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The Role of Heat Pumps for Decarbonising and Optimizing the Linz District Heating and Cooling System

Ralf-Roman Schmidt[1*], Christian Scheinecker[2], Gerhard Totschnig[1], Iná Maia-Novak[1], Christian Schützenhofer[1], Demet Suna[1], Philipp Ortmann[1], Michael Lauerman[1], Abdulrahman Dahash[1]

[1]AIT Austrian Institute of Technology GmbH, Energy, Vienna, Austria,
[2]LINZ STROM GAS WÄRME GmbH, Energieerzeugung, Linz, Austria

Abstract

LINZ AG's district heating (DH) network is the second largest in Austria with a heat generation of 1.151 GWh. It is currently supplied via gas (55.1%), biomass (13.5%) and waste incineration (31.4%). The aim of Linz AG is to reduce the fossil fuel-based generation to zero by 2040. Further, a district cooling (DC) network is under planning with a total generation capacity up to 40 MW. For determination of a cost-optimal district heating and cooling (DHC) generation portfolio, a pathway optimization is conducted in this study. Therefore, scenarios for energy prices, heat demand etc. are defined and key technology options are evaluated, including different possibilities for heat pumps (HPs) integration. The DHC system is modelled, and an optimizer is used with the objective function to minimize the total system costs (net present value) up to 2040, considering the service lifetime of the existing plants and the maximum availability of renewable fuels. Results show that HPs play an important role, since they can: 1) enhance the system efficiency via flue gas condensation; 2) use low temperature heat sources for decarbonizing the DH supply; 3) increase the storage capacity by increasing the temperature lift; and 4) provide cooling economically, simultaneously suppling waste heat to the DH network.

Keywords: decarbonization, district heating, district cooling, flue gas condensation, low temperature heat sources, storages

1. Introduction

Current state of the Linz district heating (DH) network: The networks spans over large parts of the city of Linz and neighboring communities with a total length of 350 km, and a total heat generation of 1.151 GWh in 2024. The DH generation mix includes 55.1% gas (combined heat and power (CHP) and heat-only-boilers (HoB)), 13.5% biomass CHP and 31.4% waste incineration CHP. A thermal energy storage is installed with a size of 35.000 m³. The supply temperatures range from 80 in summer to 130 °C in winter [1].

One important milestone of Linz AG is to reduce the fossil fuel-based generation to zero by 2040. To achieve this, a wide range of technology options is under consideration. Further, Linz AG plans a new district cooling (DC) network to cover the expected increase in summer cooling demand due to ongoing climate change, with an initial generation capacity of 20 MW, and anticipated expansions to 28 MW and 40 MW [2], [3]. The commissioning of the new DC network enables synergies for the DH decarbonization, since the waste heat from the cooling generation could be reused in the DH network.

Objective: In this contribution, the focus is on the main research question: "*How can heat pumps (HP) support the decarbonization and optimization of the Linz DH network, considering the expansion of the DC network at the same time?*"

2. Methodology

The analysis is based on the development of a cost-optimal district heating and cooling (DHC) generation portfolio. Therefore, a pathway optimization is carried out as illustrated in Figure 1.

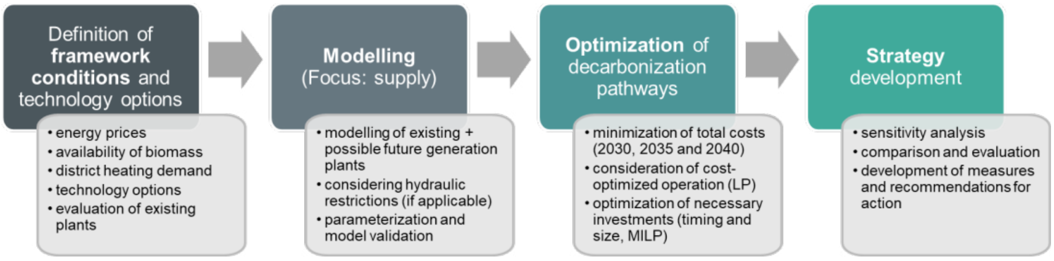

Figure 1 Methodology overview (LP = Linear Programming; MILP = Mixed-Integer Linear Programming).

One of the most important framework conditions are the energy prices. Therefore, three energy price scenarios are used: ”low“, ”central“, and „high” (details cannot be shown due to their commercial confidentiality). Those scenarios show a high variability in hourly electricity prices, with a trend of lower electricity prices in summer (a result of the increasing trend in electricity generation from PV), and higher prices in winter, including periods of very high and very low prices. For HPs, it is assumed that the electricity used would be 100% renewable from 2030 onwards. Further on, the availability of renewable fuels was restricted e.g. considering provisions from the RED III.

In a second step, key technology options are evaluated together with the DH operator and a technical consultant, including their potential, characteristics (e.g. efficiency, coefficient of performance (COP)), service lifetime, CAPEX and OPEX and others. This includes different

- waste heat sources from the industry (assumed to be climate-neutral [4]),
- heating plants, including direct electric HoB; biomass HoB and a biomass CHP,
- storages options, including steel tanks like the existing storage and a so called “2-zone storage”, enabling storage temperatures of up to 115°C. Further, a seasonal thermal energy storage (sTES) in the form of a cavern thermal energy storage (CTES) is considered, since the space in Linz for a pit sTES is limited. Finally, a cold storage is considered for optimizing the DC generation; and
- anergy sources for large scale HPs, including air, river and groundwater, sewage treatment plant effluent, geothermal energy. Also, flue gas is considered as a heat source – see section 3.1.

And finally, the option to integrate a “central HP” was included. This HP can cool the sTES below the DH return temperature (to a certain technical limit). Thereby, it can increase the temperature lift in the sTES above the difference between the DH supply and return temperatures and thus can increase its capacity.

The DHC system with all technology options is modelled and the system model is validated for the status-quo. Finally, an optimizer is used with an objective function for the minimization of the total system-costs (net present value) for 2030, 3035, and 2040 (and in-between years for some analysis). The optimization model uses mixed integer investment planning and linear unit commitment. It combines heating and cooling in one optimization and enables complex and nested configurations of the DHC supply units (i.e. sequential heating of the DH water for reaching the supply temperatures). It also allows for modelling storages with multiple temperature levels, part load operation, as well as startup costs, minimum on- and off-times. The optimization model decides to invest in different technology options in order to achieve the interim targets set (decarbonization and DC expansion), while taking into account restrictions such as the service lifetime of the existing plants and the maximum availability of renewable fuels. More details can be found in [5] and [6].

3. Results

Following the conducted analysis, it is observable that large scale HPs play an important role for decarbonising the Linz AG DHC systems in following areas:

3.1. Increasing the efficiency of the system

The first important application area of HPs is to increase the efficiency of the existing combustion processes in the Linz CHP plants. In this regard, flue gases are cooled below its dew point temperature and the latent heat released by the resulting condensation of water can be thus recovered. With the HP, this heat is recovered, while temperature boosted and injected in the DH system.

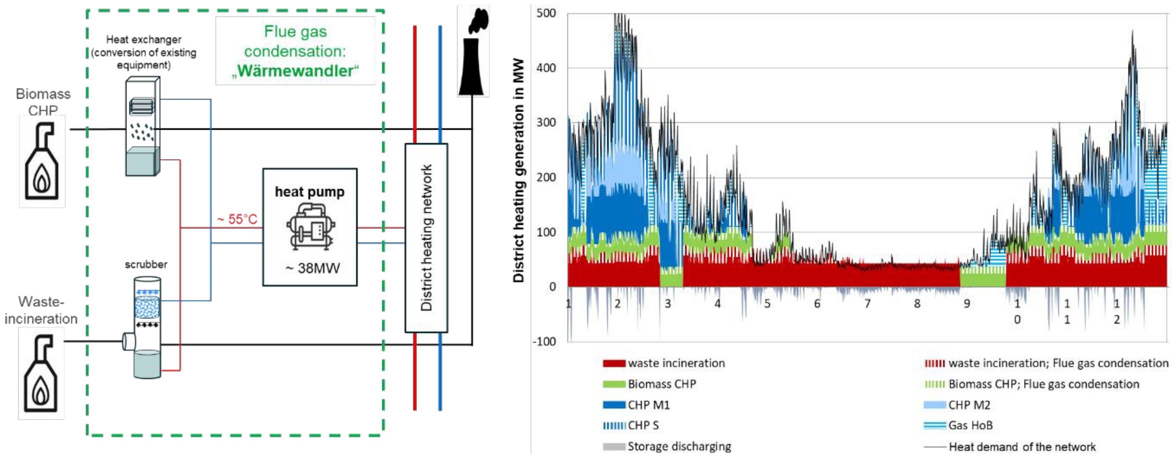

Figure 2 left: functional principle of the flue gas condensation [7]: at the biomass CHP, a heat exchanger is installed in the exhaust gas duct. At the waste incinerator, the existing scrubber for flue gas desulphurization is modified to extract the heat of the flue gases. Both heat exchangers cool the flue gases and thus serve as heat sources for the HP. Right: DH supply with flue gas condensation (optimization for a Business-As-Usual (BAU) scenario 2040 without decarbonization).

The concept of so-called "Wärmewandler", is to combine the flue gas condensation from the waste incineration and the biomass CHP as shown in Figure 2, left [8]. It is designed for a thermal output of 38 MW and has a high efficiency and flexibility (the annual average COP > 6). The concept includes an integration with chillers from the new DC network (see section 3.3). The "Wärmewandler" will boost the share of renewables in the Linz DH system by up to 18% as shown in Figure 2, right.

3.2. Making low temperature heat sources available and increasing the capacity of the storage

The second and third important application area of HPs is to make low temperature heat sources available for decarbonizing the DH network and to increase the capacity of the storage by increasing its temperature lift.

In all scenarios without industrial waste heat, a share of around 1/3 will come from HPs in the decarbonized DH supply by 2040. The other shares will come from 1/3 waste incineration (which is assumed to be climate-neutral via carbon capture and storage technologies); and 1/3 renewable fuels (biomass, biomethane) as illustrated in Figure 3, left. Here it is important to mention, that the availability of biomass was restricted to the current use, and the availability of biomethane was restricted to the biomethane potential in Austria, scaled down to Linz.

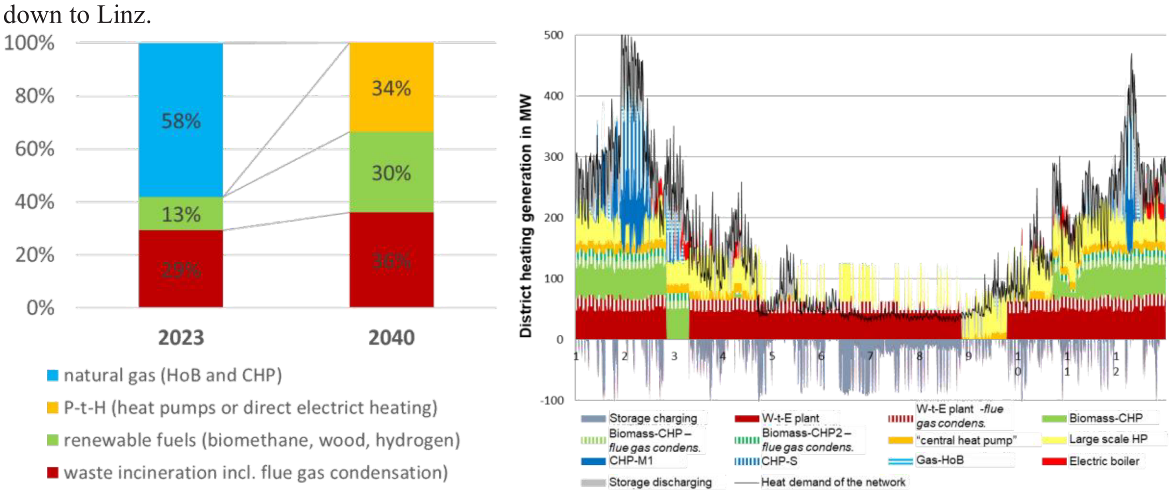

Figure 3 Results from the year 2040, scenario without industrial waste heat and with high energy prices; left: heat supply mix for 2023 and scenario for 2040, right: yearly distribution of heat demand and renewable / climate neutral DH supply.

Due to the assumed relatively low investment costs and low electricity prices, ambient air seems to be the most economic source for the large-scale HP. Anergy sources such as the Danube, groundwater and sewage water, as well as geothermal energy, are not used for decarbonization in any of the scenarios considered.

The overall share of HPs can be reduced in a) scenarios with relatively low electricity prices where HPs will be substituted increasingly with direct electric HoB since the high investment costs of HPs are increasingly unprofitable. When energy prices are relatively high, the heat comes mainly from HPs, since the unmatched efficiency of HPs compared to direct electric HOB compensates for the high electricity prices; and b) scenarios with an increasing availability of waste heat from the industry, that will replace the heat generation from HPs, supplying 10% to 25% of the overall heat generation (under the assumption of zero waste heat prices[1]).

In general, the operation of the HPs can be optimized following the electricity prices constraint. However, HPs also operate partly in times with medium electricity prices, to partially cover the heat load in winter, since the CHP operation is limited to times with very high electricity prices only as illustrated on the right-hand-side of Figure 3.

With rising energy prices, thermal energy storage systems become increasingly feasible, leading to sTES with volumes up to 1 million m^3. In the scenario in Figure 3, the sTES is charged in summer mainly via the HP to take advantage of the low electricity prices. Here, the use of a "central HP" increases the capacity of the storage and thus makes it economically feasible, which is the third important application area of HPs.

3.3. Compression chillers can provide DC economically and at the same time create synergies to DH

The fourth important application area of HPs is to provide DC economically and at the same time create synergies to DH by reusing the waste heat from the cooling process.

From the analysis performed, it is observed that for cooling generation, compression chillers are more feasible than absorption chillers, although "free" waste heat from industry and waste incineration is available in summer. This was mainly due to limited operation hours and the costs of additional cooling towers – due to their low efficiency, absorption chillers create more waste heat than compression chillers.

The developed DC concept features 40 MW DC generation with only 13 MW additional chillers due to the dual use of the HP for flue gas condensation ("Wärmwandler") for cooling (see section 3.1), see Figure 4, left.

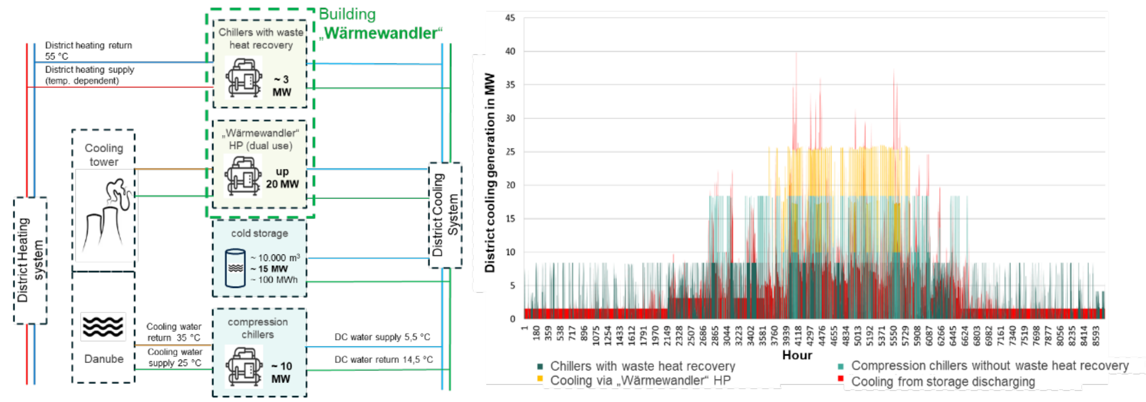

Figure 4 Left: concept for the generation of DC in combination with the soon to be implemented "Wärmewander" (flue gas condensation, see section 3.1) [7], right: yearly distribution of DH supply

In this concept, above 50% of the waste heat from the cooling process can be supplied to the DH network using additional HPs, thereby contributing to its decarbonization. In the final expansion state (40 MW), about 30 GWh waste heat can be feed-in to the DH network.

Finally, a large-scale cooling storage (approx. 10,000 m³, 15 MW charging/ discharging capacity) showed its economic benefits in all scenarios. The DC storage allows the compression chillers to operate at times with low electricity prices and helps to cover peak loads as shown in Figure 4, right.

For more details, the reader is referred to [6], [7], [8], [9], [10].

4. Summary and Discussion

The conducted analysis showed following areas were HPs support the decarbonization and optimization of the Linz DHC network: **1.** Increase the efficiency of the system by flue gas condensation, **2.** Make low temperature heat sources available for decarbonizing the DH network, **3.** Boost the storage capacity by expanding its temperature lift, and **4**. Compression chillers can provide DC economically and at the same time create synergies to DH.

[1] No running costs were assumed for waste heat supply (i.e. 'free waste heat'). By comparing the heat production costs in the scenarios with and without waste heat, the maximum acceptable waste heat price can then be determined by calculating backwards.

However, following aspects and barriers for HP integration can be seen:

- **Very low electricity prices:** Although this may appear counterintuitive, (very) low electricity prices reduce the share of HP generation in favour of direct electric HoB. In this case, both power-to-heat (p-t-h) units have very low operational costs, thus the extra investment in HPs to increase the efficiency compared to direct electric HoB is not economic. When electricity prices are high, the higher efficiency of HPs compared to direct electric HoB compensates for the high prices, resulting in a larger share of HPs. However, in all scenarios, electricity prices are not “high enough”, to justify the additional investment in anergy sources with a higher COP compared to air-source-HPs.
- **Competing energy sources:** Industrial waste heat has the potential to substitute large shares of heat supply from the HP, especially if the waste heat prices are low.
- **High network temperatures:** The Linz DH network has relatively high network temperatures, resulting in a low COP and can make the use of additional heating units necessary (although HP are available reaching up to 150°C, their integration might not be economic for a limited operation time).
- **Central HP:** The concrete integration options for the “central HP” at the Linz DH network needs further investigations, including the temperature levels achievable in the sTES, the placement of the central HP and hydraulics as well as electrical network aspects.
- **Limited electricity network capacity:** For the integration of p-t-h units, the electricity network needs to be expanded or further reenforced. However, first discussions with the transmission system operator indicate some possible delays in the provision of this capacities.

Following aspects should be noted for the general development of DHC networks considering any significant integration of HPs:

- **Storages** will play a key role in the optimization and decarbonization of the Linz DHC system. This applies both for heat and cold storages, and both for using low electricity prices in HPs when the demand is low, as well as supporting the provision of peak loads.
- **Higher levelized costs** of heat in decarbonization scenarios compared to business-as-usual scenarios due to a) large up-front investments for HPs, storages etc., b) increasing costs for buying electricity for the p-t-h units, and c) lower revenues from CHP electricity generation.
- **Increasing complexity** of the decarbonized and optimized DHC system, including the integration of different interlinked heat and cold supply units as well as storages, the optimization of temperature levels and cascading, as well as by trend increasing fluctuations of electricity prices.
- There are several **uncertainties** regarding the future development of key factors such as energy prices (electricity, renewable fuels) but also options for p-t-h units to participate in short term electricity markets (e.g. balancing markets). Further, uncertainties related to the availability and price of competing energy sources such as waste heat, demand side developments and network temperatures as well as local, regional and national regulatory framework conditions.

5. Outlook

The so-called “Wärmewandler” (see section 3.1) and the new DC system (see section 3.3) are currently in the engineering phase, and will be put into operation by 2029/2028 [7], [8], [9], [10]. Further on, some questions are still open and needs further investigation:

- Although air-source HPs seem to be an economic solution, their detailed feasibility needs to be further investigated, e.g. the area for the heat exchangers, local air flow conditions and realistic COP values, additional equipment needed to avoid defrosting. This also includes a detailed assessment of the properties of competing ambient heat sources such as groundwater, river water/cooling water.
- The projects HEATROCK[2] and INTERSTORES[3] are investigating the concrete feasibility and the reduction of the specific investment costs for CTES and the optimized integration of a central HP.
- The project DeRiskDH[4] investigates options to optimize the building stock with regard to return temperatures and flexibilities, as well as the integration of seasonal storage.

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[3] https://www.ait.ac.at/en/research-topics/integrated-energy-systems/projects/interstores and https://interstores.eu/
[4] https://www.ait.ac.at/en/research-topics/flexibility-business-models/projects/deriskdh

- To consider new geopolitical developments, and resulting changes in energy prices scenarios, as well as incorporating new findings related to the potential from renewables, waste heat and storages a continues adaptation of the decarbonization scenarios will be done.

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