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AbSolut - Integration of Absorption Technologies in District Heating and Cooling Systems for Enhanced Economic and Ecological Impact

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Abstract. District heating (DH) systems play a crucial role in meeting heating demands across the European Union (EU) and Austria, with significant potential for energy efficiency improvements and decarbonization. However, the transition towards climate neutrality by 2040 poses significant challenges, particularly in decarbonizing existing DH systems and integrating renewable energy sources. This work explores the application of absorption technologies, specifically absorption heat exchangers (AHX), absorption chillers (AC), and absorption heat pumps (AHP), in optimizing DH systems. The study investigates the utilization of AHX as transfer substations to increase heat capacity within existing grids by up to 30%, facilitating the integration of renewables and reducing distribution heat losses. Additionally, AC implementation for cooling supply demonstrates efficiency improvements through dynamic operation modes, renewable energy integration, and reduced electricity demand. Furthermore, AHP for waste heat utilization in DH power plants showcases environmental benefits, cost savings, and enhanced energy security. Through detailed techno-economic analyses and case studies, the paper evaluates the viability and economic feasibility of absorption technologies in DH applications. Challenges such as system integration, spatial requirements, and driving energy optimization are addressed, offering insights into overcoming barriers to adoption. Overall, the research highlights the transformative potential of absorption technologies in enhancing the efficiency, sustainability, and resilience of DH systems. By leveraging these technologies, DH operators and stakeholders can navigate the transition towards climate neutrality, while ensuring reliable and cost-effective heating and cooling solutions for urban areas.

Keywords: District Heating, Absorption Heat Pump, Energy Efficiency, Economic Benefits, Decarbonization

1 Introduction

Heating comprises nearly half of the final energy consumption within the European Union (EU) and Austria [1]. Among various heating technologies, district heating (DH) grids stand out as an appealing choice for ensuring a consistent provision of space heating and domestic hot water (DHW) for buildings or industry. This is attributed to their capacity to offer an energy-efficient and economical heating solution, particularly in densely populated urban areas with concentrated heat demands that are economically viable [2]. However, the potential for decarbonizing DH systems remains largely untapped, primarily due to the prevalent use of fossil fuels, which constitute approximately 75% of the total heat supply in European DH grids and on average in Austria 48 % [3].

1.1 District Heating in Austria

In 2020, the Austrian final energy consumption provided by district heating was 20 TWh. The share of final energy consumption accounted for by district heating was around 20 % and has more than doubled since 1993.[3] Approximate 55 % of total DH sales occur in the nine largest Austrian DH supply areas (Vienna, Graz, Linz, Salzburg, St. Pölten, Klagenfurt, Lienz, Wels, Villach). Most of these DH grids are operated at temperatures from 80-130 °C and supplied by different, mainly fossil energy sources, which have to be substituted in future. In Austria, in 2020, district heating systems relied on a mix of energy sources: 52% came from renewable sources, 34% from natural gas, 7% from heat generated by thermal waste treatment, and the remaining 7% from other energy sources [3]. Over the decade, the length of district heating pipelines operated by Austria's heat supply companies increased from 4,100 kilometers in 2010 to about 5,600 kilometers in 2020 [3]. Forecasts indicate that by 2030, this network's length is expected to reach 6,500 kilometers [3]. District cooling systems (DC) with an installed capacity of 160 MW and a pipe length of around 25 km are in its early stages but with a steady rise.

1.2 Climate Neutrality by 2040 – District Heating

The current heat supply as well as robustness of DH systems is guaranteed by the versatility and ease-of-use of fossil fuels. To achieve the ambitious targets of the European Green Deal to reduce the greenhouse gas emissions by 55 % until 2050 [4] and achieving a climate-neutral heat supply in Austria by 2040 this requires an extensive change in heating technologies and additional measures to increase efficiency. In addition to phasing out decentralised gas and oil heating systems, the entire district heating system, which is currently provided by centralised fossil fuels (primarily natural gas) in urban areas, must be decarbonised. Not only the existing generation must be decarbonised, but also the future increase in district heating demand to up to 30 TWh by 2040 must be considered in the technology transition [5]. The number of district heating customers will therefore increase from 2020 to 2040 by approx. 50 % from the current approx. 1.5 million to 2.3 million end customers [5].

In general, district heating grids enable innovative integration and combination of re-newable energies, waste heat utilization, storage systems, heat consumers and coupling with various sectors and infrastructures (e.g. electricity, gas, wastewater, etc.). DH grids will con-tinue to gain in importance, especially in urban areas, as they can be used to collect, store and transport (industrial) waste heat or renewable energy and thus actively balance the temporal and spatial imbalance between supply and demand. Nevertheless, current supply standards need to be maintained in an affordable way, even in a more complex system than today, con-sidering storage, renewables, volatility, prosumers, control, etc. In addition, the reduction of temperature levels plays a major role in increasing the efficiency of renewable technologies.

Technologies such as electrically driven heat pumps and thermal absorption heat pumps (AHPs) are widely used to improve the overall efficiency of different energy supply systems in different applications [6]. Both technologies have a wide potential to contribute to the decar-bonization of DH system and the efficient use of renewable energy sources. Therefore, heat pumps are being increasingly utilized in district heating systems across Europe. This includes integrating heat pumps with wastewater treatment plants [7] [8], incorporating booster heat pumps for buildings in Austria [9], utilizing large thermal energy storages in combination with heat pumps in Denmark [10], employing high-temperature heat pumps to lower the operating temperature of district heating networks [11], and deploying large-scale heat pumps capable of efficiently harnessing waste heat and electricity from 100% renewable sources [12].

1.3 Absorption Heat Pump Technology for District Heating

Besides compression heat pump technology absorption technologies play crucial role in DH by offering efficient cooling and heating solutions, especially when favourable driving energy is available. The possibilities of using thermally driven AHPs in district heating and/or cooling grids are wide and cover a broad spectrum for increasing energy efficiency. [6]

Absorption technologies harness the exothermal physical effect of absorption processes, where a gas is accumulated into a fluid, to facilitate heating or cooling processes. In a basic absorption heat pump (AHP), which serves as an illustrative example, four heat exchangers operate at three temperature levels: high, intermediate, and low. The AHP can function at various temperature ranges, typically requiring a minimum of 100°C to operate efficiently. With a single effect, AHPs available in the market can achieve a Coefficient of Performance (COP) of up to 1.7 and can elevate fluid temperatures by up to 50°C, reaching a maximum of 90°C. [13] In the AHP setup, refrigerant and absorbent mixtures fill four internal chambers. The process involves the evaporation of refrigerant in the generator at high temperatures, leading to its condensation in the condenser (providing useful heat output). The absorbent, with low refrigerant concentration from the generator, moves to the absorber, absorbing refrigerant from the gas atmosphere (generating additional useful heat output). The liquified refrigerant collected in the condenser is evaporated again in the evaporator to meet the demand in the absorber, driven by an external heat source. Absorption technologies rely on specific working pairs to facilitate their operations, with lithium bromide/water (LiBr/H2O) and water/ammonia (H2O/NH3) being the most common combinations. Each pair has distinct temperature limitations and chemical properties that dictate their operational parameters.

Absorption technologies offer services depending on their application. Absorption chillers (AC) produce thermally generated cold, while absorption heat pumps (AHP) and absorption heat transformers [14] (AHT) provide useful heat at different temperature levels. Additionally, absorption heat exchangers (AHX) can shift temperature levels and differences for an energy stream. An important aspect of absorption technologies is their minimal electricity consumption, limited to circulation pumps and control actuators, as the driving energy is always heat. This makes them particularly suitable for utilizing low-exergy heat streams such as waste heat or solar thermal energy. When waste heat is utilized as the driving source, consumption-related costs are reduced to electricity costs for pumping, resulting in significantly low overall electricity consumption compared to the heat or cold provided.

Economically, absorption heat pumps entail higher system costs, typically 2.5 to 4 times more than compression heat pumps with similar heating capacity. However, the utilization of high-temperature waste heat (>100°C) or fuel combustion heat offers a cost-effective energy source for driving absorption heat pumps. Manufacturers in Europe offer absorption technologies ranging from 25 to 350 kW_{th}, while some Asian companies have operational installations with outputs reaching up to 73 MW_{th}.

The concerning AbSolut project address the potential of absorption technologies to tackle the current challenges in decarbonisation, integration of waste heat or solar thermal, transport capacity bottlenecks and the extension of district heating grids as well as suitable business models for cold supply.

2 Aim, Methodology and Scope

The aim of AbSolut was to develop and evaluate system concepts for the optimized and cost-efficient integration of absorption technologies in district heating/cooling systems. These concepts will be based on case studies provided by project partners, undergo detailed techno-economic analysis and evaluation, and ultimately be disseminated to stakeholders to facilitate widespread adoption of absorption technology in future district heating and cooling applications. The project address various challenges faced by district heating operators and engineering companies, including decarbonization of peak loads, transport capacity bottlenecks, expansion of district heating systems, utilization of waste heat, and provision of cold during summer months.

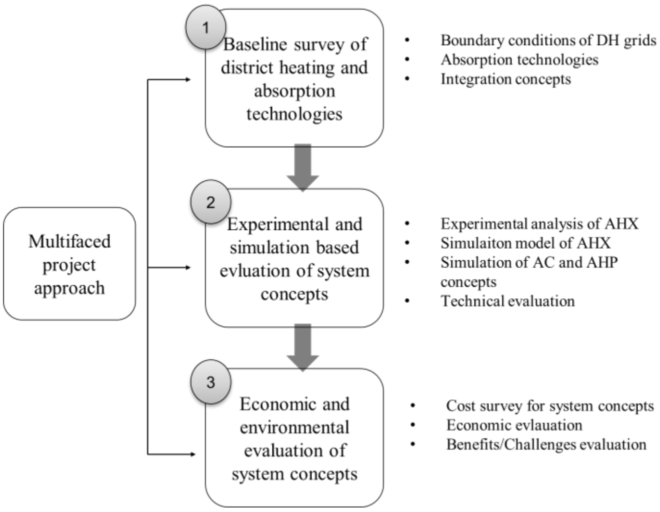

***Figure 1**: Methodology approach for development of integration concepts of absorption technologies in district heating.*

The methodology adopted by the project involves a multifaceted approach. Initially, there's a concerted effort to enhance knowledge and understanding of absorption technologies at both component and system levels. This includes rigorous research and experimentation to delve into the intricacies of these technologies, their operational dynamics, and their interaction within the broader district heating and cooling infrastructure. Building upon this foundation of enhanced understanding, the project moves forward with the development and evaluation of system concepts. These concepts are tailored to address specific challenges identified within the district heating and cooling landscape. Case studies provided by project partners serve as invaluable real-world scenarios, allowing for the refinement and validation of proposed concepts through practical application. A crucial aspect of the project involves conducting detailed techno-economic analyses. This involves assessing the viability and cost-effectiveness of the developed concepts, considering factors such as investment costs, operational efficiency, and potential environmental impacts. Such analyses provide critical insights into the economic feasibility and scalability of proposed solutions, guiding decision-making processes for stakeholders. Furthermore, the project places significant emphasis on the improvement of modelling and evaluation tools. By enhancing existing methodologies and developing new modelling frameworks, the project aims to provide stakeholders with robust tools for simulating different configurations of absorption technologies under diverse operating conditions. This enables stakeholders to make informed decisions regarding system design, optimization, and performance assessment. In parallel, the project focuses on the development of new business models, particularly in the realm of district cooling and waste heat integration. By exploring innovative approaches to business model design, the project aims to unlock new streams for revenue generation and sustainability within the district heating and cooling sector. Ultimately, the overarching goal of the AbSolut project is to advance the integration of absorption technologies in district heating and cooling systems, fostering sustainability, resilience, and innovation within the energy sector.

3 Reference Business Case Evaluation

This work explores the diverse applications and benefits of absorption heat exchange and absorption heat pump technologies within district heating (DH) systems. From utilizing waste heat from power plants to preheating DH return flows, to implementing absorption chillers for cold supply, and using absorption heat exchanger to reduce the return supply temperature, these innovative solutions offer promising concepts for enhancing energy efficiency, reducing emissions, and promoting sustainability in DH networks. Each application is examined in detail, highlighting its unique advantages, challenges, and potential economic implications. Through these discussions, readers gain insight into the transformative role that absorption technologies can play in optimizing the performance and resilience of district heating systems in the pursuit of a cleaner and more sustainable energy future.

3.1 Absorption Heat Exchanger as Transfer Substation in DH Grid

The application of an absorption heat exchanger (AHX) as a transfer substation in a district heating grid (Figure 2) involves utilizing the temperature difference between the primary and secondary supply temperatures to subcool the primary return temperature below the secondary one. This process allows for increasing the heat capacity within an existing grid between 20-30 % without changing flow and temperature inlet conditions. By lowering the return temperature more than the supply temperature, a larger temperature spread is achieved, enhancing the heat capacity of the district heating grid. The AHX achieves this by using the exergetic potential based on the temperature difference between the supply temperatures to subcool the primary return temperature. Compared to conventional heat exchangers, an AHX can effectively reduce the return temperature of heating grids, enabling the integration of renewables like geothermal or industrial waste heat. The AHX operates by absorbing heat from a cold source, transferring it to a mid-temperature sink, and desorbing the refrigerant to complete the cycle, thus improving the overall efficiency of the district heating grid. [6]

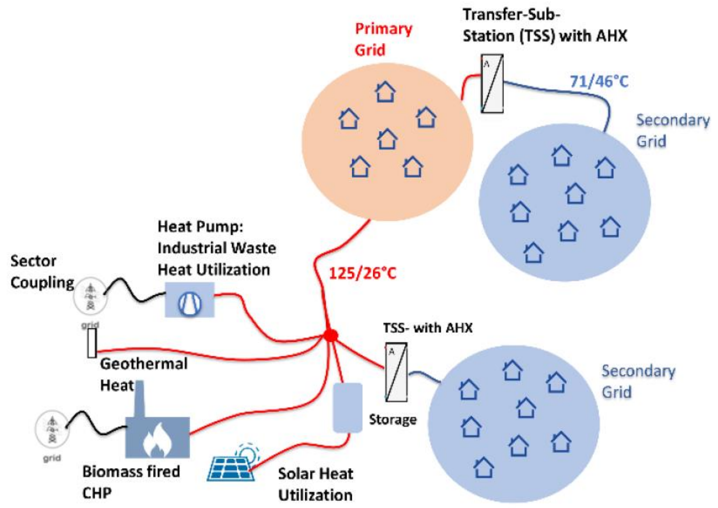

***Figure 2**: Scheme of an optimized future district heating grid supplied by renewable (geothermal, industrial waste heat, solar thermal etc.) with primary grid and sub-grids operating at different temperature levels using an absorption heat exchanger as transfer substation. [6]*

Designing an absorption heat exchanger (AHX) presents several challenges identified in the experimental and simulation-based results, that need to be addressed for optimal performance. They include [6]:

- **Subcooling performance**: Achieving high subcooling performance in an AHX requires a balance of a high primary supply temperature, a low secondary return temperature, and a high secondary-to-primary mass flow rate. Designing the system to handle these temperature differentials effectively is crucial for maximizing subcooling efficiency.
- **Optimizing Mass Flow Rates**: The partitioning of the secondary mass flow between the absorption chiller and the heat exchanger plays a significant role in the subcooling performance of the AHX. Balancing and optimizing mass flow rates from different components within the system is essential for achieving the desired subcooling levels.
- **System Efficiency**: Ensuring overall system efficiency while designing an AHX is vital. This includes considering factors like pressure losses, irreversibility in each heat exchanger, and temperature glides within the system. Maximizing efficiency while minimizing losses is a critical challenge in AHX design.

- **Integration in District Heating Grids**: Integrating an AHX into existing district heating grids faces challenges due to fixed pipe diameters and limitations on maximum mass flow rates. Overcoming these limitations without extensive infrastructure changes, such as installing larger pipes, requires innovative design solutions.
- **Temperature Spread and Heat Capacity Increase**: Designing an AHX to achieve a significant temperature spread between primary return and supply temperatures is essential for increasing the heat capacity of district heating grids. Ensuring that the AHX can effectively subcool the primary return temperature below the secondary one without compromising system efficiency is a key challenge.

Addressing these challenges through careful design considerations and optimization is crucial to harnessing the full potential of absorption heat exchangers in district heating applications. Firs experimental results show that the heat capacity within existing grids can be increased up to 30% with unchanged flow and temperature inlet conditions and more renewables can be integrated easily. The highest subcooling at 20 K can be reached at pilot-scale at high primary supply temperatures of about 145°C at lower primary supply temperatures at about 125°C subcooling resulted in 12,5 K. [6] The dynamic simulations showed a reduction of the return temperature at the primary side of the whole year, and it is estimated to be in the range of 7 to 25 K. This means, a reduction of the mass flow rate at the primary side of a yearly average of about 22%, or the grid could be extended of about 22% without the need of any change on the primary side piping. These results underlined the theoretical considerations that can be used by the AHX [6]. All in all, a large difference between the supply temperature of the primary and secondary circuit is required to subcool the return temperature at its highest value. This condition applies to DH grids of future generations with associated sub-networks.

To analyse the economic efficiency, dynamic year-round simulations were carried out to see the overall effect and to evaluate it from an economic point of view. The economic added value arises from the higher capacity in the network sections, which can therefore be measured in terms of a reduction in line-related costs. Lower heat losses and pumping capacity also have a measurable economic effect. In addition, efficiency effects from the integration of renewables can also be considered. This is offset by the additional investment costs and ongoing operating costs of an AHX. Overall, the different scenarios show that an internal rate of return of up to 10 % is achievable, taking future grid temperatures into account. Figure 3 gives an overview of the main benefits of an AHX as transfer substation and their concerning challenges.

Overall, the following benefits of an absorption heat exchanger (AHX) in a district heating grid can be summarised:

- **Increased Heat Capacity**: An AHX can boost the heat capacity within an existing grid between 20-30% without altering flow and temperature inlet conditions. By subcooling the primary return temperature below the secondary one, the AHX enhances the heat capacity of the grid, allowing for more efficient heat transfer and distribution.
- **Integration of Renewables**: Using an AHX enables the easy integration of renewable energy sources like geothermal or industrial waste heat into district heating systems. By lowering the return temperature more than the supply temperature, an AHX facilitates the incorporation of renewables, contributing to a more sustainable energy mix.
- **Reduction of Distribution Heat Losses**: Lowering the return temperature in heating grids using an AHX helps reduce distribution heat losses. By achieving a larger temperature spread between primary return and supply temperatures, the AHX optimizes the efficiency of the district heating network, leading to decreased heat losses during distribution.
- **Efficiency Improvement**: Compared to conventional heat exchangers, an AHX can effectively reduce return temperatures in heating grids, enhancing overall system efficiency. By utilizing the exergetic potential based on temperature differences, the AHX improves the performance of district heating systems, making them more energy efficient.

- **Flexibility and Adaptability**: AHX technology offers flexibility in adapting to varying temperature levels in district heating grids. By subcooling the primary return temperature below the secondary one, AHXs provide a versatile solution for optimizing heat transfer and capacity within existing heating networks.

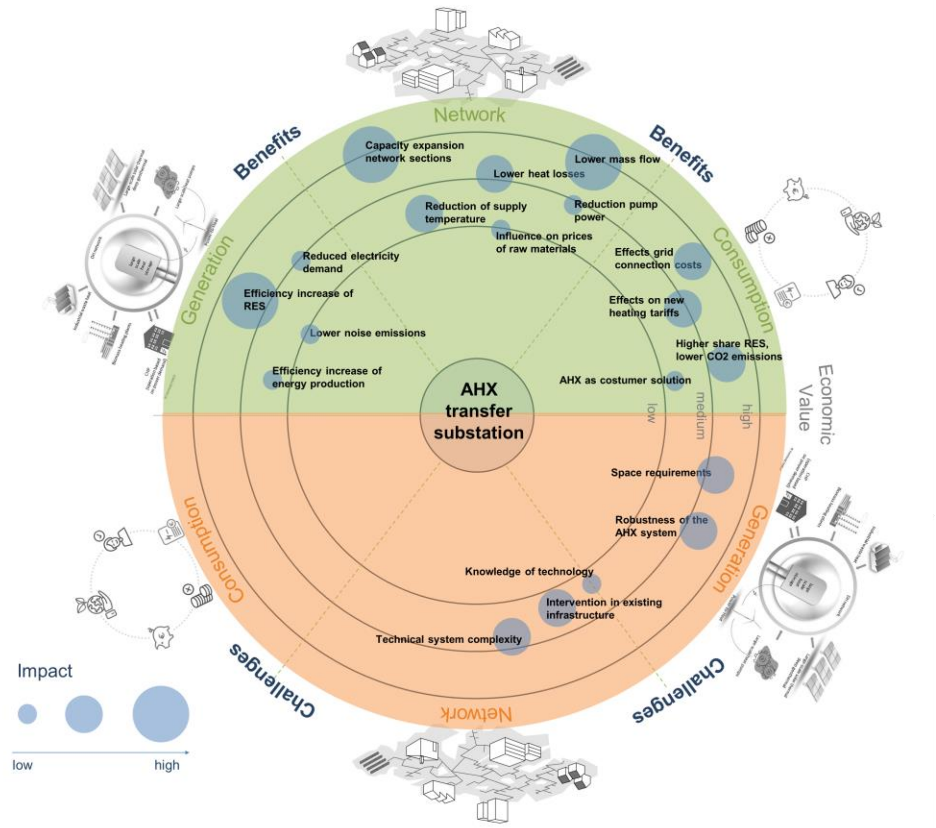

***Figure 3**: Overview of the benefits and challenges to use an AHX as transfer substation in existing DH grid. The overview integrates monetary and non-monetary results.*

These advantages highlight the significant role that absorption heat exchangers play in enhancing the efficiency, sustainability, and performance of district heating systems.

3.2 Absorption Chiller Implementation for Cold Supply

Utilizing absorption chillers (AC) in district heating systems enhances the network's efficiency during summer by minimizing relative heat losses. Although AC require higher initial investment, they boast lower operational costs and typically handle the base load [15]. Compression chillers (CC) are employed for peak load situations. Both absorption chillers and compression chillers commonly utilize cooling towers for heat rejection. Moreover, many systems offer the flexibility of Freecooling (FC) during winter by utilizing the cooling towers directly to meet cooling demands.

While Hausher, C. et. al. [15] showed the most efficient cooling mode for absorption chillers, compression chillers and Freecooling depending on ambient temperature and cooling load for different primary energy factors for DH, the current reference case has attempted to consider the best possible operating mode for absorption chillers on that basis work.

The proposed absorption cooling system is set to play a pivotal role in providing cooling solutions for both a data center and office buildings. Cooling requirements will be met through a strategic blend of Freecooling, three traditional compression chillers, and the upcoming absorption chiller. A significant focus is placed on achieving regenerative cooling, a feat accomplished through the synergy of Freecooling and absorption methods. Heat dissipation from the systems will be facilitated by a cooling tower, effectively reducing temperatures from 37°C to 27°C. The driving force for the absorption cooling system will be district heating, operating at a temperature of 80°C. Maintaining the lowest possible return temperature for the driving force is imperative. Consequently, efforts are directed towards minimizing the driving temperature for a standard system (Single Stage). In the pursuit of enhanced efficiency, a serial connection with the compression refrigeration machines is on the agenda. Particular attention is being paid to the data center, which will operate on its dedicated circuit requiring higher temperatures. This aspect is carefully factored into the planning and execution of the absorption cooling system to ensure the delivery of efficient and dependable cooling solutions.

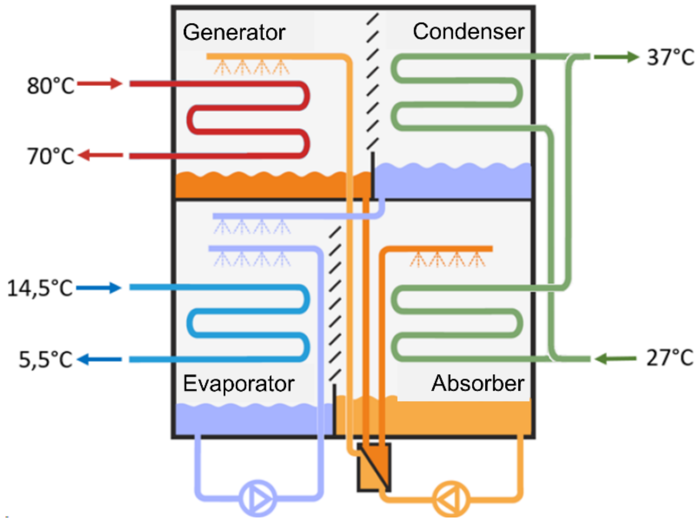

Figure 4*: Reference concept of an absorption chiller for cooling supply. Image Source: StepsAhead*

To optimize energy usage in the district cooling system, the strategy involves utilizing the low-exergy energy from the cooling tower during its most efficient operation times, which vary depending on ambient temperature. This approach ensures that the cooling process operates at maximum efficiency.

Additionally, the reference case tries to increase the share of renewable energy sources (RES) in the system up to 60%. By incorporating more renewable energy, reliance on fossil fuels is reduced, and the environmental impact of the cooling operation is minimized. To enhance overall efficiency, a dynamic system will be implemented to select the most efficient cooling mode based on prevailing conditions at any given time. This approach has the potential to increase efficiency by up to 15% compared to traditional static operation modes. By optimizing cooling tower operations, increasing the utilization of renewable energy sources, and dynamically selecting the most efficient cooling mode, significant improvements in the energy efficiency and sustainability of the district cooling system can be achieved. The strategy of allocating base and peak loads typically involves activating CC when AC reaches capacity limits [15]. FC is engaged when ambient temperatures drop below a specified switchover threshold [15].

The economic evaluation of absorption chillers is influenced by several main factors, including the price of driving energy, electricity market price, full load hours, and investment costs. The price of driving energy is crucial as it directly impacts the operating costs of absorption chillers. A lower price for driving energy can reduce overall operating costs and improve the profitability of the systems. The electricity market price also affects the economics of absorption chillers as it influences the costs of operating the systems. Fluctuations in the electricity market price can directly impact the profitability of the systems. The number of full load hours, during which absorption chillers operate at maximum capacity, is another important factor. The higher the number of full load hours, the more efficiently the systems can operate, and the higher their profitability. Investment costs for the purchase and installation of absorption chillers also play a crucial role in the economic evaluation. Lower investment costs (e.g. subsidies) can shorten the payback period and improve the profitability of the systems.

The cooling generation costs for the concept of absorption chillers typically range between 70 €/MWh and 100 €/MWh when calculated across different scenarios. In addition to these main factors, absorption chillers offer various benefits.

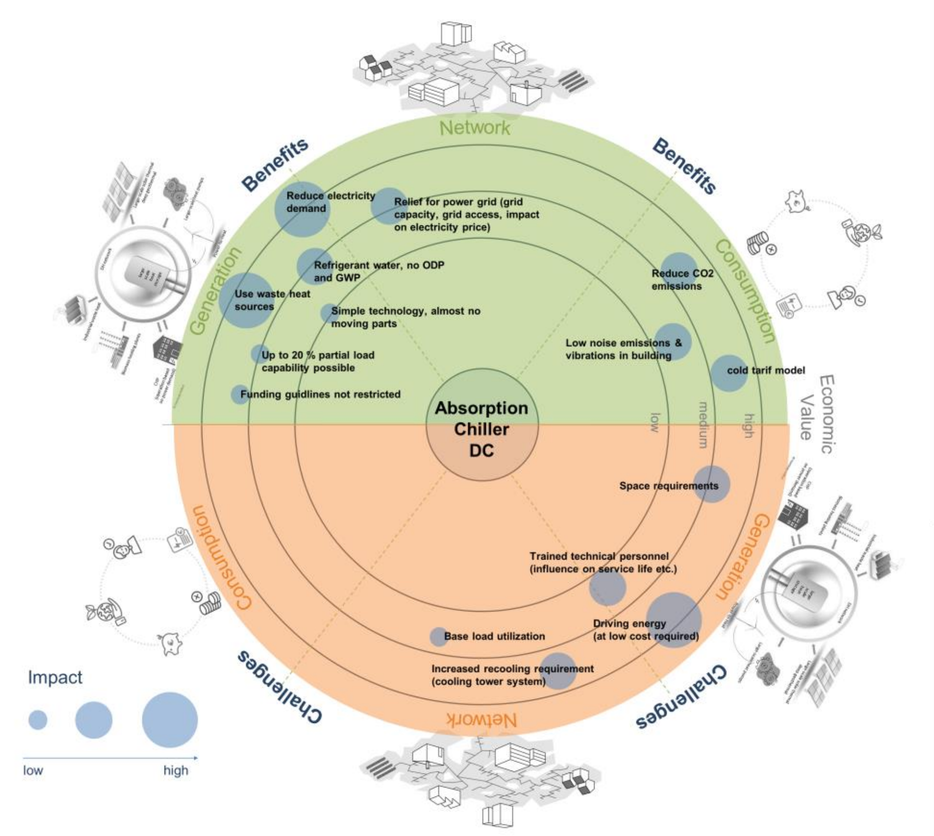

***Figure 5**: Overview of the benefits and challenges to use an absorption chiller as part of cooling grid. The overview integrates monetary and non-monetary results.*

The utilization of Absorption Chillers (AC) presents a multitude of advantages, yet it also entails several challenges. AC reduces electricity demand and associated CO_2 emissions by efficiently harnessing available waste heat sources. Utilizing only water as a refrigerant eliminates contributions to Ozone Depletion Potential (ODP) and maintains low Global Warming Potentials (GWP).

The technology behind AC is relatively simple, with few moving parts, simplifying maintenance. Additionally, AC allows for up to 20% partial load capability, facilitating efficient adaptation to demand. Furthermore, AC can alleviate strain on the power grid, positively impacting grid performance, access, and potentially lowering electricity prices. Minimal noise emissions and vibrations within buildings foster a comfortable working and living environment, while achieving 2°C chilled water is easily attainable without efficiency losses. Moreover, the availability of funding opportunities for AC is unrestricted, supporting their adoption.

Nevertheless, there are several challenges to consider. Increased cooling tower demand in cooling tower systems may impact electricity costs. Cost-effective driving energy is necessary to maintain AC efficiency. Given their propensity for base load usage, continuous energy supply is crucial. Additionally, trained technical personnel are indispensable for operation, as they significantly affect the lifespan of the systems. Moreover, the spatial requirements for AC installation can pose challenges and must be accounted for during planning.

3.3 Absorption Heat Pump for Waste Heat Utilization in DH

In the application scenario of preheating the district heating (DH) return flow, an efficient supply concept involves utilizing waste heat from the cooling circuits of gas and steam turbines at DH power plants. This waste heat can be directly employed to preheat the DH return flow or to supply commercial return flows.

The DH return flow, initially at 55°C, could be increase up to 70°C. The driving source for this process is the 97°C district heating supply. The heat source originates from the cooling circuits of the power plants (gas and steam turbines. Temperature levels vary depending on turbine specifications and seasonal variations. The source, originating from the oil cooler with an intermediate circuit, operates in the concept within the temperature range of 62-53°C, providing 4MW. District heating at 70°C considering 55°C return temperature can be provide 8,6 MW. The driving force is provided by a hot water storage unit, reducing the temperature from 97°C to 87°C, with a thermal output of 4.6 MW is needed.

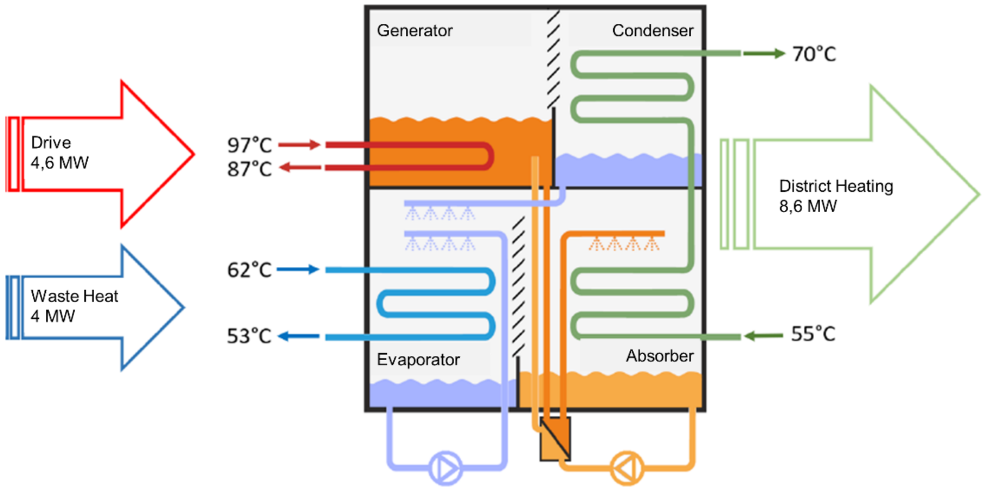

***Figure 6**: Reference concept of an absorption heat pump for waste heat utilization form the cooling system of gas and steam turbines for DH. Image Source: StepsAhead*

This concept aims to enhance the efficiency of the DH power plant by harnessing waste heat, consequently reducing reliance on fossil fuels. The DH return flow, initially at 55°C, is raised to 70°C utilizing waste heat, while the driving source for this process is the 97°C district heating supply. The primary purpose is to achieve significant environmental benefits, including the reduction of up to 8,500 tons of CO_2 emissions annually. By efficiently utilizing waste heat, the project contributes to mitigating climate change and promoting sustainability. Additionally, the utilization of waste heat supports the security of energy supply by maximizing the efficiency of the power plant operations. In additon, there is no alternative use available for this waste heat, presenting no opportunity cost. This contributes to alleviating strain on the power grid and expands the portfolio of available energy sources. Additionally, the cascading utilization of waste heat potentials enables efficient utilization of existing resources.

Furthermore, integrating waste heat utilization into the DH system helps stabilize heat tariffs by reducing operational costs associated with conventional heating methods. Moreover, customers can benefit from grid connections at the return flow, ensuring reliable access to heating services while maximizing the utilization of available resources.

Economic advantages are also measurable, as the utilization of this waste heat source can lead to cost savings. Furthermore, it improves the CO_2 balance by reducing emissions and the potential to obtain CO_2 certificates. The use of only water as a refrigerant in the absorption heat pumps eliminates the risk of ozone depletion potential (ODP) and reduces the global warming potential (GWP). The technology is simple and low maintenance, with almost no moving parts and a partial load capability of up to 10%. Moreover, cost-effective driving energy can be utilized, further reducing operating costs.

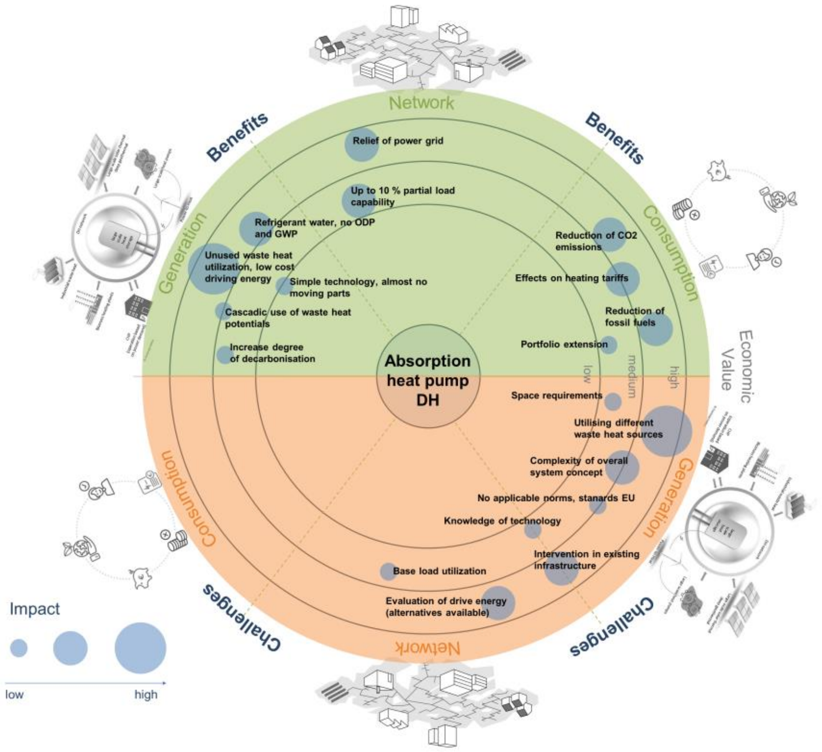

Figure 7: *Overview of the benefits and challenges to use an absorption heat pump for waste heat utilization. The overview integrates monetary and non-monetary results.*

However, there are also several challenges to address. Solutions need to be found to efficiently utilize and integrate the different waste heat sources into existing systems, which may affect warranty contracts and maintenance procedures. The spatial requirements for installing absorption heat pumps are also a challenge. Assessing the driving energy is complex due to the existence of alternative options. The volatility and complexity of overall requirements, as well as limited knowledge of the technology within the EU, and the absence of applicable norms and standards, present additional hurdles that need to be overcome.

Overall, this application not only enhances the efficiency of DH power plants but also contributes to environmental sustainability, energy security, and customer satisfaction through optimized heat supply and reduced emissions.

4 Discussion and Conclusion

The integration of absorption technologies, including absorption heat exchangers, absorption chillers, and absorption heat pumps, presents a significant opportunity for enhancing the efficiency, sustainability, and resilience of district heating (DH) systems. Throughout this exploration, various applications, and benefits of absorption technologies within DH networks have been discussed, ranging from utilizing waste heat for preheating DH return flows to providing cooling solutions during summer months.

Absorption Heat Exchanger (AHX) as Transfer Substation:

- AHX increases the heat capacity within existing DH grids by 20-30% without changing flow and temperature inlet conditions.
- It facilitates the integration of renewable energy sources into DH systems.
- AHX reduces distribution heat losses, leading to improved overall system efficiency.
- Challenges include achieving high subcooling performance, optimizing mass flow rates, ensuring system efficiency, and integrating AHX into existing DH grids.

Absorption Chiller Implementation for Cold Supply:

- Utilizing AC in DH systems reduces electricity demand and associated CO_2 emissions.
- AC offers benefits such as simplicity in technology, up to 20% partial load capability, and minimal noise emissions.
- Challenges include increased cooling tower demand, maintaining cost-effective driving energy, ensuring continuous energy supply, and addressing spatial requirements for installation.

Absorption Heat Pump for Waste Heat Utilization in DH:

- AHP utilizes waste heat from power plant cooling circuits to preheat DH return flows.
- It contributes to reducing CO_2 emissions by efficiently utilizing waste heat and promoting sustainability.
- Economic advantages include cost savings, improved CO_2 balance, and simple, low-maintenance technology.
- Challenges include efficiently integrating waste heat sources into existing systems, addressing spatial requirements for installation, and assessing driving energy options.

Overall, the integration of absorption technologies presents opportunities to enhance the efficiency, sustainability, and performance of DH systems. However, challenges such as technological optimization, economic feasibility, and integration into existing infrastructure need to be addressed for widespread adoption and realization of benefits.

In conclusion, the AbSolut project has provided valuable insights into the application, benefits, and challenges of absorption technologies in DH systems. By developing and evaluating system concepts, conducting detailed techno-economic analyses, and disseminating findings to stakeholders, the project has paved the way for the widespread adoption of absorption technologies in future DH applications. Moving forward, continued research, collaboration, and innovation will be essential in realizing of demonstration projects of absorption technologies in their defined concepts and evaluate their further scalability.

Data availability statement

The authors do not have permission to share data.

Author contributions

Carina Seidnitzer-Gallien: Conceptualization (lead), Investigation (experimental & simulation; support), Formal analysis, Methodology, Economic Evaluation, Visualization, Project management, Writing – original draft & review (lead). **Carles Ribas Tugores**: Dynamis simulation of reference cases (lead), Support with simulation results. **Gerald Zotter**: Technical concept development of reference cases (lead), test bench (lead & supervision), dynamic simulation (support and supervision).

Competing interests

The authors declare that they have no competing interests.

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