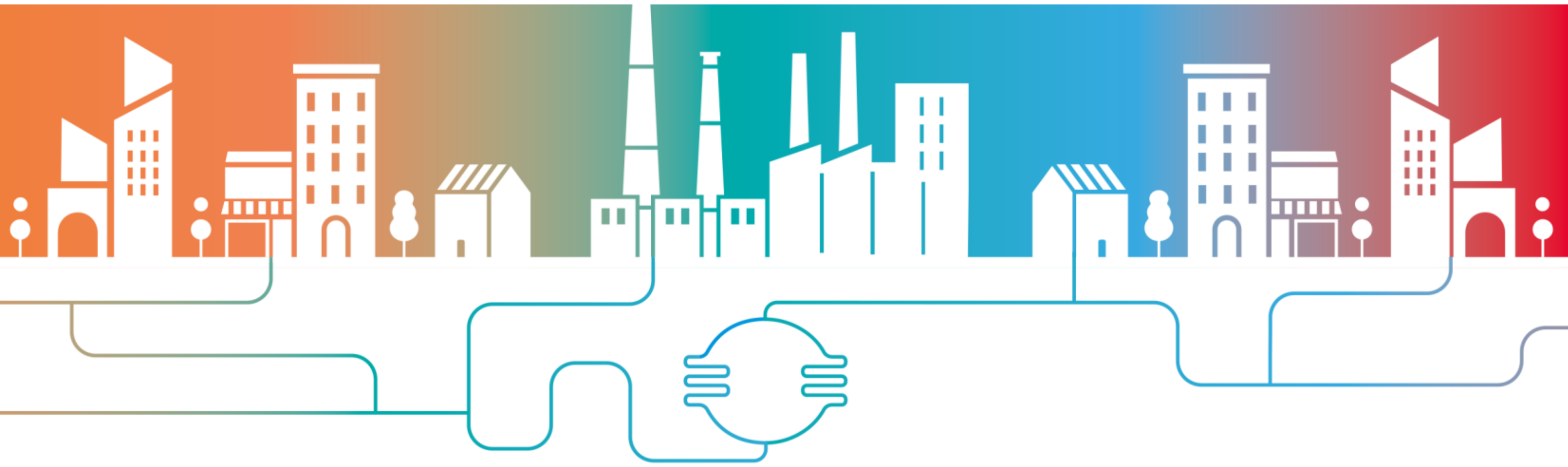
LIFE 4 HEAT RECOVERY

E.1.3 – Project Booklet



Low temperature, urban waste heat into district heating and cooling networks as a clean source of thermal energy

LIFE4HeatRecovery

Project Title: Low temperature, urban waste heat into district heating and cooling networks as a clean source of thermal energy

Project Acronym: LIFE4HeatRecovery

Deliverable Title: Project Booklet

Lead beneficiary: EURAC

Riccardo Marchetti, EURAC

Marco Cozzini, EURAC

Daniele Anania, EURAC

Roberto Fedrizzi, EURAC

Date: 14 June 2024

This document has been produced in the context of the Life4HeatRecovery Project.

The project has received funding from the LIFE programme of the European Union under contract number LIFE17 CCM/IT/000085

LIFE 4 HEAT RECOVERY

Table of Contents

1 Foreword

As global urbanization continues, an urban approach to heating and cooling is becoming increasingly important. This approach focuses on reducing energy imports by utilizing local energy sources, tailored to the local climate, and guided by long-term strategic decision-making.

Urban areas have substantial heating and cooling demands, but they also generate large amounts of low-grade waste heat from sources such as air conditioners, industrial cooling systems, refrigeration units, sewer pipes, and data centres. For example, the waste heat produced by the refrigeration units of a small, 1000 m² supermarket could potentially cover the space heating needs of approximately 25 apartments.

Traditional 3rd-generation District Heating (DH) networks, which distribute heat at 80-90°C from a central generation plant, are well-established solutions across many EU Member States. However, these systems face several challenges:

1. Significant heat losses
2. Underutilization of various available energy sources (e.g., renewables and waste heat) that could be integrated into the network
3. High installation costs

In contrast, 4th-generation district heating networks reduce supply temperatures to 55-60°C, minimizing distribution losses and enabling the use of low-temperature urban waste heat.

Neutral-Temperature District Heating and Cooling (NT-DHC) networks, or 5th-generation DHC networks, take this further by using distributed heat pumps to cover both heating and cooling demands simultaneously within the same pipeline, further reducing distribution losses. Additionally, these systems can effectively integrate multiple energy sources, including low-temperature renewables and waste heat, where available along the network.

NT-DHC networks represent a significant advancement because they not only allow customers to draw energy from the network, but also to contribute energy back into it by discharging waste heat from cooling and refrigeration systems. They are also more cost-effective in settings where both heating and cooling needs coexist.

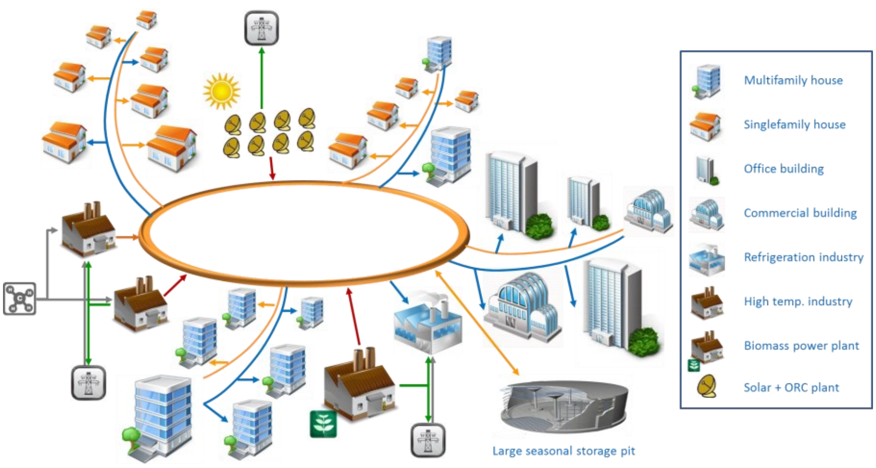


Figure 1 - Concept of a DHC network based on the water-loop principle

These advanced configurations make managing DHC networks more complex than conventional systems, as they require a higher level of digitalization. However, they also open up new opportunities:

- Heating and cooling can be marketed both as a commodity and a comfort service. Utility companies can take advantage of digital tools to manage the energy exchanged with individual buildings, enabling Demand Response practices.
- The widespread use of compression-driven heat pumps strengthens the link between the heating and electricity sectors, allowing for services like peak shaving and grid balancing.

Efficient management of these new generation networks will lead to significant primary energy savings, resulting in reduced CO2 emissions, while ensuring both investment returns and operational profitability.

The LIFE4HeatRecovery project successfully demonstrated the recovery of low-temperature waste heat in various network types. In three different configurations, the project showed how waste heat can be effectively recovered and integrated into district heating and cooling networks.

This document does not aim to provide detailed technical guidance on waste heat recovery but rather serves as a source of inspiration for utility companies, urban planners, and decision-makers beginning the planning process for waste heat recovery solutions. For a broader perspective on the solutions discussed here, detailed information can be found in the technical deliverables published on the LIFE4HeatRecovery website: http://www.life4heatrecovery.eu.

2 Waste heat integration in DHC networks

The LIFE4HeatRecovery project shows how low-temperature waste heat (below 40°C) from urban sources can be captured and reused in energy-efficient district heating and cooling networks. The project has three demonstration cases:

- Ospitaletto: Waste heat from a foundry's cooling system is recovered into a cold network.
- Aalborg: Waste heat from a data centre is recovered into a medium-high temperature network.
- Heerlen: Similar to Ospitaletto, waste heat from a foundry's cooling system is recovered into a cold network.

The goal is to capture waste heat from cooling processes and feed it into district heating and cooling networks. When the waste heat is at low temperature, a heat pump is needed to increase the temperature to make it useful.

There are different ways to connect heat pumps to district heating and cooling systems, depending on the type of heat involved. Generally, there are three types of heat processes to manage:

1. A heating process (the user that consumes heat).
2. A cooling process (the source that produces waste heat).
3. A balancing process (the district heating and cooling network), which both supplies or recovers heat.

If a facility both produces and consumes heat (known as a “prosumer”), the connection to the district heating and cooling network must be able to transfer heat in both directions. Heat pumps can either switch between heating and cooling modes or work simultaneously to handle both operating conditions at the same time.

3 Ospitaletto: integration of waste heat from a foundry into a low temperature DHC

The Ospitaletto demonstration network is a low-temperature 2-pipe system spanning 2.3 km, capable of providing heating and cooling through the same pipelines. It serves public buildings, private residences, with a total heat demand of approximately 1.9 GWh/year.

The heat sources include low-temperature waste heat from the ASO steel mill's cooling circuit before the cooling towers, and groundwater wells at around 15°C. The waste heat temperature varies between the ambient wet bulb temperature and a minimum value of 25°C, kept as a safety threshold by the mill's cooling system in all seasons. The groundwater temperature remains relatively constant throughout the year.

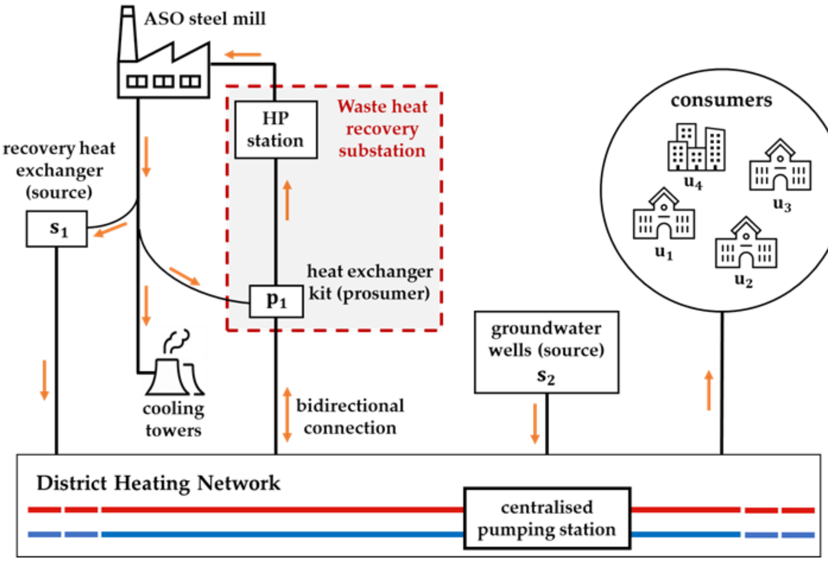


Figure 2 – Ospitaletto case.

Initially, ASO was used only as a source for the network and a gas boiler provided space heating and hot water for the factory. Within LIFE4HeatRecovery, Cogeme and ASO agreed to implement a new bidirectional waste heat recovery system using a heat pump station. The heat pump utilizes waste heat from the mill's cooling circuit when available, otherwise drawing heat from groundwater wells via the district heating network. In this way, the factory gas boiler could be completely dismissed.

The heat recovery system consists of two main components:

- Heat pump station / skid: Equipped with a water-to-water heat pump to achieve the desired temperature level, and a 3,500 litres thermal energy storage tank, that stores heat for sanitary hot water production and acts as a buffer when the heat pump output differs from the space heating demand.
- Heat exchange kit / skid: Comprises a new waste heat recovery heat exchanger, circulation pumps, and a bidirectional connection to the district heating network. This allows the ASO steel mill to supply waste heat to the network (producer mode) or to draw heat from the network (consumer mode), depending on the ongoing energy balances, thereby acting as a full prosumer.

The measured COP of the heat pump (i.e., including only the electricity consumption of the heat pump itself) is about 4.3. The average effective COP of the entire system, including the pumping consumptions for the relatively long (130 m) piping connecting the two skids, is of the order of 3.

The system was sized with a condenser outlet temperature of 60 °C and a variable evaporator inlet temperature between 13 and 25 °C (corresponding respectively to the ground-source operation mode and to the waste heat operation mode). Therefore, the heat pump power varies as well, in the range 124-160 kW (condenser side).

Figure 3: construction works (Ospitaletto).

4 Heerlen: waste heat recovery from mines to swimming pool heating

The Heerlen network is managed by Mijnwater and is a fully neutral-temperature district heating and cooling (NT-DHC) system, supplying both heating and cooling through a two-pipe configuration. The network has a main “backbone” connected to smaller, hydraulically separated sub-networks called “clusters”. The temperature in the warmer and cooler pipes ranges between 28°C and 16°C. Decentralized heat pumps in the connected buildings adjust the temperature as needed. The network distributes around 3.5 GWh/year of thermal energy, with 3.2 GWh/year coming from waste heat sources such as data centres, supermarkets, and space cooling systems.

The LIFE4HeatRecovery project focused on recovering waste heat from the VDL foundry, which utilizes cooling towers to capture low-temperature waste heat. Most of this heat is reused at the Otterveurdt swimming pool, where a heat pump-based substation transfers the heat to a “warm” buffer, connected to the heating system. The heating system has a low-temperature circuit (35-55°C) and a mid-temperature circuit (45-65°C). The maximum heating demand of the swimming pool is about 740 kW, which is nearly matched by the heat supplied from the VDL foundry. While cooling for the swimming pool is not yet implemented, the substation is designed to easily accommodate this feature in the future.

All the necessary equipment is housed in two compact skid units—one at the VDL foundry and one at the swimming pool. The VDL skid consists of a heat exchanger for waste heat recovery, with a thermal capacity of around 600 kW. The heat recovery system can utilize cooling water from the furnaces at temperatures up to 42°C, using a heat exchanger connected to the district heating and cooling network. The cooling process for the melting furnace requires a temperature difference of 12-15°C, with return temperatures that could potentially reach 55-60°C in the summer. Since this is too high for the NT-DHC network, a dedicated control system ensures the temperature does not exceed the 42°C limit. In addition to the melting furnace, a warming furnace continuously provides about 102 kW of heat, even when not in use, while the melting furnace generates intermittent peaks of up to 400 kW, with an average of 227 kW during production. In total, around 4133 GJ of waste heat can be harvested annually from these sources, supplying the Zwembad Hoensbroek swimming pool and possibly regenerating underground storage via the district network.

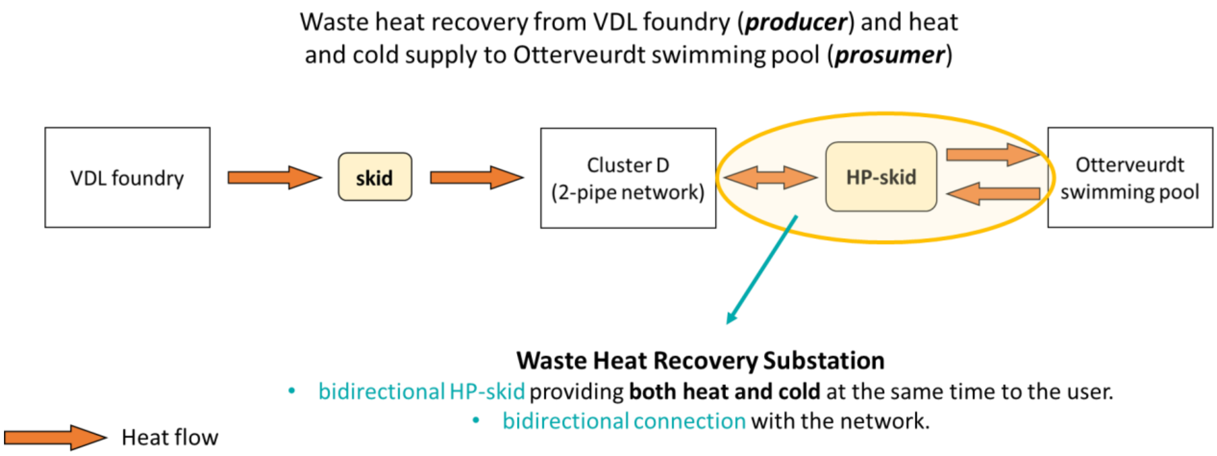


Figure 4 – Schematic of the Heerlen demonstration case, Phase 2.

The heat recovery system showed peaks exceeding 700 kW, as anticipated. Between February and May 2024, the period with the most detailed monitoring, around 280 MWh of waste heat were recovered. The swimming pool installation started operating on August 1st, 2023, initially drawing heat from the backbone. During the winter, the system recorded heat recovery peaks of about 800 kW. In the same February-May period, the swimming pool's total consumption was measured at 750 MWh, with the foundry supplying about 37% of the pool's energy needs. The lower-than-expected balancing was due to reduced factory activity. On the positive side, the average COP of the heat pump skid, including circulation pumps, was measured at 3.5, demonstrating good system efficiency.

- Swimming pool area: GFA = 7200 m²
- Low-temperature circuit: 55-35°C, 555 kW
- Mid-temperature circuit: 65-45°C, 185-740 kW
- Power connection: 400 kVA

Figure 5 – The skid mounted heat pump modules at the swimming pool.

The average recovered waste heat was in line with design expectations, though peak power output was significantly higher than predicted. While outdoor temperatures had little effect, power demand for the pool heavily depended on the use of indoor equipment. Overall, the installation was successful, with potential for further control optimization.

5 Aalborg: waste heat from servers to low temperature DHC

The district heating network in Aalborg, operated by Aalborg Forsyning, is an extensive two-pipe system that serves most of the city. The supply and return temperatures are adjusted based on the season, outdoor temperature, and wind, ranging from about 80°C in winter to 60°C in summer.

At Aalborg University's data centre, a demonstration site is connected to the district heating and cooling network and a waste heat recovery system. Heat is captured from the data centre's server cooling systems and is primarily used to heat the building that houses the data centre and offices. Any excess heat can be sent to the district heating and cooling network.

The project features a complete prefabricated waste heat recovery system, designed to efficiently transfer heat from the server racks to the local district heating network supply.

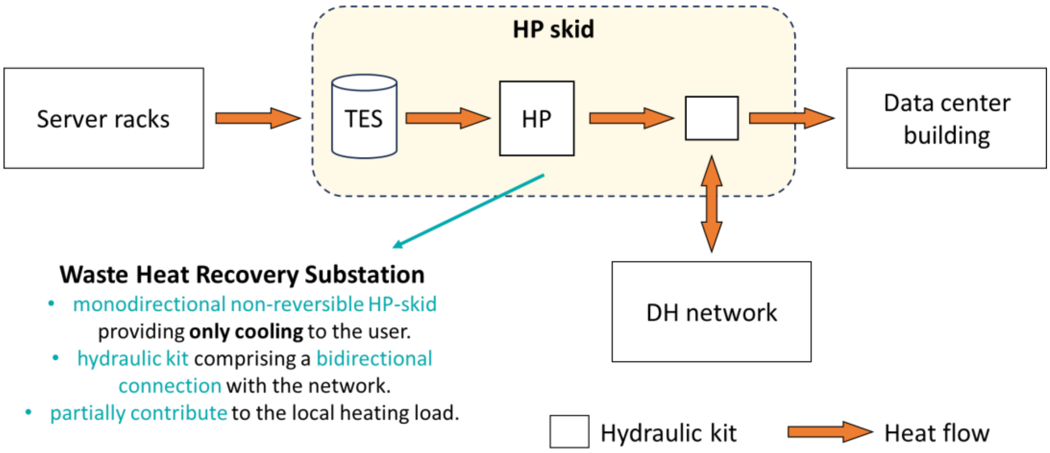


Figure 6 - Diagram of the Aalborg demo case.

This scalable system uses a two-phase passive rack cooling technology developed by HEATFLOW, combined with an intelligent control system by ENISYST. The passive system operates using a thermosyphon process, installed on a few test server racks, while the rest of the data centre is cooled using traditional air cooling. The thermosyphon system controls the temperature of the server chips, reaching up to about 60°C at the thermosyphon condenser. A heat pump is used to raise the temperature to the district heating network supply pipe.

The thermosyphon cooling system is designed to provide around 10 kW from 2 server racks; the heat pump, sized at 30 kW, allows for future expansion to include more racks or air cooling. A thermal storage unit separates the waste heat recovery from the utility's cooling process, helping to balance differences between the cooling demand and the heat pump's output.

The highest temperature recovered from the thermosyphon system during demonstration was 59°C, but lower temperatures were found to allow a more stable system operation. Heat pump's COPs were assessed very high, with a COP of 4.5 measured when the evaporator inlet temperature was 45°C and the condenser outlet temperature was 70°C. This highlights the advantages of using innovative cooling systems for servers, which not only handle higher power demands (needed by newer server models) but also improve heat recovery efficiency.

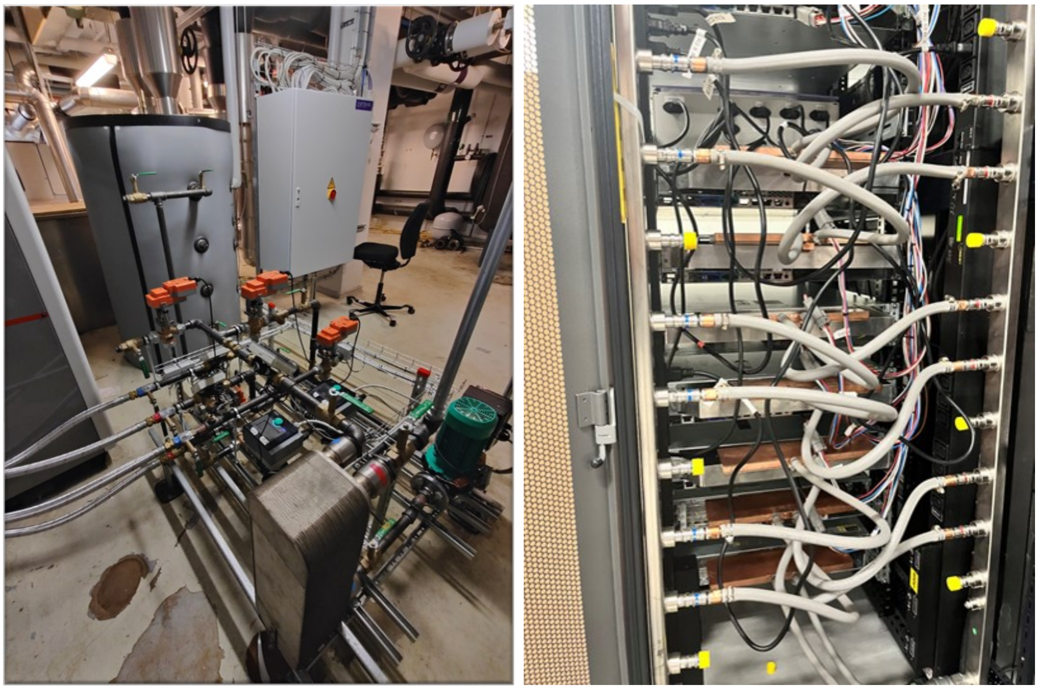


Figure 7 – Pump station and connection of HEATFLOW heat exchangers to the manifold

6 Financial and contractual aspects

The cost-revenue analysis of the three demonstration sites considered real costs, agreements, technical choices, and usage patterns. While each scenario had its unique characteristics, key factors emerged that are crucial for the success and sustainability of the investments.

The demo site analysis provided valuable insights into the balance between costs and revenues, based on real-world data. Although no one-size-fits-all formula exists for determining investment feasibility, several key factors emerged that can drive success and affordability. Utility companies play a pivotal role, relying on customer payments while maintaining competitive rates. Additionally, government support and diversified revenue sources are critical to ensuring long-term viability. A carefully balanced strategy that takes into account financial, operational, and market conditions is essential for the success of heat recovery projects.

Generally speaking, national authorizations are not required for heat recovery projects, but local permits may be needed, particularly for building modifications. When public spaces are involved in connection works, specific approvals are required, typically taking anywhere from a few weeks to three or four months, depending on the scope and location. These timeframes are relatively short for projects of this nature.

The waste heat recovery contract negotiation process is an essential part of heat recovery projects. Based on LIFE4HeatRecovery experience with three industrial sites, there were variations in how agreements were finalized, sometimes taking years to complete due to external factors like global crises. However, several best practices were identified, including:

- Signing multiple agreements in stages, making interaction progressively more binding, maintaining customer engagement, and reducing failure risk.
- Using standardized preliminary contracts to provide clear frameworks for customers and speed up negotiations.
- Offering combined heating and cooling services to showcase the broader advantages of heat recovery and enhance customer perception.

These practices should be paired with careful consideration of technical and business factors, including available incentives and positive environmental impacts.

During the project, 59 risks were identified, and a risk management template was created to help future adopters classify, assess, and mitigate risks. While financing, risks, and circumstances differ across projects, similar risks often have common solutions. Key risks were categorized into project management, energy projects, and waste heat projects. One significant challenge was ensuring long-term commitments from waste heat providers. However, offering a service-based approach rather than simply buying waste heat helped mitigate this issue.

7 Socio-economic impact

Overall, waste heat recovery in district heating and cooling networks presents a positive outlook for the energy transition, with substantial reductions in fossil fuel use, emissions, and energy costs, while maintaining employment and promoting cleaner urban environments. The LIFE4HeatRecovery socio-economic assessment displays:

1. Decreasing Energy Consumption: Energy consumption, particularly from fossil fuels, is decreasing significantly, thanks to the adoption of district heating networks and renewable systems like heat pumps.
2. Accelerated Phase-Out of Fossil Fuel Boilers: The early ban on fossil fuel boilers, ahead of the EU directive, is expected to accelerate the shift to greener technologies. This will be driven by the end of gas boiler incentives by 2025, leading to a faster transition to renewable systems.
3. Promising CO_2 Reductions: A clear decline in CO_2 emissions, as well as other pollutants (NOx, SOx, PM10, and PM2.5), is expected, contributing to cleaner urban air quality as renewable and DH systems take hold.
4. Cost Competitiveness: District heating technology proves to be economically competitive, particularly in various scenarios where it outperforms fossil fuel technologies in terms of levelized cost of heat. This is supported by the expectation of reduced electricity costs as renewable energy penetration increases.
5. Employment Stability: The shift from fossil fuel technologies to renewable systems is projected to have a neutral or positive impact on employment. Workers transitioning from fossil fuel installations can adapt to renewable technologies, ensuring job retention.
6. Potential for Policy Support: Policies such as carbon taxes and incentives could play a crucial role in accelerating the adoption of renewable technologies, bridging the gap between fossil fuels and cleaner energy.
7. Smooth Transition to Renewable Systems: The transition to renewable energy is progressing smoothly, supported by clear market dynamics and reasonable assumptions. The assessment indicates that incentives can significantly speed up the adoption of cleaner technologies.

8. Strong Prospects for District Heating: District heating, particularly with waste heat recovery, has shown positive results in most simulations. The only exception is a specific scenario with low urban density, where the challenges are minimal and can be overcome with modest incentives.