Upgrading the performance of District Heating Networks

Impacts and Action Plan of Upgrade DH Solutions

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Dissemination Level: Public

Website: Upgrade DH project website: www.upgrade-dh.eu

Cover: Ferrara's District Heating Storage Systems

Project relation: WP4, Deliverable 4.4

Disclaimer: This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 785014. The sole responsibility for the content of this report lies with the authors. It does not necessarily reflect the opinion of the European Union nor of the Executive Agency for Small and Medium-sized Enterprises (EASME). Neither the EASME nor the European Commission are responsible for any use that may be made of the information contained therein.

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1 Introduction and Executive Summary

Upgrade DH (upgrade-dh.eu) is an EU Horizon 2020 funded project aiming to improve the performance of District Heating (DH) systems by supporting selected demonstration cases through various upgrading measures, which can be replicated in Europe and globally.

This document constitutes a summary of the upgrading and retrofitting measures identified and analyzed during the project[1] across the various climate regions of the involved demo case countries: Bosnia-Herzegovina, Croatia, Denmark, Germany, Italy, Lithuania, The Netherlands and Poland.

The project aims at finding solutions for the next generation of district energy systems. Starting from a comprehensive analysis of the challenges of the current networks, operating in different frameworks and conditions, the partners were able to evaluate the most appropriate approaches to leverage on available resources, maximize the improvement opportunities and increase the overall efficiency of district energy assets.

The project has seen the contribution of partners from very heterogeneous countries, defining a comprehensive picture of the current state of the district energy industry across Europe and provide a significant summary of best practices application in different situations (see also the *District Heating Handbook*[2] developed within the project). Players from this international consortium, formed by large utilities, technology partners, research centers, academic institutions and key European energy associations, have had the opportunity to compare a variety of resolution strategies for challenges that are often shared, even if characterized by different contextual conditions.

The project shows that every system, even very efficient ones, have margins for improvement if new technologies, methodologies and tools are implemented. Examples are:

- Technological and Infrastructural investments (e.g. solar or biomass systems, thermal storages, industrial heat pumps)
- Digital Tools (e.g. tools for district energy network optimal design and operations, as well as generation optimization)
- High-Level expert coaching and consultancy (e.g. analysis of refurbishment strategies, regulation and operations strategies coaching).

The pre-feasibility studies highlighted great improvement potential, partly already in course of implementation, others being investigated further taking into account business model and economic feasibility refinement, in order to generate action plans balanced with national and regional frameworks.

It was also shown very clearly how the district energy industry has a significant scale-up improvement potential, almost regardless of the local context, provided that the necessary commitment is ensured at all levels of the decision making process, increasing the confidence that the next generation of district energy systems is going to be characterized by greater efficiency and decreased environmental footprint, in line with the EU's challenging Green Deal's objectives.

[1] More specifically, this is object of the Work Package 4 of the project

[2] UpgradeDH (2019): "Upgrading the performance of district heating networks Technical and non-technical approaches - A Handbook", Public (Deliverable 2.5)

2 Today's Challenges to District Heating improvement

The basic concept of District Heating (DH) consists in the heat supply from one or multiple centralized production plants to an ensemble of heat consumers, through a piping network transferring hot water or, in some cases, steam. According to the EU Strategy on Heating and Cooling (EC, 2016), the contribution of DH in the EU currently accounts for 13% of the total heating energy and is mainly driven by fossil fuels such as gas (40%) and coal (29%).

District heating is being utilized since the end of the 19th century and it's now entering what is referred to as the 4th generation of district heating networks, where the integration of higher shares of renewable energy into the production mix will provide increasing levels of flexibility and opportunities for energy coupling (i.e. transformation of energy vector into another, like in the case of power-to-heat units, leveraging for instance on increasing availability of renewable energy).

Yet, as stated above, DH systems accounts for a relatively minor share of the energy used nowadays for heating purposes in the EU. Over the years different technologies, such as individual heating systems (house boilers) or cheap coal-fired plants, have played a large role in the industry, challenging the capacity of DH operators to provide the flexibility and adaptability requested by market conditions. While some Nordic countries (e.g. Denmark or Sweden) are champions of the technology, other countries are surely not gaining the full benefits of modern District Heating as one of the key transition technologies in the path towards decarbonisation.

Investments in network upgrades can be considered one of the greater challenges. In some instances, the network was designed and built over 40 years ago, like in Eastern Europe where DH were highly incentivized and developed in the '60s and '70s. Examples are the systems in Šalčininkai (Lithuania) or in Tuzla (Bosnia and Herzegovina), where the management faces the necessity to reconvert to radically new technical and operational conditions, with respect to the original design, such as the requirement to renew the network or re-modulate production resulting from building renovation campaigns.

In other cases, the focus may be new piping design and/or technology, like in Middelfart (Denmark), where low-temperature plastic piping has been introduced, aiming at reducing the network temperature and pressure levels, decreasing losses while improving security and quality of service to customers.

Pumping optimization is also a very relevant and diffuse topic, since electricity operating costs are a major component of the economic balance of DH operators. While the technology has advanced substantially, with widespread diffusion of frequency-regulated pumps, there is always the need for accurate hydraulic models, in order to understand how the network behaves, identifying critical points and bottlenecks, and fully maximize the optimization potential. A thorough analysis of the hydraulic profiles of the network was a key point in the improvement strategies for multiple demo cases, such as Marburg (Germany) and Salcininkai (Lithuania).

Furthermore, the integration of renewable energy sources is key to increasing the system's efficiency and reduce the environmental impacts. Yet, it does pose other challenges, in terms of financial feasibility and increased plant complexity. Solar thermal systems in Tuzla (Bosnia Herzegovina), or biomass, like in Purmerend (Netherlands) and Grudziadz (Poland), are just examples of significant applications that may serve as examples for other replication cases.

Where renewable sources are not immediately applicable, there are often other ways to reduce the environmental impacts of the systems, such as a thermal storage, like in Sisak (Croatia), where this enables a broader operating range for the CHP units, or heat pumps, like in Bologna

(Italy), where enhanced sector coupling in a multi-energy supply system was the major focus of the retrofitting action.

Lastly, but not less important for the future of district heating, is the realization that the technology expansion is a challenge not only from a technical and operational standpoint, but also from a social and political point of view, since there is a growing need to involve stakeholders at all levels, from policy makers to investors, from technicians and operators to service companies, in order to increase the awareness on the sector's challenges and the broader environmental issues linked to the entire energy industry and accelerate its development in the future.

3 Upgrading opportunities for District Heating

Activities developed in the course of Work Package 4 of the Upgrade DH project provide a broad view of the opportunities and impacts of improvement actions from a technical, economic and environmental point of view, which may be used as a guideline for future actions to be considered for replication or inspiration by other European district heating operators, highlighting trends, methods and technologies that are readily applicable in the district energy industry.

3.1 Strategy, Approach and Concepts Overview

The project was designed to provide guidelines and promote shared approaches and strategies, enabling a cross-fertilization experience among multiple players with different roles within the district heating and energy value chains.

An ensemble of tools[3] was leveraged upon, in order to increase the awareness on the potential of digitalization of the decision-making process or adoption of selected technologies, based on the long-lasting experience of the consortium partners in the know-how sharing process.

The upgrading measures described in the following paragraphs were identified and developed during working groups, internal one-to-one workshops and coaching sessions, with the goal to maximize the impacts of the retrofitting process and proceeding towards the development of modern and efficient DH systems.

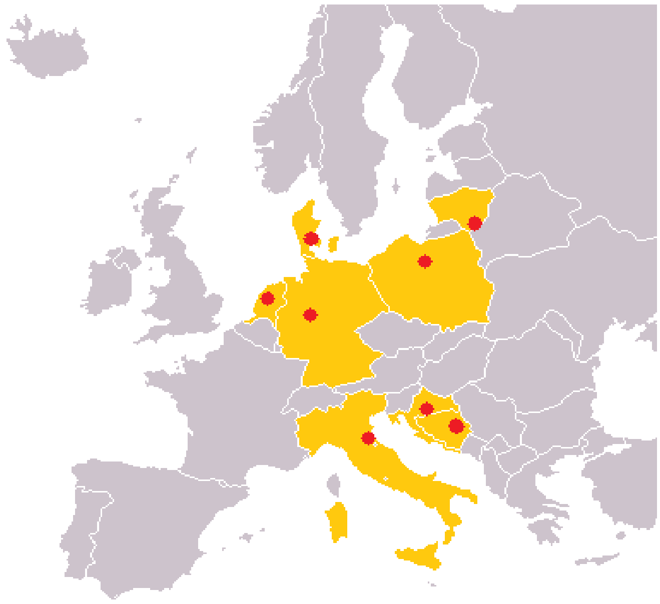
All information has been authorized for its public dissemination, with the intention to provide a benchmark to other utilities that face similar challenges and inspire practical approaches to DH improvement across Europe and globally. Individual demo cases can be contacted by eventual interested parties, for additional information.

[3] Upgrade DH (2018): Upgrading the performance of district heatin networks. Best practice instruments and tools for diagnosing and retrofitting of district heating networks. Hg. v. Solites - Steinbeis Research Institute for Solar and Sustainable Thermal Energy Systems. Online verfügbar unter www.upgrade-dh.eu, zuletzt geprüft am 26.11.2018

3.2 Project's Demo Cases

The following paragraphs provide a brief overview of the activities and the results for each demo case involved in the project.

Locations of the demo cases are shown in the map, clearly displaying the wide areas covered among the countries and, therefore, giving a perspective on the different approaches used to harmonize the different upgrading measures studied and analysed by the different consortium's partners.



3.2.1 TUZLA, BOZNIA AND HERZEGOVINA

The city of Tuzla has experienced substantial changes over the past years and its district heating system, which supplies energy to 80% of the population, needs to adapt to these changes.

Tuzla's District Heating System, 190 km in length with 325 GWh/a of thermal energy generated, has been operating for almost 35 years and is now facing multiple challenges, such as a foreseen expansion potential, coupled with a decrease in demand of the current users due to building stock renovation, need for a refurbishment of the coal-fired generation assets and a sub-optimal pumping regime due to hydraulic bottlenecks in the network.

The project aimed at finding immediate and practical solutions to these issues leveraging upon the experience of the consortium partners. In particular, EPBIH worked closely with Optit, AGFW, Solites and WIP to design, study and develop the solution explained in the following sections.

The district heating company wishes to create a long term and sustainable network going beyond commonly used solution to address expansion issues and upgrading needs. The company decided to take an incremental modernization approach implementing solutions such as the installation of energy meters in each substation, refurbishment of old assets or the integration of different energy sources in the company energy mix.

The goals are quite ambitious:

- Reduce supply temperatures and minimize heat losses
- Integrate renewable sources and waste heat into the energy mix
- Implement a smart energy system balancing demand and supply at all times
- Ensure a sustainable planning strategy from a technical and economic standpoint.

Facility	**Tuzla City / DH system supplied by CHP Tuzla**
Upgrading Measures	**Description of the Upgrading Measures and their Impacts**
Optimization of CHP Operations with integration of heat storage	The upgrading measure leverages upon Optit's solution for energy production optimization for both electricity and thermal energy generation, analysing opportunities to maximize the operating economic margin while respecting the technical constraints of the system. In addition, the introduction of a storage unit has been considered, identifying the optimal sizing and assessing the potential impacts on the production planning strategies in the current and perspective operating conditions (i.e. heat load variations). The solution allows for**:** • Increased flexibility in the operational strategies, allowing a different approach to the electricity market; • Increased efficiency of the system, reducing the environmental impacts for heat production; • Significant economic gains due to the optimized operating patterns, with return on invested capital well within one year.
Solar Thermal Integration	The integration of solar thermal energy derives from the will to increase RES share in the energy production mix, and it is expected to be a significant driver in the emission reduction strategy for the future. In collaboration with Solites and AGFW, two different sites have been identified and the potential impacts assessed both from an environmental and economic viewpoint. It has been estimated that the total generation of the solar portfolio could reach up 14 GWht per year. The measure will yield a reduction in GHG emissions and a significant increase in renewable energy share, as well as a decrease in operating costs, due to the new low-maintenance assets.

Hydraulic optimization via expert coaching	The Eastern part of the City of Tuzla (in which around 60% of the total demand is concentrated) has insufficient available Δp, currently representing the main technical issue for the development of Tuzla DH system. Therefore, the challenge consists in determining how to best improve the distribution and regulation system, also taking into account the projected additional load to be connected in the future. EPBiH and AGFW have collaborated in the analysis of the current scenario, identifying various possible actions: • Refurbishment of the main pipeline; • Supply Temperature Reduction; • Installation of temperature limiters at the users; • Installation of Variable Speed Driver (VSD) pumps for the main network distribution. The implementation of such measures will enable a greater capacity to be available at the plant, enabling a better regulation flexibility, while, at the same time, reduce primary energy demand and GHG emissions.
Installation of thermostatic valves at the users, coupled with the change to consumption-based billing	Currently, the vast majority of users are subject to surface-based billing (instead of kWh based billing), so that only 15% of flats within Tuzla DHS are equipped with thermostatic valves. This is a significant source of inefficiency in the system. Therefore, a pilot campaign of thermostatic valves installation has been carried out, as well as a communication and information campaign, in order to promote and assist gradual change towards consumption-based billing. The analysis will produce the following outcomes**:** • Field test benchmarking current regulation capability and consumption patterns with and without the thermostatic valves at the users; • Sensitivity analysis on the technical and economic impacts of different regulation and payment schemes.
Replacement of inefficient circulation pumps[4]	In order to improve the system's efficiency, a quick win strategy is to replace inefficient circulation pumps, producing significant benefits both in terms of increasing the network energy efficiency and reducing emissions and operating costs.

[4] This upgrading measure and the following two were not developed specifically within UpgradeDH. They are the focus of other European projects (Horizon 2020 Project "BIOFIT") or internal activities at EPBiH power utility and Tuzla heat distribution utility, yet they are reported here to provide a complete picture of the full degree of retrofitting undertaken in the demo site.

Biomass co-firing on Unit 6 in TPP Tuzla	The introduction of biomass combustion within unit 6 of Tuzla power plant could increase significantly efficiency, reduce GHG emission through a carbon neutral feedstock and be a valid transition option towards a cleaner power sector. Biomass will substitute fossil fuel, increasing RES share and reducing emissions, with a positive impact on the local environmental profile. Also, under the assumption that biomass feedstock is cheaper than coal, significant economic savings are to be expected.
Revitalization of Unit 6 turbine in TPP Tuzla	The measure includes the installation of new equipment at Tuzla Power plant unit 6. The reconstruction aims at extending the life of the turbine with increased efficiency, reliability and power capacity. Major impacts are expected from this upgrade: • Extension of the calculated working life of vital parts of the Unit by 150,000 hours; • Availability, reliability and safety of the boiler at an extended operating range, with an increased capacity; • Reduction of the heat production cost with respect to the current state.

3.2.2 SISAK, CROATIA

Sisak's district heating system is powered by a cogeneration plant, fueled by natural gas and biomass. It is operated by the HEP group, the largest utility in Croatia, and it supplies 80 GWht per year to the 450 connected users. The energy distribution system is quite modern, while the production side could be improved, since it is currently driven by electricity production, rather than pursuing the maximum efficiency of heat generation.

This is happening in the city of Sisak (Croatia), where a biomass cogeneration plant has been built recently. It experiences significant heat losses since it operates constantly at full load in order to sell electricity at the rather convenient feed-in tariff, but this leads to wasting heat during the night, when the heat demand is lower than production.

The resolution strategy, analyzed with the support of the University of Zagreb, is a thermal storage system in the form of a buffer tank, which would store heat when heat demand is low in order to be used when demand rises up again.

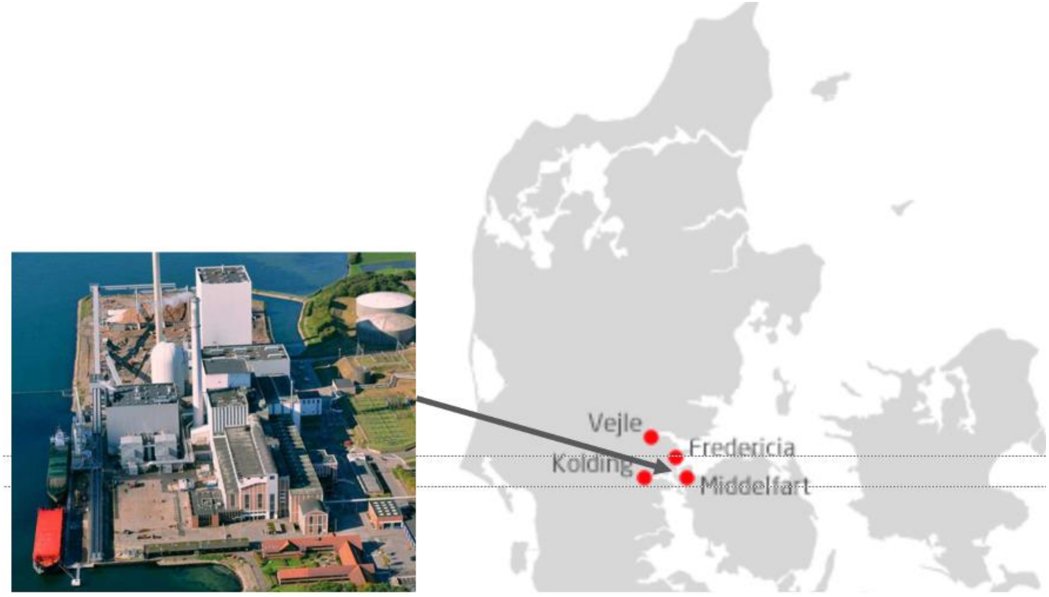
Facility	**City of Sisak, Croatia**
Upgrading Measures	**Description of the Upgrading Measures and their Impacts**
Integration of a thermal storage system	The need of producing electricity at full capacity 100% of the time is creating imbalances in the district heating system, where the heat production is excessive at night and not high enough at the morning peak hours. By installing a 1,360 m^3 (66 MWh) heat storage tank at the location of the biomass cogeneration plant, the system could achieve significant heat savings of 9,722 MWh, which amounts to almost 2,000 tons of CO_2 emissions saved annually. The measure is expected to yield the following benefits**:** • Energy and Financial Savings (€ 286,000 of Natural Gas Savings) • Investment payback less than 4 years • Minimize the use of gas-fired units, prioritizing the use of the biomass CHP system, reducing environmental impacts in terms of primary energy demand and emissions • Reduce grid losses and shave peak demand.

3.2.3 MIDDELFART, DENMARK

The district heating network in the city of Middelfart, in Denmark, is to be supplied by a larger amount of heat produced from renewable energy sources, thanks to the implementation of a new biomass CHP plant. This solution is related to the aim defined by the Danish government of becoming fossil fuel free in the coming years.

The district heating network needs also to be renovated in some of its old and inefficient service pipes. In order to make the renovation process more efficient, a control system is going to be implemented, with COWI's support, so that a detailed analysis can be conducted to identify which service pipes need to be replaced before others, guiding the renovation process not only on the employees' experience or assumption, but through analysis of real field data.

As last step of the upgrade, the DH network in Middelfart will be merged with the network located in the neighbor city of Ejby, achieving a higher level of optimization thank to additional leverage on all the available resources.



Facility	Middelfart District Heating company, Denmark
Upgrading Measures	**Description of the Upgrading Measures and their Impacts**
Conversion to Biomass fuel	Before 2018, approx. 2/3 of the heat supplied to the DH transmission system TVIS was from a natural gas-fired CHP plant. With increased focus on climate change and the higher standards required by the Danish governments, Municipalities (including Middelfart's) agreed to build a biomass-based CHP unit, which should substitute production from the gas-based CHP plant, to be dismissed. The following impacts are expected: • Reduced waste heat and natural gas boilers use, respectively down to 2% and 4% of the total production • Reduced GHG emissions, due to the switch to biomass-fueled generation.

Refurbishment of old service pipes	A methodological approach based on analyses, measurements and simulations for the replacement of old service pipes is going to be introduced. The old service pipes (around 30 years old) need to be replaced with more efficient ones, to prevent the current relatively high losses and leakages in the network. The analysis was executed by COWI using TERMIS, connected to the energy meters placed along the network, highlighting the pipes with the higher heat losses. The following impacts are expected: • Heat Losses Reduction • Heat Demand reduction, from 145 GWH/a to 140 GWh/a • Analytical planning and budget creation • Easier identification of broken or inefficient pipes.
Organizational Optimization	The two district heating networks of Middelfart and Ejby, a city nearby, were managed separately with an inefficient use of the available assets. By integrating the two systems a more efficient operation and maintenance of the district heating systems will be achieved, with the following impacts: • Operations Optimization and economic savings • Better exploitation of human and economic resources.

3.2.4 MARBURG, GERMANY

Stadtwerke Marburg (SWMR) runs a 9 km pipeline, in part recently acquired by the local University, with significant expansion potential and a range of improvement measures that were rapidly identified by the local staff, supported by AGFW, SWMR and Optit.

The creation of a hydraulic network model (that had previously been attempted with no success) was identified as the cornerstone for most other upgrading measures. Given a data acquisition system with a low degree of automation, the real status of the current situations in the grid could only be inferred, making it difficult to trace the causes of a series of performance issues, while thanks to the adoption of hydraulic models and expert support, it is now possible to identify bottlenecks in the grid, check the effects of in the system configuration and plan future optimized strategies.

Due to its large share of heat consumption, the local University is an important partner in improving and increasing the efficiency of the district heating system in Marburg. Through the activities within the Upgrade DH project and the participation of AGFW (the German district heating association), contacts to important decision makers of the University could be established, enabling a very fruitful exchange, from which various optimization strategies on the customer side emerged, which will help to improve further the efficiency of the whole DH system.

Facility	**Marburg, Germany**
Upgrading Measures	**Description of the Upgrading Measures and their Impacts**
Lower return temperature	Philipps University uses 60% of the heat supply, creating both advantages and disadvantages in the system operations. Issue on the University's influence on the entire District heating network and decision about renovation requires strong involvement of the consumer

<table>
<tr><td></td><td>side, since some buildings are still operating with old equipment at very high temperature both on supply and return side.

Through the involvement of University personnel, the Upgrade DH consortium partners were able to collect data and evaluate simple solutions on the customer side as well as design a compete refurbishment of old substations.

Expected impact are:
• Energy Savings due to reduced heat consumption by University buildings
• Cost reduction

Bonus tariffs have been agreed, if particular conditions are achieved, to distribute benefits along the value chain.</td></tr>
<tr><td>Optimization of pumping operations</td><td>Pressure difference has always been measured at plant and mainly monitored through the experience of the operators. Following the significant changes of some design parameters re-modeling the network through a thermo-hydraulic simulation and understand the real conditions had become of paramount importance.

Temperatures, bottlenecks and pressure issues were all evaluated leveraging upon Optit’s tools. Critical Points, which greatly influence the pressure load at the plant, were identified and some solutions, such as a decentralized pumping system or replacement of current pumps, were evaluated.

The upgrading measure has provided the following outcomes:
• Improved pump operations
• Increased capacity for new connections
• Pressure reduction to approx. 2-3 bar
• Supply temperature reduction from 150 °C to 120 °C.</td></tr>
<tr><td>Plant Operations Optimization</td><td>When the project started, the heat sources of SWMR consisted in 3 x 10 MW Gas Boilers and the newly installed Endothermic Engine was not fully integrated in the production process. Unit commitment planning tools such as Optit’s solution could be adopted to optimise the integration of new assets, e.g. smaller CHP engines or absorption chillers.

Such measures can have significant impacts, increasing in the system’s generation efficiency, achieving higher operating margins, improve environmental performance as well as facilitating integration of future renewable sources.</td></tr>
<tr><td>Network expansion Strategies</td><td>Based on the simulation model of the Marburg DH system, the feasibility of expansion strategies was assessed. Depending on the individual strategy of SWMR and the city of Marburg, different targets can be defined for the analysis, e.g. the most convenient buildings (close to the existing pipes), the highest potential consumers (lowest</td></tr>
</table>

	insulation, oldest houses) or the users with highest emissions (areas where oil-fired individual systems are common). It is expected that the expansion of the network will increase the general acceptance of DH and will reduce the environmental impacts of the heating sector through the conversion of inefficient individual systems into an efficient centralized generation, fully exploiting the potential of current and future assets.

3.2.5 BOLOGNA / FERRARA, ITALY

Hera runs a dozen of DH systems across Emilia Romagna, including 3 separated networks in Bologna and a rather large (>70 km) system in Ferrara.

Full exploitation of the sector coupling potential and better integration with electricity trading are the key to maximize the overall efficiency of district energy systems, considering the entire spectrum of energy demands (heat, chill, electricity).

That is the rationale that has driven Hera to invest heavily into the generation mix, through the integration of heat pumps into the energy mix of the Berti-Pichat plant in Bologna, ensuring a marked decrease in the use of its gas boilers.

The increased flexibility and efficiency of the system will improve the environmental impact, as well as increasing the economic performance, with positive effects on the local stakeholders.

The current Italian regulation, that provides incentives to DH systems if certain conditions are met (50% heat production from RES or waste heat, 75% heat production from CHP or 50% heat production from a combination of the above), favor investments in alternative sources / technologies or in changes of the production structure to achieve efficiency objectives, through revamping of CHP systems or coupling CHP systems with RES or waste heat.

A key enabler in managing the resulting complexity (over a rather diverse plant portfolio) is process digitalization, with the adoption and progressive sophistication of Optit's energy production optimization software, used to support the strategic and tactical planning, from long term and budgeting to the day-by-day operations, integrated with trading on the energy markets.

In addition, technological measures have been analyzed, designed and partly implemented in Ferrara. District heating in this city has already a rather limited environmental impacts, thanks to the significant contribution of waste heat and geothermal energy to the heat production mix.

Infrastructural investments have been pushed through in order to increase this share even more, through the refurbishment of the heat exchange section in the WTE unit (already completed) and in the geothermal system (still at a design stage). These measures will decrease the fossil fuel-based heat production further, placing the Ferrara's system in the proximity of a 100% emission-free system.

On top of that, a major digitalization effort is currently being undertaken at the consumer side, where a large number of users' substations are planned to be replaced by smart metered substations. An analytics-driven approach has showed the opportunity to extract great value from the extensive data that may be acquired, indicating the potential for a reduction in pumping electricity demand through the real-time optimization of the flow requirement on the primary grid.

Facility	**Hera: Berti-Pichat, Ecocity, Cogen Barca Plants**
Upgrading Measures	**Description of the Upgrading Measures and their Impacts**
Heat Pumps Integration	Installation of heat pumps in the system allows for a greater utilization of the CHP units, recovering a share of heat not currently utilized (because of its low temperature). The heat pumps installation enables a more flexible heat production strategy, leveraging on the link between CHP operations and the variability of the electricity prices, leading to a decreasing reliance on gas-fired boilers.
Digital Solution for energy production optimization	Hera has adopted Optit's solution for CHCP systems optimization, which has been integrated into the SCADA system, in order to leverage upon the capability for a fully automatized process, providing each day the optimal unit commitment patterns as well as operational and management reporting. Integration of the short and long-term management process has allowed for a more dynamic operational capability, enabling both day-ahead and long term what-if investigations that can rapidly be brought in production. Moreover, integration of short-term operational practice with long term/yearly policies and constraint management unlocks advanced economic leverages opportunities to manage at best regulatory constraint, particularly significant in the current markets, where energy prices can be highly volatile. Optit's solution has allowed to maximize the potential for economic margin increase, taking into account the specific leverages of each plant in Bologna (and indeed the full portfolio across Emilia Romagna, including Ferrara), while supporting both the day-to-day operations and the strategic management of the assets.

Facility	Hera: Ferrara DH System
Upgrading Measures	**Description of the Upgrading Measures and their Impacts**
Smart Substations Analytics	Historically, substations were set to measure the heat sold to customers, solely aimed at billing purposes. In an increasingly digital world, this model can be evolved towards the concept of smart substations, that enable better customer knowledge and profiling through analytics (potentially allowing future Demand Side Management practices) and achieving overall greater efficiency. Hera decided to proceed with a proof of concept initiative, installing temperature and flow metering devices at 10 pilot substations, collecting data that can be utilized in an analytics-driven approach supported by Optit. The goal is to increase as much as possible the operational differential temperature between supply and return on the primary side, while ensuring that the heat demand is fully met. The successful (and rather innovative) pilot project provided insights on its applicability and impacts on a large scale, since Hera intends to install metering devices at over 1,200 substations. Furthermore, the implementation of such measure may pave the way for activities on Demand Side Management, which may be implemented in the future. The pilot has demonstrated the following advantages**:** • Reduced pumping effort, achieved through the maximization of the temperature differential; • Lower environmental impacts, due to the lesser primary energy consumption and GHG emissions; • Reduced operating costs.
Heat Exchanger refurbishment at geothermal source	Currently, the average annual heat production from the geothermal source is around 73.7 MWht. The exchanged power varies during the year, with an average winter supply of 12.8 MWht. It has been assessed that the geothermal source may bear some additional extraction without compromising its long-term integrity. Therefore, the focus is to achieve a better exploitation of the geothermal source and ensure a greater output, especially during the winter period when the demand is higher and gas boilers are used the most. The intervention is aimed at refurbishing the heat exchange section of the geothermal system, increasing its efficiency and capacity, reducing use of gas-boilers, thus leading to lower primary energy demand and GHG emissions.

3.2.6 SALCININKAI, LITHUANIA

Salcininkai, located in the south-east of Vilnius, Lithuania, is the capital of the homonymous district. The city is served by a DH network, which is operated by UAB Šalčininkų šilumos tinklai. The supply is ensured through a portfolio of 14 boiler houses, with the total capacity of 48 MW. A 18.7 km long distribution pipeline serves the 2,168 connected users, which are residential for the most part (96.8%). The network has been in operations for more than 30 years resulting in a sub-optimal functioning compared to current days demands and flexibility requirements.

Within the framework of the Upgrade DH project, the company was able to experience the possibility to improve the current network performance with the implementation of different measures to reduce the currently wasted energy.

In particular, a comprehensive hydraulic analysis that leveraged on Optit's models allowed for a better understanding of the network behavior under the current and perspective scenarios, identifying and qualifying long-term refurbishment and development strategies. In addition, the potential for solar thermal integration was assessed together with Solites, providing interesting insights not only for Salcininkai DH system, but also a template for future replication analysis throughout other Lithuanian networks.

Facility	**Salcininkai DH Network**
Upgrading Measures	**Description of the Upgrading Measures and their Impacts**
Network Optimization	Heat losses in 2018 accounted for approx. 10.2 GWh (26.1%), the highest figure among Lithuanian DH companies. To make the annual investments in pipeline maintenance most cost-effective and in order to reduce heat losses of the DH system, network optimization with regards to the ongoing massive house renovation had to be achieved. After an in-depth analysis of the current and perspective state of the network some significant insights were gathered. These will support the local decision making for the future retrofitting strategy, which is expected to decrease thermal distribution losses through a piping renovation plan, thus reducing also GHG emissions: it is estimated that 2.6 GWh per year may be saved in the process.
Solar Thermal Integration	The DH company is currently struggling with the low summer demand (<1 MW), which creates problem for the sustainability and durability of the equipment. Implementation of Solar thermal fields, coupled with heat storage could ease or even resolve the issue. This will also help in reaching a lower level of maintenance costs for the generation system. The main expected advantages are: • Low usage of fuel run boilers during low demand seasons; • Reduction of CO, CO_2 NO_x and SO_2 emissions; • Hedge against fuel prices fluctuations; • Economic savings on maintenance and fuel.

3.2.7 PURMEREND, THE NETHERLANDS

Stadsverwarming Purmerend B.V. (SVP) is a DH company that supplies heat to 25,876 customers, through a 281 km pipe network, using a 44 MW biomass plant.

The company has the objective of increasing the use of renewable energy in the production of heat for the DH network, decreasing the use of gas boilers, which will remain available as backup only for peak periods. However, the expansion of the city, together with the exploitation of local gas boiler as district heating supply, will lead to a higher heat load connected to the network.

In order to satisfy the higher demand and increase the share of renewable energy in the DH system, the company decided to introduce a new biomass plant, which will supply part of the necessary heat, replacing the use of fossil fuels.

In addition, to face the new heat demand and production, the existing network needs to be upgraded. The plan is to introduce a new control system that reduces the temperature in the network, achieving lower heat losses, while ensuring adequate heat supply to the customers. However, the network has also to be physically upgraded, implementing larger pipes that can support the higher capacity.

In the context of the Upgrade DH project, with COWI's support and use of the Termis solution, the company was able to understand better the activities that needs to be performed on the network and the impact that new measures could have on emissions and energy consumption.

Facility	**Purmerend, NL / Stadsverwarming Purmerend B.V., The Netherlands**
Upgrading Measures	**Description of the Upgrading Measures and their Impacts**
Heat Losses Reduction	Heat losses in the network resulted to be above 33% of the supplied energy, increasing operational costs. In addition, very high return temperatures and leakages at households reduce the overall system efficiency. The upgrading measure is designed around the opportunity to optimize the flow temperature (FTO module) and the return temperature (RTO module) using Termis connected to the Scada system.

	It is expected that the measure will decrease heat losses in the network (around 4 GWh per year), thus decreasing both primary energy demand and GHG emissions.
Hydraulic optimization of the main DH line	The necessity to increase production to meet the future demand requires a detail analysis of the hydraulic conditions of the network in order to determine bottlenecks, find existing pipes issues and determine possible upgrades. Expected benefits are: • Network bottlenecks reduction • Pumping costs reduction • Supply security increase.
Connection of new biowaste/biomass plant	Due to the expected increase of users connected to the district network, SVP intends to build a second biomass plant of 16 MW capacity + 8 MW buffer capacity. The integration requires the upgrade of the network and a study, performed using Termis RTO, was necessary to minimize design risks. Main expectations are: • Increase production from Renewable sources • Reduction in network pressure losses • Increase potential of the DH system.

3.2.8 GRUDZIADZ, POLAND

The district heating company in the city of Grudziadz, in Poland, is developing an upgrading plan of its network in order to increase the share of renewable energy in the network and optimize its performance.

The first steps of the network optimization, supported by COWI, consider further implementation of Termis solutions including SCADA measurements, in order to obtain more information about their entire network and operation.

The tests driven on Grudziadz network clearly show that there is a potential for heat loss savings by optimizing the operating parameters of the DH network, such as supply temperature and flow adjustments. Furthermore, OPEC (the local DH company) intends to optimize the heat production and distribution efficiency by a dynamic control of temperatures, flows and pressures using Termis software.

The optimization system has to consider also the further expansion of the network, with the connection of new customers, which calls for optimal placement of booster pumps, shunts and heat exchangers for improved operational conditions in the perspective network configurations.

Facility	**Grudziadz OPEC, Poland**
Upgrading Measures	**Description of the Upgrading Measures and their Impacts**
Hydraulic optimization and expansion of DH network	OPEC-SYSTEM intends to optimize its district heating networks efficiency and heat distribution by dynamic control of temperatures, flows and pressures using the Termis software. Different scenarios were analyzed in order to understand the current network conditions and the necessary measure that needs to be taken in order to expand heat delivery and optimize the operations. The expected impacts of the analysis are: • Reduction of primary energy demand (around 4 GWh per year)

	• Reduction in GHG emissions (over 1,000 tonsCO_2 per year) • Reduction in the use of individual heating systems.
New Biomass Plant	OPEC-SYSTEM intends to increase its reliance on biomass as fuel to meet the increase in the future demand and reduce its carbon footprint. Collaborating with COWI, an analysis of the possible solutions was made and the expected reduction in coal usage is significant, leading to a saving of over 16,000 tonsCO_2 per year.
New Storage Tank	The variability of demand coming from large industrial users requires the introduction of a storage tank to increase efficiency and improve operations. Peak Boilers usage will also be limited reducing GHG emission even further. The main expected impacts are: • Reduction in fuel usage, thus GHG emissions • Lower temperature heat supply, reducing heat losses and increasing the overall process efficiency.

4 Expected impacts on the project's key performance indicators

The upgrading measures reported in the previous chapter and analysed by the consortium partners will generate a significant impact on economic, environmental and overall global decarbonisation terms, providing a strong incentive to promote a more general upgrade in the overall District Heating industry.

Some demo cases tested an extensive range of designs and digital options to improve efficiency and system operations, while others focused on technical opportunities to improve their assets' portfolio to reach more challenging environmental objectives. In all demo cases, the solutions could reduce both the primary energy demand and the GHG emissions, as well as increase the share of renewable capacity integrated in the current systems.

Upgrade DH had set a goal for reduction of primary energy demand up to 190 GWh per year and a reduction of GHG emissions up to 77,000 tons CO_2 per year. The solutions analyzed in the project went beyond this target by a significant margin, exceeding the initial expectations.

In fact, primary energy demand is expected to be reduced to 1,200 GWh from 1,451 GWh per year, through a combination of strategies aimed at reducing energy losses, digitalization and optimization of the operations and the decision-making throughout the whole value chain and strategic actions to increase the efficiency at the user's side.

Also, GHG emissions are expected to be lowered, primarily as a consequence of the primary energy demand decrease, yet also thanks to a higher share of renewable energy sources (+16%) and waste heat sources (+2%) in the heat production mix. The overall reduction could be as high as approximatively 146,000 tons CO_2 per year (almost twice than the target).

The table below highlights the impact of the strategic measures for the different demo cases, presenting a strong case for a common strategy at EU level regarding DH.

		Primary Energy Demand[5] (GWh/a)	GHG emission (tonCO2/a)	Share Waste Heat (%)	Share RES (%)
Tuzla, Bosnia	**Baseline**	350	115,271	0%	0%
	Expected Impact	**230**	**39,547**	**0%**	**29%**
Sisak, Croatia	**Baseline**	107	34,335	0%	0%
	Expected Impact	**82**	**16,305**	**0%**	**93%**
Middelfart, Denmark	**Baseline**	145	12,528	43%	20%
	Expected Impact	**126**	**1,446**	**26%**	**70%**
Marburg, Germany	**Baseline**	60	12,000	0%	0%
	Expected Impact	**34**	**5,680**	**0%**	**5%**
Bologna/Ferrara, Italy	**Baseline**	168	34,300	20%	25%
	Expected Impact	**140**	**28,179**	**28%**	**23%**
Salcininkai, Lithuania	**Baseline**	43	1,660	0%	81%
	Expected Impact	**37**	**1,424**	**0%**	**87%**
Purmerend, Netherlands	**Baseline**	354	18,337	0%	72%
	Expected Impact	**349**	**9,263**	**0%**	**87%**
Grudziadz, Poland	**Baseline**	224	62,230	0%	22%
	Expected Impact	**209**	**43,843**	**1%**	**50%**
All Demo Cases	**Baseline**	1,451	290,661	8%	30%
	Expected Impact	**1,206**	**145,687**	**10%**	**51%**

[5] Upgrade DH (2018): "Methodology for project performance indicators and their quantification". Internal Documentation (deliverable 4.5), Confidential. Optit (www.optit.net)

5 Conclusions

The current the District Heating industry in Europe shows a quite vast range of situations, with different generation technologies, distribution networks and state of infrastructure.

The Upgrade DH project is an attempt to provide sound evidence for a common strategy for future developments and provide experience-based guidance on how to solve some of the issues that DH operators are currently facing. Learning from sound best practices in terms of digitalization, renewable sources integration and system optimizations, demo site partners were able to determine the solutions that could have the biggest impact on efficiency, thus defining future investments.

The project has now reached the point where practical and impactful solutions have been defined, and in some cases, are already at the implementation stage. After this initial pre-feasibility analysis, the next step consists of refining economic analyses in order to finalize business models and financing strategies, essentials for the transposition of the pre-feasibility studies into actionable implementation plans.

A detailed analysis of the different countries policies and sustainability objectives is being completed[6], together with an economic overview of current market conditions for fuels, heat and electricity prices. This will lead to a thorough financial analysis for each case, to provide additional insights on economic returns, financing costs based on the different country's incentive schemes, and support the decision makers in investment planning based on a fully informed basis.

The results of both the technical and economic analysis will be used to draw a detailed European and, where possible, national roadmaps for the development of district heating systems.

The district heating industry is facing multiple challenges, like the entire energy industry, and this will prove even more the case in the years to come. Yet, projects like Upgrade DH provide a good example of how the industry could consolidate state-of-the-art measures that can help in the improvement of current systems as well as guarantee their future evolution, expansion and long-term sustainability, contributing greatly to the achievement of challenging environmental and decarbonization objectives for the next decades.

[6] This is object of the current Work Package 5 of the project

6 Abbreviations

BPE	Best Practice Example
CHP	Combined heat and Power
CHCP	Combined Heat Cooling and Power
DC	Demo Case
DH	District Heating
DSS	Decision Support System
GHG	Green House Gases
KPI	Key Performance Indicator
MCHP	Motor CHP
P2H	Power to Heat
ROI	Return on Investment
RES	Renewable Energy Sources
SCADA	Supervisory Control and Data Acquisition
UM	Upgrading Measure
WP	Work Package
WTE	Waste to Energy