FTI Initiative Energy Model Region

Publishable final report

Programme control:
Climate and Energy Fund

Programme management:
The Austrian Research Promotion Agency (FFG)

Final Report
created on
30/06/2023

ThermaFLEX - Thermal demand and supply as flexible elements of future sustainable energy systems

FFG project number: 868852

Call	2nd Call FTI Initiative Energy Model Region
Project Starting Date	01/11/2018
Project Ending Date	31/10/2022
Total duration of project (in months)	48 Months
Project holder (Institution)	AEE - Institute for Sustainable Technologies
Contact person	Joachim Kelz
Postal address	Feldgasse 19, 8200 Gleisdorf
Telephone	+43 (0)3112 5886 236
Fax	+43 (0)3112 5886 18
E-mail	j.kelz@aee.at
Website	www.aee-intec.at, https://greenenergylab.at/projects/thermaflex/ https://thermaflex.greenenergylab.at/;

ThermaFLEX

Thermal demand and supply as flexible elements of future sustainable energy systems

Authors:
AEE – Institut für nachhaltige Technologien: Joachim Kelz, Ingo Leusbrock
Technische Universität Graz - Institut für Wärmetechnik: Thomas Mach, Philipp Wagner
Technische Universität Wien/Energy Economics Group: Georg Lettner, Daniel Schwabeneder
StadtLABOR: Isabella Weichselbraun, Barbara Hammerl, Hans Schnitzer

Supported by
Abwasserverband Gleisdorfer Becken: Peter Schiefer
AIT Austrian Institute of Technology GmbH: Bernd Windholz, Ralf-Roman Schmidt
ALOIS HASELBACHER GmbH: Wolfgang Haselbacher
BEST - Bioenergy and Sustainable Technologies GmbH: Daniel Muschick, Valentin Kaisermayer
ENAS Energietechnik und Anlagenbau GmbH: Jakob Edler, Thomas Hohenecker
Energie Steiermark AG: Mathias Schaffer
Feistritzwerke-STEWEAG-GmbH: Christian Baierl
FH Joanneum Gesellschaft mbH: Josef Bärnthaler, Matthias Teissing
FRIGOPOL Kälteanlagen GmbH: Johann Herunter
Green Tech Cluster Styria GmbH: Markus Simbürger, Johann Koinegg, Bernard Puttinger
GREENoneTEC Solarindustrie GmbH: Harald Poscharnigg
Horn Consult: Wolfgang Horn
JOANNEUM RESEARCH ForschungsGmbH: Martin Beermann, Johanna Puckinger Singer
NAHWÄRME TILLMITSCH GmbH & Co KG: Markus Haselbacher
Pink GmbH: Christian Halmdienst, Werner Pink
Rabmer GreenTech GmbH: Rainer Wiedemann
ROTREAT Abwasserreinigung GmbH: Robert Gampmayer
Salzburg AG: Thomas Herbst, Christian Pugl-Pichler
Salzburger Institut für Raumordnung und Wohnen: Alexander Rehbogen, Oskar Mair am Tinkhof
Schneid Gesellschaft m.b.H.: Wolfgang Rossegger
SOLID Solar Energy Systems GmbH: Hannes Poier
Stadtwerke Gleisdorf GmbH: Josef Schröttner, Benjamin Schaffer
STM Schweißtechnik Meitz eU: Johann Meitz
Wien Energie GmbH: Rusbeh Rezania, Anna Gantner, Holger Huschka

Table of content

Executive Summary

In the future, Austria's district heating supply infrastructure, which currently spans 5,600 kilometers, needs to increasingly rely on renewable heat sources. Presently, district heating is primarily generated in centralized plants, with fossil fuels like oil, gas, and coal contributing to half of this energy production. Biomass is currently a significant source of renewable energy. However, to rapidly increase the share of renewables and overcome the limited availability of biomass in certain regions, it is crucial to integrate other energy sources and carriers into the district heating system. This transition and utilization of local resources require a decentralized approach for the entire district heating sector. This shift leads to a greater number of generation plants and increased complexity due to limited availability and fluctuations in energy supply. To maintain the current level of supply reliability, which is based on the flexibility provided by fossil fuels, it is necessary to enhance the overall flexibility of energy systems. This flexibility will enable the integration of renewable energy sources that fluctuate seasonally and diurnally. Achieving this objective requires particular attention to be given to the heating and cooling sector, which accounts for approximately 50% of overall energy consumption.

District heating systems, in general, facilitate the integration and combination of renewable energies, waste heat, storage systems, heat consumers, and the coupling with different sectors and infrastructure such as electricity, gas, and waste water. This integration can lead to improved overall efficiency, cost-effectiveness, and reduced emissions in future energy systems.

However, a significant requirement is to ensure that the energy supply remains affordable, secure, and resilient, taking into account present and future conditions, while also being technically, economically, and ecologically sustainable. To meet these demands, future systems must exhibit a high degree of flexibility, incorporating smart operation and control. This, in combination with minimizing environmental impacts, ensuring security of supply, and keeping energy costs affordable for end customers, is essential. It has become evident that flexibility is one of the main factors influencing a sustainable and renewable-driven district heating sector, as well as enabling the transition towards a 100% renewable energy supply.

Extensive research and testing have been conducted to examine the interaction of various components within real heating networks. This research encompassed technical, non-technical, and systemic measures implemented on a large scale across eight Austrian district heating networks. Multiple heat sources and flexibility elements were employed, with a focus on heat storage, integrating different energy sectors and infrastructures, introducing intelligent control concepts, deploying large-scale heat pump applications, utilizing solar thermal energy, and leveraging locally available heat and waste heat sources.

- Waste heat utilisation Therme Wien: utilisation of the waste heat available in the thermal water using a heat pump concept and integration into the Vienna district heating system.
- High-temperature heat pump Vienna-Spittelau: Waste heat utilisation from the flue gas condensation of the waste incineration plant as a heat source for a high-temperature heat pump.
- Renewable heat and cooling from wastewater - Wien Kanal: Energy recovery from wastewater for heating and cooling with innovative heat exchanger and heat pump system.
- Virtual heating plant: Coupling district heating with the sewage treatment plant in Gleisdorf for heat supply from wastewater and implementing a novel "virtual heating plant" control system.

- Large-scale solar thermal plant Mürzzuschlag: Integration of a solar thermal plant of around 5,000 square metres in combination with a 180 cubic metre storage tank into the heating network.
- 100 percent renewable district heating for Leibnitz: Using fluctuating industrial waste heat through a bidirectional coupling of two heating networks and developing a high-level predictive control of network and heat generation units.
- Biomass heating plant modernisation concept: Developing a two-stage retrofitting concept in Saalfelden. Technical modernisation (stage 1) was implemented. A heat pump integration (stage 2) was developed and implementation is planned for 2023.
- Industrial waste heat utilisation: Implement an absorption heat pump to increase waste heat utilisation at the AustroCel site in Hallein to be fed into the district heating network of Salzburg.

Concurrently, highly integrated planning, implementation, and operational management processes were employed. This included innovative spatial energy planning methods, system evaluations through life cycle analyses, approaches for user and stakeholder engagement, and comprehensive monitoring and data analysis. These measures resulted in a significant increase in the share of renewable energy, as well as the decarbonization and diversification of the respective district heating systems.

Within the timeframe of ThermaFLEX, large-scale decarbonization measures and implementations were already realized within 8 linked demonstrators. These measures showcased the great potential of the developed elements and solutions within ThermaFLEX to provide sustainable and flexible district heating supply in different Austrian cities and regions. Based on monitoring and simulation data, sustainbalbe heat will be generated in the range between 180 and 200 GWh/a in future with the realized implementations leading to a yearly substitution of around 45,000 tons of CO_2.

Currently, the total energy production from district heating in Austria amounts to approximately 85 PJ (petajoules), with a significant biogenic share of 48% produced by biomass-based district heating systems. The primary users of district heating are private households (45%), the commercial sector (40%), and the industrial sector (15%). Presently, district heating systems fulfill about 25% of Austria's spatial heating and hot water demand, and this share is steadily increasing.

Based on research findings, it is estimated that Austria is home to approximately 2,500 to 3,000 local and district heating networks. This highlights the widespread adoption and significance of district heating as a heating solution throughout the country. The total amount of heat sold in the whole sector was around 20.1 TWh in 2020 and has increased by 73% since 2000 as well as about 2.1 million citizens are served by DH. The total pipe length has doubled since 2000 to currently about 5,800 km. Future expansion dynamics will be fostered in combination with the developed flexibility measures and a boost in new customers will undergo constant growth in the coming years. This growth is assumed to accelerate in the coming years due to increased political ambition to decarbonize the Austrian heat supply and the aim of the Federal Government to achieve climate neutrality for Austria by 2040.

The future market potential for the technologies and concepts of ThermaFLEX is thus expected to be much higher than at present. The results from ThermaFLEX and the derived Best Practices are expected to play an integral role in meeting the set emission reduction targets due to the high practical relevance and enable potential market openings for project partners and beyond to initiate the rollout of these technologies and concepts. Furthermore, implementations of ThermaFLEX concepts into the market may open new markets in the near future. DH networks in neighbouring European countries (Germany, Switzerland, Italy) and the overall EU are facing similar challenges to Austria and thus represent huge potential for the export of Austrian know-how and technologies.

The project placed special emphasis on handling strategy and multi-stakeholder processes, project development, demonstration site support, and exploitation and dissemination strategies. Stakeholder and user integration processes were carried out, involving governmental organizations, local authorities, property developers, landowners, citizens, and end-users. Close cooperation with the Green Energy Lab (GEL) and Austrian Climate and Energy Fund was also established, and collaborations with other subprojects within GEL were fostered. Workshops and webinars were organized to engage representatives from GEL, funding agencies, and ministries, facilitating discussions on relevant topics for flexible district heating networks and providing guidance to all ThermaFLEX partners.

In addition to direct project partners, numerous national and international parties from various sectors, cities, and municipalities expressed interest in the project results. These included industry associations, energy organizations, international delegations, and cities and municipalities from Austria and beyond. ThermaFLEX experiences and results were frequently invited for presentations and discussions at events, webinars, and workshops. The project lead and partners actively participated in different GEL-organized events and workshops, highlighting the achievements and networking activities of the flagship project. This extensive engagement with external stakeholders enhanced networking, exploitation, and dissemination of the project results, significantly expanding the reach and impact of ThermaFLEX.

Scientific as well as economic exploitation was of high relevance for the scalability and transferability of the gained knowledge and outcomes of the project and was continuously carried out during the entire project. A professional process for exploiting the results including methods and tools for exploitation within the project was developed and carried out. The main goal was an appropriate exploitation plan for the whole consortium as well as for individual partners and identified relevant fields and tasks of exploitation.

To showcase the impact of the gained project results as well as the flexibility measures realized within the demonstrators and its replication potential, targeted dissemination activities were performed and several communication channels were used. The main aim of using different communication channels was to reach different target groups (experts, stakeholders, communities, policymakers, etc.) at different levels/locations (local, national and international). The dissemination of the project aims, methods, results and impacts beyond the scope of the project is vital for increasing the visibility of the project, informing stakeholders that are or will be connected or concerned with the issues addressed in the project and for the positioning of the individual experts, the research and industry partners and the project consortium as a whole.

In conclusion, the Austrian flagship project ThermaFLEX exemplifies how existing district heat infrastructure can be efficiently utilized and expanded. Through demonstration projects in Styria, Salzburg, and Vienna, ThermaFLEX showcased the feasibility of implementing large-scale solutions within a relatively short timeframe.

1 Introduction

Within this chapter a brief introduction into the maint content and challenges is given and the applied overall methodology is explained. Furthermore, a first indication and the structure of the work is included.

1.1 Content and challenges

Broad consensus exists on national[1,2] and on EU-level[3] that the utilization of renewable energy sources (RES) has to be further increased to reduce greenhouse gas emissions and ultimately decarbonize whole energy sectors. This has to be achieved while a) ensuring and increasing efficiencies, b) providing an affordable, secure and resilient energy supply suitable for current and future boundary conditions, and c) being technically, economically and ecologically sustainable. The increase of fossil fuel prices due to increasing energy demand coupled with limited resources as well as changed and precarious boundary conditions (e.g., geopolitical changes, CO_2 taxes and emission schemes, increased demand for energy autarky) is a major driving force towards renewable and locally available energy sources[4].

Countries around the world have defined ambitious targets for the reduction of greenhouse gas emissions (by 2030 compared to 2005) and the transformation of their energy systems (DE -38%, FR -37%, AT -36%, SWE -40%)[5]. To achieve this goal, special attention must be paid to the long-term planning and sustainability of the heat supply: 51% of total energy consumption in Europe is currently used for heating and cooling purposes (space heating 26%, hot water preparation 5%, cooling 1%, industry 17%, cooking 2%)[6], similar ratios apply for Austria. Currently, about 35% of this heat demand in Austria is covered by renewable heat sources, the rest is supplied by fossil fuels with natural gas being predominant. Achieving these goals thus requires a strong increase in the share of renewable energy sources (RES) and efficiency technologies in the heating sector, combined with a reduction in heat demand through building renovation (by 2050, the aim is to achieve a building stock in Austria that is as CO_2-free and energy-efficient as possible)[7].

District heating (DH) systems allow for the integration of renewable energy sources and are highly suitable for measures to increase flexibility and sustainability in terms of renewable supply sources, sector coupling with other infrastructures and local value creation. While DH already plays a large role in the current heat supply in Austria with more than 3,000 operational systems and a share of about 20% of the total heat supply, the share of renewables is only 50% here. Thus, further action is needed to increase this share and to utilize the described benefits, especially with the necessary extension of DH systems and the phase-out of gas and oil.

To enable the steps for these benefits to be used, system-wide and holistic approaches, as well as scientific methods such as simulation and optimization during conceptualization, implementation and

---

[1] https://www.bmk.gv.at/themen/klima_umwelt/energiewende/waermestrategie.html
[2] mission2030 - Die österreichische Klima- und Energiestrategie, BMNT und BMVIT, 2018
[3] REGULATION (EU) 2018/842 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.156.01.0026.01.ENG
[4] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en
[5] REGULATION (EU) 2018/842 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.156.01.0026.01.ENG
[6] Fleiter, T., Steinbach J., Ragwitz, M. et al. (2016): Mapping and analyses for the current and future (2020 - 2030) heating/cooling fuel development (fossil/renewables) – Executive Summary. Brussels: European Commission, DG Energy
[7] #mission2030 - Die österreichische Klima- und Energiestrategie, BMNT und BMVIT, 2018

operation, next to innovative technical solutions need to be applied. In this context, the following challenges, i.e., research needs, for implementation of flexible and sustainable DH systems and integration thereof in larger energy supply concepts are present:

- Integration of high shares of renewables and waste heat
- The temporal mismatch between heat demand and supply (non-dispatchable sources)
- Sector-coupling and hybridization
- New heat supply options for DH systems
- User integration and business models
- System operation, monitoring and control and system design

The Austrian flagship project Thermaflex addressed these challenges and derived solutions along the whole value chain. Through demonstration projects in Styria, Salzburg, and Vienna, ThermaFLEX showcased the feasibility of these large-scale solutions within a relatively short timeframe.

1.2 Overall methodology

ThermaFLEX aims to develop, demonstrate, and evaluate potential concepts for integrating individual technologies to address the unique demands and challenges of different district heating (DH) systems. Additionally, it includes the development and evaluation of concepts for system solutions, such as storage integration and management, and advanced control systems, to meet the demands and challenges of DH systems. Initial concepts were used to identify a wide range of individual technologies and system solutions that could enhance flexibility and decarbonization in DH systems. Further development involved simulations and evaluations of various flexibility options for DH systems under different operational and boundary conditions. Subsequently, the most suitable concepts for future implementation in a connected demonstrator were selected, and specific concepts for each demonstrator case were developed and prepared for implementation. This approach involved two stages: the "general concepts" describing suitable concepts for the DH sector as a whole, and the "concept for linked demonstrator" focusing on specific concept solutions for later demonstration cases. As vital part of ThermaFLEX, the developed solutions were implemented and demonstrated in multiple demonstration cases using what we call demonstrators.

ThermaFLEX explicitly had the ambitions to tackle the challenges and to demonstrate the developed solutions together with in total of 28 partners from research and industry in 10 demonstrators. To address the challenges, a methodology with three different pillars was applied (see Figure 1): These three pillars include i) technical measures, ii) systemic approaches and iii) non-technical measures. Through this intelligent combination and holistic approach, it was possible to

a) adapt and further develop existing district heating networks to meet future requirements (e.g., decentralized generation and storage, load changes, different temperature levels, low summer load with increased heat losses, necessary enlargement, etc.),
b) achieve corresponding climate goals,
c) establish far-reaching user and stakeholder integration and
d) strengthen economic benefits along the value chain.

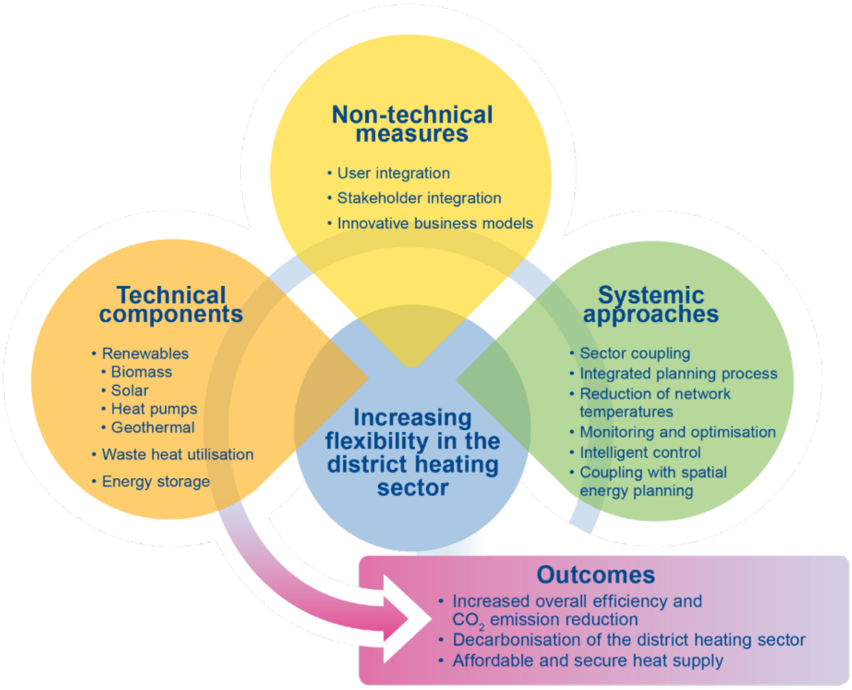

Figure 1: Methodology applied within ThermaFLEX (Source: AEE INTEC)

The work was carried out in close collaboration with research partners, energy suppliers, DH operators, and technology/know-how providers throughout the entire innovation and implementation process: from problem definition to concept development to evaluation and selection to implementation and start-up, operation and optimization.

ThermaFLEX utilized demonstrators to showcase, validate, and optimize the developed concepts. The results and experiences gained from the implementation and operation of these demonstrators were used to derive best practices, highlight promising concepts and pathways, and quantitatively demonstrate the technical, economic, and ecological benefits and impacts of the demonstrators. Furthermore, ThermaFLEX provided the means to replicate these concepts and recommendations, paving the way for a significant rollout of flexibility options for DH systems in Austria and Europe.

The demonstrators varied greatly in scale, addressing different types of challenges and demonstrating various solutions. The knowledge and experiences gained from these demonstrators, along with the associated processes, have broad applicability to district heating systems and can serve as blueprints for similar endeavors throughout Austria and Europe.

1.3 Structure of the work

Within this publication, the outcomes of the ThermaFLEX project are described concisely. The publication is structured as follows. First, in Chapter 2, the broad range of flexibility options for the demands of DH operators were summarized. The developed concepts for implementation as well as the gained results from the planning, realization, monitoring and evaluation phase including possible roll-out scenarios and their market potential were summarised in Chapter 3 for the respective linked demonstrators. Chapter 4 includes relevant user and stakeholder integration aspects and Chapter 5 deals with the roll-out potential and exploitation results while in Chapter 6 the overall conclusions and a brief outlook is given.

2 Flexibility in the district heating sector

Chapter 2 summarizes the broad range of flexibility options for the demands of DH operators. Aftern a short introduction, the definition of flexibility within the project context and the Key performance indicators and evaluation methods were explained. Finally, the individual as well as systemic measures of the project are summarized.

To mitigate climate change, it is crucial that future energy systems move away from relying on fossil fuels. This necessitates a transition towards 100% renewable energy sources in the near future. However, to maintain the current level of supply reliability, which is based on the flexibility provided by fossil fuels, it is necessary to enhance the overall flexibility of energy systems. This flexibility will enable the integration of renewable energy sources that fluctuate seasonally and diurnally. Achieving this objective requires particular attention to be given to the heating and cooling sector, which accounts for approximately 50% of overall energy consumption.

District heating systems, in general, facilitate the integration and combination of renewable energies, waste heat, storage systems, heat consumers, and the coupling with different sectors and infrastructure such as electricity, gas, and waste water. This integration can lead to improved overall efficiency, cost-effectiveness, and reduced emissions in future energy systems.

However, a significant requirement is to ensure that the energy supply remains affordable, secure, and resilient, taking into account present and future conditions, while also being technically, economically, and ecologically sustainable. To meet these demands, future systems must exhibit a high degree of flexibility, incorporating smart operation and control. This, in combination with minimizing environmental impacts, ensuring security of supply, and keeping energy costs affordable for end customers, is essential. It has become evident that flexibility is one of the main factors influencing a sustainable and renewable-driven district heating (DH) sector, as well as enabling the transition towards a 100% renewable energy supply.To evaluate the flexibility potential and identify the main influencing parameters as well as relevant boundary conditions an evaluation of the flexibility potential and the creation of an overview of flexibility options in urban DH systems was investigated as a first step. The methods applied are based on literature studies, questionnaires, workshops and meetings. The main results were

i. a definition of flexibility within the project context and
ii. evaluation methods and key performance indicators (KPIs) to evaluate flexibility qualitatively and quantitatively as well as
iii. a systematic categorisation of measures, concepts and technologies, which were identified to increase the flexibility of DH systems.

2.1 Definition of flexibility

For a common understanding of flexibility, a definition was developed within the project as a uniform definition of flexibility in the energy system does not exist in literature as well as available definitions do not fit in the content of the addressed research needs respectively[8,9,10]. The definition of flexibility in the DH sector in the framework of the research questions within the project was defined as

"Flexibility of the overall system is the ability of a system to keep the balance between supply and demand of heat (and cold) at each point of time."

Based on this more general definition of flexibility, finally, various types of flexibility were specified to cover different perspectives, namely flexibility of the overall system, flexibility of the supply side, flexibility of the distribution infrastructure, flexibility of the demand side as well as flexibility in planning and design. Combined with the goals and challenges of the DH operators as well as energy service companies to transform existing DH system towards to a 100 % renewable energy system, it builds the basis for the proposed definition of different flexibility aspects, related indicators and the developed flexibility concepts.

- **Definition 1: Flexibility of the overall system**
  Flexibility of the overall system is the ability of a system to keep balance between supply and demand of heat in each point of time.
- **Definition 2: Flexibility of the supply side**
  Flexibility of the supply side is the ability to integrate energy sources of diverse origin, which potentially are intermittent, constant or adjustable in their supply rate and / or supply quality. Flexibility of the supply side leads ultimately to the ability to shape the heat profile of the supply side at the feed-in point(s).
- **Definition 3: Flexibility of the distribution infrastructure**
  Flexibility of the distribution infrastructure is the ability to deliver heat to the desired place, with the desired temperature and pressure at the desired time. It can also be defined as the ability of decoupling demand and supply.
- **Definition 4: Flexibility of the demand side**
  Flexibility of the demand side is the ability to shift thermal demands on the demand side while providing heat to every consumer without any loss in comfort at any time.
- **Definition 5: Flexibility in planning and design**
  Flexibility in planning and design is the ability to adapt to new operational requirements as they occur. According to this definition properties of flexible infrastructure are adaptivity (achievable by modular design), scalability (achievable by platform design), expandability (achievable by phased design). This definition is based on Spiller et al.[11]. Flexibility in planning and design will not be handled within ThermaFLEX and is partly covered within the project Spatial Energy Planning (see www.waermeplanung.at).

Please note that heat can be exchanged in these definitions with cold.

[8] S. Paiho et al., "Increasing flexibility of Finnish energy systems—A review of potential technologies and means," Sustain. Cities Soc., vol. 43, no. February, pp. 509–523, 2018, doi: 10.1016/j.scs.2018.09.015
[9] P. D. Lund, J. Lindgren, J. Mikkola, and J. Salpakari, "Review of energy system flexibility measures to enable high levels of variable renewable electricity," Renew. Sustain. Energy Rev., vol. 45, pp. 785–807, 2015, doi: 10.1016/j.rser.2015.01.057
[10] A. Vandermeulen, B. van der Heijde, and L. Helsen, "Controlling district heating and cooling networks to unlock flexibility: A review," Energy, vol. 151, pp. 103–115, 2018, doi: 10.1016/j.energy.2018.03.034
[11] M. Spiller, J. H. G. Vreeburg, I. Leusbrock, and G. Zeeman, "Flexible design in water and wastewater engineering - Definitions, literature and decision guide," J. Environ. Manage., vol. 149, pp. 271–281, 2015, doi: 10.1016/j.jenvman.2014.09.031.

2.2 Key performance indicators and evaluation methods

Considering the overall complexity of the investigated DH systems, the approach applied was to define a pool of various indicators, to evaluate flexibility measures. One approach from a technological point of view, is the evaluation based on the five degrees of freedom, namely temperature, heat load (power), heat (energy), time and location. These KPIs can define flexibility mainly qualitatively and gives a first indication of which impact various concepts may have on flexibility.
To measure flexibility quantitively, KPIs within different categories, namely minimisation of short &. long-term fluctuation of the load pro-file, increase in energy efficiency and reduction of blackouts and shortages were identified and developed. To additionally quantify the flexibility, a set of well-established standard KPIs like the share of renewable energy, CO_2 savings (based on primary energy use), energy savings, storage losses, cost savings, etc. can be used for interpretation and evaluation of flexibility (e.g. evaluation before and after the implementation of a flexibility measure). To evaluate the flexibility measures for the overall DH system a combination of qualitative, quantitative and standard KPIs will lead to an overall evaluation criteria.

2.3 Measures for increased flexibility

A comprehensive overview and a systematic categorisation of flexibility measures, concepts and technologies on component (individual technologies) and system level (system solutions) for increased flexibility and decarbonisation of DH systems were compiled. Based on this overview a broad range of individual technologies and system solutions were identified to increase flexibility and decarbonise DH systems. In the following table (Table I) the investigated flexibility measures and suitable concepts were illustrated.

Table I: Investigated flexibility measures and suitable concepts within ThermaFLEX

Individual technologies
Integration of compression heat pumps for better low – exergy / waste heat utilization
Integration of absorption heat pumps for better low – exergy / waste heat utilization
Integration of compact and decentral sorption storage
Alternative heat supply concepts for buildings
System solutions
Integration of multiple previously separated DH systems in one main DH system
Integration of different infrastructures as heat / energy consumer, supplier and producer in DH systems
Development of smart control strategies and unit commitment procedures
Development of large-scale solar thermal supply concepts with combined seasonal storage
Development of a Virtual Heating Plant approach
Development of low-temperature system solutions in combination with urban redevelopment

The identified suitable concepts are concepts for the whole DH sector. The further development included simulations and evaluations of different flexibility options for DH systems with different boundary and operation conditions. Finally, the most suitable concepts for a later implementation within a linked demonstrator were selected and a demonstrator-specific concept for the addressed demonstration site was developed (realized concepts see Chapter 3). This approach led to a broad understanding of the possibilities for the integration of individual technologies and system solutions in the DH sector. Main results and findings as well as highlights will be described briefly in the following.

2.3.1 Individual technologies

2.3.1.1 Integration of compression heat pumps for better low – exergy / waste heat utilization

Heat pumps are a well-known technology and deliver heat to a heat sink (high-temperature level) by converting heat from the heat source (low-temperature level) consuming electric energy. Heat pumps can be used for both, heating and cooling. Concepts for heat pump integration based on different sources (e.g. thermal water, waste water, cleaned waste water, flue gas condensation, etc.) were developed and evaluated, and control concepts were simulated and evaluated. Dimensioning of heat pumps and storage was supported using different simulation techniques aiming at technically and economically optimal solutions. These consider electricity market prices and the grid tariff, as well as the annuities of the investments. Analyses of balancing market participation to increase the operational benefits of the heat pump were also carried out.

Different heat pump solutions were developed and realized within the linked demonstration cases Virtual Heating Plant Gleisdorf (Chapter 3.2), Retrofit and heat pump Saalfelden (Chapter 3.5), Renewable heating and cooling from wastewater (Chapter 3.7), Waste heat utilization spa Vienna (Chapter 3.8) and High-temperature heat pump Spittelau (Chapter 3.9)

2.3.1.2 Integration of absorption heat pumps for better low – exergy / waste heat utilization

Since corrosion is a widespread problem within absorption heat pump (AHP) integration, a detailed literature review dealing with this topic was conducted. AHPs for heating purposes with a heat source temperature above 0 °C normally use Water/Lithium bromide (H_2O/LiBr) as working pair. However, in combination with oxygen the solution has a corrosive effect on the materials used. The most vulnerable part of the AHP is the generator. During the desorption process the concentration of Lithium bromide (LiBr) in the solution increases which also increases the corrosiveness of the solution. Therefore, it is necessary to choose a material for the generator heat exchanger which withstands high temperatures and is resistant to corrosion. In general, the heat exchanger can be designed as a falling film or a flooded one. A falling film heat exchanger in the generator can slightly increase the efficiency due to a higher temperature of the solution and the refrigerant but has the drawback of giving the intake air direct contact with the heat exchanger pipes. This may lead to corrosion at the inside of the heat exchanger pipes which causes material removal periodically. Within a flooded heat exchanger most of the material surface inside the AHP is covered by the H_2O/LiBr solution and protects the pipes from direct contact with air.

Furthermore, different types of simulation models which are suitable for detailed and/or overall system analysis were investigated. It was found that the most promising approach for a highly accurate and computationally efficient model for the system simulation will be a comprehensive characteristic diagram based on a detailed simulation model. Based on this, a simulation model has been set up in Engineering Equation Solver (EES). Within the demonstrator Eco-energy park Salzburg (Chapter 3.6) the installation of an AHP was realized.

2.3.1.3 Integration of compact and decentral sorption storage

The innovative sorption storage technology with its ability of virtually loss-free storage and high compactness was investigated on it’s potential to use as decentralized storage in district heating networks. Within a literature study, the state of the art, as well as technical boundary conditions and limitations from the thermochemical storages as well as from the district heating side, were summarised. Based on the findings, a holistic overview of possible configurations of integrating thermochemical storages in district heating networks was developed and a mind-map was generated to have an overview of all these combinations.
Since the storage is very flexible in design and application 132 possible combinations of integration concepts were identified, e.g. different grid temperature levels, demand (DHW, heating, cooling), available heat source (solar thermal, PV, DH) or centralized/decentralized application. Based on qualitative (aspects like efficiency, feasibility, availability, etc) evaluations the most promising concepts (in total 16) were selected and integration schemes were established[12]. A cost calculation and subsequent sensitivity analysis were performed to indicate the concepts with high economic potential. The analysis showed that charging the storage via surplus-electricity from PV (or grid) instead of solar thermal is a very interesting option since this method enables to increase the efficiency of the charging process significantly. Using the technology as power-to-heat storage also enables to participate in the electricity market and use the fluctuation of the prices favourably. A new application of sorption storage, the so-called temperature boost, was also investigated and highlighted as an interesting option. Nevertheless, further investigations with more detailed simulations and demonstrating developed concepts would be necessary to prove the feasibility and gain more knowledge on the operation behaviour of decentralized thermochemical storages integrated into DH networks.

2.3.1.4 Alternative heat supply concepts for buildings

An evaluation was conducted to explore alternative and non-standard options for supplying heat via district heating, with a specific focus on utilizing the return line of a district heating (DH) system as the primary heat source. The concept of connecting customers to the DH return line aims to reduce the return temperature of the DH system. This reduction leads to decreased heat losses and increased transport capacity within the network without the need to increase the flow rate due to a larger temperature difference. Additionally, maintaining a low return temperature is advantageous for implementing renewable energy sources (such as solar thermal energy) and utilizing waste heat. Various possibilities for supplying buildings from the return line were investigated, resulting in the development of technical design variants, application possibilities, and design criteria. One of the general approaches involves a two-pipe connection from the DH network to the building, where a portion of the mass flow from the return line is directed to the building. Heat is transferred to the building's in-house system at a substation, and the return flow is then returned to the DH return line. For buildings and customers requiring higher temperature levels, a three-pipe house connection is an option. This approach involves an additional connection from the flow line of the DH system. It allows for the utilization of higher temperature water from the flow line, which may be necessary for tasks such as

[12] Master thesis “Development and techno-economical evaluation of new concepts for the integration of compact storage solutions in district heating systems”

domestic hot water (DHW) preparation or space heating on colder days. In this case, the temperature of the return water can be increased by mixing it with the flow water.
It is important to note that connections to the DH return line should be considered as individual projects and only partially connected to the processes involved in classical supply connections. Prior clarification of the economic and technical feasibility is necessary. Technical clarifications include determining the mass flow and flow direction in the relevant pipeline section under all operating conditions, considering the use of the system for space heating and, if applicable, domestic hot water preparation. Furthermore, response effects on the district heating network must be analyzed to ensure the continuous supply of customer systems. An approbriate cascading heat use concept was realized within the demonstration case in Gleisdorf (see Chapter 3.2).

2.3.2 System solutions

2.3.2.1 Integration of multiple previously separated DH systems in one main DH system

The interconnection of formerly separated DH networks or subsections was investigated. On the one hand, merging of existing grids is a reoccuring event within growing DH systems, on the other hand, it can be used as a strategic concept for increasing the flexibility, efficiency and share of renewable in DH networks. The main design aspects of interconnections of DH networks are the connection type, which are direct and indirect (hydraulically separated) connections and the direction of heat transfer, which is either unidirectional or bidirectional. Additional factors that influence the choice of design are pressure and temperature levels and the impacts associated with these parameters. Challenges for the control of interconnected DH networks are mainly pressure control according to multiple feed-in points and changes of flow directions as well as the minimum and maximum available thermal power of the supplying network.
The configuration and topology of heating networks depend on factors associated with the distance from the point of delivery, consumer needs, whether these consumers are already existing or newly constructed, the method of supplying heat and the terrain. Interconnecting DH networks is usually a matter of time in urban areas. Starting from multiple single networks the network expansions result in the interconnection of networks to tree, ring and finally meshed structures.
There are several reasons for interconnecting separate DH systems or subsections. Some are to increase the overall efficiency, the security of supply, flexibility and the share of renewable sources and can be achieved with the following benefits of interconnecting DH systems with each other:

- the utilization of surplus capacity due to additional heat sources or a reduction in demand
- the improvement of the grading of nominal power with additional generation units
- the increase of the capacity of limited subnetworks
- the integration of prosumers and/or micro-networks with existing central heating systems.

In conclusion, by interconnecting DH (sub)networks several goals can be pursued, like integrating new energy sources, improving utilization of existing production capacity or increasing flexibility and supply security. These goals can be achieved by an increased number of available energy generation units within the overall network leading to a higher diversity of energy sources, improved grading of generation capacities and more options of combination. The additional flexibility of interconnected DH networks furthermore enables fuel and CO_2 savings (e.g. higher efficiencies due to improved utilization, shift from fossil to renewable sources due to increased diversity).

In the demonstration case in Leibnitz (Chapter 3.3) an interconnection via a bidirectional heat transfer station was installed.

2.3.2.2 Integration of different infrastructures as heat / energy consumer, supplier and producer in DH systems

Wastewater treatment plants (WWTP) are a key infrastructure in municipalities and have been identified as potential energy hubs. They are frequently their largest energy consumer and play an important role in purifying sewage water. There are more than 1,800 WWTPs in Austria with 136 having a size (>20,000 population equivalents) and structure (digester for biogas production) to play a vital role as an energy hub for DH networks. Other energy-related infrastructures like the electricity grid and gas grid are obvious examples and are excessively discussed elsewhere and shall not be discussed here. Public road and railway systems might play an increasingly important role in the future energy system with electrification and hydrogen systems.

Within ThermaFLEX, a special focus was put on the integration of wastewater treatment plants (WWTP)[13]. Several actions have been carried out to analyse potential integration possibilities of the WWTP to the district heating network:

- detailed analysis of multiyear 15-min-wastewater flow and temperature values of selected WWTP for daily and seasonal difference for a heat pump integration;
- concept development for combined heat pump and biogas utilization;
- evaluation of overarching WWTP design concepts for increasing energy surplus and flexibility for energy grids. The combined analysis of biogas utilization and heat pump integration is important to maximize the potential for district heating networks.

Biogas is available if an anaerobic stabilization of the activated sludge of the WWTP is done in a digester. This is usually the case for WWTPs with at least 20,000 population equivalents. However, the potential of biogas is limited: the WWTP aims to cover the internal heat demand, but not produce surplus heat. The potential of wastewater heat pumps exceeds the biogas yield manifold. However, the temperature is lower and coupled with efficiency considerations. To best combine those two potential heat sources, 3 heat-pump integration-options were investigated.

Nitrogen removal is the bottleneck for many biogas-increasing measures since the COD (chemical oxygen demand) is required for conventional nitrogen removal in the aeration basin: The alternative method of removing ammonia (nitrogen) in the concentrated centrifugal water via membrane distillation (MD) was investigated intensively and detailed concept development for demonstrating a MD plant was performed. MD can remove ammonia from wastewater and recover it as a valuable product and thus increase the capability of biogas production by optimizing the operation parameters needed in the different basins on the other. MD is furthermore a thermally driven technology, which uses mainly low-grade heat (i.e., ~35-40°C).

Ammonia removal from wastewater is an energy-intensive problem that sums up to appr. 1/3 of the electrical energy demand of WWTP. In the state-of-the-art process to eliminate ammonia from wastewaters (i.e.: nitrification/denitrification) the ammonia is lost in the form of N_2 and mostly electricity is used for the necessary aeration. MD is a robust technology that can recover this ammonia for further use

[13] Gruber-Glatzl, W., Brunner, C., Meitz, S. & Schnitzer, H.. From the Wastewater Treatment Plant to the Turnstiles of Urban Water and District Heating Networks. Front. Sustain. Cities. doi: 10.3389/frsc.2020.523698

and eventually close the N-cycle by using mainly thermal energy. In the energy coupling scheme, MD will be a sink for low-temperature heat while the extra biogas production will be used to supply the heat generation for the DH network.

Based on lab results it was decided to install a MD pilot plant at the WWTP in Gleisdorf. With this pilot plant, uncertainties regarding the operation and performance of an MD plant on larger-scale can be examined more precisely. The optimal process parameters and the achievable recovery rates of ammonia as well as the stability and fouling behaviour of the modules (different membrane surface sizes) were investigated. Moreover, the quality of the obtained fertilizer was evaluated by approbriate chemical analyses and first general distribution channels were identified. The pilot MD plant was realized as a container solution and installation was realized by the end of 2020 and long-term performance testing was performed[14]. For the first time in Austrian research, a pilot plant for selective ammonia removal from the centrate water of a WWTP was studied for long-term operation.

Based on the overall findings a specific concept for the WWTP integration in Gleisdorf was developed (see Figure 2) and was subsequently realised within the sector coupling concept of the Virtual Heating Plant demonstration case (see Chapter 3.2). In dashed lines other key measures are indicated: An approbriate PV plant expansion and the MD is integrated as a bypass for demonstrating and researching purposes.

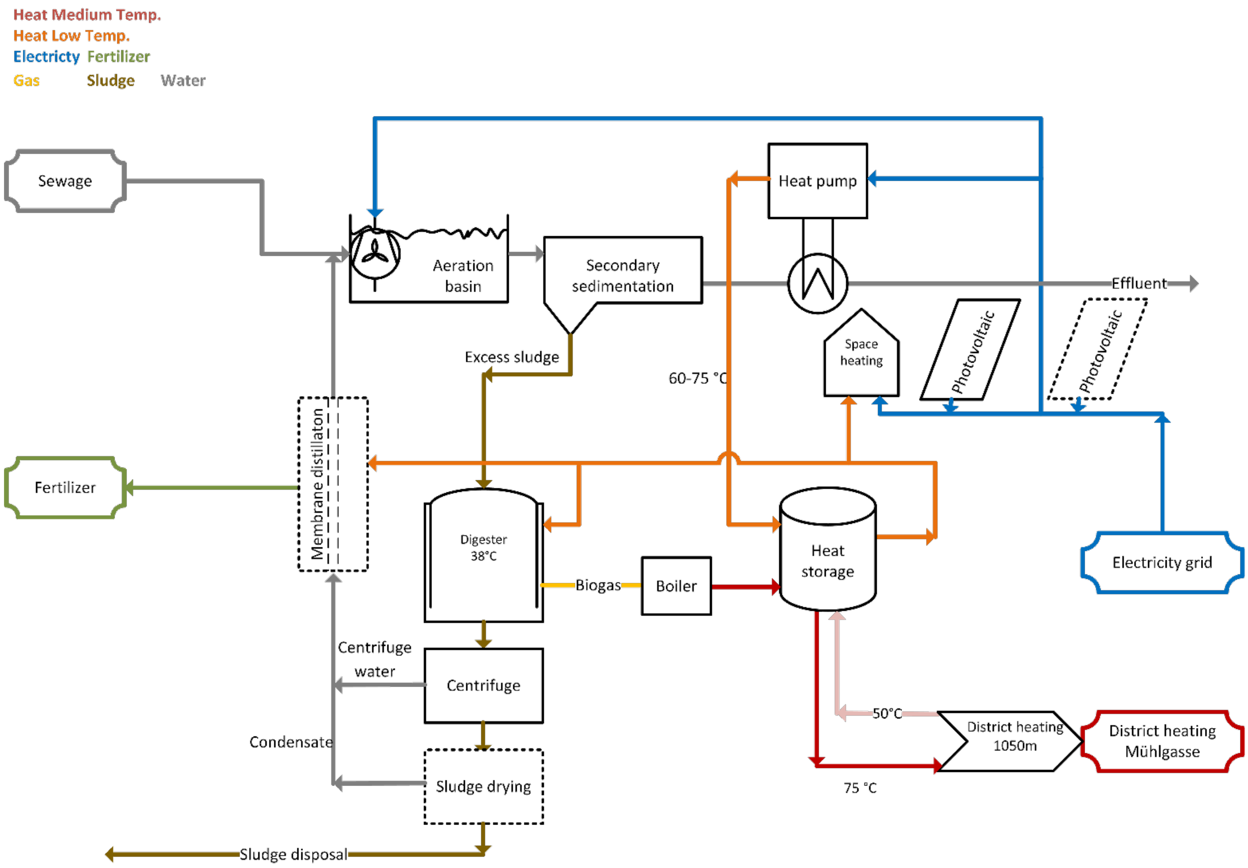

Figure 2: Specific concept for the integration of the Gleisdorfer waste water treatment plant into the district heating network

[14] E. Guillen-Burrieza, E. Moritz, M. Hobisch, B. Muster-Slawitsch, Recovery of ammonia from centrate water in urban waste water treatment plants via direct contact membrane distillation: Process performance in long-term pilot-scale operation, Journal of Membrane Science (2022), doi: https://doi.org/10.1016/j.memsci.2022.121161

Development of smart control strategies and unit commitment procedures

The research here focused on investigating optimization-based procedures to address the unit commitment problem, which involves making real-time decisions on which heat producers should supply the required heat to consumers and how to operate thermal storages efficiently.

To tackle this problem, an optimization approach in the form of a model predictive controller utilizing demand and yield forecasts was explored. This approach offers a structured, modular, and scalable method for solving the unit commitment problem. Additionally, methods for implementing the results of this optimization-based operating strategy using low-level (hydraulic) controllers were examined.

In addition to optimizing the producer side, there is also the potential to actively influence consumers to shift their heat demand from one time period to another. This practice creates a virtual thermal storage that helps avoid peak loads. This concept, known as demand-side management, was also investigated.

Finally, methods for optimization-based supervisory control, specifically an energy management system (EMS), as well as demand-side management (DSM), were developed. These approaches aim to provide efficient and effective control and management of the overall energy system, considering both the producer and consumer sides.

Overall, the research focused on optimizing the unit commitment problem through an optimization-based approach, investigating methods for integrating low-level controllers, exploring demand-side management strategies, and developing optimization-based supervisory control systems to ensure efficient and sustainable operation of the energy system.

Mixed-integer linear programs (MILP) based EMS (see Figure 3) solving the unit commitment and economic dispatch problem consist of three main parts:

1. forecast methods which provide estimates of future demand, yield from renewables, and possibly also prices for electricity;
2. the formulation of the optimization problem based on the current state of the system, the forecasts, and mathematical models of the system and for evaluating the operating strategy;
3. a solver for the optimization problem that delivers the optimal operating strategy.

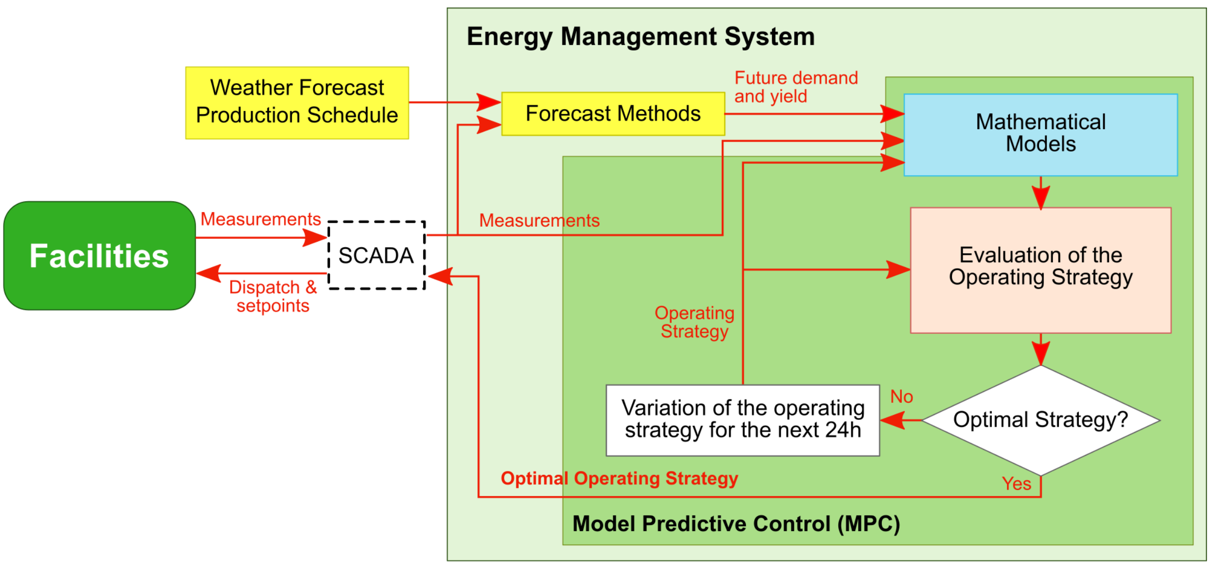

Figure 3: Structure of an optimization-based Energy Management System (Source: BEST)

The MILP-based energy management system for coordinating the producers and storage was developed with an easy application to new, different networks, possibly additional technologies and other SCADA systems in mind. The MILP-based energy management system requires a working SCADA system as its single point of communication; otherwise, interfaces to a multitude of different sensors and actuators would have to be implemented, which would not be financially viable. Another obstacle is the innate scepticism of operators towards a fully automated solution. Therefore, it is necessary to provide a fail-safe fall-back solution which continuously monitors the health of the system and can decide to take over if certain safety margins are violated. This adds to the complexity of the approach.

In implementing demand-side management (DSM) methods, access to transfer stations is necessary, and it involves some level of interference with the heat provision to consumers. It is crucial to ensure that these measures do not negatively impact consumers or that consumers willingly agree to the changes made at the transfer station. Consequently, handling large consumers with significant influence on the network becomes challenging, as they typically have stricter contracts with the network operator and specific requirements for factors like feed temperature. However, DSM can still be practical if a large number of small and less complex consumers can be easily engaged in complying with the demand-side management measures.

DSM algorithms themselves are highly flexible, as they automatically adapt to different consumer profiles and can be easily configured from a central control application. The primary implementation challenges for DSM systems lie in the need for a robust communication infrastructure and ensuring individual cooperation from each consumer. However, the proposed system offers the advantage of being non-invasive by default, meaning it ensures that its actions do not compromise user comfort.

In summary, while DSM methods may encounter challenges related to consumer contracts and requirements, they remain practical by targeting a large number of small consumers. DSM algorithms provide flexibility and can be configured centrally, with the main implementation challenges revolving around communication infrastructure and ensuring consumer cooperation. The system's default setting prioritizes non-invasiveness to guarantee user comfort.

Both strategies were tested within the demo 100% Renewable district heating Leibnitz (see Chapter 3.3) and EMS was implemented for the operation of the district heating network.

2.3.2.3 Development of large-scale solar thermal supply concepts with combined seasonal storage

The development and feasibility of large solar thermal supply systems with combined seasonal storage or daily to weekly storage was addressed, aiming at decarbonizing the energy supply mix and reducing dependence on energy imports, was investigated.

Large-scale solar thermal concepts were explored to achieve high renewable energy shares in existing district heating networks. Solar thermal energy played a significant role in achieving a substantial share of renewable energy. However, a major challenge in integrating these systems was the high flow and return temperatures associated with the existing distribution infrastructure that has evolved over many years.To increase the proportion of renewable energy, the integration of large-scale solar thermal installations (consisting of extensive arrays of solar thermal collectors supplying solar energy to the heat network) emerged as a promising option. Given the temporal mismatch between heat supply from solar systems and heat demand, the use of thermal energy storage (TES) became necessary to accommodate higher solar fractions.

By combining the solar district heating concept with seasonal storage, it became possible to achieve high solar shares in the district heating supply.
Furthermore, the integration of a heat pump into the system offered additional advantages. The heat pump facilitated higher energy storage density and enabled the attainment of flow temperatures required by the network even when the storage was depleted to a low level.
Overall, the research aimed to investigate the development and feasibility of large solar thermal supply systems with combined seasonal storage. These systems presented a potential solution for achieving high renewable energy shares and reducing dependence on energy imports, with the integration of thermal energy storage and heat pumps playing crucial roles in their effective implementation.
The demonstration of large scale solar integration a district heating network in combination with storage, targeting the decarbonisation of the energy supply mix and the decrease of dependence on energy imports, was realized in the demonstration case Mürzzuschlag (see Chapter 3.4).

2.3.2.4 Development of a Virtual Heating Plant approach

The overall element was the development and implementation of the virtual heating plant (VHP) approach based on a fully digitised system. This allows for a comparably fast, cost-efficient, save and flexible integration of new control concepts while using the existing control, measurement and data acquisition infrastructure. A virtual heating plant is a white-box approach using a mathematical model of the entire district heating system, real-time operating data and, based on those, day-ahead simulations to generate an optimised set of control parameters which overrule the low-level control system to improve the overall system performance.
The basic idea was to use the existing control systems of the individual units/components (boilers, solar plants, district heating grid control, substation controller, etc.), add sensors and broadband data connections to all distributed systems and implement the intelligence by connecting them based on new approaches for district heating comprising the following features:

- Real-time data acquisition and exchange with other control systems
- Real-time network simulation
- Prediction of future operating, storage and heat demand conditions
- Determining a targeted optimum and the corresponding required control parameters
- Committing the optimised control parameters to the low-level control units

The VHP control system, overlaying the existing conventional DH control system, was fully developed and implemented for the district heating network in Gleisdorf (see Chapter 3.2). The concept was developed and improved in several development steps to ensure stable plant operation and a secure supply to customers at all times. The functionality was continuously optimised and further improved as an ongoing process extending over a longer period and consisting of continuous readjustment of the higher-level control system accompanied by regular monitoring, analysis and evaluation of the effects and were based on a thermohydraulic real-time simulation of the district heating network as well as storages and production units. Derived from the respective analysis and simulation, further steps for improvement and an approach to an optimal and intelligent plant operation resulted.
As an example improved storage models were integrated, resulting in an adapted virtual storage approach. This function was added to the VHP approach during the development of the future heat demand scenario and strategic development plans and is a promising alternative to central large storage facilities. All existing and upcoming central and distributed storage capacities will be coupled to this

virtual storage and will lead to a highly efficient operation of the DH network and the best possible use of integrated renewable energy sources. This led to an improved and more flexible unit commitment, higher solar yields and more stable operating conditions.

2.3.2.5 Development of low-temperature system solutions in combination with urban redevelopment

A necessity for sustainable district heating is the reduction of system temperatures, as this leads to various advantages. Here, ThermaFLEX worked on the development of concept options and the quantitative evaluation of low-temperature system solutions in district heating supply. One general advantage of lower system temperatures lies in the reduction of thermal transportation losses of the network. Furthermore, low operating temperatures of district heating systems offer the possibility to increase the utilization of renewable energy sources (e.g. solar heat, surplus waste heat), which lowers the share of fossil fuels in the supply system. The reduction of operating temperatures also opens up a high potential to significantly improve the flexibility of the supply system and resulting in additional transport capacities in the district heating network, which can be used to connect new consumers and save investment costs for new, larger pipes. Reducing temperatures also leads to a lowering of heat demand and heat losses.

The most relevant issues to realize the stepwise conversion of district heating supply to low-temperature district heating were identified. This conversion necessitates the development of innovative concepts for generating, storing, distributing, and supplying thermal energy at low temperatures, particularly to facilitate the utilization of heat from renewable and alternative sources. Implementing low network temperatures also helps to reduce operational and investment costs. Furthermore, the study evaluated the barriers and opportunities associated with converting existing conventional district heating networks to low-temperature applications. It assessed various measures and the resulting benefits of such conversion. A specific focus was placed on investigating cascading heat use concepts in district heating applications, as this approach holds promise in the transition process.

In one specific case, the feasibility of implementing low-temperature district heating supply in a new planned city quarter, located in Leibnitz, was investigated as part of the demonstrator project 100% renewable district heating Leibnitz (see Chapter 3.3). A simulation study was conducted, considering different concepts for cascading heat supply to utilize the high-temperature return from a commercial district heating customer. The results demonstrated that approximately 50% of the heat demand could be met by utilizing the "hot" return. Distribution losses could be reduced by up to 68% compared to the reference concept, resulting in a decrease from 8.1% to 2.6%. Additionally, the overall return temperature at the heating plant could be reduced by 1 to 2 °C, from 68 °C to 67 to 66 °C. The cascading heat utilization also improved the transport capacity of the district heating network, allowing for potential expansions to double the capacity.

Overall, the research highlighted the importance of low-temperature district heating conversion and evaluated the benefits of implementing cascading heat use concepts. The specific case study in Leibnitz demonstrated the potential for significant energy savings, reduced losses, and improved network capacity through the utilization of high-temperature returns from commercial customers.

3 Demonstration sites

In this Chapter, the developed and subsequent realized flexibility measures for the addressed demonstration sites (demonstrators) will be described in more detail. The results of the planning, realization, monitoring and evaluation phase including possible roll-out scenarios and their market potential were summarised for each demonstration case.
The map of the linked demonstrators is illustrated in Figure 4. The scientific, technical and organisational support for the demonstrators takes place throughout the whole innovation and implementation process. The entire process covers problem identification, idea & concept development via planning and implementation to commissioning, start-up & operation as well as monitoring with evaluation and optimisation steps. Consequently, the results led to efficient and effective demonstration cases. Therefore, the ideas and concepts demonstrated and realized in the demonstration sites provide the background for developing, implementing and optimizing innovative DH concepts and technical solutions for a further roll-out.

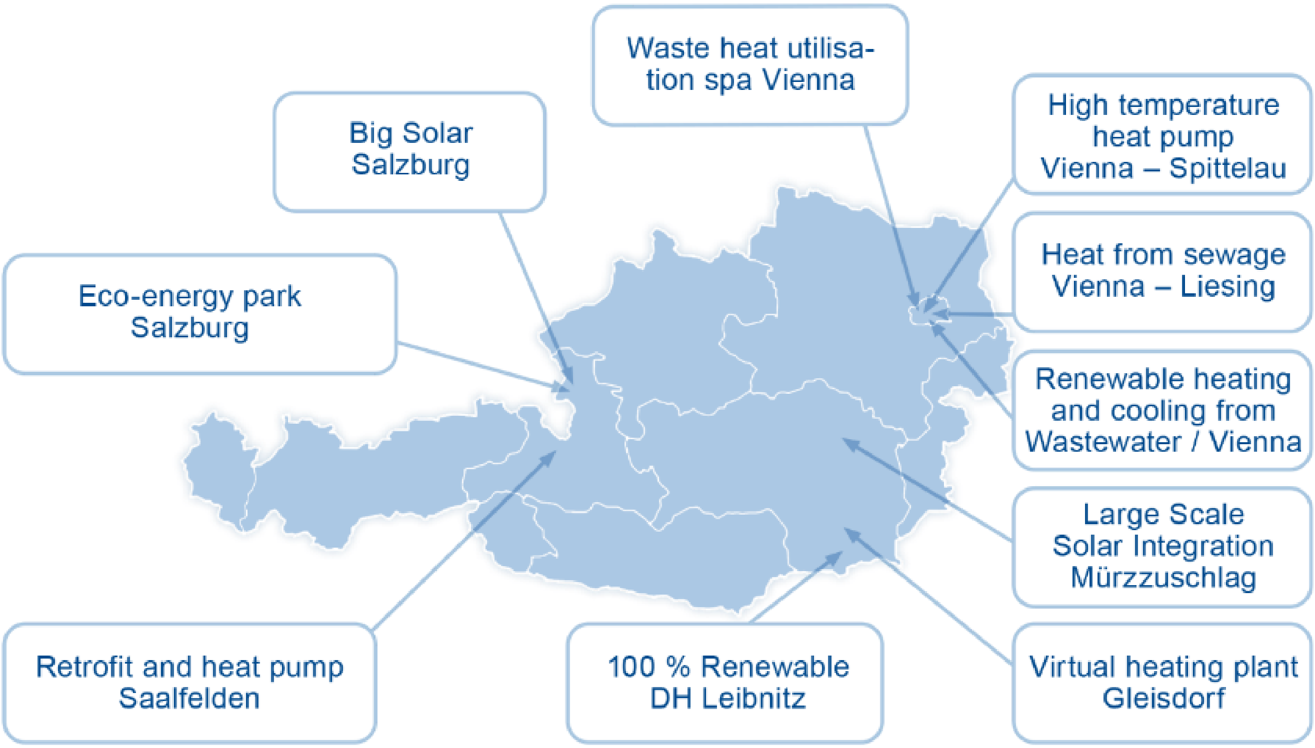

Figure 4: Map of ThermaFLEX demonstrators (Source: AEE INTEC)

The demonstrators differed largely in scale and complexity as well as starting point and rate of progress. Adaptions and/or adjustments are thus frequently encountered within the dynamic environment of demonstration sites. Delays within the implementation and realization of developed flexibility measures mainly occur due to external factors (e.g. changing boundary conditions in the real environment of the demonstrator, changing strategies of the energy suppliers/investors, Corona pandemic situation, etc.) as well as long-lasting decision-making processes in general. Modifications and monitoring of implementation progress were continuously made to meet the specific local boundary conditions. Table II summarizes the main elements within the demonstration sites.

Table II: Main flexibilty measures within the demonstration sites

Demonstration site	Main elements/flexibility measures
Virtual heating plant Gleisdorf	Sector coupling of DH with WWTP and waste heat utilization concept with a heat pump (~800 kW) and biogas burner (~ 100 kW) Subordinate control (Virtual heating plant) approach for efficient DH network operation including storage management
100 % Renewable district heating Leibnitz	Use of fluctuating industry waste heat (4 MW) through bidirectional coupling of two district heating networks. Development of a high-level predictive control of DH network operation and heat generation plants.
Large scale solar integration Mürzzuschlag	Integration of 5,000 m^2 solar thermal system with 180 m^3 storage tank as well as optimization through network simulations Simulation based solar yield expansion planning (2,000 m^2 solar and 120m^3)
Retrofit and heat pump integration Saalfelden	Two-stage biomass heating plant retrofitting concept. Holistic technical modernisation (stage 1, e.g. flue gas condensation 400 kW, 150m^3 storage, etc.) fully implemented. Heat pump integration (stage 2, ~ 700 kW) developed. Implementation planned for autumn 2023.
Eco-energy park Salzburg	Implementation of a new industrial large-scale absorption heat pump (8 MW) to increase waste heat utilization at a cell manufacturer in Hallein Concept for an eco-energy park for the city of Salzburg including a biomass boiler (9 MW), biomass CHP (8 MW) as well as absorption heat pump (14 MW) developed.
Renewable heating and cooling from wastewater	Waste heat utilization from wastewater (sewer system) for heating (460 kW) and cooling (430 kW) with innovative heat exchanger and heat pump system. Monitoring for optimisation of heat pump operation and analysis of the influence on the sewer and wastewater treatment plant downstream
Waste heat utilization spa Vienna	Use of the waste heat from thermal water after internal use in the spa Vienna. The waste heat utilization with an heat pump system (2.2 MW) was directly integrated into a secondary network of the Vienna district heating system.
High temperature heat pump Spittelau	Waste heat utilisation (~16 MW) from the flue gas condensation of the waste incineration plant as a heat source for a high-temperature heat pump.
Heat recovery from sewage Vienna Liesing	Concept development for the use of waste water directly from from the sewer channel as a heat source for a heat pump (~2 MW) and feeding into a secondary network of the district heating Vienna.
Big Solar Salzburg	Detailed concept development for a large-scale solar thermal system (~30,000 m^2 collector area), a large storage tank (~20,000 m^3) and the integration of an absorption heat pump (~14 MW).

Note: The realisation of the developed flexibility measures within the demonstrators “Heat recovery from sewage Vienna Liesing” and “Big Solar Salzburg” are currently on hold mainly due economic but also due to strategic and political aspects and have not been considered in this report. Contents within these demonstrators are covered by other demonstrators, thus no risk given here on failing the goals of ThermaFLEX.

3.1 Methodology applied

To transfer the findings and results of generally suitable flexibility measures and to select the most suitable concepts to meet the specific local boundary and operation conditions of the demonstration sites, further concept developments based on simulations, planning and evaluation methods were completed and demonstrator-specific concepts were developed.

To complete the implementations as well as scientific monitoring concepts successfully and ensure an efficient and effective operation of the demonstrators and appropriate data for later evaluation, different methods were applied:

- Development implementation plan and support implementation for each demonstrator including
  - timeline and necessary steps,
  - support in non-standard technical and concept questions and
  - development of potential solutions and support in legal, financial and organizational questions to prepare implementation.
- Development of start-up and operation plan for each demonstrator including potential countermeasures and alternatives in case of technical failures or problems.
- Supervision of start-up and operation for each demonstrator including discussion with demonstrator partners on
  - start-up/operational status and
  - support of potentially necessary modifications as well as
  - feedback to partners responsible for the monitoring of each demonstrator.
- Development of technical and scientific monitoring concepts for each demonstrator to identify necessary monitoring data and to be able to derive flexibility KPIs (Key Performance Indicators)
- Implementation of monitoring concepts by the development of implementation plans for each monitoring concept
- Identification of additionally necessary monitoring equipment to standard monitoring to fulfil requirements and setup of a data exchange platform for monitoring data exchange between partners and flagship region Green Energy Lab (GEL)

To analyse and evaluate the monitoring results for further optimization as well as to process and prepare monitoring data for system evaluation (results see respective subchapters “Monitoring and system evaluation” within the demonstration sites) and exploitation (see Chapter 5) the following different measures were completed:

- Collection, analysis and evaluation of monitoring results to collect monitoring data, check the operational status and behaviour, and perform a technical and scientific analysis of monitoring data based on different methods (e.g. energy balances, simulation tools, etc.), to evaluate the plausibility of monitoring results with partners and experts from the consortium and to prepare the evaluation results for later usage.
- Re-evaluation of developed concepts based on monitoring results and potential concept modification.

To evaluate and compare the effects of the implemented concepts on different levels, the subsequent methods for system evaluations were applied:

- The impact was evaluated individually directly by the demonstrators based on Key Performance Indicators (KPIs). The KPIs are grouped into four categories: economic, technical, environmental and social (see Appendix A: Summary of KPIs for system evaluation). Note: not all KPIs are relevant for each measure. Some demonstrators implement multiple measures. The KPIs are evaluated either or individual measures or for a bundle of different measures and were discussed in the respective subchapters “Monitoring and system evaluation” within the demonstration sites.
- Five demonstrators including different flexibility measures, namely Virtual heating plant Gleisdorf, 100% Renewable district heating Leibnitz, Large scale solar integration Mürzzuschlag, Renewable heating and cooling from wastewater and absorption heat pump integration Hallein as part of demonstrator Eco-energy park Salzburg, have been selected for a Life Cycle Assessment (LCA). It evaluates the environmental impacts associated with all stages of the life cycle of a product or service. Hence, it provides a more detailed and comprehensive assessment than the KPI evaluation, also including long-term effects. LCA is a structured, standardized and internationally recognized method (ISO 14040[15]) for environmental assessments and addresses the environmental aspects and potential environmental impacts throughout the life cycle of a product or service from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal. Results were summarized in the respective subchapters “Life Cycle Assessment” within the demonstration sites.

Additionally, the replicability and scalability potential was estimated on the national level (for selected demonstrators and/or flexibility measures). Based on the key requirements of the demonstration sites, roll-out scenarios were defined using the Austrian Heat Map database[16]. These roll-out scenarios are used to evaluate the impact and market potential. Results were summarized in the respective subchapters “Roll-out scenarios and market potential” within the demonstration sites.

[15] International Organization for Standardization (ISO). ISO 14040:2006(E); 2006
[16] Austrian Heat Map. https://austrian-heatmap.gv.at

3.2 Virtual Heating Plant Gleisdorf

3.2.1 Demo description and realized concept

The local utility companies Stadtwerke Gleisdorf GmbH (heat, water, waste disposal, etc.), Feistritzwerke GmbH owned by Stadtwerke Gleisdorf (power production, power grid operator, PV installations, etc.) and Abwasserverband Gleisdorfer Becken (wastewater disposal and treatment) have strong ambitions to use renewable and locally available energy sources, to increase the efficiency and the flexibility of their systems in order to cope with current and future challenges. The main target is to ensure a regional, environmental friendly and economic (affordable) energy supply for the region in the long term. Starting point of the planed demonstration project is the necessary enlargement of the solar and biomass-based district heating system operated by Stadtwerke Gleisdorf and the local wasetwater treatment plant operated by Abwasserverband Gleisdorfer Becken. Here, an enlargement of the treatment capacity in combination with an overall modernization is necessary in near future.
At the beginning of the project the main district heating system has a route length of 5.1 km supplying 79 consumers with a load of 5.7 MW_{th} and a yearly consumption of approx. 6,500 MWh were connected. Due to the hydraulic set-up and current operation strategy, natural gas boilers are used for base and peak load supply leading to 15 – 19% of the final energy demand being supplied by natural gas while the remainder was supplied by biomass and solar thermal (77 – 83% biomass / 2 – 4% solar thermal). The values vary depending on the operating period, the therewith related climatic conditions and other parameters. Supply capacity of biomass and solar was at its limit before recent implementations.
The WWTP in Gleisdorf has a capacity of 32,000 PEs (population equivalents) and treats the waste water of 7 municipalities in the "Gleisdorfer Becken". It comprises of an activated sludge treatment with a 480 m³ digestion tower and no pre-cleaning step. The biogas production at the project start is about 73 kW (yearly average) due to a short retention time in the digestion tower and the missing pre-cleaning step. The WWTP is currently in the pre-planning stage for an expansion to approximately 49,000 PEs, which involves a significantly larger digester to increase biogas production.
The future concept focusses on the so-called "Virtual Heating Plant" control approach, incorporating technical measures, sector coupling (e.g. integration of the waste water treatment plant – WWTP), low-temperature heat use/cascading heat supply) and advanced monitoring and control for central and decentral renewable heat supply as innovative elements under one umbrella.
Overall element is the implementation of the virtual heating plant (VHP) approach based on a fully digitised system. Several flexibility and innovative measures were specified and evaluated:

- Applying a new supervisory control system based on a VHP approach using real-time district heating simulations, real time operating data and weather data. The VHP approach is operational, further functionality were implemented stepwise.
- Intelligent utilisation of biogas and low temperature heat from waste water by integrating the local waste water treatment plant (WWTP) as a heat source (sector coupling). Therefore, a new technology and an innovative concept was realized.
- Implementation of cascadic heat use for a selected customers by supplying them out of the return line. A first implementation was realised end of 2019 and was monitored and optimised while further implementations are pursued.

- A stepwise enlargement of central and distributed storage capacity related to the growth of the system to increase the system flexibility. Moreover, adding storages at specific positions in the network ease the strain on the networks transport capacity during peak load operation and increase the supply security. Integration of an intelligent management for central and distributed storages by adopting the VHP concept to a virtual (thermal) storage concept (VSC). The development and implementation of the VSC concept was realized stepwise.
- Resource recovery with membrane distillation and modernization of the WWTP: An extension and modernisation concept for an optimised operation of the WWTP via membrane distillation (MD) was developed. Based on the results of the performed economic analysis it was decided to install a MD pilot plant for demonstration purposes as a first step to gain elevated information and data as a basis for the further planning. With this pilot plant, uncertainties regarding operation and performance of a MD plant were examined more precisely.
- Various supporting activities such as continuous measures to lower system temperatures as well as the enlargement of the DH network and heat supply capacities in combination with network extension and connection of new customers are ongoing. Therefore, a holistic planning of ongoing and future network enlargements supported by the spatial energy planning of the city of Gleisdorf was done. The smart enlargement strategy will lead to a meshed DH network rather than the current linear topology to increase transport capacities, supply security and again increase the operational flexibility.

3.2.2 Monitoring and system evaluation

Detailed concepts for innovative measures (individual technologies as well as system solutions) were developed and evaluated. As a result, future heat demand scenarios and strategic development plans including all relevant and available local heat sources were conducted for the DH network of Gleisdorf. This was done in close interaction with spatial energy planning tools and methods as well as DH network simulations.

3.2.2.1 Sector coupling

The sector coupling of the infrastructures from the DH network with the WWTP is identified as a central element for the future DH supply and is the aimed starting measure for the implementation of an “Energy Hub” at the WWTP site. An innovative concept including intelligent control to fully exploit the available biogas was developed. The concept includes a respective modular heat pump (~800 kWth, see Figure 5) for the utilisation of low temperature heat from waste water, a biogas booster heating unit (~ 100 kWth) and a DH connection pipeline (~ 1,100 m) to the existing heating network. First implementations realized within 2021 (DH network). Final realisation was done within 2022 and system operational since autumn 2022.

It is expected that the sector coupling concept provide 4,320 MWh/a thermal energy (heat pump) and the biogas will add 864 MWh/a thermal energy, resulting in approx.. 5,200 MWh/a. Thermal losses of 5% at the plant are considered, leading to total thermal savings of 4,925 MWh/a. The current natural gas boilers of the DH network have an efficiency of 90%, thus 5,472 MWh of natural gas are substituted each year. Therefore, the sector coupling will save 1,368 to CO_2/a.

Figure 5: Heat pump within sector coupling concept in Gleisdorf (Source: Stadtwerke Gleisdorf)

The sector coupling as well as subsequently Energy Hub concept is supported by all relevant stakeholders (City of Gleisdorf, Stadtwerke Gleisdorf, Abwasserverband, etc., decisions and agreements of the respective boards available) and paves the way for the integration of various further implementation steps which are necessary to cover the continuous growing heat demand of approx. 500 kWth/a in the DH network. The next planned and declared steps from the stakeholders within the "Energy Hub" development are a new biomass heating plant (size range 2-4 MWth), the implementation of additional heat pump systems (total potential 3 MWth available), integrate sewage sludge drying and resource recovery processes in combination with MD technology, sector coupling with the electricity sector by enlargement (~300 kWp) of the existing PV plant (200 kWp) and/or integration of a water power plant nearby (size range: 110 kWel). Consequently, a further enlargement of the DH network and connection of new heat consumers as well as potential waste heat utilization (e.g. animal crematorium) along the new installed DH piping take place.
Furthermore, the sector coupling concept combined with the planned Energy Hub at the WWTP site will allow the operation of a low-temperature network. Due to the low temperature heat demand of relevant WWTP processes (e.g. digestion tower at 38 °C) as well as existing buildings at the plant site an efficient use of the generated low temperature heat is possible and leads to highly efficient operation of the Energy Hub system.

3.2.2.2 Cascade heat use

The new alternative heat supply concept was applied to a newly connected heat consumer (modernized multifamily house with 10 flats, base area: 1,018 m², timber frame construction, Alois Grogger Gasse 2a) allowing a cascading heat use only out of the return line. According to the construction design, an annual heat demand of 28,569 kWh (28,06 kWh/m² a) was calculated. The heat will be provided by an underfloor heating system. The maximum required flow temperature of approx.. 40°C can be secured out of the return flow of the DH system (approx.. 50-55 °C). A two-pipe setup without a third pipe from the supply line was chosen, since mass flow should always be sufficient and no heating for domestic hot water production needed to be considered. The domestic hot water demand (calculated demand: 13,006 kWh/a) is covered by a power2heat application (PV and electrical heater). An innovative monitoring concept was developed and installed.

The innovative substation (and control of the substation) is in regular operation since beginning of 2020. Evaluations show a mean return temperature of < 30 °C (by a feed temperature of approx. 50 °C) and lead to an increase of the transport capacity as well as demonstrate the high potential from the cascading heat use in terms of lowering the DH system temperatures with reduced heat losses. According to the construction design, an annual heat demand of about 29,000 kWh was calculated. Because of the cascading heat use this heat demand must not to be generated and in the specific case of Gleisdorf 4,930 kWh of natural gas are substituted each year resulting in CO_2 savings of 1,230 kg/a.

3.2.2.3 Membrane distillation

WWTPs have been identified as potential energy hubs within the project. In the particular case of the demonstrator in Gleisdorf, both the WWTP and the DH system capacity must be expanded. This was seen as an opportunity to take a combined approach for improving both the energy efficiency and the resource recovery via an innovative thermal technology, the membrane distillation (MD).

MD is a technology than can on the one hand, remove ammonia from wastewater and recover it as a valuable product and increase the capability of the biogas production by optimizing the operation parameters needed in the different basins on the other. MD is in addition, a thermally driven technology, which uses mainly low-grade heat (i.e., ~35-40°C). Ammonia removal from wastewaters is an energy intensive problem that sums up to 1/3 of the electrical energy demand of WWTPs. In the state-of-the-art process to eliminate ammonia from wastewaters (i.e.: nitrification/denitrification) the ammonia is lost in the form of N2 and mostly electricity is used. On the contrary, MD is a robust technology that can recover this ammonia for further use and eventually close the N-cycle by using mainly thermal energy. In the energy coupling scheme, MD will be a sink for low-temperature heat while the extra biogas production will be used to supply the heat generation for the DH network.

First an extension and modernisation concept for an optimised operation of the WWTP via MD was developed. Based on the results it was decided to install a MD pilot plant for demonstration purposes as a first step to gain elevated information and data as a basis for further planning. To identify optimum operating conditions first lab-scale experiments were performed and afterwards demonstrated in the pilot plant. The evaluation of this first lab phase led to further optimization strategy which was subsequently led to long-term performance testing, reduced chemical consumption and higher product concentrations. The pilot membrane distillation (MD) plant for recovery of resources and increased biogas production was planned and realized as a container solution and installation was realized by the end of 2020. From beginning of 2021 up to mid-2022 different test runs and test conditions were performed. For the first time in Austrian research, a pilot plant for selective ammonia removal from the centrate water of a WWTP was studied for long-term operation. With this pilot plant, uncertainties regarding operation and performance of a MD plant were examined more precisely. The optimal process parameters and the achievable recovery rates of ammonia as well as the stability and fouling behaviour of the modules (different membrane surface sizes) were investigated. Moreover, the quality of the obtained fertilizer was evaluated and possible distribution channels were identified.

The continuous operation of the pilot showed very stable performance in the long-term and was not affected by incidental operation interruptions, proving to be a robust system configuration for practical applications. The high alkalinity of the centrate water was found to be the main fouling issue, requiring filter (i.e., only pre-treatment) changes every 2-3 weeks. The sleeve filters were an effective and cheap pre-treatment for the MD module which only needed mild acidic cleaning (i.e., citric acid solution at 2% w and 50ºC for one hour) once per month. However, reduced performance was detected after cleaning only with water. A good future optimization exercise would be to identify the best time, cleaning agent and temperature combination in order to reduce chemical consumption and cleaning frequency.

Based on the gained experimental data of the MD container pilot plant test runs, the planning basis of the demonstration plant was re-evaluated and adapted to the process conditions tested. Other planned optimisation and modernisation measures at the WWTP (new digestion tower, primary clarifier, etc.) will further improve the overall efficiency of the WWTP in near future. The WWTP has currently no pre-treatment installed, which is a missed opportunity in terms of increased biogas production. The sector coupling concept allows the full exploitation of the currently and future produced biogas and adds another important positive effect in terms of efficient use of resources and circular economy, thus flare of biogas (excess) will be avoided. The implementation of an industrial MD plant in combination with the extension and modernisation of the WWTP as well as sewage sludge treatment processes (drying) are planned next steps.

3.2.2.4 Supporting activities

In parallel, various supporting activities and additional flexibility measures were identified during the development processes. For example, the interconnection of the main DH network with an existing network in the northwest of Gleisdorf was investigated and evaluated (two routing scenarios). The interconnection increases the system flexibility, reduces the share of fossil fuels and leads to a better economic performance of the overall system. Detailed investigations and evaluations are ongoing and support the decision-making process. Due to the coupling two additional heating plants (each with a 400 kWth pellets boiler), storages and a thermal solar plant will be integrated into the overall system and significantly increases the production flexibility of the system allowing to further reduce the fossil fuel share.

Due to the DH network enlargement and connecting of various new heat customers (non-innovative parts which is not considered here) further environmental effects (substitution of fossil fuels and therewith related reduction of CO_2-emissions) are triggered. Other environmental effects which are not quantified at this point, involve the temperature decrease (2-4 K) of the discharge water of the WWTP into the Raab river. The Raab river is a sensitive water body having a number of industries along its way. The heat pump will also be operated in summer time and can thus reduce the thermal stress on the flora and fauna of the Raab river. Another important positive effect in terms of efficient use of resources and

circular economy is the complete energetic utilisation of the biogas from the WWTP by an intelligent control system, thus flare of biogas (excess) will be avoided.
The sum of all these different measures lead to a strong substitution of fossil fuels in the local energy supply for the city of Gleisdorf and allows to cope with current and future challenges regarding heating, cooling and power supply while ensuring a reliable, economic and ecologic supply and disposal infrastructure.

3.2.2.5 Virtual heating plant and virtual storage concept

Applying a new supervisory control system based on a VHP approach using real-time district heating simulations, real time operating data and weather data. The basic idea is to use the existing control systems, add sensors and broadband connections to all systems and implement a new high-level control system. No relevant changes occurred. The VHP concept combines all innovations and flexibility measures in the DH network. The VHP control system is fully implemented into the DH system and operational. The functionality will be continuously extended and improved.
Large-scale thermal storage concepts were developed and evaluated. During development of the future heat demand scenario and strategic development plans the initial concept was replaced by a virtual large thermal storage approach. All existing and upcoming central and distributed storage capacities will be coupled to a virtual large thermal storage and will support lead to a highly efficient operation of the DH network and best possible use of the RES.
In Figure 6 (left graph) the annual heat generation from 2017 up to 2021 is illustrated and shows a significant increase from 7.7 (2017) to about 10.4 GWh in 2021. This underlines the steadily growth of the main DH network, especially in 2020 and 2021, and the need of flexibility measures to meet future requirements, e.g. an intelligent control concept. By the development and implementation of the VHP control and in parallel other continuous optimization measures the energy mix (see right graph in Figure 5) to cover the heat demand was comparable stable, although of a heat generation increase of approximately 35%. The main part of the heat generation was provided by biomass as well as biomass boilers respectively. The yearly heat production from biomass increased by 41% (from 5.8 in 2017 to 8.2 GWh in 2021). The increase in the transition period is partly due to increased heat demand but mainly due to the virtual heating plant control including innovative storage management and control as well as summer operation in 2021. In parallel the solar yields were improved by about 26 % (from 310 in 2017 to approximately 390 MWh in 2020 and 2021) over the years supported by different measures. The improvements result on decreased return temperatures from the virtual heating plant (VHP) control, adapted solar plant control and storage management control strategies as well as changed feed-in points at the distributed solar plant locations.

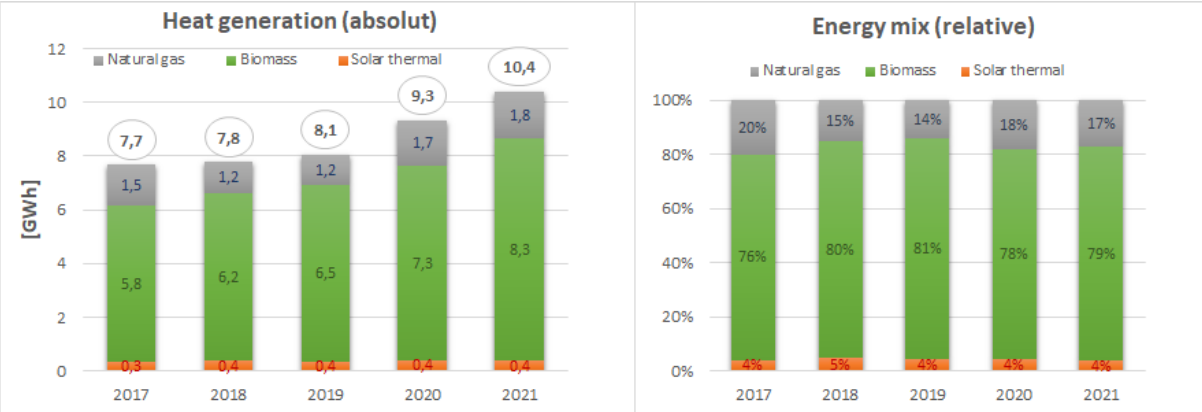

Figure 6: Annual heat generation (left) and corresponding energy mix (right) (Source: AEE/Pink)

The remaining heat generation to cover the demand is covered by natural gas boilers. In 2018 and 2019, natural gas heat generation was significantly reduced (-25 %) by the VHP control. In 2020 the elevated heat demand was a result of the new connections in combination with gas boiler operation in summer as well as limited heat generation of the installed biomass boilers in winter (maximum 1,150 – 1,200 MWh/month). Also, for the first months in 2021 natural gas was needed to cover the heating demand. During summer the natural gas boiler was substituted by the biomass boiler operation and led to a small reduction (compared to 2020). It has to be pointed out that the natural gas boiler at Forum Kloster is not integrated in the VHP control by now and represents another possibility for a future reduction.

The main growth rates in the heat production appeared in the spring period (March to May) and between October and December, while in January and February the heat generation growth was unincisive. The heat generation during the typical summer months (June to September, primarily necessary for hot water preparation) were on a comparable level of about 250 MWh per month and was quite stable over the years. This clearly indicates the gained optimizations during this crucial operation phase by the implementation of the intelligent control and no elevated heat losses due to additional piping for new heat consumers were detected.

A detailed determination of the effects of the “virtual heating plant” control and the “virtual storage concept” is not possible due to the steady growth and dependencies as well as gross-impacts from the entire DH network operation. However, a rough estimation of the optimization potentials which could be gained by an intelligent “virtual heating plant” control system results in 5% less natural gas demand (5% of the 2021 heat sale result in about 425 MWh/a less gas) and corresponds to CO_2-savings of about 105 to CO_2/a.

In general, the implementation of the Virtual Heating Plant control concept combined with continuous optimization activities pursued during the implementation activities (based on systematic evaluation of operating data and heat consumer analyses) lead to reduced system temperatures of currently 81/49°C but has still further reduction potential and increase the flexibility regarding a low temperature implementation of the WWTP at supply temperatures in the range of 70-75°C.

3.2.2.6 Life cycle assessment

The enlargement of the main DH network due to the continuous connection of new heat consumers is a very dynamic process in Gleisdorf and adds another challenge. Within the development of this strategic expansion scenarios the merging of the main DH network with an existing network in the northwest of Gleisdorf was investigated and evaluated. Due to the coupling two additional heating plants (each with a

400 kWth pellets boiler), a storage and a thermal solar plant will be integrated into the system and significantly increases the production flexibility of the system allowing to reduce the fossil fuel share.
Two scenarios including the sector coupling (reference: separated networks, ThermaFLEX: interconnected networks) were analysed and compared using life cycle analysis (LCA). Both scenarios have the same heat demand (including grid losses) of nearly 11,500 MWh and represents the situation in 2021. Yearly GHG emissions of the two scenarios were calculated, with 1,069 t CO_2eq/a in the reference scenario and 155 t CO_2eq/a in the ThermaFLEX scenario. This equals to a reduction of GHG emissions of 85%. In relation to the supplied heat, the specific emission factors are 94 g CO_2eq/kWh heat in the Reference scenario and 14 g CO_2eq/kWh heat in the ThermaFLEX scenario.
The primary energy demand was evaluated with 14,780 MWh/a in the reference scenario and 15,259 MWh/a in the ThermaFLEX scenario. In relation to the supplied heat, the specific primary energy demand is 1.31 kWh/kWh heat in the reference scenario and 1.35 kWh/kWh heat in the ThermaFLEX scenario scenario. Primary energy demand includes not only fossil and renewable energy generated by technical means, but also the renewable energy contained in the waste water as used in the heat pump in order for the energy balance to be complete.
The fossil primary energy demand was reduced by 89% (4,552 MWh/a in the reference scenario and 408 MWh/a in the ThermaFLEX scenario. In relation to the supplied heat, the specific fossil primary energy demand is 0.4 kWh/kWh heat in the reference scenario and 0.04 kWh/kWh heat in the ThermaFLEX scenario scenario.

3.2.3 Roll-out scenarios and market potential

The overall objective for the future heat demand for the DH network in Gleisdorf is to generate an intelligent energy system to a) increase the overall efficiency and flexibility, b) allowing best possible utilisation of renewable and locally available energy sources, c) fully exploit the synergies of urban infrastructures like WWTP and DH networks and d) creating a future-proof and resilient system allowing to further improve and integrate innovative flexibility measures in future. The sector coupling of infrastructures is the next step and an essential cornerstone for the future heat supply. Therefore, the developed concepts for the innovative measures within ThermaFLEX will strongly support the transformation process for the future DH supply of the growing city of Gleisdorf and will have a substantial effect and boost for a fast realisation of the different measures.
Austria has 1,836 WWTP, around 10% (183) of them have a capacity of at least 20,000 P.E, which shows that this is the critical size for the wide-spread usage of using biogas. 136 WWTP with a capacity >20,000 P.E. have a digestion tower. The potential biogas production for the 136 WWTPs with digestion tower depending on their capacity and their actions toward pre-purification (sedimentation basin with different retention time) and nitrogen removal (AR-MD). With standard equipment and business as usual, these WWTPs could provide 50,000 kW of biogas. In contrast, with longer retention time and the implementation of AR-MDs the biogas production raises to 56,500 kW. District heating systems are a valuable infrastructure and initial point for new technologies (e.g., 4th generation district heating characterized by efficiency, flexibility, renewable and resilient) like the demonstration project in Gleisdorf. In many areas with district heating there are already or in in near future usable alternative heat sources (e.g. low temperature waste heat from waste water. Heat from waste water treatment plants can only be used for district heating if there is a district heating grid nearby. Hence, to get a better estimation of the

actual potential the locations of the waste water treatment plants are matched with the locations of the district heating grids from the dataset of the Austrian Heat Map. In total, 219 waste water treatment plants and 219 corresponding district heating grids would qualify for a maximum distance of 2 km with the potential for annual heat production of approximately 2 GWh.

Main barriers of implementing it are the mismatch between load profiles of supply and demand, temperature levels, technical concepts for the integration, insufficient system flexibility and adequate control systems and strategies. Since the Gleisdorf demonstration project is dealing exactly with these challenges it is highly relevant for many other district heating operators in Austria and beyond. It is highly probable, that realized demo projects such as the one in Gleisdorf trigger further projects and the transition to intelligent, efficient and renewable energy systems.

To summarize, the DH network of Gleisdorf is a promising example of the transition to 4th generation of district heating in small scale and the therewith related challenges and requirements regarding optimisation of system temperatures, intelligent operation and control of the system, integration and management of multiple heat sources of different kind and size, management of distributed storages, system hydraulics and short and mid-term enlargement scenarios.

In conclusion, the so-called “Virtual Heating Plant” control approach, incorporating technical measures and advanced monitoring and control for central and decentral renewable heat supply as innovative elements under one umbrella was completed successfully within the reporting period.

3.3 100% Renewable district heating Leibnitz

3.3.1 Demo description and realized concept

The district heating supply of the city of Leibnitz and the surrounding communities was massively expanded over the last years. It was planned to use nearly 100% renewable energy from biomass (heating plants in Tillmitsch and Kaindorf operated by Nahwärme Tillmitsch, NWT) as well as from waste heat from a rendering plant (TKV) situated in Gabersdorf (operated by Bioenergie Leibnitzerfeld, BEL). At the same time, the efficiency of the district heating network and the energy producers has to be increased. In order to achieve these goals, various measures shall be realized to increase the flexibility of the district heating system including i) inter-connection of the DH networks of NWT and BEL with a bi-directional heat transfer station, ii) smart control with an overall energy management system (EMS) for both networks including demand side management (DSM) and iii) low-temperature DH supply of a new city quarter (see Figure 7). Thus, the cooperation of the district heating operators Nahwärme Tillmitsch (NWT) and Bioenergie Leibnitzerfeld (BEL) as well as their flexibility goals grew in importance: Increased security of supply and 100% renewable heat supply.

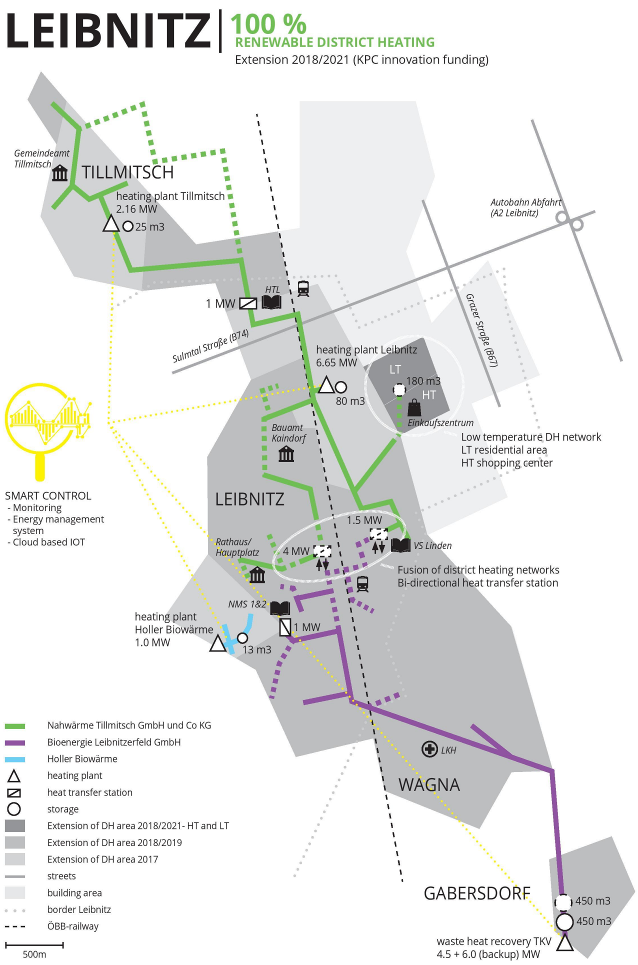

Figure 7: DH network of Leibnitz including realized flexibility measures (Source: Haselbacher)

The central approach is to interconnect the two separated heating networks in order to enable the mutual exchange of heat (bi-directional heat transfer station). This ensures an efficient and resource-saving supply, by a maximum utilization of waste heat (excess heat is transferred to NWT) or biomass in combination with a substitution of natural gas. The installation of the bi-directional heat transfer station (4 MW_{th}) was finalized in March 2021, thus the two separated networks are now connected hydraulically. For optimisation purposes (ecological and economical aspects) smart control systems (EMS and DSM) were developed and both systems were implemented. Potential concepts for a low-temperature supply of a new city quarter were developed and simulated. The planning and decision-making processes of the local government, the landowners and the property developers were delayed, due to several reasons (spatial planning, negotiations on land sales, increasing construction costs). Implementation is planned within the next 5 years and is currently pending.

3.3.2 Monitoring and system evaluation

3.3.2.1 Heat transfer station and EMS

The bi-directional heat transfer station is the core element of the interconnection of the main DH systems in Leibnitz and represents the infrastructure to interconnect the two main DH networks of Leibnitz (see Figure 5). To utilize the advantages of the interconnection, an overall control system was required to define when and how much thermal energy shall be exchanged between them. Therefore, an Energy Management System (EMS) was implemented.

The evaluation of the overall effects of the interconnection is based on the energy balances and shares of energy sources. Since the heat transfer station was taken into operation in April 2021, the year before (May 2020 to April 2021) and after (May 2021 to April 2022) were compared to each other. Overall the share of renewable energy sources increased from 81 to 84 %. The main reason for the improvement was the additional biomass heat of the northern network of HNW, which was transferred to BEL via the heat transfer station. Also the waste heat utilization from an biogas CHP was improved by 621 MWh. The total amount of heat from the gas boiler could be reduced by 372 MWh from 6,787 to 6,415 MWh. At the same time the total heat produced increased by 4,275 MWh to 39,450 MWh (05/2020 – 04/2021: 35,175 MWh). The monitoring of the overall system showed, that the interconnection of the DH networks improved the share of renewables by 3 %.

The total waste heat utilization () of the rendering plant in Gabersdorf (Bioenergie Leibnitzerfeld – BEL) amounts to 8,400 MWh in 2020 and 6,800 MWh in 2021 and directly replace the gas boiler operation in situ saving in total 3,000 to CO_2 in 2020 and 2021.

Figure 8: Waste heat utilization of the rendering plant in Gabersdorf (Source: Klimafonds/Krobath)

There is still potential to decrease the share of the natural gas boiler in near future. By adding the full potential of the EMS the share of renewables could be increased up to 96 % as potential analysis show

[17]. Gas boiler output can be reduced by 69% by transporting heat from the biomass heating plants from Leibnitz to Leibnitzerfeld, leading to a substitution of in total 7,500 MWh from the gas boiler.

3.3.2.2 Life cycle assessment

Different scenarios were defined for the impact analysis and are based on the same yearly heat demand, which corresponds to the heat demand in the interconnected network. Briefly, the "reference scenario" describes the situation of 2017 (before implementation of ThermaFLEX measures and installations) and the scenario "ThermaFLEX Grid optimization" describes the situation of 2021 with the district heating grids NHW and BEL interconnected and bidirectional heat exchange between the grids enabled. The shift from fossil to renewable energy carriers has a significant impact on GHG emissions which are decreasing from 6,500 t CO_2eq/a to 2,100 t CO_2eq/a and corresponds to specific emission factors between 247 g CO_2eq/kWh and 80 g CO_2eq/kWh heat supplied. Due to the large share of biomass and the lower heating value of biomass, the primary energy demand increases from 57,900 MWh/a to 84,200 MWh/a and corresponds to specific primary energy demand between 2.2 MWh/MWh and 3.2 MWh/MWh heat. However, the fossil share of primary energy decreases by 71% from 27,700 MWh/a to 8,000 MWh/a.

3.3.3 Roll-out scenarios and market potential

To identify potential follow-ups of the demonstrated ThermaFLEX measure, existing district heating grids were filtered by proximity to other district heating grids by the distance between the available coordinates of the networks (provides a single location per district heating grid, used methodology described in Chapter 3.1).

The number of potential reproducers for interconnecting district heating grids depends on the maximum distance allowed between two neighbouring grids. It increases with the maximum feasible distance and was evaluated to 214 at a maximum distance of 1 km, to 490 grids for 2 km and to 893 for 3 km.

For the 490 DH networks that are less than 2 km away from others, the potential joint demand was investigated. For 199 of these district heating networks no information on their annual demand is available. The majority (153) of the remaining district heating grids have an annual demand below 1 GWh. 90 grids show an annual demand between 1 and 10 GWh. Further 43 district heating grids have an annual demand between 10 and 100 GWh and the remaining five grids serve an annual demand above 100 GWh. Due to the lack of more detailed geospatial data for district heating grids this approach is not exact. This means that there might be further district heating grids that could be interconnected, because they are actually closer to each other than the geographic information of the single coordinates indicates. Nevertheless, this approach provides a valuable estimation of the general potential for a roll-out of the demonstrated ThermaFLEX measure.

[17] Kaisermayer V, Binder J, Muschick D, Beck Gü, Rosegger W, Horn M, Gölles M, Kelz J, Leusbrock I, Smart control of interconnected district heating networks on the example of "100% Renewable District Heating Leibnitz", Smart Energy (2022), doi: https://doi.org/10.1016/j.segy.2022.100069

3.4 Large scale solar integration Mürzzuschlag

3.4.1 Demo description and realized concept

The demonstration of large scale solar integration in the district heating system of Mürzzuschlag aims to proof feasibility of a large solar-thermal system in combination with storage, targeting the decarbonisation of the energy supply mix and the decrease of dependence on energy imports. Next to high solar shares storages will be used for solar and biomass in parallel operation to use synergies. The first construction phase with 5,000 m² of solar area and 180 m³ of storage was implemented in 2020 (see Figure 9).

Figure 9: Solar plant in Mürzzuschlag (Source: Klimafonds / Krobath)

The heat producers currently supply the grid in Mürzzuschlag are distributed over 5 locations. Solar and biomass capacities will be extended in 2022 and 2023. Therefore, the planed extension of the large scale solar plant by another 2,000m² as well as storages (120 m³) was investigated and simulated. The expansion of the solar system and part of the new storage tanks near the solar plant have been scheduled for 2023. In addition, additional storage facilities in the network centre are foreseen as next step.

3.4.2 Monitoring and system evaluation

3.4.2.1 Large scale solar system

The monitoring results served two primary purposes. Firstly, they were used to enhance the accuracy and design of simulations by incorporating the collected information. This helped to improve the reliability and precision of the simulated models. Secondly, the monitoring data was utilized to optimize the operation of both the solar plant itself and the entire system. By analyzing and interpreting data from numerous sensors, operators could optimize the operation of the solar plant and make informed decisions for the overall system.
The collected data encompassed various state variables, such as temperatures, pressures, and volume flows, which provided insights into the condition of each component within the system. This information was crucial in understanding the performance of different parts of the system and identifying any potential issues. Furthermore, data from actuators in the system were analyzed to evaluate the functionality of the control system, ensuring that all components were operating as intended.
Moreover, apart from the sensors within the solar plant, communication with the district heating network control system was established. This allowed for the exchange of important data between the solar plant and the district heating network control system, enabling synchronized operation of all production units.

This coordination ensured optimal integration and performance of the solar plant within the broader district heating network.
Overall, the monitoring data played a vital role in improving simulation accuracy, optimizing the operation of the solar plant and the entire system, and enabling effective coordination with the district heating network control system.

3.4.2.2 Life cycle assessment

The objective was to increase the renewable share of the heat supplied in the district heating grid by a solar thermal field and an additional biomass plant and thus to substitute shares of heat supplied by natural gas. In total three scenarios were analysed and compared

- In the reference scenario the heat to the district heating grid is supplied by two biomass heating plants (1.5 and 2 MW_{th}) and three natural gas heating plants
- In the scenario "ThermaFLEX 2021" a solar thermal plant with 5,000 m2 as additional heat source is connected to the district heating grid, including heat storage of three times 60 m³.
- In the scenario "ThermaFLEX 2022" the solar thermal field is extended by additional 2,000 m2 of solar collectors, including two additional heat storages with 60 m³ each. A third biomass heating plant with 2 MW is connected.

The heat supplied by the heating systems is 28,505 MWh/a in all three scenarios. The energy carrier mix shifts from fossil carriers to renewable carriers: in the reference scenario the renewable share is 70%, in "ThermaFLEX 2021" 72%, and 92% in "ThermaFLEX 2022". The shift from fossil to renewable energy carriers has a significant impact on GHG emissions of the three scenarios, especially from the reference scenario to "ThermaFLEX 2022" with GHG emissions decreasing from 2,975 t CO_2eq/a to 1,114 t CO_2eq/a. This corresponds to specific emission factors between 104 g CO_2eq/kWh heat in the reference scenario and 39 g CO_2eq/kWh heat in "ThermaFLEX 2022". The primary energy demand of slighty decreases from 36,687 MWh/a in the reference scenario over 36,383 MWh/a in "ThermaFLEX 2021" and 35,480 MWh/a in "ThermaFLEX 2022". Although the overall primary energy demand remains comparable in the three cases, the fossil share decreases by nearly 70% from 13,277 MWh/a in the reference case, to 4,145 MWh/a in "ThermaFLEX 2022".

3.4.3 Roll-out scenarios and market potential

In the roll-out scenario for large scale solar plants the national potential of heat produced from solar energy in district heating grids was evaluated. The solar potential for roof-top and open field amounts to 340 TWh/a and for open field to 296 TWh/a within a radius of 1 km distance to district heating grids. This is an overestimation on the actually usable potential of solar energy for district heating because it neglects the heat demand in the district heating grids. Hence, the actually usable solar potential needs to be limited by the heat demand.
Given an annual heat demand for a district heating grid, the solar potential at its location and a maximal solar production factor in terms of the annual demand (e.g. 10 %) the actual potential is the minimum of the solar potential and the production factor multiplied with the heat demand. With this limited potential the potential for direct solar usage for heat production can be calculated. With a solar production factor of 10 % the roll-out potential for the considered district heating grids would amount to 780 GWh and for a solar production factor of 20 %, the total potential increases to about1,500 GWh.

3.5 Retrofit and heat pump Saalfelden

3.5.1 Demo description and realized concept

For the comprehensive demonstration and evaluation of a retrofitting concept combined with the integration of a heat pump, a 2-step modernization process was started in the DH network of Saalfelden. The biomass heating plant Saalfelden was built in 1996/1997 and supplies 50 customer stations via the 5.3 km long district heating network. The heat in the biomass heating plant is mainly generated by a 2.5 MW biomass boiler and a 0.3 MW economiser. A 5 MW gas boiler and a 0.4 MW electric instantaneous water heater are located in the plant as a failure reserve and to cover peak loads. As an additional failure reserve, Salzburg AG operates a gas boiler system in the Saalfelden elementary school with an output of 0.4 MW.

During the first stage the existing heating network was comprehensively retrofitted and different measures were developed and implemented. These measures cover adaptations to the existing biomass furnace incl. performance increase of the flue gas condensation and improved flue gas cleaning, implementation/renewal of the control technology, implementation of buffer storage and buffer management, implementation of a flue gas cleaning system in combination with the flue gas condensation (see Figure 10) as well as in the heating network (targeted network expansion, optimization of the network temperatures, renewal of the thermal hydraulics, etc.).

Figure 10: Flue gas condenstation and biomass boiler in Saalfelden (Source Klimafonds / Krobath)

After implementation the retrofitting measures were monitored and evaluated during the whole operation phase. The heat generated of the biomass and gas boiler, the economizer and the flue gas condensation unit were continuously recorded. In addition, the in- and output energy flows from the heat storage were monitored and a proper storage management was implemented. The implemented measures resulted in a significant increase in the energy efficiency of the existing biomass boiler and a reduction in the fossil share in the energy mix.

3.5.2 Monitoring and system evaluation

During the first stage the existing heating network was comprehensively retrofitted, and different measures were developed and implemented. These measures cover adaptations to the existing biomass furnace incl. performance increase of the flue gas condensation and improved flue gas cleaning, implementation/renewal of the control technology, implementation of buffer storage and buffer management as well as in the heating network (targeted network expansion, optimization of the network temperatures, renewal of the thermal hydraulics, etc.).
During the monitoring phase, the power output of the biomass furnace, the gas boiler, the economizer and the flue gas condensation were measured. In addition, the power in- and output of the heat storage were monitored. In the initial situation (2019), the yearly output of all units was around 13 GWh. While the share of the gas boilers was 11,3%. After the retrofitting process, which took place in 2020, the total yearly output of the district heating has increased to nearly 15 GWh. Despite the higher total generation, the share of the gas boiler could be reduced to 3,7%. This leads to a reduction of around 1 GWh of natural gas and therefore a reduction of 200t CO_2 emissions per year.
The gas boiler was mainly used to produce energy in peak load times (Winter months) and during maintenance times of the biomass unit (usually 1 month during Summer). In comparison, after the retrofitting, the operating hours of the gas unit in the winter month has been reduced tremendously. The main infeed of the gas boiler took place in July 2021, when the biomass unit was under maintenance. The same effect can also be seen when the production in the winter months January and February is compared. For example, the share of power output of the gas boiler between 2019 and 2022 was reduced from around 25% in January 2019 to less than 1% in January 2022 and from 15% to around 3% in February. One reason for the reduced usage of the gas fired unit is the performance increase of the flue gas condensation and optimization of the network temperatures. As a consequence, the energy production of the economizer and the flue gas condensation has more than doubled from around 700 MWh in 2019 to 1.500 MWh in 2021. A further reduction of natural gas could be achieved due to the installation of a heat storage (150 m^3) including a proper storage management system. Via the heat storage the overall power output can be increased by almost 3,000 kW. Thereby the supply could often be ensured only with the infeed of biomass, even in winter peak load hours.

3.5.3 Roll-out scenarios and market potential

Based on these results and findings, technical concepts for the integration of a heat pump to further increase efficiency and the share of renewable energy in the energy mix were developed. The integration of a heat pump pursues the following main objectives:

- Provision of additional power capacity for network expansion in the range of 1.5 – 2 MW
- Increasing the overall efficiency of the heating plant through flue gas condensation and thus recovering heat from the flue gas
- Further reduction of fossil energy use for peak load coverage

The detailed technical design of the heat pump integration in terms of performance, temperatures, efficiency (COP) etc. as well as hydraulic integration was investigated. By integration into the return line of the biomass boiler and cooling the return flow of the flue gas condensation from currently approx. 52 °C to approx. 35 °C in combination with the heat pump, a considerable increase in efficiency of the flue gas condensation will be achieved. The district heating return serves as the heat sink. Thus, the energy is used for preheating the boiler circuit. Simulations and calculations result in a further increase in performance and efficiency as well as to an optimization of the heat recovery from the flue gas condensation process. The investigations show that the optimal power output of the heat pump is around 650 kW, with a COP between 4.5 and 5. It is also planned to increase the network capacity in the range of 1.5 - 2 MW, in order to reduce grid losses. The implementation of the heat pump and a further expansion of the DH network is planned for 2023.
Biomass-based district heating systems represents an important component in Austria’s heat supply. Currently, appr. 2,400 biomass heating plants and about 150 biomass CHP plants in Austria[18] are operational. The total energy production from DH is about 85 PJ with a biogenic share of 48% (produced in biomass-based DH systems). The main users of DH are private households (45%), the commercial (40%) and the industrial sector (15%).
Biomass-based DH networks are also quite common in neighbouring European countries (Germany, Switzerland, Italy) and the EU and similar challenges like the Austrian based systems represent huge potential for export of national know-how and technologies in this field.

[18] Strimitzer (2021) Biomasseheizungen in Österreich – Energieholz Marktentwicklung 2021; Österreichische Energieagentur, Wien, 2021.

3.6 Eco-energy park Salzburg

3.6.1 Demo description and realized concept

The eco energy park Salzburg includes two flexibility measures for the demonstration of the usability of an absorption heat pump (AHP) on an industrial scale. The first flexibility measure covers the development of a so-called eco-energy park in the south of the city Salzburg which is currently postponed and will be re evaluated once the regulative framework conditions are specified. Therefore, the developed concept of the eco energy park Salzburg is not described further within this report.
The second flexibility measure covers the implementation and optimisation of a new absorption heat pump to increase the waste heat utilisation of unusable low temperature waste heat of a largescale waste heat source at the cellulose manufacturer AustroCel in Hallein. An existing absorption heat pump, which was in operation from 2006 to 2018, was taken out of service and replaced by a new absorption heat pump after several damages and repairs over the last years. Figure 11 shows the absorption heat pump after the implementation phase at AustroCel Hallein GmbH.

Figure 11: Implementation of the new absorption heat pump, Source: Klimafonds / Krobath

The operating conditions are also similar to the old absorption heat pump with only a difference in the heating capacity which is now 8 MW. The installation of the absorption heat pump was started in October 2019 and finalised during November 2019 and January 2020. After the commissioning phase the absorption heat pump started it’s trail operation in February 2020. Final adjustments and parameter settings at the absorption heat pump were carried out at the end of 2020. Furthermore, there were some challenges with the operation of the absorption heat pump, which were finally solved during the first half of 2021.

3.6.2 Monitoring and system evaluation

3.6.2.1 Absorption heat pump operation

Data for the monitoring was collected from July 2020 until March 2022. Detailled monitoring was performed for a full year between April 2021 and March 2022. In this phase external volume flows and temperatures at the absorber, condenser, desorber and evaporator were measured. The corresponding external energy flows as well as the Coefficient of Performance (COP) of the AHP were derived from the measured temperatures and volume flow rates.
Figure 12 shows exemplarily the the monitored data of week number 15 in 2021 (Explanation: energy flows (1), COP (2), volume flows (3), temperatures (4)). In the first diagram the energy flows are shown. The energy output (energy of absorber, condenser and heat recovery, red line) which was delivered to the heat distribution system Q_{dh} was rather constant at around 7.5 MW, while the input energy at the desorber (Q_{hw}green line) was at approximately 4.5 MW. The blue line which shows the recovered heat flow from the flue gas ($Q_{so,EVA}$) can be seen as “free energy” and was at approximetlly 3 MW. In the second diagram the COP is shown, which was between 1.7-1.8 Furthermore, in the third and fourth diagramm the corresponding measured volume flow rates and temperatures are shown.

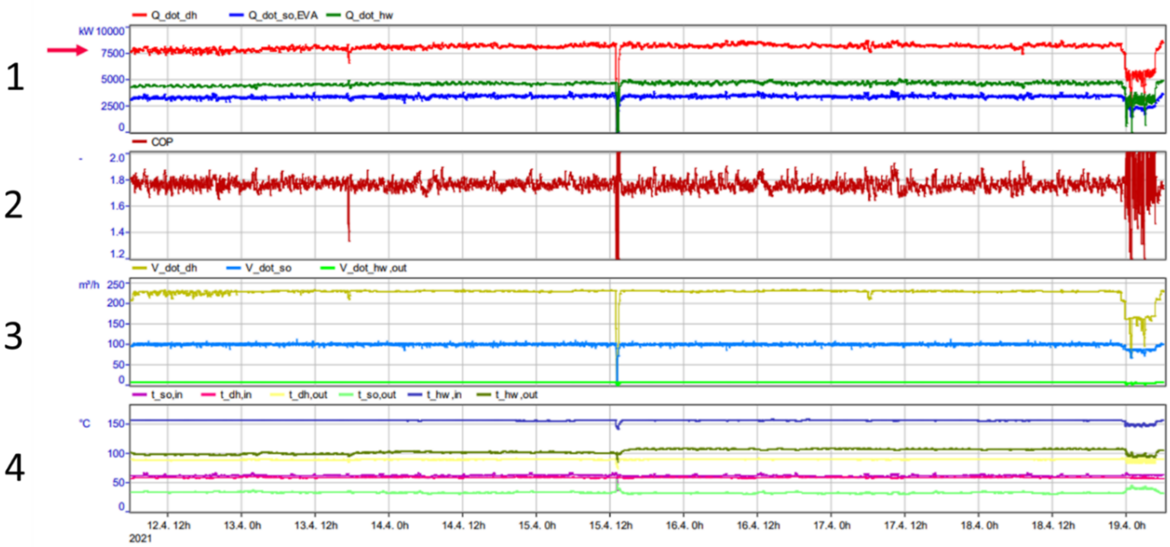

Figure 12: Monitoring data of the AHP in week number 15, 2021 (Source: TU Graz)

The power output of the AHP from April 2021 to March 2022 amounts 48,300 MWh leading to a CO_2 reduction of 9,660 to (in the reference case the equal amount of energy would have been produced with an gas boiler). It should be noticed that, due to external factors (limited input energy from the biomass plant of the cellulose manufacturer due to a reduced production), the AHP was mainly operating at around 6 MW.

3.6.2.2 Life cycle assessment

For LCA two scenarios were analysed and compared. As reference scenario a natural gas boiler is assumed to supply the same amount of heat as natural gas boilers are part of most district heating systems for larger grids, which need to be substituted midterm on the path towards climate neutral heat supply. In the scenario “ThermaFLEX AHP” an absorption heat pump utilizes heat of the exhaust gas stream of an industrial biomass CHP-plant from flue gas condensation. The AHP is operated with low temperature heat (from flue gas condensation) in the evaporator and high temperature heat in the

generator (from biomass boiler). Lithium-Bromid is used as solvent. The system boundaries include the materials for the construction of the AHP and the upstream processes for the additional biomass to the CHP boiler required to supply the high temperature driving heat of the AHP. The operation of the AHP requires a minor amount of electricity for the fluid pumps. The CHP plant is part of the industrial site as the primary user of the generated process energy and therefore not included in the system. Due to lacking data from the industrial operator, the impact of the additional biomass used in the CHP plant on its overall operation (shares of electricity and heat generated) has not been considered. Both scenarios were calculated for 53,410 MWh/a heat generation, as it is the expected heat generation for 2022.
The yearly GHG emissions results in 16,829 t CO_2eq/a for heat supplied by a natural gas boiler (reference scenario), which corresponds to 315 g CO_2eq/kWh heat. The scenario “ThermaFLEX AHP” results in 204 t CO_2eq/a, which corresponds to 3.8 g CO_2eq/kWh heat. GHG emissions in this scenario are mostly related to the supply of biomass (10,950 t/a) to the CHP station for the supply of the driving heat (35,080 MWh/a) to the AHP and amount to about 160 t CO_2eq/a. The primary energy demand of the two scenario is 75,168 MWh/a in the reference scenario and of 36,329 MWh/a in “ThermaFLEX AHP”. The fossil primary energy demand in the reference scenario is almost entirely fossil primary energy, while in “ThermaFLEX AHP” the fossil share of primary energy is 205 MWh/a.

3.6.3 Roll-out scenarios and market potential

Absorption heat pumps offer significant potential for utilizing low-temperature heat sources and elevating them to a suitable level for heating purposes. Several absorption heat pumps are currently employed in district heating systems across Europe. In Austria, they are often combined with biomass boilers to ensure the condensation of water vapor in the flue gas. In certain European countries, absorption heat pumps are also utilized for cooling purposes during the summer, where waste heat drives the absorption process. The rejected heat from these systems is sometimes channeled into the district heating network, satisfying the low heat demand during the summer season. This report provides an overview of national and international reference cases showcasing the potential of absorption heat pumps.
However, due to operational constraints and safety considerations, absorption heat pumps are limited to low-temperature district heating systems. Supply temperatures of approximately 90 °C, which may be too low for most district heating systems, can be achieved. To deliver heat to the district heating system, an additional heating system is required to raise the supply temperature above the district heating system's level.
If absorption heat pumps are used as the primary heat source in district heating networks, they should be operated as continuous base load units due to their slow start-up time. Particularly, absorption heat pumps with heating capacities in the range of several MWs require time to start and adjust to changing operating conditions. Additionally, absorption heat pumps are typically coupled with a heating plant, such as biomass or waste heat. In such cases, the performance of absorption heat pumps is contingent upon the availability of waste heat and the varying rates of the heating plant, specifically the boiler.
While absorption heat pumps may not offer additional flexibility to district heating networks due to their operational characteristics, they significantly contribute to increasing the share of renewable energy in the district heating system. Furthermore, when combined with waste heat recovery, they can reduce the environmental impact of other processes and simultaneously decrease the reliance on fossil fuels for generating hot water used for heating purposes.

3.7 Renewable heating and cooling from wastewater

3.7.1 Demo description and realized concept

The enormous energy potential available in wastewater and especially in wastewater sewers is continually available, throughout the year. Energy from wastewater reduces import dependence on fossil fuels, such as natural gas. The energetic utilisation of wastewater reduces CO_2-emissions. Within the project the demonstration of a smart renewable energy, waste water based new system for heating and cooling of a new company headquarter of WienKanal located in Vienna-Blumental was realized. The unique combination of innovative heat exchangers, smart monitoring, efficient heat pump systems etc. guarantees the sustainable energetic supply (heating and cooling) of the headquarter. The following highlights and innovative elements were implemented:

- Identification of appropriate sewage lines, volume/mass flows and temperature profiles
- Development of a new innovative wastewater based system for heating and cooling.
- Planning and design, based on the specific requirements of the building and energy system
- Construction and proper integration of the wastewater heat extraction system based on a heat exchanger unit in the sewer and heat pumps for heating and cooling purposes
    - Development and implementation of special heat exchangers (approx.. 80 meters, tailored to the respective sewer) for effective hydraulic connection with subsequent heating/cooling system (heat exchanger performance of about 160 kW (heating case) and 530 kW (cooling case))
    - Two identical heat pumps with a capacity of in total 460 kW for heating and 430 kW for cooling
- Development and demonstration of new, innovative monitoring, remote management and operation control in connection with temperature, volume/pressure, filling level etc. management to increase the efficiency of the wastewater energy utilisation.

The installation of the heat exchangers (see Figure 13), specially produced/tailored to meet the needs of the existing channel took place by the end of 2020. The heat exchangers are made of high-quality alloys and have a special surface configuration for maximum energetic utilization and minimization of biofilm. The modules are double-shell pressure vessels made of stainless steel, which is resistant to pitting and corrosion and is ideally suited for use in wastewater.

Figure 13:Custom made heat exchangers in the existing sewer (Source: Rabmer)

3.7.2 Monitoring and system evaluation

3.7.2.1 Heat exchanger operation

For heating, energy is taken out of the wastewater (ca. 15 °C) using a special heat exchanger system. The heat transfer medium is water. With the compression heat pump the temperature is raised to the required level (40-70 °C). An innovative monitoring system was developed and used for the first time in Austria in this form to secure operation of the required heating and cooling capacity. Furthermore, the influence on the sewer operation (filling levels, influences on temperatures due to energetic use, hydraulics) were controlled continuously. The data transmission for the monitoring was realized as a redundant system, web-based and via the central control facility of the headquarters. Main findings were listed below:

- The monitoring system has been working trouble-free.
- Heat exchangers and heat pumps can secure the necessary cooling and heating capacity, spreading for the heat pumps etc.
- The installed system can supply 100% of the office´s heating and cooling needs.
- The temperature changes in the sewer in the case of heating and cooling are lower than in the design and there is no negative impact on sewer operation
- Based on the project experience, the innovative monitoring will be mandatory for new projects in Austria, a rollout of 20-40 plants in the next few years is to be expected.
- Findings are already being used for new projects in Austria (planning, tendering, operation, monitoring).

3.7.2.2 Life cycle assessment

Within this demonstration case two scenarios were analysed by performing a life cycle assessment. As reference scenario a natural gas boiler is assumed to supply heat (495 MWh/a) and cooling demand (200 MWh/a) is produced by a conventional compression chiller. Natural gas boilers are part of most district heating systems for larger grids, which need to be substituted midterm on the path towards climate neutral heat supply. The compression chiller is operated with 100% PV electricity from the roof-mounted modules. Excess PV electricity fed into the public grid is considered to substitute the average Austrian electricity mix in the grid, which results in an emission credit. In the scenario “ThermaFLEX” a heat pump supplies heat from wastewater from the urban sewage system to a new office building, in winter for heating and in summer for cooling. The system comprises a heat exchanger located in the sewer, a heat pump and heat/cold storage. The heat pump is operated with electricity from PV modules on the roof of the office building, the rest is supplied via the public grid. PV electricity is 100% used for the heat pump.

The reference scenario results in 168 t CO_2eq/a, with 156 t CO_2eq/a for from gas boiler operation for heating energy and 12 t CO_2eq/a for cooling energy from the compression chiller operated with electricity from the roof-mounted PV. Together with -25 t CO_2eq/a emission credit for the PV electricity fed into the public grid, overall GHG emissions in the reference scenario sum up to 143 t CO_2eq/a. The ThermaFLEX scenario results in 19 t CO_2eq/a, with 14 t CO_2eq/a from PV electricity for heat pump operation and 5 t CO_2eq/a from upstream material related emissions for the construction of heat exchanger, heat pump and storages. The primary energy demand is comparable in the two scenarios: 748 MWh/a in the “ThermaFLEX” scenario, 707 MWh/a in the reference scenario including the PV credit and 921 MWh/a without PV credit respectively. The share of fossil energy demand shows a bigger difference, with 60 MWh/a in the "ThermaFLEX" scenario and 624 MWh/a (considering 107 MWh/a PV credit) in the reference scenario.

3.7.3 Roll-out scenarios and market potential

In order to implement the measure of extracting heat from sewage channels a minimum pipe diameter of DN 400 mm, a minimum flow of 10 l/s, a minimum water temperature of 8 °C and proximity to heat demand or a district heating grid is required. Unfortunately, data for waste water pipes with these parameters and geospatial information is not available for all over Austria. However, limited data is available for individual cities (e.g. Vienna) and municipalities. These could act as frontrunners in this regard.

3.8 Waste heat utilisation spa Vienna

3.8.1 Demo description and realized concept

The overall system was developed to utilise the waste heat of the thermal (waste)water of "Spa Vienna" located in the district "Wien-Oberlaa". The system is based on two water-cooled compact heat pumps that supply the DH network with about 2,2 MW, depending on the temperature and the mass flow of the source. Within the concept development phase, the whole system (thermal spa/bathing and energy system) was analysed regarding the thermal (waste) water characteristics in terms of availability, temperature levels, chemical properties, etc. Due to its variations in temperature and mass flow hydraulic separators are used on the cold side of the system. Due to the corrosive thermal water, plate heat exchangers made of Titan, separate the heat pumps from the thermal water.
The heat pumps, illustrated in Figure 14, are designed to get a maximum output temperature of 84°C. An additional electrical boiler of 375 kW thermal energy increases the temperature up to 90°C if the outdoor temperature is below -5°C (reference is the heating curve of the nearby located secondary district heating network). The heat pump system was placed in the underground parking lot and an appropriate engine room has been built. The heat pumps were designed as water-cooled compact heat pumps and consist of two identical heat pumps (single-stage high-pressure heat pumps based on piston compressors) with ammonia (NH_3, R717) as refrigerant.

Figure 14: Heat pump system at spa Vienna (Source Klimafonds / Krobath)

The following innovative aspects were implemented and realized within the whole concept:

- The refrigerant ammonia was chosen for the heat pumps due to the low GWP and ODP value. The leakage of ammonia can be deadly for humans, therefore special safety precautions have to be carried out: gas sensors, a special ventilation system and a scrubber. The implementation of the scrubber was an additional demand of the local authorities.

- The existing medium voltage system of spa Vienna had to be increased for the heat pump system. The assembly operations took place for a very short period of time during one night. Therefore, the electricity grid connection was fully interrupted for the expansion of the medium voltage system. The electrical supply for the heat pumps is provided by the public electricity grid of the City with 20 kV. For this purpose, a so-called "Three-winding transformer" (approx. 1,315 kVA) with 2 secondary voltage levels (690 V and 400 V) was integrated in a not equipped transformer box. The transformer supplies 2 switchboards in the electric room.
- A connection between the secondary district heating system and the heat pump system was built. The profiles of heat source (wastewater) and sink (district heating) have to be matched: Therefore, to ensure a sufficient energy input to the sink at the needed temperature level, the following technical and digitalisation aspects were implemented: Hydraulic separators and a communication system between the existing heat exchangers and pumps of the district heating and the heat pump system.
- Connection with the thermal (waste)water: The assembly operations for the connection between heat pump system and sink had to take place during the night because of emptying the existing piping system.
- Use of special material due to hydrochemical composition of the thermal water: The thermal water is very corrosive and cannot be connected directly to the heat pumps. An intermediate circuit is necessary. In order to choose the best material for the intermediate circuit, especially the heat exchangers, some evaluations of the existing piping system were performed. Samples were taken of the i) thermal water and ii) of the precipitates in a dismounted heat exchanger. The results of the hydrochemical analysis showed a very high amount of sulphate (up to 1,400 mg/l). The results of the analysis of the solids showed a very high amount of elemental sulphur, but also high amounts of Cr, Ni and Mo. This leads to the assumption that the corrosion led to erosion within the heat exchanger and/or the piping system. Therefore, a heat exchanger with titanium coating was chosen in the intermediate circuit.

3.8.2 Monitoring and system evaluation

Heat pump integration and installation was finalized within the first half of 2022 and first monitoring data of the commissioning were analysed. The following exemplary analysis focuses on a stationary operation (28.10.2022, 8:54 to 11:05 am). The inlet temperature of the thermal water was on average 37.3±0.2°C, the inlet temperature of the evaporator was on average 36.7±0.1°C. The condenser outlet temperature was on average 78.9±0.2 °C and the evaporator outlet temperature was on average 28.7±0.3 °C. The difference between those to temperatures (so-called lift) has a big influence on the efficiency of the heat pump system: The higher the lift, the lower the efficiency. The heating capacity was on average 769.2±22.9 kW and the cooling capacity was on average 685.0±20.9 kW. As sufficient long time monitoring data for this demonstration case was not yet available the assumed KPI´s were an increase in renewable heat production of about 11 GWh/a and a reduction of 2,600 to CO_2eq/a.

3.8.3 Roll-out scenarios and market potential

The objective in the roll-out scenario for Spa Vienna is to identify potential spas in Austria, where the concept investigated for Spa Vienna can be reproduced. For this purpose a dataset of Austrian spas is used. The dataset includes 45 spas with information on the water temperature and the spring flow. Regarding the temperature the spas are categorized in the groups <20 °C, 20-37 °C, 37-70 °C, 70-100 °C and >100 °C. The majority of the spas (33) has a water temperature between 20 °C and 70 °C. Nine spas have a water temperature below 20 °C and three spas have a water temperature above 70°C. With respect to the spring flow the spas are grouped into three categories. 18 spas have a flow below 5 l/s, 16 spas have a flow between 5 and 25 l/s and 11 spas have a spring flow above 25 l/s.

3.9 High-temperature heat pump Spittelau

3.9.1 Demo description and realized concept

The demonstrator aims to build a waste heat recovery system in the waste incineration plant Spittelau (see Figure 15). The waste heat from the flue gas and the cooling water will be used as a source for the DH network in the city of Vienna. As a result, the thermal capacity of the incineration plant will be increased from 60 MW to approximately 76 MW.

Figure 15: Waste incineration plant Spittelau (Source: Wien Energie / Schedl)

In the following the key functions of the different technical elements were explained briefly: The extraction of the latent heat from the flue gas is realized by water vapor condensation in a packed column and will be installed directly after the second stage of the SO_2 scrubber system within the flue gas cleaning section. One packed column is required for each incineration line (of in total two). An appropriate heat exchanger transfers the heat from the condensate circuit to an internal intermediate circuit which is directly connected to the high-temperature heat pump section. The calculated supply temperature is around 52°C and the return temperature to the heat exchanger is approximately 42°C. The condensate is partly recirculated into the packed column (as the cooling medium for the flue gas) and partly discharged and purified by a multi-stage water treatment plant, including an ultrafiltration, a reverse osmosis and an activated carbon filter. The treated condensate will be used within the waste incineration processes later on. In addition, the waste heat from the cooling water system, the oil coolers and the engine cooling will also be utilised through the high-temperature heat pumps. The simulated waste heat capacity of the cooling water system is around 1.5 MW and will be with utilised by another (small) heat pump system within an inlet temperature of about 30°C. The large high temperature compression heat pumps have a total thermal capacity of approximately 16 MW_{th}. The output temperature (90°C) is further increased by steam generated in the waste incineration plant up to temperature levels required for the primary district heating network of about 110°C – 150°C. The main benefits and innovations of the demonstration case are summarized below:

- Increase of the overall efficiency of the incineration plant
- Integration of waste heat into the district heating network
- Primary energy reduction for district heating supply
- CO_2 reduction in the heat generation
- Reduction of heat supply in the cooling water system and the "Donaukanal"
- Reduction of wastewater mass flow to the subsequent wastewater treatment plant
- Internal use of the condensate generated

The current planned main milestones and timelines are summarized in the following:

- Q3/23: engineering and construction work
- Q2/23: installation of packed column of the second incineration line during major overhaul
- Q3/23: installation of first high-temperature heat pump
- Q2/24: electric and control installations
- Q2/24: installation of packed column of the first incineration line during major overhaul
- Q3/24: commissioning, performance test and optimisation

3.9.2 Monitoring and system evaluation

As a result, the thermal capacity of the incineration plant will be increased from 60 MW to approximately 76 MW. Due to the complexity the implementation is still in process and consequently monitoring data for this measure is not yet available. The assumed increase in renewable heat production is about 100 GWh/a with a reduction of about 23,000 to CO_2eq/a.

3.9.3 Roll-out scenarios and market potential

The complexity and roll-out of this demonstration case yields in a less potential number of reproducers. Nevertheless, there are further waste incineration plants in Austria with different latent heat potentials that can be used. The total unused latent heat from waste incineration plants in Austria amounts to approximately 118 MW.

3.10 Demonstrator summary

Within the timeframe of ThermaFLEX, large-scale decarbonization measures and implementations were already realized within eight (8) linked demonstrators. These measures showcased the great potential of the developed elements and solutions within ThermaFLEX to provide sustainable and flexible district heating supply in different Austrian cities and regions. Based on monitoring and simulation data, sustainbalbe heat will be generated in the range between 180 and 200 GWh/a in future with the realized implementations leading to a yearly substitution of around 45,000 tons of CO_2.

4 User and stakeholder integration

Chapter 4 includes an explanation of the role of social acceptance as well as relevant user and stakeholder integration aspects realized within ThermaFLEX. For a broad stakeholder integration a specific approach was developed for each demonstration site. Furthermore, a mobile application "EnergieApp" to establish a connection with userswas developed.

4.1 The role of social acceptance

Climate change and its consequences are among the greatest challenges for our society. Social acceptance of renewable energy innovation has often been underestimated by energy suppliers, authorities or private investors in the past. Following Wüstenhagen et al.[19] social acceptance can be understood by distinguishing three dimensions: Socio-political acceptance which means acceptance on the broadest, most general level by the public, the policymakers or key stakeholders and which very often is quite high concerning renewable energy technologies and policies. Community acceptance refers to the specific acceptance of renewable energy projects by local stakeholders, local users (residents) or local authorities which very often has a time dimension following a U-curve from high acceptance before the project to relatively low acceptance during the implementation stage back up to a higher acceptance once a project is running. Market acceptance finally can be interpreted as the process of market adoption of an innovation and does not focus on end-users alone but also on investors.
The citizen dialogue "Bürgerdialog. Energiezukunft"[20] implemented on behalf of the Austrian Climate and Energy Funds has shown that more than half up to two-thirds of the Austrian population knows about the classical renewable energy sources (solar, wind, hydro) and renewable energies get significantly higher rates than non-renewable energy sources. However, still, there is a lack of knowledge and understanding about renewable energy technologies and innovations. Combined with misinformation (e.g. higher costs), this fact leads to barriers and a lower acceptance and demand for renewable energy technologies in practice. Ideas and suggestions for increasing the acceptance comprise better, user-specific, transparent, objective and more personal information, usability, user integration, prototyping and testing and evaluation as well as simple framework conditions or incentives and funding schemes for related projects. The work were closely related to the specific demonstration cases. To show pathways for enhanced user integration in DH development plans, different contents were completed:

- Identification and analysis of relevant user groups and strategic stakeholders in cooperation with GEL (Green Energy Lab)-Innovation Lab
- Establishing user integration labs for selected demonstration cases
- Defining case specific user integration and stakeholder involvement plans based on the stakeholder analysis and relevant project specific framework conditions
- Providing ongoing transparent, objective and user specific information (via on-/offline communication)

---

[19] Wüstenhagen, et al. (2007) Social acceptance of renewable energy innovation: An introduction to the concept. In. Energy Policy 35 (2007) 2683-2691
[20] https://www.klimafonds.gv.at/press/laut-studie-65-prozent-der-bevoelkerung-an-erneuerbaren-energien-interessiert/, Zugriff am 01.03.2022

- Accompanying the innovation process applying various open innovation methods (e.g. design thinking, co-creation workshops, prototyping)
- Development of business model proposals, energy service companies (ESCO) and customer loyalty concepts for DH operators and heat suppliers on base of ThermaFLEX demonstrators
- Development of tools such web and mobile applications for increase user integration and identification and to supply necessary data for e.g., operators, planners and municipalities
- Activities Leibnitz as starting point, other demonstrators as follow-ups
- Supporting of activities in other work packages regarding stakeholder processes
- Integration of ThermaFLEX results and experiences on user integration in GEL-Innovation Lab

4.2 Stakeholder integration

The main objective of this part of ThermaFLEX was to assess the acceptance issues and stakeholder structure of the demonstrators in order to evaluate the social feasibility of the planned innovations in ThermaFLEX, alongside technical and economic feasibility. It was essential to develop appropriate tools for stakeholder engagement to ensure transparent and comprehensive communication with end customers (private households, trade, and industry) regarding innovative solutions within the district heating networks, with the ultimate aim of attracting new customers.

In general, stakeholders are individuals, groups, or organizations who are directly or indirectly affected by a planned project and have the potential to influence it. For the project, it was crucial to consider stakeholders both within the demonstrators (management, technical staff, legal experts, personnel, works council, etc.) and outside (local politicians, neighbors, business/cooperation partners, associations, interest groups, etc.). The stakeholder analysis for each demonstrator aimed to achieve the following objectives: i) identifying relevant stakeholders, ii) assessing their level of involvement and attitudes toward the project, iii) understanding their interests, needs, resources, and competencies, and iv) providing the project team with an internal strategic basis for deciding whether and how stakeholders should be involved in the project's future course.

By conducting a comprehensive stakeholder analysis, the project team sought to ensure effective stakeholder engagement, gain support from key stakeholders, and make informed decisions regarding stakeholder involvement throughout the project. This approach aimed to enhance the project's social feasibility and maximize stakeholder satisfaction and acceptance of the innovations being implemented in the district heating networks.

In order to obtain an overview of the stakeholder landscape of the individual demonstrators, a quick scan and a stakeholder analysis were set up and applied to all demonstrators.

This analysis is based on a Quickscan with questions and assessments, the results of which flow into a stakeholder matrix. The objective of the quick scan is to take stock of the demonstrators in terms of acceptance issues and the stakeholder structure in order to check the social feasibility of the (process) innovations planned in ThermaFLEX at an early stage, in addition to the technical and economic feasibility. The stakeholder analysis template can be found in Appendix B: Stakeholder analysis template.

After the first survey (Quickscan) and answering of questions, the second step of the stakeholder analysis asked for the degree of affectedness as well as the attitude towards the project. Each stakeholder was rated on a scale of 0-4. The results were illustrated in a stakeholder matrix. An exemplary example is shown in Figure 16 and the resources/competencies were visualized via the size of the circle.

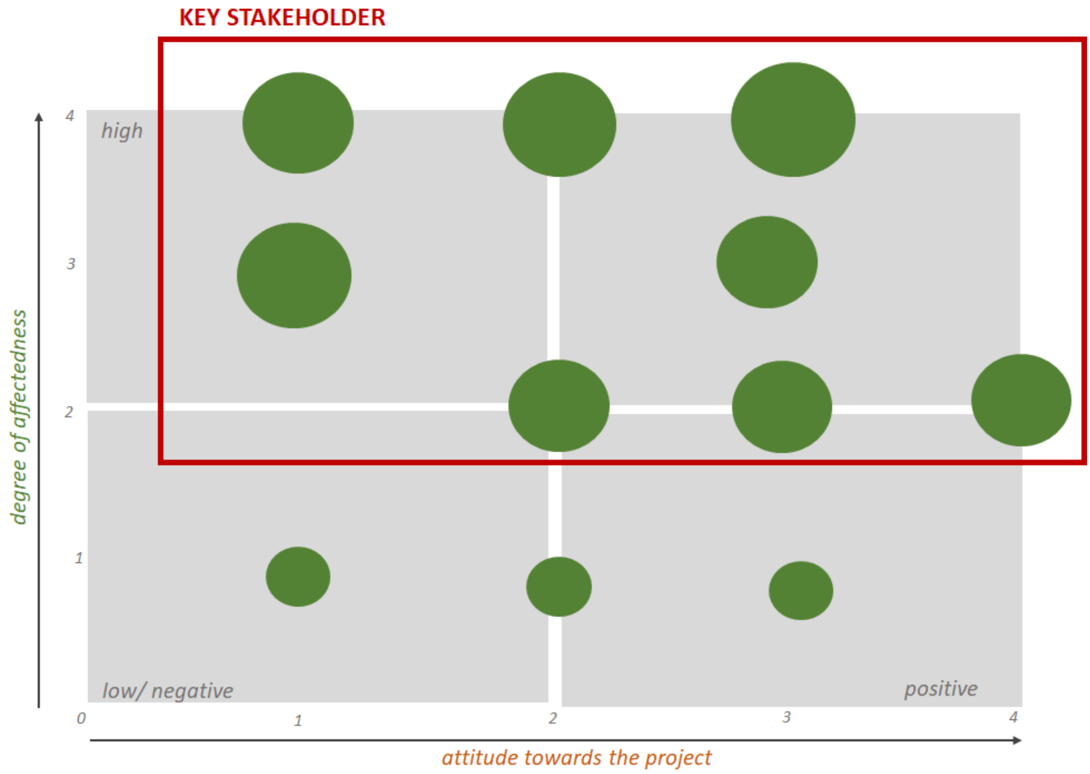

Figure 16: Stakeholder matrix (Source: StadtLabor)

In all the demonstrators, both internal and external actors were identified who needed to be engaged stronger through personal discussions and transparent information. In Salzburg, some demonstrators faced opposition from grassland conservationists and organized civil society groups. It was recommended to initiate early and proactive dialogues with these stakeholders, identify areas of conflict, and work together to find solutions. For the Vienna demonstrators, there were no specific stakeholder-related actions required. However, in Leibnitz and later in Gleisdorf, a communication campaign was launched to inform citizens comprehensively about the expansion of the district heating systems. The aim was to highlight the relevance of these projects for climate protection and position Leibnitz and Gleisdorf as pioneers in active climate policy. Various communication channels were utilized, including press conferences, citizen information points, community newspapers, public information evenings, media partnerships, and brochures.

The evaluation of stakeholder matrices and initial discussions with project stakeholders revealed differing perspectives on stakeholder importance and involvement. While some demonstrators primarily considered stakeholders within the project and immediate project surroundings, others identified a broader stakeholder landscape, including media and citizens. Operational work highlighted the challenges of reconciling different stakeholder strategies and approaches. Despite having similar fundamental motives of sustainability and CO_2 reduction, stakeholders had varying economic and sustainability-focused strategies. Balancing and optimizing these motives and approaches for all stakeholders remained a significant ongoing challenge.

4.3 User integration

To establish a connection with users, the concept for an energy app, called "EnergieApp," was developed. This web and mobile application aimed to enhance user integration, identification, and provide necessary data to operators, planners, and municipalities. The development of the EnergieApp took place in collaboration with another project called "Spatial Energy Planning for Heat Transition" under the Green Energy Lab framework. The app's click prototype was created based on workshops and offered various calculations and information on all aspects of heat supply. The EnergieApp aimed to increase the willingness of potential customers to connect to the district heating network by providing valuable information and support.

5 Roll-out potential and exploitation results

Chapter 5 deals with the impact analysis and general roll-out potential (especially for Austria) as well as gained exploitation results and dissemination activities.

5.1 Roll-out potential

Austria has a rich history of both small and large-scale district heating systems. Several decades ago, large Austrian cities began implementing district heating supply based on fossil fuels and combined heat and power (CHP) plants. In contrast, the establishment of local heating networks powered by solid biomass started in smaller towns and villages during the 1990s. Over the past few decades, district heating has undergone extensive expansion and has become a crucial component of Austria's heat supply.

Currently, the total energy production from district heating in Austria amounts to approximately 85 PJ (petajoules), with a significant biogenic share of 48% produced by biomass-based district heating systems. The primary users of district heating are private households (45%), the commercial sector (40%), and the industrial sector (15%). Presently, district heating systems fulfill about 25% of Austria's spatial heating and hot water demand, and this share is steadily increasing.

Based on research findings, it is estimated that Austria is home to approximately 2,500 to 3,000 local and district heating networks. This highlights the widespread adoption and significance of district heating as a heating solution throughout the country.(see Figure 17).

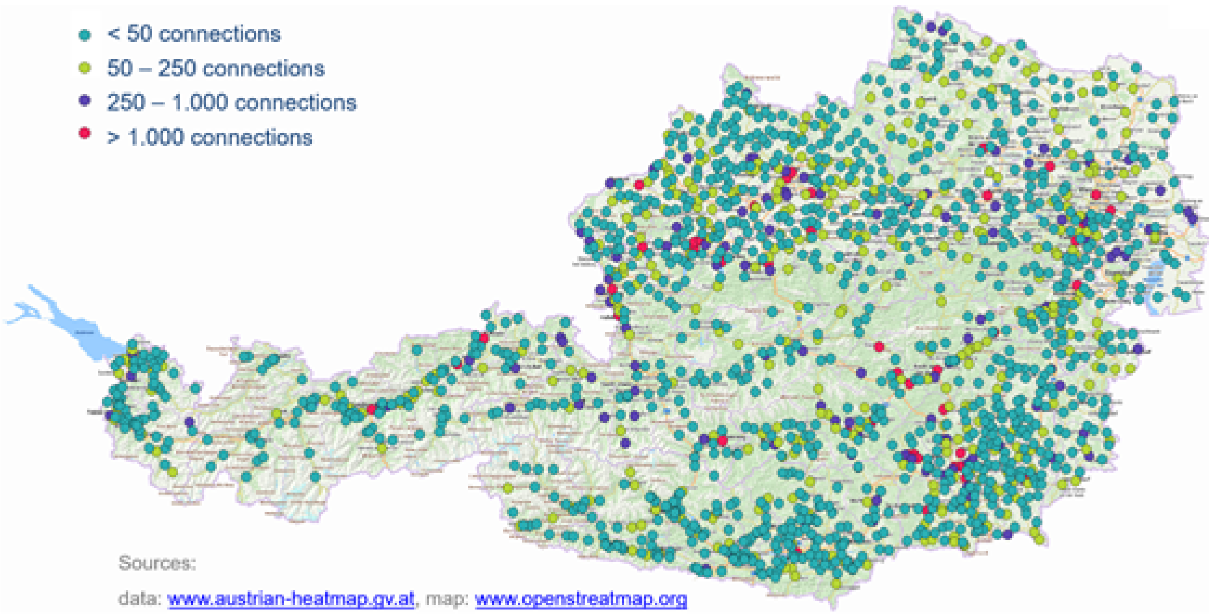

Figure 17: Distribution of DH Networks throughout Austria (grouped by size, Source: AEE INTEC)

The intended target market of DH operators is to include consumers (existing and new customer groups) connected to heating networks including single and multifamily households, recreational facilities, office buildings, industries, etc. The total amount of heat sold in the whole sector in 2020[21] was around 20 TWh and has increased by 73% since 2000 as well as about 2.1 million citizens are served by DH. The total

[21] Statistik Austria (2021) Gesamtenergiebilanz Österreich 1970 bis 2021; Statistik Austria, Wien

pipe length has doubled since 2000 to currently about 5,800 km[22]. In 2020, a total of 23 TWh of district heating was generated in Austria to cover the respective heat demand (20 TWh). The future heat demand will increase up to 27 TWh in 2040 and leads to a heat generation of 31 TWh[23]. This future expansion dynamics will be fostered in combination with the developed flexibility measures and a boost in new customers (especially industry) will undergo constant growth in the coming years. This growth is assumed to accelerate in the coming years due to increased political ambition to decarbonize the Austrian heat supply (e.g. Erneuerbaren-Ausbau-Gesetz – EAG[24], Österreichische Wärmestrategie[25]) and the aim of the Federal Government to achieve climate neutrality for Austria by 2040.
The market potential for the technologies and concepts of ThermaFLEX is thus expected to be much higher in the coming decades than at present. The results from ThermaFLEX and the derived Best Practices are expected to play an integral role in meeting the set emission reduction targets due to the high practical relevance and enable potential market openings for project partners and beyond to initiate the rollout of these technologies and concepts. Furthermore, implementations of ThermaFLEX concepts into the market may open new markets in the near future. DH networks in neighbouring European countries (Germany, Switzerland, Italy) and the overall EU are facing similar challenges to Austria and thus represent huge potential for the export of Austrian know-how and technologies[26].

5.2 Scientific and economic exploitation

Scientific as well as economic exploitation was of high relevance for the scalability and transferability of the gained knowledge and outcomes of the project and was continuously carried out during the entire project. A professional process for exploiting the results including methods and tools for exploitation within the project was developed and carried out. The main goal was an appropriate exploitation plan for the whole consortium as well as for individual partners and identified relevant fields and tasks of exploitation.

Energy suppliers and DH operators

The project provides wide technical and non-technical knowledge to all involved energy suppliers, DH operators and infrastructure owners regarding the flexibilization of their systems, planning and operating these. The results from the demonstrators provide direct input and ideas for daily business, where business models and best practice guides can be directly used. Thus, the operators will be able to further apply these results at numerous sites around Austria where deemed suitable, creating many potential projects for the operators in the future.

Technology / Know-How provider

The knowledge and experience gained from the project support technology/know-how provider in increasing the efficiency of their respective products and services and thus help strengthen each technology and know-how provider's position in the market. Due to new or adapted products/services and concepts from ThermaFLEX, the technology and know-how providers see a considerable increase

[22] FGW (2022): Zahlenspiegel 2022; Fachverband Gas Wärme, Wien, 2022
[23] Österreichische Energieagentur – Austrian Energy Agency (2022): Aktualisierung der Roadmap zur Dekarbonisierung der Fernwärme in Österreich, Wien, 2022
[24] https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=Bundesnormen&Gesetzesnummer=20011619, Zugriff am 27.02.2022
[25] https://www.bmk.gv.at/themen/klima_umwelt/energiewende/waermestrategie.html, Zugriff am 27.02.2022
[26] Euroheat & Power (2023): DHC MarketOutlook Insights &Trends, Brussels, 2023

in their markets with the potential for entirely new openings in related fields. DH and energy networks are highly complex, and no two systems are the same – therefore the providers gained opportunities and extended their gained knowledge in developing a whole range of solutions and technologies best to the needs of the DH networks/customer at hand.

The individual technologies and system solutions analysed and demonstrated within the different demonstration sites led to further improvement in effectiveness through replication and coupling with other technologies/sectors, leading to a stronger collaboration between the providers and further increasing their know-how and public recognition.

Academia & research institutes

The research partners raised their respective status as research institutes and universities on the national and international level through the dissemination and publication of project results, methods and/or tools, simulation and conceptual studies, results of the scientific monitoring and validation. This led to higher visibility and potential increase in share in funded Austrian and European research projects as well as in R&D projects with other companies in the field of heating and cooling beyond ThermaFLEX in the coming years.

Scientific publications of results, especially those resulting from the real-scale demonstrations, were an important measure to further increase its international reputation and visibility and thus also lay the foundations for the acquisition of further research contracts. Publications in journals (peer-reviewed or non-reviewed papers), as well as contributions to conferences (national and international) in the linked fields (e.g. energy systems, renewable and thermal energy, thermal energy storage and intelligent network control), were a cornerstone here for the exploitation within academia. Most relevant scientific dissemination activities were listed in Appendix C: Relevant publications. Besides scientific dissemination, also public dissemination including Social Media activities were performed by the scientific partners to increase the outreach of the ThermaFLEX results (see also Chapter 5.3).

Networking and collaboration

Close collaboration was established with the Green Energy Lab (GEL), an associated Energy Model Region and a research initiative for sustainable energy solutions. GEL is part of the Austrian innovation campaign "Vorzeigeregion Energie" led by the Climate and Energy Fund. It serves as Austria's largest innovation laboratory for green energy, encompassing test markets in Vienna, Lower Austria, Burgenland, and Styria, with a combined total of approximately five million end customers. Over 280 partners from research, industry, and the public sector, including energy suppliers from the four Austrian provinces, collaborated to develop customer- and demand-oriented scalable solutions from prototypes to marketability.

GEL provided valuable support to the ThermaFLEX project and linked demonstrator sites through various services in the area of implementing innovation projects. Its direct access to the core market of energy suppliers facilitated large-scale testing of new developments. Economic and market-oriented networking played a significant role in the development and later demonstration of flexibility measures in the demonstration cases in Vienna, Styria and Salzburg. This involved extensive cooperation and collaboration with different companies, including planners and technology suppliers, as well as authorities responsible for approvals and the KPC funding agency.

The project placed special emphasis on handling strategy and multi-stakeholder processes, project development, demonstration site support, and exploitation and dissemination strategies. Stakeholder

and user integration processes were carried out, involving governmental organizations, local authorities, property developers, landowners, citizens, and end-users (see Section 4.2). Close cooperation with the Austrian Climate and Energy Fund was also established, and collaborations with other subprojects within GEL were fostered. Workshops and webinars were organized to engage representatives from GEL, funding agencies, and ministries, facilitating discussions on relevant topics for flexible district heating networks and providing guidance to all ThermaFLEX partners.
In addition to direct project partners, numerous national and international parties from various sectors, cities, and municipalities expressed interest in the project results. These included industry associations, energy organizations, international delegations, and cities and municipalities from Austria and beyond. ThermaFLEX experiences and results were frequently invited for presentations and discussions at events, webinars, and workshops. The project lead and partners actively participated in different GEL-organized events and workshops, highlighting the achievements and networking activities of the flagship project. This extensive engagement with external stakeholders enhanced networking, exploitation, and dissemination of the project results, significantly expanding the reach and impact of ThermaFLEX.

5.3 Public and scientific dissemination

To showcase the impact of the gained project results as well as the flexibility measures realized within the demonstrators and its replication potential, targeted dissemination activities were performed and several communication channels were used. The main aim of using different communication channels was to reach different target groups (experts, stakeholders, communities, policymakers, etc.) at different levels/locations (local, national and international). The dissemination activities were aligned with the dissemination activities of the GEL as well as the Climate and Energy Fund and a deep cooperation and information exchange was implemented. The dissemination of the project aims, methods, results and impacts beyond the scope of the project is vital for increasing the visibility of the project, informing stakeholders that are or will be connected or concerned with the issues addressed in the project and for the positioning of the individual experts, the research and industry partners and the project consortium as a whole. An overview and a brief explanation of the different realized communication channels and activities is given in the following:

- Project website www.thermaflex.greenenergylab.at (with goals, methods, results, literature, etc.)
- Publications for targeted audiences (professional magazines, workshops, events, webinars) on practise oriented, demonstrator specific and/or scientific topics
- Scientific publications (national and international conferences, peer-reviewed articles, etc.) on results, developed methods, concepts and tools, simulation studies, results of monitoring, etc.
- Participation in different expert networks and international collaboration programmes such as IEA DHC, IEA SHC and IEA EBC
- Workshops to present project results and get feedback from the different stakeholder groups
- Webinars on the demonstrators and the related activities and results
- Dissemination via social media platforms (e.g., Twitter, Facebook, LinkedIn, YouTube)
- Continuous use of results as lecturing material in academic courses and student education

Most relevant dissemination activities were listed in Appendix C: Relevant publications. By using the above-mentioned different communication channels a high level of information about the project was reached in the target groups. Especially in the local field of the demonstrators a broad awareness was formed by increased activities in local media and public information events. Companies and research institutes dealing with the project topics beyond the consortium also became interested in know-how transfer and future cooperation leading to new projects and proposals. In addition, the project also emphasized on transparent communication with customers and the public. This was particularly important to establish long-term sustainable cooperation and understanding, which we believe is necessary for a fast heat transition. A key aspect was the development of communication tools and methods for the integration and identification of relevant stakeholders as well as the active involvement of users and citizens. To communicate this transformation in a target group-specific way, an interactive online brochure (https://greenenergylab.at/virtuelle-touren/) was created.

6 Conclusions and outlook

Within Chapter 6 the overall conclusions and a brief outlook is given. The ThermaFLEX project focused on developing and demonstrating the interaction of different components within real district heating networks. Technical, non-technical, and systemic measures were combined and implemented in large-scale district heating networks across various Austrian cities and regions. The results of the project showcased the significant potential of the developed elements and solutions for decarbonizing the heat infrastructure.

Within the timeframe of ThermaFLEX, large-scale decarbonization measures and implementations were already realized within 8 linked demonstrators. These measures showcased the great potential of the developed elements and solutions within ThermaFLEX to provide sustainable and flexible district heating supply in different Austrian cities and regions. Through monitoring and simulation data, it was projected that sustainable heat generation in the range of 180 to 200 GWh/a could be achieved in the future, leading to a substitution of approximately 45,000 tons of CO_2. The project utilized a wide range of heat sources and flexibility elements, with a central emphasis on heat storage, energy sector and infrastructure coupling, smart control concepts, large-scale heat pumps, solar thermal energy, and the utilization of locally available heat and waste heat sources. The project included the following demonstrators, each focusing on specific aspects of sustainable heat generation and utilization:

- Waste heat utilisation Therme Wien: utilisation of the waste heat available in the thermal water using a heat pump concept and integration into the Vienna district heating system.
- High-temperature heat pump Vienna-Spittelau: Waste heat utilisation from the flue gas condensation of the waste incineration plant as a heat source for a high-temperature heat pump.
- Renewable heat and cooling from wastewater - Wien Kanal: Energy recovery from wastewater for heating and cooling with innovative heat exchanger and heat pump system.
- Virtual heating plant: Coupling district heating with the sewage treatment plant in Gleisdorf for heat supply from wastewater and implementing a novel "virtual heating plant" control system.
- Large-scale solar thermal plant Mürzzuschlag: Integration of a solar thermal plant of around 5,000 square metres in combination with a 180 cubic metre storage tank into the heating network.
- 100 percent renewable district heating for Leibnitz: Using fluctuating industrial waste heat through a bidirectional coupling of two heating networks and developing a high-level predictive control of network and heat generation units.
- Biomass heating plant modernisation concept: Developing a two-stage retrofitting concept in Saalfelden. Technical modernisation (stage 1) was implemented. A heat pump integration (stage 2) was developed and implementation is planned for 2023.
- Industrial waste heat utilisation: Implement an absorption heat pump to increase waste heat utilisation at the AustroCel site in Hallein to be fed into the district heating network of Salzburg.

The project employed highly integrated planning, implementation, and operational management processes. These included innovative spatial energy planning, system evaluations with life cycle analyses, methods for user and stakeholder integration, and comprehensive monitoring and data analysis.

Overall, the ThermaFLEX project demonstrated concrete solutions for efficiently using and expanding existing district heating infrastructures. The successful demonstration projects in Styria, Salzburg, and Vienna proved the feasibility of large-scale implementations within relatively short timeframes.
However, there are still open questions that have not yet been fully solved. As example, biomass-based district heating networks and systems play a central role in sustainable heat supply covering around 2,400 systems in operation in Austria. Ongoing technical innovations (e.g. new combustion and control strategies, particulate matter abatement technologies), digitalization as well as systemic changes in heat supply (e.g. sector coupling, waste heat utilization, integration of local energy sources and infrastructures) offer further potential to expand and strengthen this market position. Currently and in near future, there is an increased need for retrofitting and modernization of these existing heating networks, especially of the first and second generation, in order to meet current and future technical, economic and regulatory challenges combined with a sustainable and strategic expansion of the heating system. Moreover, research and development within long-term storage concepts, the phase-out of the large gas-fired CHP plants and advanced digitalization and control methodologies were needed.
In 2020, a total of 23 TWh of district heating was generated in Austria to cover the respective heat demand (20 TWh). The future heat demand will increase up to 27 TWh in 2040 and leads to a heat generation of 31 TWh. This future expansion dynamics will be fostered in combination with the developed flexibility measures within ThermaFLEX. In conclusion, ThermaFLEX was a first, but immensely important step to reach the decarbonization and expansion goals.

7 Directories

7.1 List of Figures

7.2 List of Tables

8 Contact details

Project manager
Joachim Kelz
j.kelz@aee.at
Phone: +43 3112 5886 236

Institute
AEE – Institute for Sustainable Technologies (AEE INTEC)
Feldgasse 19, 8200 Gleisdorf, Austria
Phone: +43 3112 5886 0
www.aee-intec.at, https://thermaflex.greenenergylab.at/

Project partners (in alphabetic order)
Abwasserverband Gleisdorfer Becken
AIT Austrian Institute of Technology GmbH
ALOIS HASELBACHER GmbH
BEST - Bioenergy and Sustainable Technologies GmbH
ENAS Energietechnik und Anlagenbau GmbH
Energie Steiermark AG
Feistritzwerke-STEWEAG-GmbH
FH Joanneum Gesellschaft mbH
FRIGOPOL Kälteanlagen GmbH
Green Tech Cluster Styria GmbH
GREENoneTEC Solarindustrie GmbH
Horn Consult
JOANNEUM RESEARCH Forschungsgesellschaft mbH
NAHWÄRME TILLMITSCH GmbH & Co KG
Pink GmbH
Rabmer GreenTech GmbH
ROTREAT Abwasserreinigung GmbH
Salzburg AG für Energie, Verkehr und Telekommunikation
Salzburger Institut für Raumordnung und Wohnen GmbH
Schneid Gesellschaft m.b.H.
SOLID Solar Energy Systems GmbH
StadtLABOR - Innovationen für urbane Lebensqualität GmbH
Stadtwerke Gleisdorf GmbH
STM Schweißtechnik Meitz eU
Technische Universität Graz - Institut für Wärmetechnik
Technische Universität Wien –Energy Economics Group (EEG)
Wien Energie GmbH

9 Appendix

9.1 Appendix A: Summary of KPIs for system evaluation

Table III: Summary of KPIs for system evaluation

Economic KPIs	**Unit**
Change in annual total cost	EUR/a, EUR/MWh or %
IRR of investment	%
Technical KPIs	**Unit**
Impact on capacity factor	%
Impact on peak load	MW, number of peaks, or h
Impact on load factor	%
Impact on simultaneity factor	%
Impact on heat losses	MWh/a or %
Impact on not supplied heat	MWh/a or %
Impact on power adjustment rate	kW/min
Increase in renewable heat production	MWh/a or %
Environmental KPIs	**Unit**
Impact on GHG emissions	kg CO_2eq/a, kg CO_2eq/MWh or %
Primary energy demand	MWh/a or %
Fossil primary energy demand	MWh/a or %
Social KPIs	**Unit**
Community and customer engagement	-
Contribution to national energy targets	-

9.2 Appendix B: Stakeholder analysis template

Projekt Thermaflex

STAKEHOLDERANALYSE

erstellt von StadtLABOR GmbH

Name des Demonstrators:

Stakeholderanalyse durchgeführt von:

Stakeholder (Name, Organisation, Funktion)	**Grad der Betroffenheit?**					**Einstellung zum Projekt / zu neuen Lösungen?**					**Interessen / Bedürfnisse /Erwartungen**	**Ressourcen & Kompetenzen**
	Wie stark ist der Stakeholder vom Projekt/Vorhaben (direkt/indirekt) betroffen?					*Wie ist die Einstellung des Stakeholders zu innovative Ansätzen/ bestimmten Szenarien/ Veränderungen?*					*Was sind die konkreten Interessen und Erwartungen des Stakeholder in Bezug auf das Projekt/Vorhaben?*	*Welche Ressourcen kann der Stakeholder einbringen (Knowhow, Netzwerke, Entscheidungsmacht, finanzielle Mittel, ...)?*
	0 = sehr gering	1 = gering	2 = mittel	3 = hoch	4 = sehr hoch	0 = sehr negativ	1 = negativ	2 = neutral	3 = positiv	4 = sehr positiv	offene Frage / qualitativ	offene Frage / qualitativ

Figure 18: Template (in German) of the stakeholder analysis (Source: StadtLabor)

9.3 Appendix C: Relevant publications and channels

Note: A number of publications will be published beyond the project end in different national and international magazines and newsletters.

9.3.1 Articles

Broad public and scientific publications for different stakeholder groups on project aims, methods and results were successfully completed. Public publications were vital for increasing the visibility of the project, for informing different stakeholders that are or will be connected or concerned with the issues addressed and for the positioning of the individual experts, the research and industry partners and the project consortium as a whole. To highlight the larger impact of the project results in Austria and Europe and to showcase the demonstrators and its replication potential, targeted dissemination activities were necessary. Scientific publications in journals (peer-reviewed or non-reviewed papers) as well as contributions to conferences (national and international) in the fields of energy systems, renewable and thermal energy, thermal energy storage and intelligent network control were created in teams and not per partner if the topic and content allow partnership. A list of selected publications is given in the following:

- 12/2018: Article in the Green Tech Magazine: “Thermaflex: Die Zukunft der erneuerbaren Wärmenetze”
- 12/2018: Article in Nachhaltige Technologien: “Mehr Flexibilität und mehr Erneuerbare in der netzgebundenen Wärmeversorgung”
- 02/2019: Article in EUREC: “THERMAFLEX, demonstrating zero-CO2 in district
- heating systems”
- 04/2019: Article in QM Heizwerke Newsletter: “Innovative Fernwärme-Offensive in Leibnitz”
- 05/2019: Article in Building Times: “Push für CO2-freie Fernwärme”
- 05/2019: Article in Technische Gebäude Ausrüstung: “ThermaFLEX: Intelligente Wärmeversorgung der Zukunft”
- 06/2019: Article in Forum Gas Wasser Wärme: “Großforschungsprojekt ThermaFLEX: Intelligente Wärmeversorgung der Zukunft”
- 07/2019: Article in Brochure Mission Innovation Austria: “ThermaFlex”
- 07/2019:Article in EuroHeat&Power: “Therma-Flex: Intelligente Wärmeversorgung der Zukunft”
- 07/2019: Article in Österreichischer Installateur: “Intelligente Wärmeversorgung der Zukunft”
- 09/2019: Article in Kleine Zeitung: “Leibnitz Mehr Fernwärme statt Feinstaub”
- 09/2019: Article in Leibnitz aktuell: “Leibnitz will Umwelt- und Energievorzeigestadt warden”
- 10/2019: Article in Stadtmagazin Leibnitz: ”Mit CO2-freier Fernwärme ist Leibnitz am Weg zur Umwelt- und Energie-Vorzeigestadt”
- 10/2019: Article in Woche Leibnitz: “Fernwärme ist in Leibnitz am Vormarsch”
- 11/2019: Article in Fachmagazin ÖKO+ der Wirtschaftskammer: „Die Zukunft der Fernwärme ist flexibel“
- 11/2019: Article in Standard: „Kombinierte Fernwärme aus Klärschlämm, Müll oder Solarkollektoren“

- 12/2019: Article in Jahresbericht GreenTechCluster: „Hotspot für grüne Energiezukunft“
- 12/2019: Article in QM Heizwerke Newsletter: “Local Energy Hub - Was braucht man, um sinnvoll und gezielt alle regional verfügbaren Wärmequellen nutzbar zu machen?”
- 12/2019: Article in Stadtmagazin Leibnitz: „Fernwärmeausbau in Leibnitz“
- 12/2019: Article in Report - Das Magazin für Wissen, Technik und Vorsprung: „Nichts wird verschwendet“
- 01/2020: Cover story in Woche Leibnitz: “Leibnitz ist Vorreiter“
- 02/2020: Article in Stadtmagazin Leibnitz: „Aktuelles zum Wärmenetzausbau“
- 03/2020: Information brochure “Fernwärmeausbau in Leibnitz“
- 05/2020: Two articles in energy innovation Austria: “ThermaFLEX demonstrator – High Temperature Heat Pump and “ThermaFLEX demonstrator using waste heat from sewage in Vienna’s Liesing district”
- 07/2020: Article in Leibnitz Aktuell: „Innovativer Zusammenschluss“
- 08/2020: Scientific publication (review paper) in Energy Systems: „Progressive hedging for stochastic energy management systems - The mixed-integer linear case”
- 10/2020: Article in Stadtmagazin Leibnitz: „Fernwärme Leibnitz: Wärmenetze vor Zusammenschluss Und was halten die BürgerInnen und KundInnen aus Leibnitz von der Fernwärme?
- 11/2020: Peer reviewed paper “From the waste water treatments plant to the turnstiles of urban water and district heat networks”, Frontiers in Sustainable Cities, https://www.frontiersin.org/articles/10.3389/frsc.2020.523698/full, AEE, SLG
- 09/2021: Articles in Nachhaltige Technologien 03/2021: „Kommunale und industrielle Abwasserreinigungsanlagen als Energie- und Ressourcendrehscheibe“ and „Innovative Abwärmenutzung aus dem Kanal für die netzgebundene Wärmeversorgung“, different partners
- 10/2021: conference paper „Increasing flexibility towards a virtual district heating network”, https://doi.org/10.1016/j.egyr.2021.08.075, AEE INTEC
- 10/2021: conference paper „Operation of coupled multi-owner district heating networks via distributed optimization”, https://doi.org/10.1016/j.egyr.2021.08.145, BEST
- 11/2021: Article and interview with Wolfgang Gruber-Glatzl/AEE INTEC in the Energate Magazine about the challenges of using wastewater as an energy source and about the role of sewage treatment plant as an energy hub, https://www.energate-messenger.at/news/217253/wir-brauchen-loesungen-fuer-eine-ganzjaehrige-dekarbonisierung, AEE INTEC.
- 11/2021: Article in Just Magazine, “Bidirektionales Wärmenetz ging in Leibnitz in Betrieb“, https://www.just-magazin.com/bidirektionales-waermenetz-ging-in-leibnitz-in-betrieb/, BEST.
- 02/2022: Article in GreenTechCluster Newsletter, “Zukunftland Steiermark: Auf dem Weg zu 100% Erneuerbarer Energie”, https://www.greentech.at/zukunftsland-steiermark-auf-dem-weg-zu-100-erneuerbarer-energie/#msdynttrid=45YjrRt4VxohToDctlRmijM7JwFlme3wDRnZZtKMlcA, GTC.
- 02/2022: Publication at Wien Energie Newsletter ans Blog, “Flexibilität im Wärmesektor“, https://positionen.wienenergie.at/blog/thermaflex/, AEE INTEC, WEN.

- 03/2022: Article in Nachhaltige-Technologien issue 01-22, „Ammonium-entfernung und –rückgewinnung in Kläranlagen –Erfahrungen einer Pilotstudie“, https://www.aee-intec.at/zeitung/nachhaltige_technologien-1-2022/24/, AEE INTEC.
- 04/2022: Article in Busines Monat, „Bei Wärme gibt’s noch viel zu holen“, https://www.businessmonat.at/april-2022/bei-waerme-gibt-s-noch-viel-zu-holen, AEE INTEC.
- 04/2022: Peer reviewed paper „Smart control of interconnected district heating networks on the example of “100% Renewable District Heating Leibnitz”“, https://www.sciencedirect.com/science/article/pii/S2666955222000077, BEST, AEE INTEC, Schneid.
- 05/2022: Article in BWK-Energie (VDI Fachmedien), „Biogas und Abwärme: Die Potenziale von Kläranlagen ganz ausschöpfen“, https://www.ingenieur.de/fachmedien/bwk/special-erneuerbare-energien-klimaschutz/biogas-und-abwaerme-die-potenziale-von-klaeranlagen-ganz-ausschoepfen/, AEE INTEC.
- 06/2022: Article in APA-Science. “Abwasser als zukünftige erneuerbare Energiequelle für die Dekarbonisierung der Energie- und Wärmeversorgung“, https://science.apa.at/gastbeitrag/abwasser-als-zukuenftige-erneuerbare-energiequelle-fuer-die-dekarbonisierung-der-energie-und-waermeversorgung/, AEE INTEC.
- 06/2022: Article in Erneuerbare Energie issue 01-22, “Abwasser als Energiequelle”, https://www.aee.at/zeitschrift-erneuerbare-energie, AEE INTEC.
- 06/2022: Articles in Nachhaltige-Technologien issue 02-22, “Wärmenetze im Wandel: Lösungen und Elemente zur Flexibilisierung“, „Intelligente Regelungen zum optimierten Betrieb von Wärmenetzen“, „Innovative Abwärmenutzung für die Dekarbonisierung der Wärmeversorgung in Wien“, „Nutzer*innen- und Stakeholderintegration bei der Entwicklung von Wärmenetzen“, „Modernisierungskonzepte für das Biomasseheizwerk Saalfelden“, https://www.aee-intec.at/zeitung/nachhaltige_technologien-2-2022/, different partners.
- 06/2022: Article in „unser Leibnitz – Das Stadtmagazin der Stadtgemeinde Leibnitz“, „Ist Heizen noch leistbar?“, https://www.leibnitz.at/aktuelles/gemeindezeitung, HCO
- 09/2022: Article in APA-Science. “ Die Wärme aus der Therme – zur Abwärmenutzung von Thermalwasser“, https://science.apa.at/reportage/die-waerme-aus-der-therme-zur-abwaermenutzung-von-thermalwasser, WEN, GEL, AEE INTEC.
- 09/2022: Three articles in energy innovation austria issue 03-22, “ThermaFLEX Leitprojekt für die Flexibilisierung von Wärmenetzen”, „ThermaFLEX-Demoprojekt: Fernwärme Saalfelden Modernisierung des Biomasseheizwerks“, „ThermaFLEX-Demoprojekt: Wärme aus der Therme Abwärmenutzung im Wiener Fernwärmenetz“, https://www.energy-innovation-austria.at/issue/eia-2022-03-de, AEE INTEC, WEN, SAG
- 10/2022: Article in Der Standard „Wo versteckte Fernwärme schlummert“, https://www.derstandard.at/story/2000140297662/wo-versteckte-fernwaerme-schlummert
- 10/2022: Article in Salzburger Nachrichten, “Forschungsprojekt zeigt Optimierungspotenzial für Fernwärmenetze”, https://www.sn.at/panorama/wissen/forschungsprojekt-zeigt-optimierungspotenzial-fuer-fernwaermenetze-128562619

- 10/2022: Article in Wiener Zeitung „Forschungsprojekt zeigt Optimierungspotenzial für Fernwärmenetze“, https://www.wienerzeitung.at/nachrichten/wissen/technologie/2165326-Forschungsprojekt-zeigt-Optimierungspotenzial-fuer-Fernwaermenetze.html
- 10/2022: Article in APA Science, “Forschungsprojekt zeigt Optimierungspotenzial für Fernwärmenetze”, https://science.apa.at/power-search/11607435266391119087
- 10/2022: Article in Börse Express „ThermaFLEX – Das nachhaltige Fernwärmenetz der Zukunft“, https://www.boerse-express.com/news/articles/thermaflex-das-nachhaltige-fernwaermenetz-der-zukunft-514545
- 10/2022: Article in Ökonews „ThermaFLEX – Das nachhaltige Fernwärmenetz der Zukunft“, https://oekonews.at/?mdoc_id=1176879
- 10/2022: Article in Austrian Roadmap „ThermaFLEX – Das nachhaltige Fernwärmenetz der Zukunft“, https://www.roadmap2050.at/thermaflex-das-nachhaltige-fernwaermenetz-der-zukunft/
- 10/2022: Article in Building Times, “Forschung für flexible Fernwärmenetze”, https://buildingtimes.at/projekte_visionen/forschung-fuer-flexible-fernwaermenetze/
- 11/2022: Peer reviewed paper in Journal of Membrane Science „Recovery of ammonia from centrate water in urban waste water treatment plants via direct contact membrane distillation: Process performance in long-term pilot-scale operation”, https://doi.org/10.1016/j.memsci.2022.121161, AEE
- 11/2022: Article in erneuerbare Energie 02/22, „Wärmenetze im Fokus“, https://www.aee.at/zeitschrift-erneuerbare-energie, AEE
- 12/2022: Article in „unser Leibnitz – Das Stadtmagazin der Stadtgemeinde Leibnitz“, „Erfolgreicher Abschluss des Forschungsprojektes ThermaFLEX in Leibnitz!“, https://www.leibnitz.at/aktuelles/gemeindezeitung, SLG, AEE, HCO

9.3.2 Presentations

Similar to the publication activities (described above in chapter 3.2) also a number of public and scientific presentations at different national and international conferences/events and (external) webinars were performed within the project. Especially within conferences also contributions to the respective proceedings were realized. The main presentations held were listed in the following:

- 01/2020: Award winning in the framework of the CEBC 2020 for demonstrator 100% Renewable District Heating Leibnitz
- 02/2020: contribution to proceedings and presentation at EnInnov2020: “TECHNO-ECONOMIC ANALYSIS OF USING SEWAGE WATER FOR DECENTRALIZED HEAT GENERATION IN LARGE DISTRICT HEATING NETWORKS “, presenter EEG- TU Wien
- 06/2020: contribution to proceedings and presentation at ETEI 2020: “District heating systems in combination with WWTPs as energy and resource hub “, presenter AEE INTEC
- 06/2020 – 09/2020: Three contributions and presentations in the framework of NEFI Webinar Series “Abwasserbehandlungsanlagen als Energiedrehscheibe und Ressourcenlieferant“

- 09/2020: Presentation at Jahresveranstaltung Vorzeigeregion Energie - Innovationen für den Klimaschutz Made in Austria: „ThermaFLEX: Thermal demand and supply as flexible elements of future sustainable energy systems“, presenter: AEE INTEC and Nahwärme Tillmitsch
- 10/2020: Information event in Leibnitz
- 10/2020: Presentation at Heizwerkebetreibertag 2020: „Möglichkeiten zur Erhöhung der Flexibilität im Wärmesektor anhand der Wärmenetze Gleisdorf und Leibnitz“, presenter: AEE INTEC
- 11/2020: contribution to proceedings and presentation at enova 2020: “Flexibility as a main influencing parameter for a sustainable and renewable driven district heating sector “, presenter AEE INTEC
- 03/2021: presentation at International Congress of Chemical and Process Engineering: “Ammonia separation via Membrane Distillation (MD). Experiences and perspectives “, presenter AEE INTEC
- 03/2021: presentation at Fast Pichl Seminar „Effizienter Heizwerkbetrieb“: “Niedertemperaturnetze – Grundlagen, Vorteile und Stand der Technik “, presenter AEE INTEC
- 06/2021: presentation at FGW Webinar Fokus Solarwärme: „Solare Fernwärme Stadtwerke Mürzzuschlag“, presenter SOLID
- 09/2021: presentation at DHC 2021: “Increasing flexibility towards a virtual district heating network”, presenter AEE INTEC
- 09/2021: presentation at DHC 2021: “Operation of Coupled Multi-Owner District Heating Networks via Distributed Optimization”, presenter BEST
- 09/2021: presentation at 7th International Conference on Smart Energy Systems: Interconnection & smart control of district heating networks for increased flexibility, presenter AEE INTEC
- 09/2021: presentation at ERSCP 2021 - 20th European Round Table on Sustainable Consumption and Production: Sustainable and renewable driven district heating systems as a cornerstone for future and resilient energy supply concepts, presenter AEE INTEC
- 09/2021: presentation at ERSCP 2021 - 20th European Round Table on Sustainable Consumption and Production: Optimal operation of cross-ownership district heating and cooling networks, presenter BEST
- 10/2021: presentation at QM-Feedbacktag-HeizwerkeFachtagung: Betrieb verbundener Nahwärmenetze mit getrennten Eigentümern, presenter BEST
- 12/2021: Contribution to proceedings and presentation at Euro Membrane, “Isothermal membrane distillation demonstrated in pilot scale at a communal waste water treatment plant for energy and resource efficiency”, https://euromembrane2021.eu/ , presenter AEE INTEC.
- 12/2021: Presentation at RES-DHC Workshop “Experiences on RES-DHC: lessons, good/bad practices and financing”, “Increasing flexibility in DH networks”, https://www.res-dhc.com, presenter AEE INTEC.
- 01/2022: Presentation at Green Tech Radar Webinar Integrierte Wärmewende, “Intelligente und nachhaltige Wärmeversorgung im Leitprojekt“, https://www.youtube.com/watch?v=5r2q2IEiO_c, presenter AEE INTEC.

- 02/2022: Contribution to proceedings and presentation at 17. Symposium Energieinnovation 2022, "Verortung von Energiedaten als Grundlage für das zukünftige Energiesystem", https://www.tugraz.at/events/eninnov2022/home/, presenter EEG
- 02/2022: Presentation at Enerhack webinar; "ThermaFLEX - More flexibility and more renewables in district heating", https://enerhack.ee/en, presenter AEE INTEC.
- 04/2022: Contributions to proceedings, presentations and posters at ISEC conference, "Ammonia recovery from liquid waste streams by means of Vacuum-Membrane Distillation", "Renewable Heating and Cooling with Energy from Wastewater- Contribution to Decarbonization", "Simulation-Based Feasibility Study for Low-Temperature Supply Concepts for Urban Districts", https://www.aee-intec-events.at/welcome.html, https://www.aee-intec.at/isec-2022-vortraege-pu356, different partners.
- 04/2022: Presentation at project leader meeting from GEL, "Erfahrungen zur projektübergreifenden Zusammenarbeit", AEE INTEC and SIR
- 06/2022: Contributions to proceedings and presentations at enova, "Erneuerbar Heizen und Kühlen mit „Energie aus Abwasser am Beispiel Zentrale Wien Kanal", „Innovatives Modernisierungskonzept zur Effizienzsteigerung im Biomasse-Heizwerk Saalfelden", https://www.fh-burgenland.at/events/e-nova/, different partners
- 09/2022: Presentation at Styrian Workshop on Automatic Control, "Application of Optimization-based Energy Management Systems for Interconnected District Heating Networks", https://www.tugraz.at/institutes/irt/events/retzhof/, BEST.
- 09/2022: Two contributions to proceedings and presentations at Smart Energy Systems, "Demonstration of large scale solar district heating integration with storages and biomass - synergies and challenges", "How to combine district heating and wastewater treatment plants? A demonstration example from Gleisdorf, Austria", https://smartenergysystems.eu/, AEE INTEC and SOL.
- 11/2022: Contributions to proceedings and presentation at Deutsche Kälte- und Klimatagung 2022, "Absorptionswärmepumpe zur Abwärmenutzung - Modellierung einer Anlage zur Rauchgaskondensation in einem Biomasseheizkraftwerk", TUG/IWT
- 01/2023: Presentation at Central European Biomass Conference CEBC 2023, "Lösungen und Elemente zur Flexibilisierung biomasse-basierter Nah- und Fernwärmenetze", https://www.cebc.at, AEE.
- 01/2023: Award winning in the framework of the CEBC 2023 for demonstrator Saalfelden, https://thermaflex.greenenergylab.at/auszeichnung-fuer-den-demonstrator-saalfelden/

9.3.3 Studend education

The project contents were continuously used and integrated in lecturing material, academic courses and student education. The project partners strived towards a more balanced gender distribution in their organisation. One of the measures taken in this project was, when possible, to attract more female students for the master's thesis work connected to the project. The possibilities for this were limited of course, as they are dependent on the relative number of female students in the science and technology fields involved. The following master thesis were realized within the project:

- 07/2019: Master Thesis: Effizienzsteigerung einer Müllverbrennungsanlage durch Integration einer Rauchgaskondensation, WE
- 06/2020: Master Thesis: Konstruktionskonzepte von Absorptionswärmepumpen mit Fokus auf Wärmeübertragern und Problemen im Betrieb, TUG
- 02/2021 Master thesis "Development and techno-economical evaluation of new concepts for the integration of compact storage solutions in district heating systems", AEE INTEC
- 04/2021: Master thesis " Consideration of Multiple Temperatures in Hybrid Linear Prediction Models of Multi-Energy Systems ", BEST
- 09/2021: Master thesis "Analyse der Biomasse Landheizwerke der Salzburg AG", FHJ
- 12/2021: Master Thesis, „Pilot Scale Study on Ammonia Recovery by Membrane Distillation from a Municipal Wastewater Side-Stream", AEE INTEC
- 03/2023 (expected): Master Thesis, Long Term Experience of a Membrane Distillation Pilot Study on Ammonia Removal, AEE INTEC

9.3.4 Workshops

In total two workshops were organized and held within the project. On 06th April 2022 the international workshop "More flexibility in district heating - Lessons from the ThermaFLEX project" in the framework of the ISEC (2nd International Sustainable Energy Conference, https://www.aee-intec-events.at/welcome.html) took place. In this workshop, we provide insights into the implementation steps, show results from the operational phase of the demonstrators and put the findings and conclusions from our project into the wider discussion including also a panel discussion and an international insight into the "European perspective on renewable energy sources for district heating and cooling". The workshop was well attended (approx. 70 participants) with a dynamic and interested audience. Also, time for Q&A was reserved for asking the presenters about their work.

In cooperation with project partner Rabmer Greentech GmbH a national Workshop was planned and organized for the 2nd of December 2021. The workshop was embedded in the framework of the interim project meeting and also site visits to two demonstrators, namely "Waste heat utilization spa Vienna" and "Renewable heating and cooling from Wastewater / Vienna" were organized. The venues, the program, online registration forms as well as announcements via newsletters (once again in cooperation with the Green Energy Lab as well as Climate and Energy Fund) were done by the end of project year 3 as well as the beginning of project year 4. Due to Corona restrictions, the workshop was postponed to the 18th of May 2022 and was finally held at the WKO-Wirtschaftskammer Österreich (Austrian Economic Chambers) in Vienna. Under the title "Wastewater and wastewater treatment plants as future renewable energy sources for the decarbonization of energy and heat supply", regulatory, funding and technical aspects of the use of wastewater as an energy source were addressed and discussed (https://www.aee-intec-events.at/workshop.html). Around 65 participants from industry, energy suppliers, technology providers and planning offices, research, funding bodies and ministries particapted. After the workshop, the demonstrator "Heating and cooling with wastewater" was visited at the site of the new Wien Kanal headquarters. Moreover, a number of internal project workshops were performed.

9.3.5 Webinars

Two free webinars were organized by the project leader. The webinars were recorded and are freely available via the Youtube channel of AEE INTEC (https://www.youtube.com/@aee-intec).
The free webinar "Energiequelle Abwasser", on Thursday 30.09.2021. The webinar linked results from ongoing research projects with the experiences of planning and concrete implementation in municipal and industrial contexts. It is important to focus on wastewater treatment plants and wastewater from both an energy and resource perspective and to highlight them as an important component of sustainable energy system solutions. The speakers were unanimous. There is a need for awareness among all stakeholders involved, understanding of each other's challenges and pro-active communication among them. Wastewater is a renewable energy source and both municipal and industrial wastewater offer great potential. Details available here: https://www.aee-intec-events.at/archiv/webinar-vom-30-09-2021.html.
In the webinar "Wärmenetze im Wandel", which took place on Thursday 23.06.2022, we dealt with the necessary change and flexibilization of heat networks as well as the elements and solutions required for this to push the decarbonization of the heat sector and make it fit for the future. The results of the ThermaFLEX lead project and the implementation of the project in various demonstrators and the findings were presented and discussed with around 80 participants (https://www.aee-intec-events.at/archiv/webinar-23-06-2022.html).
The presentations held are freely available via the above-mentioned event pages of the webinars. Moreover, there were in total seven articles on ThermaFLEX related topics in the magazine "nachhaltige Technologien" issues 03/2021 and 02/2022, which are also freely available under https://www.aee-intec.at/epaper-99.

9.3.6 Press events

Within the demonstration sites opening events and public presentations with accompanying dissemination activities (e.g. press conferences, press releases, articles in newspapers, social media platforms, etc.) were performed and co-organized in cooperation with the responsible partners.
A total of two press conferences were held for the demonstration case in Leibntiz. These were intended to make the milestones of the project visible and tangible. The first press conference (20.9.2019) was held to kick off the joint work with the project consortium and the city of Leibnitz. The second press conference was held for the opening of the bidirectional transfer station (07.10.2021). The operators, representatives of the city of Leibnitz , the project lead and the project partners, BEST, Schneid GmbH and StadtLABOR GmbH also participated.
The concept for sector coupling of district heating with the wastewater treatment plant within the demonstrator "Virtual Heating Plant" was also presented and introduced to the public (4th February 2022). In addition to the leading project partners the majors of the City of Gleisdorf and Hofstätten/Raab participate. Besides several reports, the Styrian ORF reported under the programme focus "Mother Earth" with a TV and radio report as well as an online article (https://steiermark.orf.at/stories/3156683/).
On 9th May 2022 an opening event including a site visit for the demonstrator "Waste heat utilization spa Vienna" was held Besides directly involved project partners representatives from the City of Vienna, the spa, the Climate and Energy Fund, the GEL and Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology participate

(https://www.wienenergie.at/pressrelease/gruene-waerme-aus-der-therme-thermalwasser-sorgt-fuer-fernwaerme-fuer-1-900-oberlaaer-haushalte/).
In the framework of the final project meeting in October 2022 a press event was realized with representatives from GEL, the Climate and Energy Fund and BMK (Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology). The press release is available via https://www.ots.at/presseaussendung/OTS_20221018_OTS0156/thermaflex-das-nachhaltige-fernwaermenetz-der-zukunft-bild).

9.3.7 Social Media

Different social media channels like “Twitter”, “LinkedIn”, “Facebook” and “Youtube” were used for continuous information on project highlights as well as news and events and allowed a fast information distribution to a broad community of experts as well as users of social media channels respectively. Tweets and Facebook/LinkedIn stories were managed by the respective partners individually in alignment with GEL and Climate and Energy Fund activities. A broad presence in the community and raised awareness for the work within the project was reached.

9.3.8 Site visits

Within the framework of the CEBC 2020 an excursion to the demonstrator in Leibnitz was performed and organized by the local DH opearators as well as Horn Consult. On the 13th of June 2022 an excursion organized in cooperation with Austria Solar to the large-scale solar plant in Mürzzuschlag takes place. Around 50 interested person from different sectors and branches gets a close inside into solar heat integration possibilities in district heating. After the site visit from the demonstrator in Mürzzuschlag also the solar plant in Friesach (from project partner GreenOneTec) was visited (https://www.eventbrite.at/e/exkursion-solare-fernwarme-in-der-stadt-tickets-296720477937).
Within the 7th Central European Biomass Conference (18-20.01.2023, https://www.cebc.at/) the sector coupling concept in Gleisdorf was visited by international experts (in the framework of an excursion) as well as an official opening event with participation from BMK and Climate and Energy Fund was realized (https://thermaflex.greenenergylab.at/ministerin-leonore-gewessler-besucht-fernwaerme-vorzeigeprojekt-in-gleisdorf/). Besides a number of individual site visits were performed and organized by the responsible project partners of the demonstrators.

9.3.9 Videos

Some videos were realized to visualize the project contents and were listed in the following:

- 04/2021: Video on demonstrator „Solare Biowärme Gleisdorf - innovative Wärme aus dem Rücklauf“, https://www.youtube.com/watch?v=abD6H9WzCW8
- 10/2021: Video on ThermaFLEX project in cooperation with Climate and Energy Fund as well as Green Energy Lab, https://www.youtube.com/watch?v=arJkhHLgUWc&t=3s
- 04/2022: TV and radio contribution, “Gleisdorf setzt auf “Wärme aus dem Klo“, https://www.aee-intec.at/download/mutter_erde_waerme_aus_abwasser.mp4, https://www.aee-intec.at/download/waermeausabwasser.mp3

9.3.10 Expert networks

Next to the partners involved directly, a number of national (e.g. Fachverband der Gas- und Wärmeversorgungsunternehmungen (FGW), Austria Solar, Austrian Biomass Association, etc.) and international parties (AGFW - Der Energieeffizienzverband für Wärme, ARGE qm Holzheizwerke, Kälte und KWK e. V., Euro Heat & Power, Different IEA - International Energy Agency Technology programs, International delegations (e.g. Finish delegation from Kuusamo), etc.) from different sectors as well as different cities and municipalities (e.g. Graz (AUT), Dorfgastein (AUT), Hamburg (GER), Lviv (UA), etc.) showed their interest in the project results gained so far and underlines the high relevance of this project on the national and international level.
Experiences and results from ThermaFLEX were also often invited for presentations and discussions within events, webinars or workshops. The project lead as well as partners participated in different events and workshops organized by the GEL and presented spotlights from the flagship project and networking activities at different levels. This strong involvement of parties outside the consortium has guaranteed stronger networking, exploitation and dissemination of the project results and increased the range and impact of ThermaFLEX significantly. In the following the participation in the international expert networks were summarized.

- 11/2019: Presentation at IEA DHC Annex TS2: "ThermaFLEX" , presenter AEE INTEC
- 04/2020: Presentation at IEA DHC Annex TS3 "Hybrid Energy Networks", Webinar on "Hybrid Energy Networks" -Austria Goes International, "ThermaFLEX: Experiences from an Austrian flagship project on flexible district heating systems", presenter: AEE INTEC
- 10/2020: Presentation at IEA SHC Task 55 "Towards the Integration of Large SHC Systems into DHC Networks" Technology Transfer Workshop: "High Level Control of Coupled District Heating Grids on the example of ThermaFLEX", presenter: BEST
- 03/2021: Presentation at Nexus Solar Energy-Water-Industry IEA SHC Task 62 – Solar Energy in Industrial Water & Wastewater Management , presenter AEE INTEC
- 10/2021: Technology cooperation programm by IEA Today in the Lab - Tomorrow in Energy?
- 10/2021: Final Report of IEA DHC Annex TS2 Implementation of Low-Temperature District Heating Systems
- 12/2021: Newsletter article, "ThermaFLEX aus Teil der IEA-Initiative "Today in the Lab - Tomorrow in Energy?" ausgewählt", https://www.aee-intec.at/index.php?preview=1&seitenId=172, AEE INTEC
- 11/2018 - 10/2022*: Case studies, presentations and networking within
  - IEA DHC Annex TS3 Hybrid Energy Networks, https://www.iea-dhc.org/the-research/annexes/2017-2021-annex-ts3, AEE INTEC and AIT
  - IEA DHC Annex TS5: Integration of Renewable Energy Sources into existing District Heating and Cooling Systems, https://www.iea-dhc.org/2019-2024-annex-ts5, BEST and AEE INTEC
  - IEA HPT Annex 57: Flexibility by implementation of heat pumps in multi-vector energy systems and thermal networks, https://heatpumpingtechnologies.org/annex57/, IWT
  - IEA EBC Annex 84: Demand Management of Buildings in Thermal Networks:, https://annex84.iea-ebc.org/, AEE INTEC

  - ERANet JPP SES (Joint Programming Platfrom Smart Energy Systems), https://www.eranet-smartenergysystems.eu/, AEE INTEC
- 11/2022: Presentation at Energy Community Workshop on achieving energy-efficient district heating with waste heat, „ThermaFLEX – flexible heating networks in Austria“, https://www.energy-community.org/events/2022/11/WSEE.html, AEE