even lower temperatures (below 70°C) and incorporates smart thermal grids. This generation aims to create a more interconnected and efficient energy system.

District heating systems can utilize a variety of heat sources [3]. Combined Heat and Power (CHP) plants generate both electricity and heat from a single fuel source, often natural gas, biomass, or coal. The heat produced during electricity generation is captured and used for district heating. Heat-only boiler stations burn fuels like natural gas, oil, biomass, or coal to produce heat directly for the district heating network. Heat extracted from the earth's core in the form of geothermal energy can be used in district heating systems, providing a renewable and sustainable heat source. Heat pumps transfer heat from natural sources such as air, water, or the ground into the district heating system. They are powered by electricity and can be highly efficient. Solar collectors can capture and convert sunlight into heat, which can be stored and

distributed through the district heating network. Excess heat from industrial processes, data centers, or waste incineration plants can be captured and re-used in district heating systems. Some district heating systems can also use excess heat generated from nuclear power plants.

Setting up a district heating system requires significant capital investment for infrastructure such as central plants, distribution networks, and customer connections. This can be a barrier, but the long-term benefits often justify the initial costs. Once established, district heating systems can be more cost-effective to operate compared to individual heating systems. Centralized production allows for economies of scale, better fuel efficiency, and lower maintenance costs. Sources like biomass, geothermal, and waste heat can reduce fuel costs and provide price stability compared to fossil fuels. District heating systems are generally more energy-efficient due to centralized production and the ability to use waste heat. This efficiency translates into lower energy consumption and reduced costs for consumers. By using renewable energy sources and improving energy efficiency, district heating can reduce greenhouse gas emissions and other pollutants. These environmental benefits can lead to financial incentives, subsidies, or carbon credits.

2.2 Flexibility options for DH systems

Heat storage in district heating systems balances supply and demand by storing excess heat during low-demand periods and releasing it during peak times. This enhances efficiency, integrates renewable energy, reduces costs, and improves sustainability. Heat storages can be classified into three broad categories: sensible, latent and thermochemical [4].

Latent heat storage uses phase change materials that absorb and release heat during phase transitions (e.g., from solid to liquid). Ice storage is a typical example, where ice is produced during off-peak hours and used for cooling during peak demand.

Thermochemical storages operate by storing heat through reversible chemical reactions. When heat is needed, the chemical reaction is reversed to release the stored energy.

Sensible heat storage involves storing heat in a medium such as water or sand. The most common form is hot water storage tanks, which can store large amounts of heat and release it when needed. Common sensible heat storage technologies in district heating include tank thermal energy storage, which uses insulated tanks to store hot water, and Pit Thermal Energy Storage (PTES), which stores heat in large, insulated pits filled with water or gravel-water mixtures. Borehole thermal energy storage and aquifer thermal energy storage store heat underground, using boreholes and natural aquifers, respectively.

2.2.1 Pit Thermal Energy Storage

Pit Thermal Energy Storage (PTES) is a pit used to store large amounts of thermal energy in a cost-effective and efficient manner. PTES involves creating a large, insulated pit or reservoir, typically filled with water or a water-gravel mixture [5]. The pit is covered with an insulating lid to minimize heat loss. Heat is stored in the water, which can be heated to temperatures up to 90°C using various energy sources such as solar thermal collectors, biomass, or excess heat from industrial processes. Water is the most common medium due to its high heat capacity and availability. The pit is insulated to reduce heat loss. This includes insulating the sides and the top cover. Heat exchangers are used to transfer heat into and out of the storage medium.

PTES is particularly useful for seasonal storage, where excess heat generated during the summer can be stored and used during the winter. It can also be used for daily or weekly storage to balance supply and demand. Denmark has several PTES installations, such as the one in Dronninglund, which stores solar thermal energy in a large pit lined with a plastic membrane and covered with an insulated lid. This system helps supply heat to the local district heating network.

2.3 Energy Modelling of DH systems

District heating systems can be modeled mathematically. Mathematical programming can be used to optimize the cost of operation and investments in DH systems.

2.3.1 Linear and Mixed-Integer Linear Programming

Danish district heating systems have been modeled with various modeling frameworks. Balmorel is one such open source modelling framework which utilizes linear programming to provide optimal operating schedule and optimal investments in models of energy systems [6]. Balmorel model has four modes of operation, which differ in the length of period of optimisation and whether investments are enabled. An advantage of the Balmorel model includes capability of handling both temporal and spatial parameters, whereas a drawback is its inability to represent stochastic behaviours.

Henrik et. al in their paper [7] assess the performance of heat pumps that source heat from air, groundwater, seawater and combination of the three sources, and concludes that a combination of sources proves more efficient. The study uses linear programming for its optimization technique. Unlike many studies on heat pumps, the study by Henrik et. al does not assume constant COP of the heat pumps during the time of the study, and rather

calculates COP for every hour. Reasons for variation of COP include heat sink temperature, climactic conditions, and the type of the heat source.

In a PhD thesis, Ommen studies the effectiveness of using heat pumps alongside CHP for district heating. Ommen et al compare three different model types operating three different optimization schemes: linear programming (LP), mixed-integer linear programming (MILP) and non-linear programming (NLP). The resulting operating schedule from the MILP and NLP models resemble actual performance in low load conditions more than the operation schedule from the LP model. Ommen prefers to continue with the MILP model over NLP due to the time-consuming nature of solving NLP programs. For the thesis, Ommen focuses on the case study of the Greater Copenhagen area, and in a paper Ommen et. al investigate the efficacy of five configurations of heat pumps at both transmission and distribution level of district heating. For each of these configurations, the authors present performance factors based on fuel costs, electricity consumption and fuel enthalpy rate. The configurations are also studied under different assumptions of district heating operating temperatures, of which the lower temperatures in district heating network yields better performance for the heat pump configurations.

3 Case Description & Data

This section includes detailed descriptions of district heating energy system of the case area which is a part of Greater Copenhagen's complex and inter-connected district heating network.

This section contains description and data that is used for model and scenario development, described in subsequent sections.

3.1 District Heating Stakeholders

3.1.1 Municipality & Heat Distribution Network

Høje-Taastrup Municipality has around 52000 inhabitants. The total heat consumption in the municipality in 2021 was 285516 MWh of which 72% was supplied by district heating. 24% of the heat consumption was from central heating with natural gas and oil. The goal of the municipality is to shift from fossil free heating, which includes reducing the dependence on natural gas and oil boilers for heating.

The inhabitants of the municipality are connected to district heating through Høje-Taastrup Fjernvarme's district heating distribution network. The distributor reports 8,436 customers at the end of 2023, and some of these customers are housing associations with many inhabitants. Majority of the district heating supplied to Høje-Taastrup Fjernvarme comes from VEKS, which operates one of the major district heating transmission networks in the Greater Copenhagen area.

Some part of the heat in Høje-Taastrup is produced locally, for example via heat pumps that simultaneously provide heating and cooling. District heating from utilization of excess heat from data centers is being explored, and there is a solar heating plant in Fløng.

Høje-Taastrup is also the host site for a Pit Thermal Energy Storage (PTES), which is capable of storing 3300 MWh which can be charged and discharged at a nominal capacity of 30 MW. The ownership of the pit storage is jointly shared by the municipality and district heating networks, and the operation of the storage is optimized by Varmelast, which is a collaboration of municipally owned district heating organizations.

3.1.2 Heat Transmission Network

VEKS supplies district heating to 19 distribution companies and 12 municipalities in the western part of the Greater Copenhagen network. VEKS buys heating from major power producers that operate large power plants which typically provide combined heat and power from incineration of fuels like biomass, waste and fossil fuels. VEKS' network also exchanges heating with a neighboring transmission network CTR. VEKS provides security of heat supply by operating peak load boilers, both fossil fuel-based and electric.

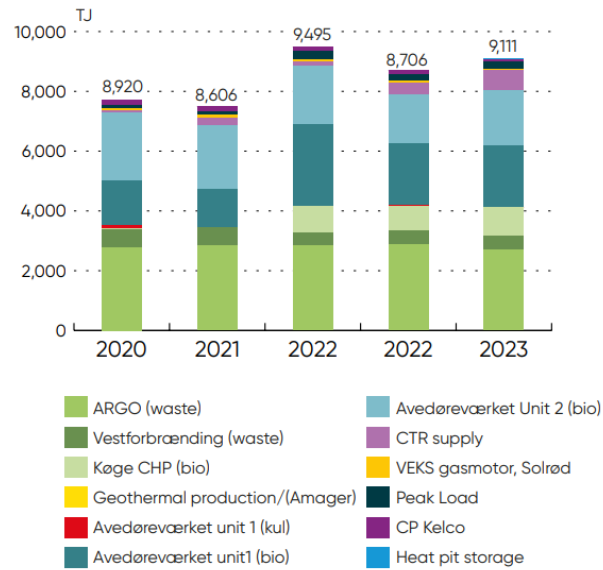


Figure 1: Heat sources in VEKS network, reproduced from VEKS 2023 annual report [1]

Roughly 135km of twin pipes consists of VEKS’ transmission network, along with 62 heat exchangers and 18 pumps as of 2023. As can be seen from the VEKS reports [1] [8] and *Figure 1*, bulk of the heat is sourced from Avedøre CHP plant and waste-to-energy plants.

To the best of author’s knowledge, the transmission capacities are not public. *Figure 2* highlights the municipality in focus in this thesis and the transmission network which is modelled in the thesis (the area in blue).

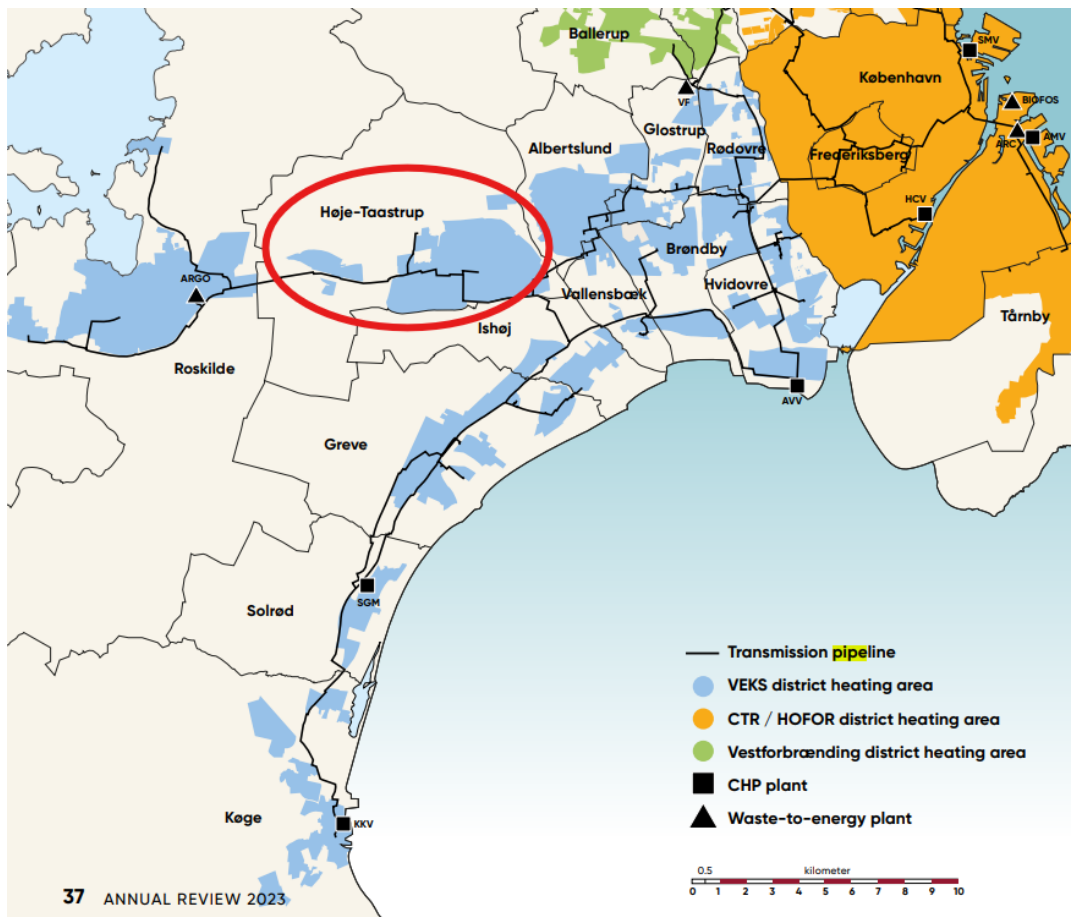


Figure 2: VEKS Transmission network, reproduced from VEKS 2023 annual report (Høje-Taastrup municipality circled in red) [1].

3.1.3 Other Stakeholders

Besides the municipalities and heat distribution and transmission networks, there are a few other relevant stakeholders:

- Danish national government, who set policy conforming to EU standards;
- Varmelast who optimize the district heating economic dispatch of centralized heat suppliers to the interconnected district heating transmission networks of Greater Copenhagen

3.2 Heat Production

Heat is supplied to the district heating networks by various power plants, and some of these CHP and waste incineration plants located in the Copenhagen area were studied by Ommen in 2014 [9]. *Figure 3* highlights the areas considered by Ommen in his study, where the area marked 2 corresponds with the region of the case study in this thesis.

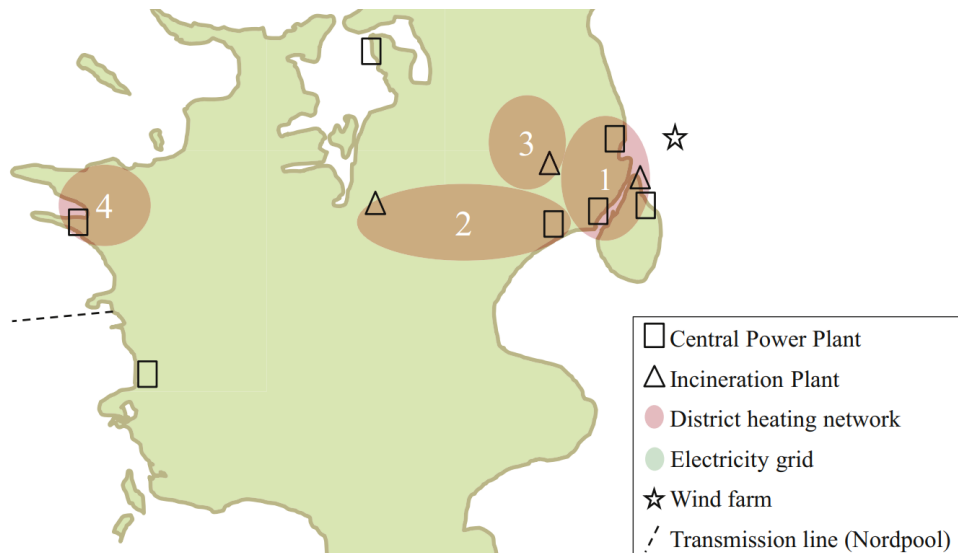


Figure 3: Location of central CHP plants in eastern Denmark, reproduced from [9]. The numbers 1-4 correspond to DH transmission networks, where the high-lighted area #2 refers to the VEKS transmission network.

Heat and power cogeneration facilities using biomass as their primary fuel provide a significant portion of heat energy during the winter seasons, whereas waste-incineration facilities provide heat energy all year and serve as baseload heat energy suppliers.

3.2.1 CHP

As seen from the VEKS reports in section 3.1.2, central CHP plants in Køge (KKV) and Avedøreværket (AVV) provided significant amounts of heat energy to the VEKS network. Among these two CHP plants, the plant at AVV provides significantly more heat to the VEKS network and is thus focused on this thesis paper.

The characteristics of the units in AVV have been gathered by Ommen [9], shown in *Figure 4*. The power plant is home to two units, AVV1 and AVV2, which are both extraction condensing units that can output heat and power at flexible relative ratios.

Plant name	Area	Type	Capacity boiler [MW]	Elec. eff. in backp. [/]	Total efficiency [/]	Max. boiler ramp rate [/]	β [MW/MJs]	Fuel	Fuel price [EUR/G]
AVV1	2	Extraction	600	0.36	0.91	0.2	0.11	Coal	3.5
AVV2	2	Extraction	1150	0.43	0.93	0.2	0.14	Biom. & NG	6.9
KARA5	2	Backp.	65	0.18	0.81	0.2	–	Waste	2.0

Figure 4: characteristics for AVV and ARGO (KARA) power plants, reproduced from [9]

3.2.2 Waste-to-Energy

One of the major waste incineration plants within the VEKS network is located in the Roskilde municipality at the ARGO facility, previously branded with the initials KARA. The facility was also studied by Ommen and the characteristics are listed in his study (see table above).

3.2.3 Peak Power

Natural gas boilers are assumed to be located within the transmission network, and these boilers are utilized as backup heat sources in cases of contingencies. Fuel efficiency characteristics for these boilers are assumed to be 80%.

3.2.4 Fuel and Electricity Prices

Estimates for fuel prices for biomass, specifically wood pellets used in AVV plant, is assumed to be low for the purposes of this thesis.

Electricity spot prices for the Denmark region were sourced from ENTSO-E Transparency Platform.

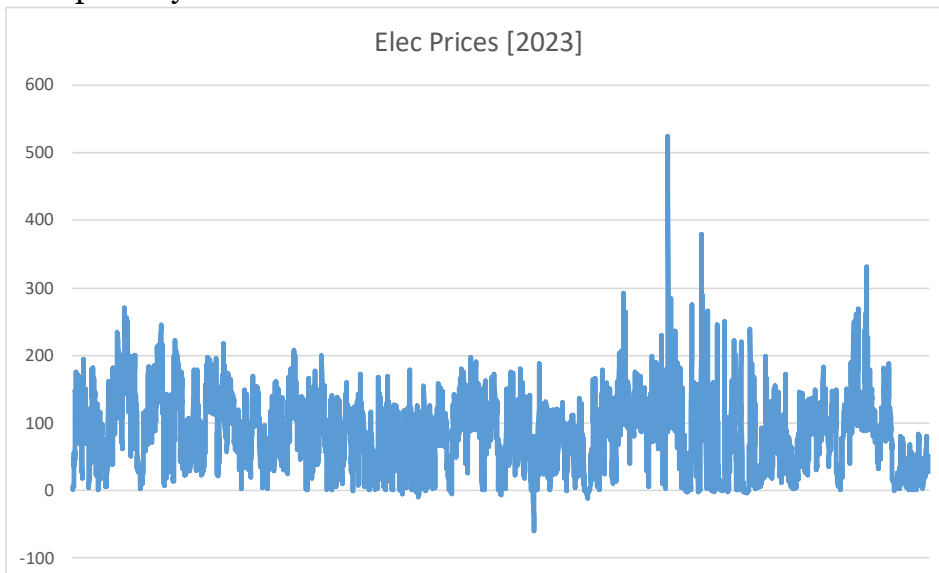


Figure 5: Electricity spot prices for 2023 in Denmark Copenhagen region.

3.3 District Heat Demand and Flexibility

3.3.1 Heat demand

Forecasts of heat demand in Greater Copenhagen Area are not public. Heat demand is assumed from the heat supplied profile available at Varmelast.dk (see Figure 6).

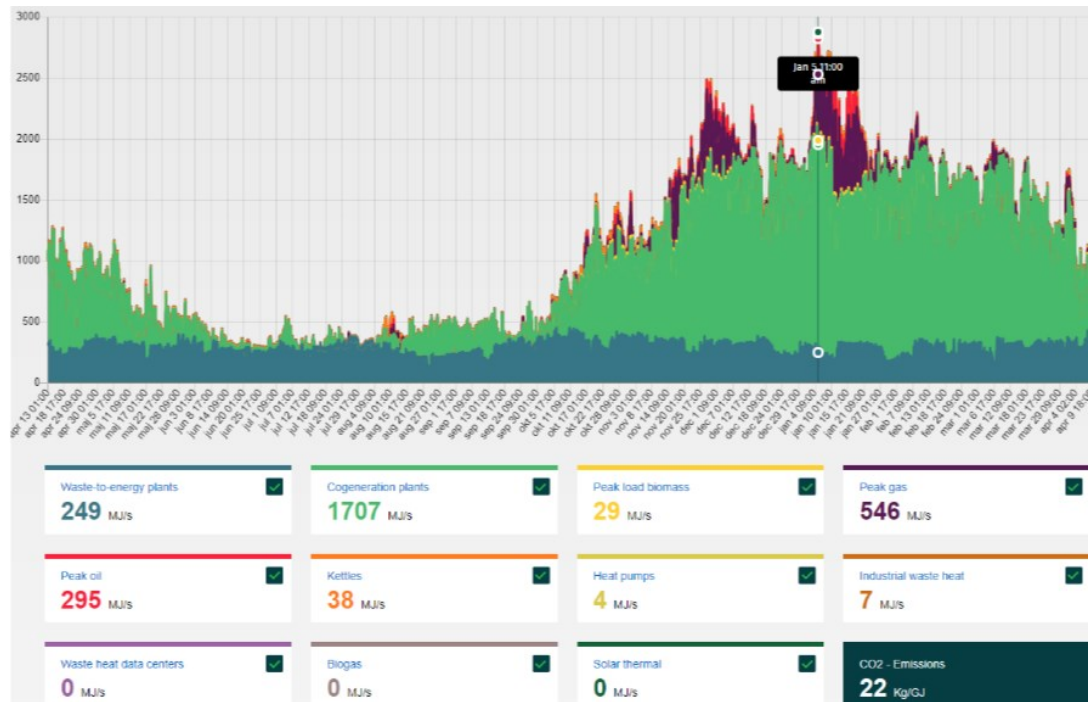


Figure 6: Profile of heat supplied in Greater Copenhagen area, sourced from Varmelast.dk, for one year. Numerical values (MJ/s) under the graph describe the rate of heat supplied during an hour in January.

The heat demand is scaled roughly according to the size of the municipalities. It is assumed that 28% of the heat supplied (shown in the Varmelast charts) corresponds to the heat supplied to VEKS transmission area [1]. Of that heat, 14% is assumed to be the demand for Hoje-Taastrup municipality and 20% is the demand for the neighbouring Roskilde municipality (see Figure 7). The demand profiles for “Municipality 1” (Figure 8) and “Municipality 2” in the model are derived respectively from these assumptions of heat supplied to Hoje-Taastrup and Roskilde municipalities. The rest of the heat supplied in the VEKS transmission network is assumed as the heat demand profile for “Other Municipalities” in the model.

Purchase of heat in the municipalities

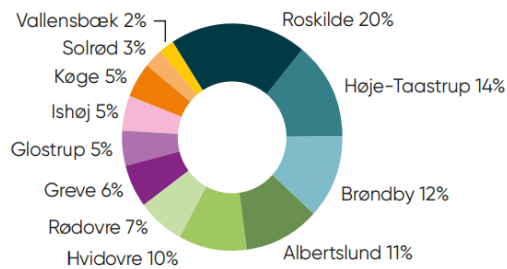


Figure 7: Proportion of heat supplied to each municipality in VEKS transmission system, from VEKS 2023 report [1]

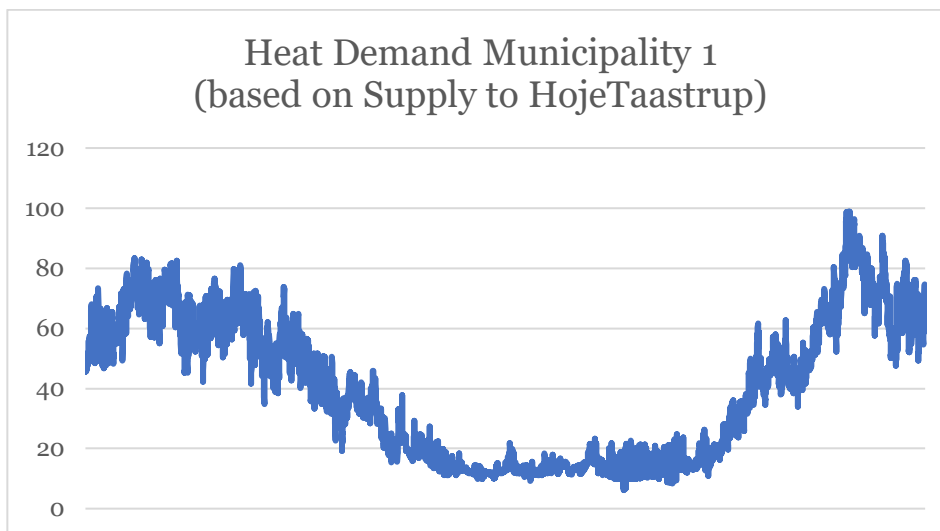


Figure 8: Heat demand profile for 1 year for Municipality 1 in the model, based on assumptions of heat supplied to Hoje-Taastrup municipality.

3.3.2 Heat storage: PTES

The Høje-Taastrup pit storage can be charged at a rate of 30 MW and can hold up to 3300 MWh of thermal energy.

3.4 Scenarios

The transmission system operators are considering shifting from centralized sources of heating (power plants) to decentralized (heat pumps using e.g. seawater as a source, excess heat from data centers). Exploration of future sources include Geothermal, PtX processes, Carbon Capture, but these scenarios are not considered in the scope of this thesis.

3.4.1 Business as usual (BAU)

Business as usual scenario consists of heating through three main sources: CHP plants fuelled mostly with biomass, Waste incineration plants (Waste-to-Energy), and peak power plants fuelled by fossil fuels, mostly natural gas.

3.4.2 Heat Pumps

Heat pumps are considered as potential replacement for biomass fueled power plants. Heat pumps would be placed spread across the network and could take advantage of low electricity prices in scenarios where there is plentiful generation of electricity from e.g. wind power plants.

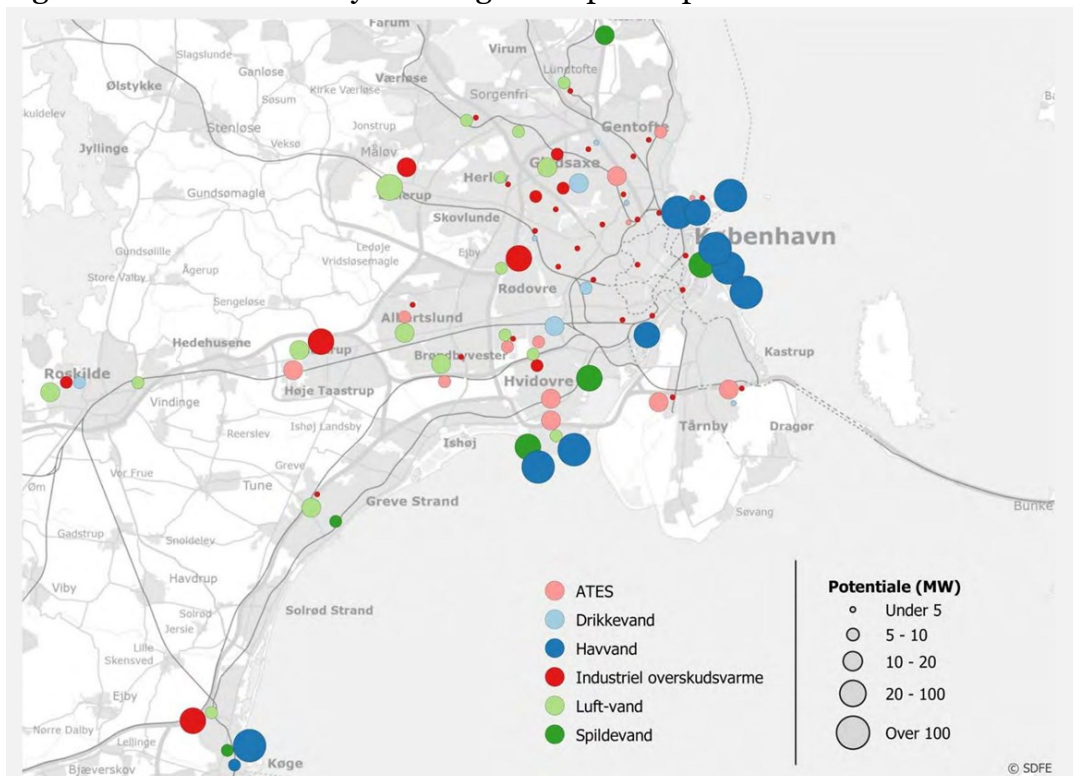


Figure 9: Potential of heat pumps in the Copenhagen area, according to a joint study by the Copenhagen transmission companies [10]

In a joint study by the Copenhagen transmission companies [10], hundreds of MWs of potential for heat pumps in the Copenhagen area is listed (Figure 9). The sources for these heat pumps include industrial waste heat, drinking water, seawater, etc.

In this thesis, investment in heat pumps is considered in two scenarios. In one scenario the capacity of the CHP plant in the model is reduced and 200 MW of heat pumps at high COP are made available for investment. In another scenario, CHP plant is fully decommissioned and another 600MW of heat pumps are made available for investment, albeit at lower COP.

4 Model

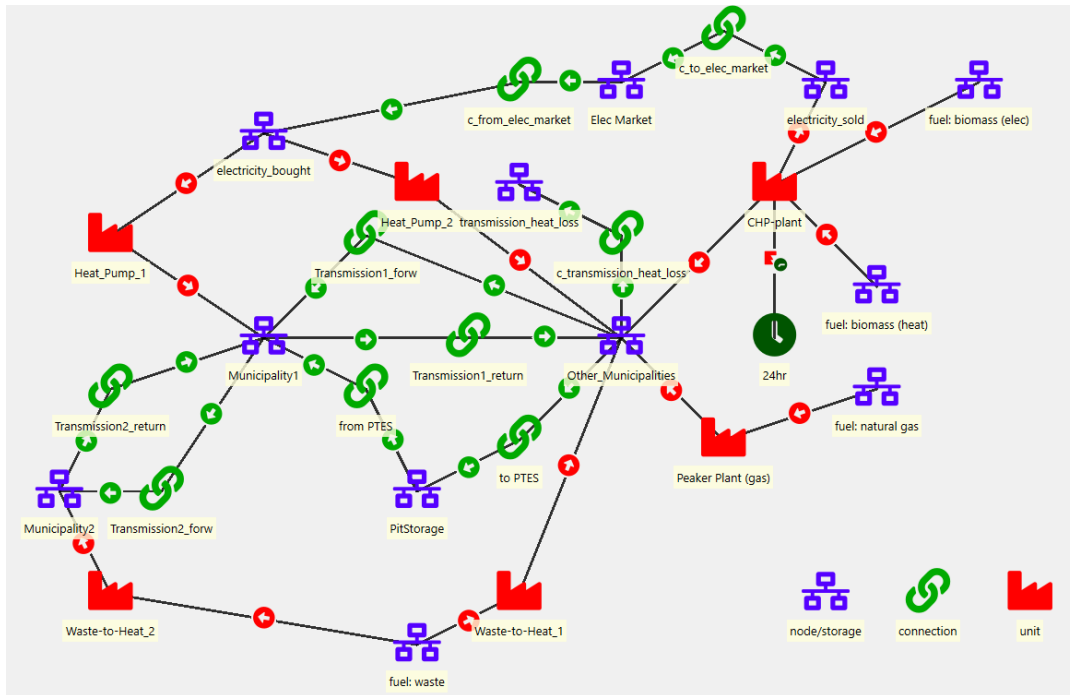


Figure 10: Energy model of the district heating network made in SpineOpt modelling framework.

The SpineOpt modelling framework allows an energy optimization model to be constructed with three major components defining the model: nodes, connections and units [11]. Figure 10 illustrates the full model.

4.1 Nodes

Energy flow in and out from nodes are balanced, unless otherwise specified for certain nodes like fuel nodes, which act like sources of energy and are hence not balanced. The municipality nodes maintain energy balance such that the energy inflow at each timestep of the model is balanced by a demand for energy at each municipality node.

To mimic the heat loss from a district heating network, a flat transmission heat loss is modelled by the `transmission_heat_loss` node, which incurs a flat demand of a few MWs of heat energy at each timestep.

The `PitStorage` node is modelling the thermal energy storage in the Høje-Taastrup municipality (Municipality 1 in has storage enabled, and at each timestep the `PitStorage` can be charged via the “to PTES” connection at a maximum rate of 30MW or can be discharged via the “from PTES” connection at a maximum rate of 30MW.

In the model in this thesis, the electricity output of the CHP plant is sold off to the electricity market via the “`electricity_sold`” node (Figure 11) and the “`c_to_elec_market`” connection. The cost of the electricity flow through the

“c_to_elec_market” connection is negative, indicating an income from each unit of electricity generated by the CHP plant. The Elec Market node acts like a source and sink of electricity and hence energy flow in and out of that node is not balanced.

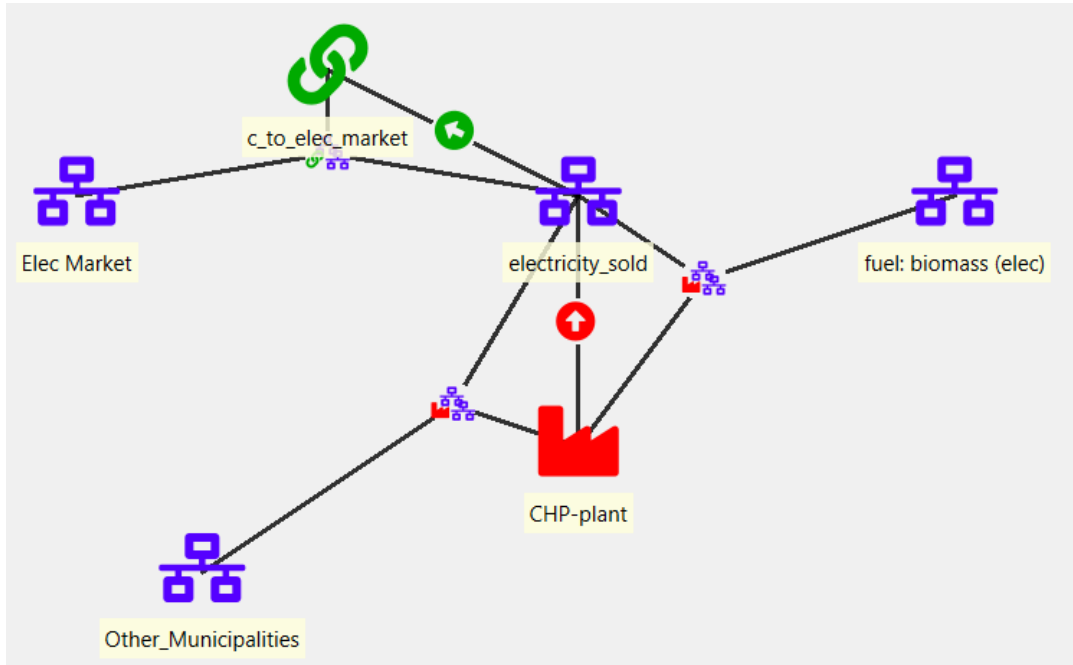
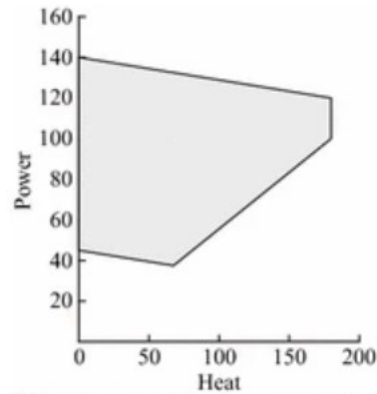


Figure 11: closer look at the electricity sold node.

4.2 Units

The units in the model convert energy from fuel nodes into heat or electricity at different efficiencies. In the case of heat pump units, the units convert electricity into heat in the ratio dictated by their coefficient of performance.

The CHP plant in the model converts fuel into heat and electricity as long as the ratio of heat and electricity produced remain within the specified operating zone of the CHP plant. The operating zone of an extraction condensing CHP plant in SpineOpt is outlined in a report by Fester [12]. More details on the shape of the operating region, as shown in *Figure 12*, of an extraction condensing plant can be found in [13].



(a) Extraction condensing steam turbine

Figure 12: shape of the operating region of an extraction condensing CHP plant as outlined in [13].

The CHP plant interacts with two fuel nodes that both represent biomass fuels. The fuel nodes are separated into two nodes to easily represent which portion of the fuel is spent on producing electricity and which fuel portion is converted into heat. Heat produced by the CHP is fed into the transmission network through the “Other_Municipalities” node.

The CHP plant modelled in this thesis has certain ramping constraints, similar to the ramping constraints described in [12]. The CHP plant also has startup and shutdown fractional constraints on heat output, listed in Figure 13.

+	unit_to_node	CHP-plant Other_Municipalities	shut_down_limit	Base	0.05
+	unit_to_node	CHP-plant Other_Municipalities	start_up_limit	Base	0.05
+	unit_to_node	CHP-plant Other_Municipalities	unit_capacity	Base	580.0
+	unit_to_node	CHP-plant electricity_sold	ramp_down_limit	Base	0.05
+	unit_to_node	CHP-plant electricity_sold	ramp_up_limit	Base	0.05
+	unit_to_node	CHP-plant electricity_sold	unit_capacity	Base	580.0

Figure 13: overview of different parameters for CHP plant in the model. Limits are fractional values of the output capacities of the CHP plant.

4.3 Temporal scale of model

The operational time scale of the model is set to hourly, i.e. each operational time step optimized by the model represents an hour. On the other hand, the decision to turn the CHP on or off is optimized at daily or 24 hour intervals. The on/off state of the CHP is recorded as a binary variable, which means this optimization model has some integer constraints and is hence a mixed integer linear program (MILP).

4.4 Scenarios

The time horizon for the model is set to one year. In every scenario, the model optimizes for operation cost for every one hour within this time horizon. In the BAU scenario, electricity is sold to the electricity market. There are no heat pumps in the BAU scenario. However, in the Heat Pumps scenarios, the “electricity_bought” node, as seen in *Figure 14* and *Figure 15*, is activated. Any unit of electricity used by heat pumps flows from “Elec Market” node through the “c_from_elec_market” connection to the “electricity_bought” node. Note that the “Elec Market” node is not balanced, i.e. the energy flow into and out of the node is not balanced, but the other electricity based nodes and connections are all balanced, ensuring balance between the inflows and outflows of those nodes.

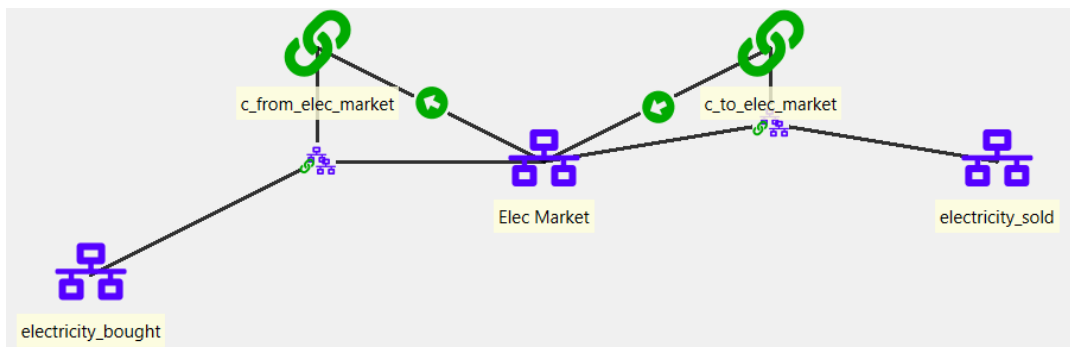


Figure 14: closer look at the “Elec Market” node

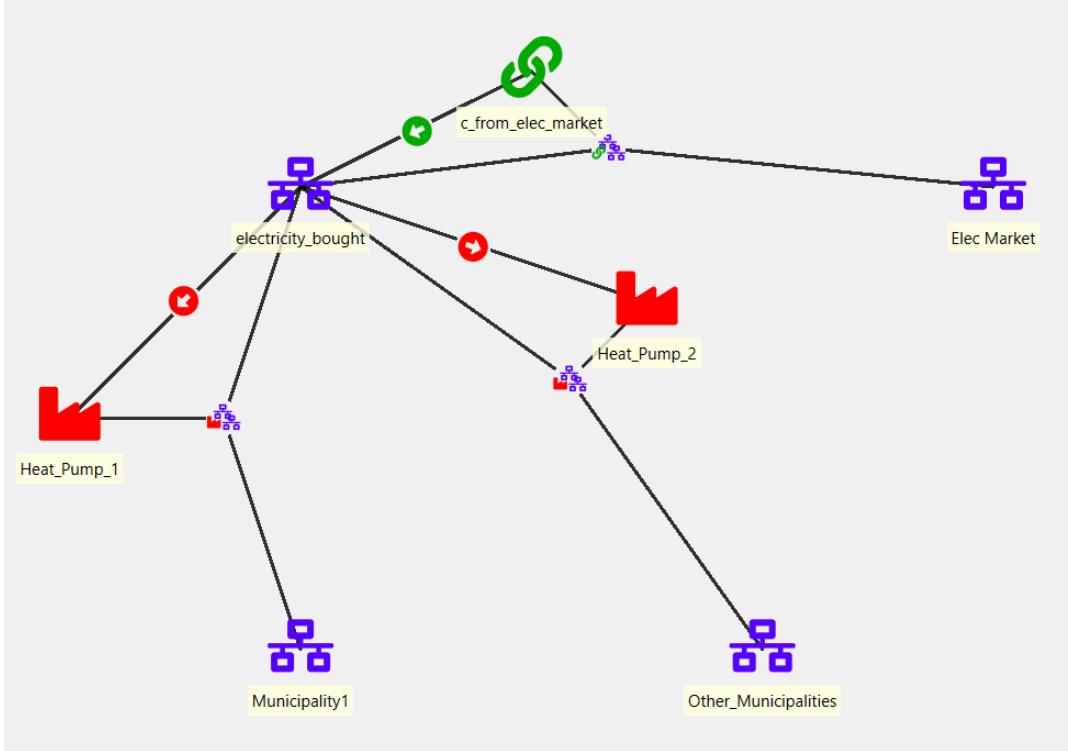


Figure 15: closer look at heat pump units.

Note that there are two different sets of heat pump units enabled in the heat pump scenarios of the model. “Heat_Pump_1” represents heat pumps that have higher Coefficient of Performance and represent heat pumps that are worth investing in at first. “Heat_Pump_2” represents heat pumps that have lower Coefficient of Performance and are second in choice for investments.

4.5 Investment parameters

In the two cases where heat pump investments are allowed, the model optimizes for investment costs at the beginning of the year. The cost of the heat pumps per unit MW is the annuitized investment cost of heat pumps, where the Net Present Value (NPV) is annuitized to get the Equivalent Annual Cost (EAC):

$$EAC = -\frac{NPV}{A_{t,r}}, \text{ where } A_{t,r} = \frac{1 - \frac{1}{(1+r)^t}}{r} \dots (I)$$

In Equation (I), the annuity factor A is derived from the discount rate r and the lifetime of the investment t . Discount rate in this thesis is assumed to be 5% and the lifetime of the heat pump investments is assumed to be 25

years, and the NPV of each MW of investment is assumed to be 0.5 million euros, leading to an EAC of 35476€ per MW.

5 Results

The operational costs of the system in three different scenarios are shown in *Figure 16*. Note that these operational costs only include fuel costs, electricity costs, and profits from electricity sales in the scenarios where CHP is enabled. The profits from electricity sales is large, hence the operational costs in the first two scenarios are negative.

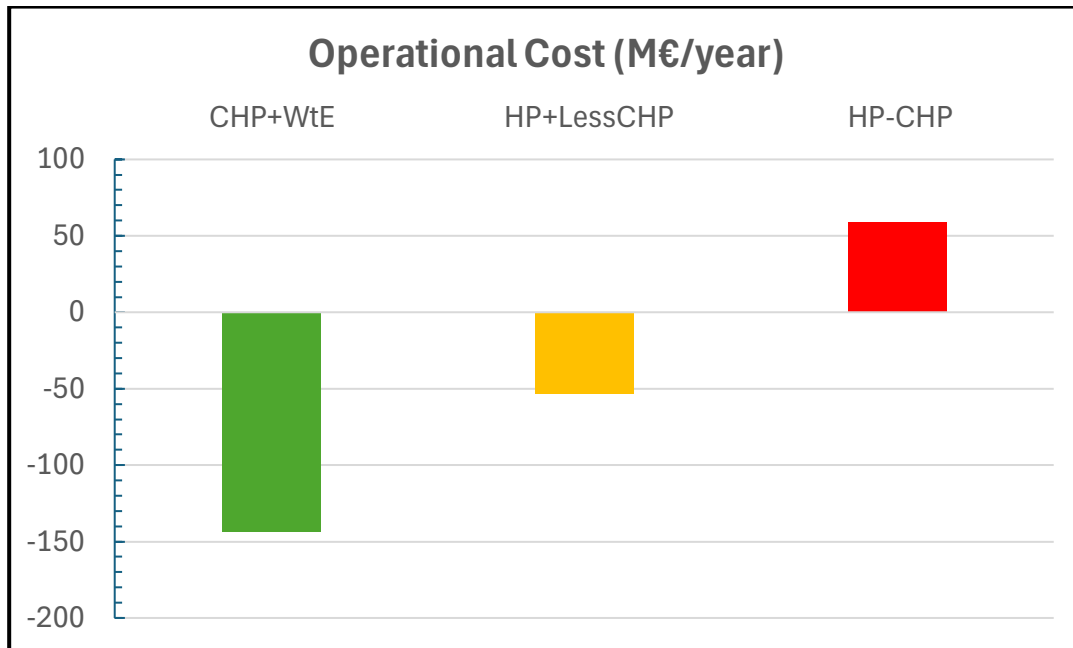


Figure 16: Operational costs incurred in the model for three scenarios: BAU, Heat Pumps & CHP, Heat Pumps without CHP

The investment costs incurred by the model is highlighted in *Figure 17*. Note that the first BAU scenario there are no investment costs since the scenario represents the current established heating system. In the second scenario where CHP capacity is lowered from 580 MW to 300 MW and 200 MW of heat pump investments are enabled, the model chooses to invest in all 200 MWs of heat pumps. In the third scenario where CHP is fully decommissioned, the model chooses to invest in an addition 330 MW of heat pumps to provide sufficient heat to meet the demand.

The total combined operational and investment costs are highlighted in *Figure 18*. For a full transition from CHP to heat pumps, about 221 million € of costs per year would be incurred.

In these scenario analyses, the role of the storage is not highlighted, and further work is required to deduce how much value the pit thermal energy storage is bringing to each of these scenarios.

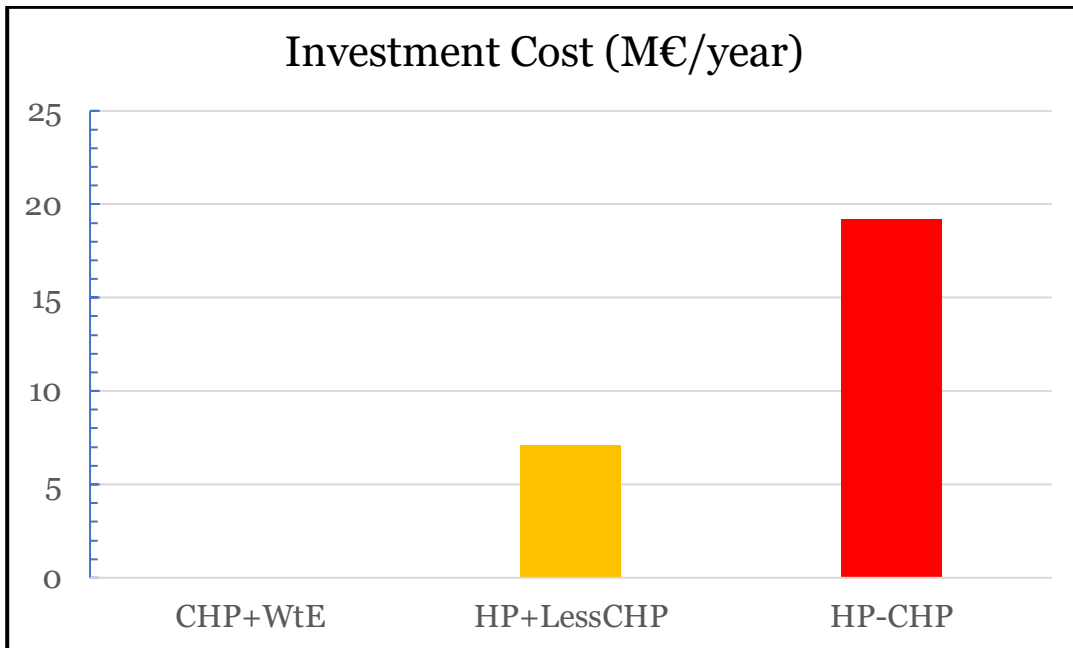


Figure 17: Investment costs incurred in the model for three scenarios: BAU, Heat Pumps & CHP, Heat Pumps without CHP

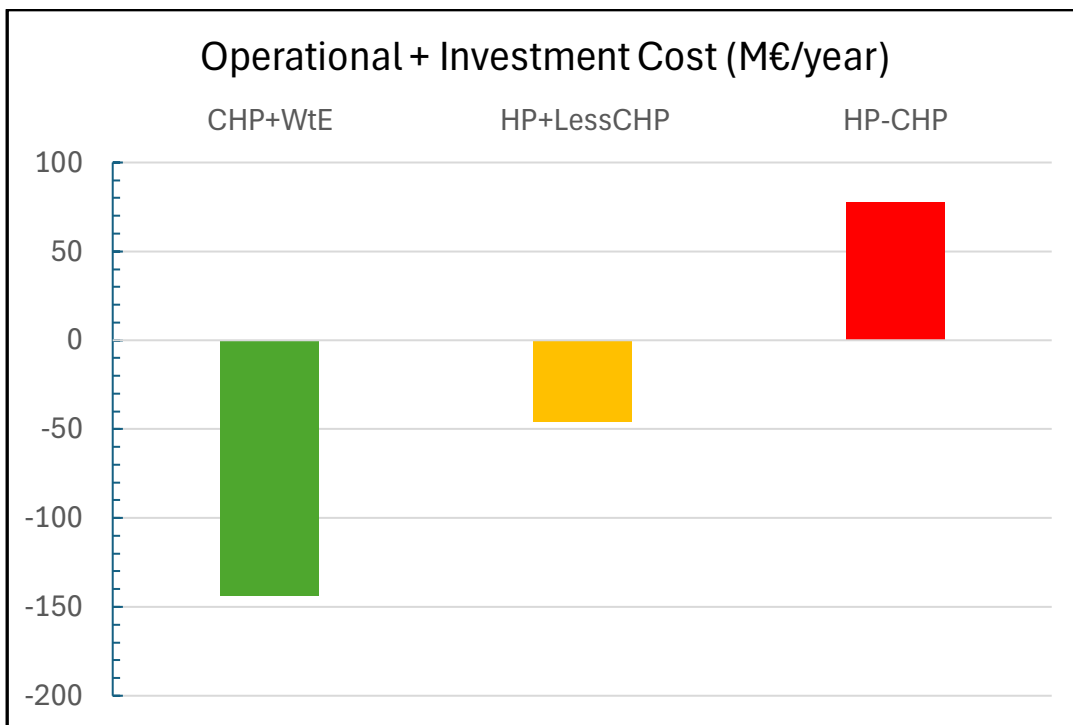


Figure 18: Total costs incurred in the model for three scenarios: BAU, Heat Pumps & CHP, Heat Pumps without CHP

6 Summary/Conclusions

In this thesis, a district heating case study is modelled using the SpineOpt modelling framework. The case area includes large biomass fuelled power plants which are being considered for decommissioning in future scenarios. The optimization model in this thesis finds that significant operational and investment costs are incurred in scenarios where the CHP plant is downsized or decommissioned in favour of heat pumps.

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