Upgrading district heating networks in Europe

Final Project Report

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Content

1 Introduction

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%) (EC, 2016).

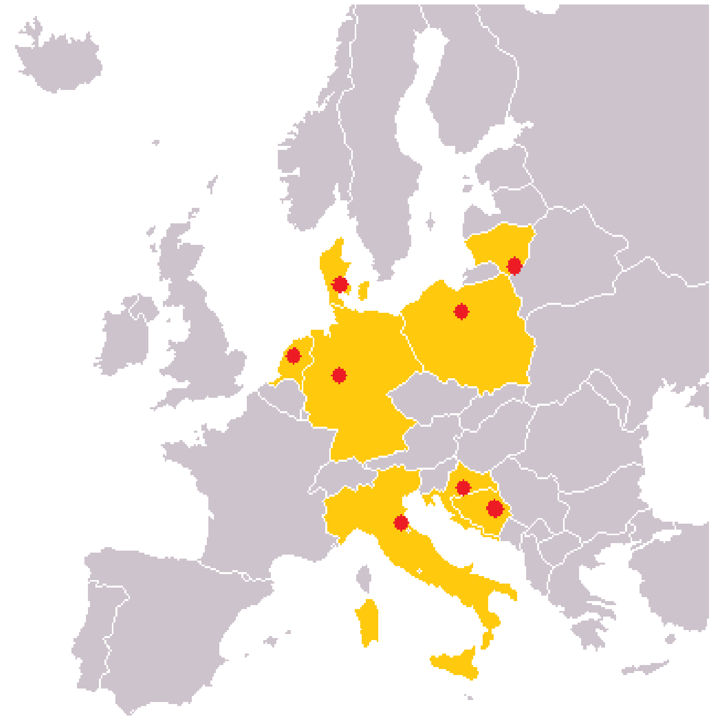

Figure 1: Upgrade DH target countries and demo cases

The EU Strategy for Energy System Integration of the EC (2020) takes up this challenge and emphasizes the need in Europe to upgrade DH networks: "The various components of the energy network will all need to evolve. Modern low-temperature district heating systems should be promoted, as they can connect local demand with renewable and waste energy sources, as well as the wider electric and gas grid –contributing to the optimisation of supply and demand across energy carriers. However, district heating networks account for 12% of the total final heating and cooling energy consumption, are highly concentrated in a few Member States, and only a limited share of them is highly efficient and based on renewables."

The overall objective of the Upgrade DH project, funded by the EU's Horizon2020 programme, was to improve the performance of inefficient district heating networks in Europe by supporting selected demonstration cases for upgrading, which can be replicated in Europe. The Upgrade DH project supported the upgrading and retrofitting process of DH systems in different climate regions of Europe, covering various countries. The target countries of the Upgrade DH project are: Bosnia-Herzegovina, Denmark, Croatia, Germany, Italy, Lithuania, Poland, and The Netherlands. In each of the target countries, the upgrading process is initiated at concrete DH systems of the so-called Upgrade DH demonstration cases (demo cases) (Figure 1). The gained knowledge and experiences were further replicated to other European countries and DH systems in order to leverage the impact.

The Upgrade DH project launched, implemented and tested the upgrading process up to the implementation phase (investment stage). As lighthouse projects, the demo cases were used to stimulate replication. The initiation of new projects in the target countries and accompanying activities at national level contributed to implement energy efficiency and renewable energy policies, regulations and legislations in the target countries.

The Upgrade DH project involved stakeholders in charge of city networks, heat suppliers, DH companies, managers of buildings blocks, housing associations and other building owners/managers and end consumers. Core activities of the Upgrade DH project included the collection of the best upgrading measures, the support of the upgrading process for selected DH networks, the organisation of capacity building measures about DH upgrading, financing and business models, as well as the development of national and regional action plans. In addition, an image raising campaign for modern DH networks was carried out in the Upgrade DH project.

The recognition of such an EU project has a large impact on national and regional level to further improve district heating networks by replication of successful technical, managerial, organisational and financial approaches identified in the Upgrade DH project.

2 Today's challenges to district heating improvements

DH systems account 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 DH as one of the key transition technologies in the path towards decarbonisation.

Investments in network upgrades can be considered as 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 of the Upgrade DH demo cases 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 Use of existing knowledge on DH upgrading

In the Upgrade DH project existing information from best practice projects, tools and strategies was collected and provided for stakeholders. Furthermore a handbook on upgrading DH systems was developed, as described below.

3.1 Best practice projects

Best practice examples were collected to present successful DH upgrading projects in various European countries (AGFW, 2020). A wide range of upgrading measures (optimisation, retrofitting, renovation, etc.) in the technical, economical, organizational and managerial areas were identified. A multi-stage selection procedure was carried out to select the examples. The following examples are described in the report (AGFW, 2020):

- Integration of Thermal Storage in Existing DH System in the City of Zagreb
- Optimisation of Pumping Operations in the DH System of Ferrara
- Integration of Tube Collectors for Solar District Heating
- Biomass Fired Boiler House at the Plant Salcininkai
- Renovation of the DH System in Akmenė
- Green Energy Park Livno
- Replacement of Fossil Fuels in the DH Sector of Lithuania
- Integration of Solar Thermal Energy in an Existing DH System
- Energy Renovation with Focus on Low-Temperature DH in Albertslund
- Interconnection of Two Separated DH Networks in Italy

3.2 Best practice tools and strategies

Best practice tools and instruments for upgrading DH (Winterscheid et al. 2018) were collected and described, 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 following tools and instruments are described in the report of Winterscheid et al. (2018):

Best practice software tools

- CoolHeating Economic calculation tool for small modular district heating and cooling projects
- EnergyPRO software
- Heat Solution™ by ENFOR™
- HOMER software tool
- LEANHEAT peak power optimization
- LEANHEAT demand response
- Optit’s Solution for Energy Production Optimisation
- Optit’s Solution for DHC network development
- TELEPERM XP (code name SPPA-T)

- TERMIS Software
- TERMIS - Flow Temperature Optimization software (FTO)
- TERMIS - Return Temperature Optimization software (RTO)

Best practice instruments

- Areal Thermographic Surveying software
- Crawler Eye
- Mass flow adjustment to the actual needs/demands, to save pumping energy and to achieve low return temperatures
- Thermal imaging via air plane

3.3 The Upgrade DH Handbook

A handbook (Rutz et al. 2019; Figure 2) was elaborated to inform any stakeholders, such as decision makers, politicians, utilities, operators, end consumers, or potential developers of DH systems, about upgrading opportunities. Thereby, the ambition of the handbook is not to provide a detailed technical guideline for technicians, but rather to give an overview on retrofitting options. Furthermore, the handbook is translated in 6 languages (Bosnian, Croatian, Danish, Italian, Lithuanian, and Polish), as in many countries there is a lack of such information in national language.

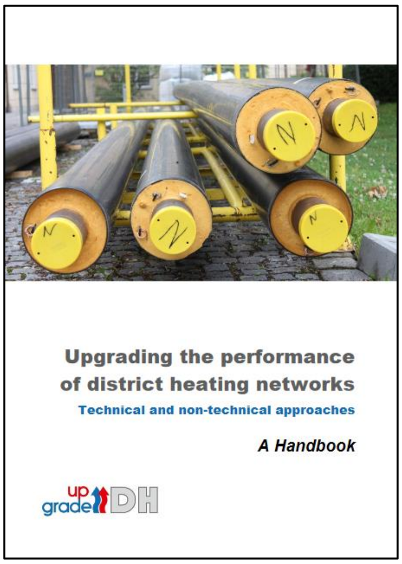

Figure 2: The Upgrade DH Handbook

4 Capacity building measures

In the frame of the Upgrade DH project, several capacity building measures were implemented in order to actively involve stakeholders in the upgrading processes of the demo cases. The capacity building measures included 5 webinars, 3 study tours, several expert exchanges, and 57 working group meetings.

The stakeholders were involved in the assessment phase of the upgrading measures and also in the selection of upgrading measures for further techno-economic analysis. The potential upgrading measures were selected using methods and tools previously identified by the Upgrade DH consortium. This was supported by outcomes of the local working group discussions, the assessments and stakeholder interviews as well as consultancy through performed webinars. These activities supported cooperation and ensured the high-quality of the diagnosis. This process also helped to effectively identify synergies between the demonstration cases and to utilize existing know-how on international level.

A challenge in the implementation of the capacity building measures was the COVID-19 pandemic which required new solutions and formats especially in the second half of the Upgrade DH project. Many capacity building events thus were organised as online events.

4.1 Local working groups

For the success of an upgrading process of a DH system, it is important that the relevant stakeholders are involved from the beginning of the process. Therefore, early in the project, local working groups (LWG) were started by the project partners. They were composed depending on the needs of each demo case and the stakeholders were selected accordingly.

The composition was kept flexible along the process. Depending on the case, heat suppliers, DH grid operators, housing associations, building owners, end users or local policy makers have been involved. Heat suppliers and grid operators have been taking part across all cases. After the initial assessment of the starting situation, regular meetings have been organized throughout the duration of the project in order to facilitate the implementation and to ensure acceptance for identified upgrading measures. In total 57 such meetings were held in Upgrade DH. Because of this, the LWGs have been crucial for the evaluation process and strategy development later in the project.

Selected success stories for the local working groups are:

Tuzla: In Tuzla the assessment process was successfully implemented. EPBiH as representatives from the project consortium, grid operators, heat suppliers, Tuzla City administration, building managers and consumer representatives are part of the local working group. 15 meetings were organized, some attended by consortium members AGFW or Optit. The technical diagnosis was assisted by site visits from AGFW. The activities resulted in a detailed overview of the challenges and problems of the network. In total 8 upgrading measures were identified. Collaboration with the consortium and the LWG continues.

Marburg: In Marburg representatives from AGFW formed the working group together with the utility SW Marburg as both supplier and grid operator, which allowed for efficient data collection for the assessment. The technical diagnosis was assisted by the consortium partner Optit, who performed simulations of network extensions. One of the main consumers connected to the DH network, Phillips University, was involved in a meeting and upgrading measures were identified with their assistance. In total 7 meetings were organized. 4 upgrading measures were identified and have been refined into upgrading strategies with the help of AGFW, Optit and SW Marburg.

Figure 3: Examples of working group meetings in Tuzla and Vilnius

4.2 Study tours

An important measure to inform decision makers and to facilitate knowledge exchange among experts is to show them real examples in life operation. Therefore, the Upgrade DH project has organised several study tours to best practice examples and DH sites. The study tours included site visits in Lithuania, Sweden, Denmark and Bosnia Herzegovina. The last study tour to Germany was organised as virtual event due to the COVID-19 pandemic. A detailed report on the study tours is provided by Grimm et al. (2021). In total, more than 140 participants, including project partners and external stakeholders attended the study tours.

Figure 4: Impressions of the Upgrade DH study tours

4.3 Technical expert coaching and webinars

Coaching webinars with the objective of mutual support and know-how transfer between project partners were organized. Working group members, local stakeholders and occasionally external DH experts participated and provided their input. The participants were introduced to the demo cases and several technologies and software solutions were presented and discussed. In total 10 webinars were held. The webinars proved to be a valuable support to the assessment and established intense collaboration within the project.

In addition to the webinars, also travels from experts to the Upgrade DH demo sites were organised in order to discuss concrete technical upgrading solutions on-site. This was very useful as the local stakeholders of the demo cases gained direct and site-specific assistance on the identification and implementation of upgrading measures.

5 Planning of upgrading measures

The timeline and complexity of the implementation of upgrading measures depends on the identified upgrading measures. It can be rather fast and uncomplicated for smaller upgrading measures, long-lasting and sophisticated ore something in between. In any case, a good planning and process is needed, and the Upgrade DH project started such a process for the demo cases.

The first phase of an upgrading process aims at creating a solid base for such a process. A good preparation is achieved by starting the organizational process together with concerned stakeholders, by establishing a detailed assessment of the starting situation and by identifying suitable upgrading measures. In Upgrade DH, the outcomes of these activities were:

- the creation of local working groups for each demonstration case, which were involved in the assessment phase, but also in the following upgrading process
- a detailed assessment of the starting situation and technical diagnosis of each demonstration case
- elaboration of a list of potential upgrading measures for each demonstration case that constituted the base of the next phases of the upgrading process.
- techno-economic analysis of the upgrading measures and planning of its implementation

implementation of upgrading measuresThe assessment and technical diagnosis of the demonstration cases was organized in three interconnected activities: a global assessment of the starting situation, technical diagnosis and the identification of upgrading measures with the help of the consortium and the local working groups.

In a first step, the demo case partners elaborated and used templates and guidelines in order to evaluate the starting situation of their systems, collect data, knowledge and stakeholder input on their networks. The results include technical and non-technical issues such as economics and organisation. The working groups and the consortium partners then used these results as well as best practice documents and tools identified earlier in the project, to conduct a technical diagnosis of the cases. In the case of Tuzla, site visits from AGFW members and OPTIT members were organized to assist the assessment A series of webinars on relevant topics was organized to support this.

Depending on the individual challenges and the strategy, the demonstration cases applied different tools. The applications range from simulation tools like TERMIS software for hydraulic analysis of the networks and temperature optimization, planning tools like Optit's solution for DHC network development for strategic development to heat mapping solutions like qGIS. In total, 9 different tools, some of them in multiple cases, were used.

The integration of the consortium into the diagnosis was useful for finding synergies between the demo cases and identifying possible collaborations for later project stages. The overall objective of the process was the identification of investigation lines concerning heat generation, distribution and use. Based on these, 3 to 8 measures were identified per demonstration case.

Common measures and cases are:

- grid temperature optimizations and heat loss reduction (Marburg, Middelfart, Purmerend, Salcininkai)
- different approaches to increase shares of renewable energy/lower emissions such as solar thermal collectors, biomass plants and waste heat utilization (all cases)
- integration of heat storages (Grudziadz, Purmerend, Salcininkai, Sisak, Tuzla)
- expansion strategies for the existing DH networks (Ferrara, Grudziadz, Marburg, Purmerend)

- operation optimization of existing plants (Marburg, Tuzla)
- hydraulic optimizations of the network (Grudziadz, Purmerend, Tuzla).

Detailed results of the assessment and diagnosis process, including the identified measures as well as the methods for their identification are stated in the publicly available report of Winterscheid et al. (2019). The report also includes descriptions of the applied tools and their implementation. Experiences of the consortium partners with the process and the LWGs are described in detail.

6 The Upgrade DH demo cases

The core action of the Upgrade DH project is the implementation of a broad range of activities to support the upgrading process of dedicated *demo cases* (Figure 1) in eight target countries.

For the 8 demo cases of the Upgrade DH project, upgrading measures 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 (Winterscheid et al. 2019). Thereby, especially the cooperation and input from main stakeholders for each demo case (e.g. heat suppliers, DH grid operators, housing associations, building owners, end users and local policy makers), through the establishment of local working groups, was very beneficial. The upgrading measures are summarized in Rutz et al. (2020).

These measures have been investigated in relation to their feasibility in confidential pre-feasibility studies. However, a summary was prepared by Morgione et al. (2020) and is 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. In the following sections, the demo cases are shortly presented.

6.1 Ferrara/Bologna, Italy

Hera runs a dozen of DH systems across Emilia Romagna, including 4 independent networks in Bologna and Ferrara, rather heterogeneous in terms of energy mix, extension and management challenges:

- The large grid in Ferrara is mainly fuelled by waste heat and geothermal source
- The Berti-Pichat system in Bologna has tri-generation and dual-temperature grids
- The Barca network in Bologna is powered by cogenerative gas turbines, presenting very tight technical constraints
- The Ecocity System in Bologna can leverage on interesting operational flexibility thank to its thermal storage.

Figure 5: Parts of the DH system in Ferrara

The main challenges targeted during the UpgradeDH project focused at increasing the share of renewables (through important infrastructural developments), a full exploitation of sector coupling opportunities and improving operational performance leveraging on advanced analytics and digitalisation.

The results have been significant:

- Heat pumps have been introduced in Berti Pichat, up to commitment, leading to a significant decrease of gas-fuelled boilers, increasing the system's flexibility
- The refurbishment of the heat exchange section in the WTE unit (already completed) and in the geothermal system (still at a design stage) in Ferrara was pursued, leading to a further shift towards a 100% emission-free system.
- A major digitalization effort is currently being undertaken at the consumer side, where a large number of users' substations have been or will be replaced by smart metered units. An analytics-driven approach has showed the opportunity to extract value from the extensive data that can be acquired, indicating the potential for a reduction in pumping electricity costs through the real-time optimization of the flow requirement on the primary grid. At the current stage, though, how to scale this approach is still under consideration given the requirement to modify the substation's control logics.

6.2 Grudziaz, Poland

Grudziadz is a large industrial town with a population exceeding 100,000. It is ranked among the major urban areas of the Kuyavian-Pommeranian Voivodship and it is an important local centre of business, education and culture. OPEC-SYSTEM is the provider of heat supply to municipal, business, residential and industrial customers of the city of Grudziadz. Recent figures show annual heat delivery, including heat losses, of about 245,340 MWh. OPEC-INEKO is the heat producer delivering 95% of the production from a highly effective co-generation. The heat is distributed via 100 km of pipes.

Figure 6: OPEC in Grudziadz

The main challenge identified in Grudziadz was that today around 50% of inhabitants use heat from the DH network. To improve the bad air quality, because of individually coalfired boilers, a network expansion was proposed, as well as an overall improvement of the network's efficiency by dynamic optimization of both temperature and pressure. Another issue was that out of 6 main DH boilers only two of them can be used to burn biomass, the rest is coal fired. Therefore, it was proposed to establish new biomass fired boilers as well as heat pumps, followed by low temperature district heating zones. This could significantly reduce the use of fossil fuels and the negative impact on air quality.

Currently, the involved companies of the DH system in Grudziadz are considering improvement options, although already today, some measures are implemented and a tendering procedure for a new biomass boiler has started. New district heating expansion zones were identified and are connected. The refurbishment of ineffective pipes to pre-insulated ones is already happening. Furthermore, the establishment of district heating zones with low temperature levels by the installation of local shunts is currently being planned.

The Upgrade DH project contributed to the upgrading of the Grudziadz's District Heating Network with the identification of different upgrading measures. All the proposed upgrading measures are in the process of being implemented! Moreover, as Grudziadz is lacking sufficient own resources, it has now more aggressively seeking private-public and hybrid financing models in order to increase energy efficiency and sustainability. Finally, the stakeholders of Grudziadz are very happy to share their experiences on the transformation goals and process with others. They are very proud for being part of the DH-Citizen campaign.

6.3 Marburg, Germany

The city of Marburg is located in the middle of the federal state of Hessen between Frankfurt and Kassel on the river of Lahn. The government of the county, in which Marburg is located, is responsible for approximately 240,000 citizens and 72,000 thereof are inhabitants of the city itself.

One of the biggest heat consumers of the district heating network of the municipal utility Marburg is the Philipps-University Marburg. It was founded in 1527 as the first protestant university in the world and it became an important factor for business, scientific and social life in the region, with currently 25,000 students. In May 2016 the state sold the 8 km district heating grid to the municipal utility Marburg. The contract also foresees that the network will be completely renewed for reasons of energy efficiency. The ambitious goal is to increase the overall efficiency with the benefit of decreasing costs and CO_2 emissions.

Besides some remediation measurers, the city is interested to lower the supply and return temperature levels. It is furthermore searching for retrofitting possibilities of inefficient heat exchangers, substations and coupled network parts. With the political claim to reach a CO_2 neutral country administration, the municipal utility Marburg needs to check numerous options and to get expert advice to develop the most efficient solution.

Figure 7: New highly efficient main grid pumps arrived in Marburg

During the Upgrade DH project work, four main upgrading measures were identified, which could be implemented. Together with relevant stakeholder, the responsible experts on site and the project consortium, detailed planning processes were started. The four main upgrading measures investigated by the Upgrade DH project are:

- UM 1: Lowering of the return temperature by improving the substations of relevant buildings of the university.
- UM 2: Optimizing the pumping operations to reduce the electrical demand for the main grind pumps.
- UM 3: Optimizing the heat generation options and increase the share of renewables
- UM 4: Developing of expansion strategies.

These measures were analysed by using the Upgrade DH tools that were published on the project website (e.g. the “Template for the global assessment of the district heating system“ or the „Guideline on business models and financing schemes for retrofitting DH networks“). The general outcomes, lessons learned, and overviews were summarised in the public reports of the project.

The realization of all measures has the potential to achieve the following impacts, if all measures can be implemented as expected: Reduction of the primary energy demand in the range of 50%, reduction of greenhouse gas emissions in the range of 60% and increase of the share of renewable energies by about 10%. Overall, the Upgrade DH project was very successful in Marburg, although not all final investment decision could be made yet. This is due to the fact that some boundary conditions need to change before the measure is economically feasible.

The investment for UM 2 is already made (see Figure 7) and the new pumps will start operation during the next month. Furthermore, the heat generation upgrading measure is under construction according to some recommendations of the Upgrade DH project. Especially the detailed analyses of the hydraulic grid situation with potential future scenarios levelled the way to connect more customers. This is an ongoing process.

6.4 Middelfart, Denmark

Middelfart is a town of approximately 16,000 inhabitants located in the central part of Denmark. The municipality's district heating company called Middelfart Fjernvarme a.m.b.a. is as private consumer-owned cooperative, which was founded in 1961. It supplies heat to approximately 5,500 customers, both residents and businesses, through 78 km of main line and 61 km of branch pipes.

The main challenge identified in Middelfart's network was that part of the grid suffered from wet insulation of old flexible PEX service pipes, and that it would take about ten years before all old service pipes will be changed. Where to start and how to prioritise the maintenance and upgrade of service pipes was a main issue that needed to be addressed. Another concern was to expand the heat demand to neighbouring areas and to keep the return temperature as low as possible at the consumers. Finally, a large part of the heat was produced by a coal-based cogeneration plant, which needed to be converted to sustainable fuels.

Figure 8: Middelfart Fjernvarme

To upgrade the network, a newly developed heat loss calculation tool was installed in the network to calculate the heat loss in the service pipes, based on real measurements and simulations. Thanks to the output of the tool, it is possible to prioritise the replacement of the service pipes in bad conditions, optimizing the use of the budget reserved to the pipe's replacement. Furthermore, the district heating company was merged with a neighbouring district heating company, to expand and optimise the operations of both networks. Lastly, the nearby cogeneration plant was upgraded from coal to biomass to reduce its environmental impact. The upgrading measures proposed are all implemented or in the process of being implemented.

The Upgrade DH project contributed with the identification of different upgrading measures that could be applied in Middelfart's DH network. Among them, thanks to the conversion of the cogeneration plant from coal to biomass, Middelfart is now one of the networks with the highest share of renewable sources in Denmark. Furthermore, thanks to the continuous upgrading of the network in Middelfart, and with the latest implementation of the heat loss calculation tool, the network is characterized by low operative temperatures, which are among the lowest in Denmark.

6.5 Purmerend, The Netherlands

Purmerend is a city of 88,000 inhabitants located 20 km north of Amsterdam. Stadsverwarming Purmerend B.V. is the DH company operating in the municipality, which supplies heat to approximately 26,000 customers, both residents and businesses, through a 281 km piping network (125 km primary and 463 km secondary network). In total, 75% of the buildings are connected to the district heating network, which is the highest DH coverage percentage in the Netherlands.

Figure 9: Stadsverwarming Purmerend B.V.

In the network, concerns are related to the high heat losses resulted to be above 33% of the supplied energy, which lead to high operation costs. The expected new user connections and the introduction of a new biomass boiler require the hydraulic optimization and upgrading of the main DH line. Without a proper optimization of the network, the amount of heat that can be supplied to the grid is limited by physical parameters such as pressure, flow, and temperature. Furthermore, the heat distribution system suffers from leakages, wet insulation, and large heat losses. In some areas with ring connection, slow moving water has been observed, which causes problems of supplying sufficient hot water to the customers. Finally, an increasing return temperature as well as leakages at household levels was observed.

Among the identified solutions to reduce the heat loss in the network, it was considered to implement a control and optimization system of the supply temperature, called flow temperature optimization (FTO), which is based on a weather prognosis and used to calculate the energy demand on an hourly basis. Furthermore, it could be interesting to implement solutions for return temperature optimisation (RTO). However, it requires extensive operations in the network, such as improved maintenance, regulation of house substations and improved customer installations. The hydraulic optimization of the main line is suggested as one of the main upgrades so that it will be possible to connect new users to the network as well as to implement a new biomass boiler, which is suggest as upgrading measure to phase out the use of natural gas boilers.

Due to the limited resources available, the DH company decided to initially focus on the optimisation network, including the opening of ring connections and optimisation of the main line. The FTO and RTO solutions are paused at the moment, while the implementation of a new biomass boiler is programmed for the coming years.

The Upgrade DH project contributed to improve the network in Purmerend, identifying a series of possible upgrading measurements, which are now considered for implementation. The hydraulic optimization of the network opens new possibilities for the connection of new customers as well as new heat production plants, which can introduce new renewable sources and phase out the natural gas.

6.6 Salcininkai, Lithuania

Salcininkai DH company operates 14 boiler houses in Salčininkai county in which it produces and distribute heat to residents and institutions in 10 different locations. The total installed heating capacity is 48 MW. Heat is supplied via 18.7 km long networks which are connected to more than 2,000 mainly residential consumers.

Figure 10: Heat generators in Salcininkai

A significant part of the district heating network has been operated for more than 30 years which means that they are not optimized for present-day demand. Network insulation is outdated in many places and does not ensure the thermal conductivity requirements which leads to considerable heat losses. The heat losses in 2019 was 9 GWh or approximately 25% from the total amount of produced heat.

The company is also struggling to deal with low summer season demand. Because of the limited boiler capacity variation (40-100%) unsustainable techniques are used to produce heat below minimum capacity. This practice decreases the lifetime of the boiler and highly reduces the efficiency.

The Upgrade DH project analysed two upgrading measures that tackled the prior mentioned problems.

One of the upgrading measures identified during the project was network optimization. The DH company was advised to develop a long-term pipeline refurbishment strategy in order to achieve maximal efficiency with the minimal capital investment.

Another upgrading measure was directed to eliminate the low summer season heat demand problem by the inclusion of a solar thermal and a storage system. The heat production would be more flexible and less dependent on biomass price fluctuations.

The Salcininkai DH company invested in hydraulic-energy calculations. As further action, the company has chosen to install an IT solution, which allows to perform automatic analysis without human resources. The result of this solution is a Digital Twin of the hydraulic network, which includes all information about the system elements and their parameters, forecasts temperature, user consumption profiles and similar data automatically, providing the optimal value of the temperature issued in the boiler room in real time. The company has already noticed first positive results of primary digitalization integration, as it already managed to achieve a 6.2% reduction in heat production and a 16% reduction in heat losses in the network, when comparing the past few months with data of the last year. These are only the first results. In accordance with the energy saving directives, the company plans to introduce real time measurements firstly for the most energy-intensive and farthest users and then for all other consumers. The online user measurements will enable even more efficient network management.

6.7 Sisak, Croatia

The city of Sisak is located in the central part of Croatia, 60 km south-east from the capital Zagreb. Overall, 33,322 people live in the urban part of the city and 4,053 households are connected to the district heating network, which distributes heat through 26.6 km of distribution pipes. One biomass cogeneration, one natural gas cogeneration and peak load natural gas boilers are currently used for the production of heat.

Since the distribution network, as well as the end user substations have recently been refurbished, the focus of the Upgrade DH project was put on the production side, where numerous improvements could be performed. Through detailed discussions with the local working group, which consisted of both the directors of the heat production and of the heat distribution companies, the potential upgrading measures were identified early in the project. These included the implementation of the thermal storage unit, integration of solar thermal collectors into the existing system and waste heat utilization from the condensate for the technological purposes in the system. Due to the high interest of the management of Sisak district heating system in the thermal storage integration, this was selected as the main upgrading measure to be analysed through the Upgrade DH project. The main reasons for this are the characteristics of the system: since the biomass cogeneration receives a feed in tariff for the produced electricity, it is operated to the maximum of its capacity. However, due to low heat demand during the night and in the summer, this results in high amounts of excess heat which is currently being wasted through the condensers. Therefore, integrating a thermal storage unit would decrease the heat losses significantly. The analysis has shown that the economic feasibility of this measure would be significant. The business model of thermal storage integration was presented to the directors of Sisak district heating, and they forwarded the results to the management board of the HEP Group, which represent the main decision makers for this system. Although the implementation did not start yet, the potential for the implementation is rather high, especially due to Upgrade DH results which showed the economic feasibility of such an upgrading measure.

Figure 11: CHP unit in Sisak (Source: https://www.hep.hr/proizvodnja/termoelektrane-1560/termoelektrane-toplane/te-to-sisak/1561)

6.8 Tuzla, Bosnia and Herzegovina

The city of Tuzla is placed in the North-Eastern part of Bosnia and Herzegovina and counts approx. 170,000 inhabitants. The district heating (DH) system Tuzla supplies thermal energy to approx. 80% of the residents of the city, whereby the number of connections enlarges each day. Thermal energy for this system is produced in a cogeneration process (CHP) in Tuzla's coal-based power plant (TPP Tuzla) operated by the power utility JP Elektroprivreda BiH d.d. – Sarajevo (EPBiH). TPP Tuzla is the heat supplier to both, to Tuzla city (220 MWth) and to Lukavac city (50 MWth), whereby another nearby town of Živinice is planned to be supplied with the thermal power of 70 MWth from this same heat source. The DH Tuzla network is operated by the distribution company owned by Tuzla City. The DH Tuzla system consists of 10 km of main pipeline (DN600-DN250) and about 180 km of heating distribution network. There are around 1,050 heating substations. The total heating area is about 1,800,000 m^2 with 23,500 consumers (almost 90% of flats, other are 10% commercials).

In the past 10 years, a large number of old substations have been replaced by new modern ones, while distribution side pumps have been replaced by electronic pumps. On the consumer side only some 15% of the connected radiators are equipped with thermostatic valves. Furthermore, information technology (IT) has been gradually implemented in the entire system of DH Tuzla. This includes remote control and management of district heating systems, SCADA - supervisory, control and data acquisition and Termis - the district energy networks simulation platform for improving system design and operation. So, the distribution network was already partially digitalized; the real time analysis and improving operation of the district heating system with Termis was provided. By using live SCADA data, the Termis model turned from a planning tool to a decision-making tool, integrated in day-to-day operations – with instant and clearly identified benefits and economic advantages. With a sufficiently large dataset, the operational management process may pass from a more "reactive" approach, based on a feedback loop - common in lots of DH systems – to a more proactive approach, where the current and perspective status of the network is analysed, taking into account possible changes in the boundary conditions, enabling more prompt and efficient system management

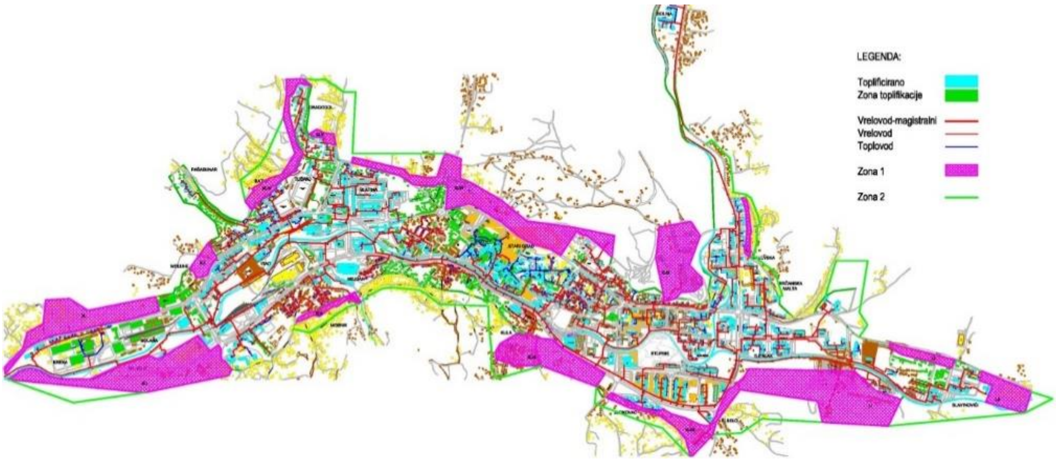

Figure 12: Tuzla DH map

Using Teleperm as a process monitoring software tool for all parameters on the production side, it was noted that the data relating to the district heating system in Tuzla highlighted values near their maximum, especially the flow. However, this applies only when it comes to the heat supply, while there is still reserve in the cogeneration heat capacity. Since the flow limit in the supply line is already reached, the regulation of the system may be achieved only through temperature regulation. Bearing in mind that DH system Tuzla has a tendency to expand and constantly connect new consumers, it is clear that something will have to be done to address this issue. Apart of that, the system is based on 100% fossil energy that needs to be changed.

Considering the objectives of the EPBiH power utility, of the distribution utility and of the city of Tuzla and their sustainable energy strategy vision, the overall project idea was developed, identifying the following key assumptions:

It is possible to convert/extend the existing DH grid to the lower temperature DH concept. Thermal storage will be a necessity in future energy systems. Integration of renewable energy sources into the district heating system is possible.

The identified upgrading opportunities are:

I. Operation optimization of two cogeneration units in TPP Tuzla with integration of heat storage.

II. Integration of renewable energy sources in the heat production portfolio of the DH system Tuzla - solar thermal collectors.

III. Upgrade Tuzla DH network to resolve hydraulic issues and increase energy savings.

   a) Upgrade the main pipeline.

   b) Reducing temperature regime of DH.

   c) Separated thermal stations for Tuzla DH, Lukavac DH and future Zivinice DH.

   d) Replacement of the existing main network pump with new frequency regulated main network pumps -for each DH system separately.

   e) Installing temperature limiters on the main return pipe on the primary side of the house substation

IV. Installing thermostatic valves for heating room temperature regulation (or heat allocators in buildings); Change the current method of consumed heat energy charging.

V. Replacement of old/inefficient circulation pumps in DHS Tuzla

VI. Biomass co-firing in CHP Tuzla

VII. Revitalization of Unit 6 turbine in CHP Tuzla and converting it into cogeneration.

The status of implementation in Tuzla is:

Replacement/revitalization/upgrade of main pipeline (to resolve hydraulic issue)

- ✓ 1 km of main pipeline in eastern part of City was replaced (from 300 DN to 400 DN and from 350 DN to 500 DN).
- ✓ 1 km of main pipeline of DN 600 has been revitalized (incl. cleaning + sandblasting).
- *The replacement or upgrading of the remaining part of the main pipeline is under consideration.*

Installation of temperature limiters

- ✓ In 2021 temperature limiters were installed on the main return pipe on the primary side of the house substation in two building blocks; reduced temp. T2 (return) and T3 (radiators). PED decreased.

Replacement of distribution pumps

- ✓ In 2020, 60 distribution pumps have been replaced by new electronic pumps. PED decreased.

Converting Tuzla Unit 6 into CHP unit (modernization of MP turbine + steam extractions)

- ➢ In 2020 a contract was awarded to GE (Alstom technology), in 2021 main design completed, Works realization planned in first quarter of 2022. – PED decrease is expected.

Biomass co-firing on CHP Tuzla

- ➢ 0.15% biomass co-firing is conducted in 2021, biomass amounts is being supplied, and biomass co-firing trial run is under preparation. CO_2 emission decrease is expected.

In addition to these technical measures, the Upgrade DH project stimulated an initiative of the City of Tuzla to subsidize the installation of heat pumps and further connections of new consumers in the periphery/hilly parts of the city, with financial and technical support. The implementation of this initiative is ongoing.

6.9 Summary of upgrading measures of the demo cases

During the process of analysing and diagnosing the DH systems of the Upgrade DH demo cases, the following upgrading measures and opportunities were identified (Winterscheid et al. 2019) for the 8 demo cases:

Heat use

- Smart substations analytics
- Connection of potential new low-enthalpy customers
- Replacement of local gas boilers for hot water with DH hot water units
- Expansion strategies
- Replacement of local gas boilers with DH
- Sanitary water delivery and/or cooling services
- Energy efficiency measures at residential buildings

Heat distribution

- Heat loss reduction by better supply and return temperature management with temperature optimization
- Increase the number of pre-insulated pipes in the system

- Lowering the return temperature
- Lower the electrical demand by optimising the pump operation
- Optimise grid maintenance
- Hydraulic optimisation of the main DH line
- Introduction of SlimNet (twin pipes) instead of traditional single pipes
- Network optimization in order to reduce operational costs
- Replacement of the existing main circulation pump with new electronic frequency regulated circulation pumps for each DH system separately
- Replacement of existing hot water pipeline (DN600) with a pipeline of a larger diameter, solving hydraulic problems

Heat production

- Further development of the energy production optimization
- Installing of heat pumps
- Heat accumulator tank for load levelling
- Optimising the heat plant operation
- Calculating the economic feasibility of a P2H unit
- Convert CHP plant from coal to biomass
- Setting up a new biomass plan
- Integration of solar energy (thermal collectors and PV) in the heat production mix
- Solar thermal implementation in a small system which can operate during summer months and replace the main heating source
- Installation of thermal heat storage to increase flexibility
- Heat recovery from the flue gas
- Waste heat utilization from the condensate for the technological purposes in the system
- Operation optimization of two coal cogeneration units
- Installation of a waste incineration facility

Management

- Merging the business with the neighbouring utility
- Setting up an energy demand prognosis 2018 -2030
- Plan for increased share of renewables

7 The Upgrade DH replication cases

In order to outreach the experiences and results gained in the Upgrade DH project, replication cases were supported, besides the demo cases. This action consisted of continuous involvement, cooperation and information sharing with the follower cases. Replication cases were provided priority access to project results, were invited to Upgrade DH events and benefitted from direct expert support for the upgrading of their DH system by the Upgrade DH expert partners.

In total, 8 replication cases (networks/cities) were selected based on most promising upgrading potentials:

- **Høje Taastrup** Fjernvarme a.m.b.a. is the district heating company located in Høje-Taastrup Municipality (Denmark). The residential area Taastrup Have needs an upgrading of the heating system. The Upgrade DH project facilitated the expert collaboration with the definition of areas where it is possible to optimise the performance of the network.
- Javno preduzeće Grijanje d.o.o. **Kakanj** is a public company, which deals with the distribution of heat energy in Kakanj (Bosnia and Herzegovina). Thermal energy is being produced by a combined heat and power facility based on coal, and estimated heat losses are 25%. They benefited from the discussions about replacement of old distribution network and introduction of deep geothermal.
- Gradska Toplana **Karlovac** is a municipality owned district heating system located in the city of Karlovac (Croatia). The main focus points of the expert support were the high water losses in the distribution network of DH Karlovac, as well as the old fossil fuel production units. Through the results of Upgrade DH, the management of Gradska Toplana Karlovac were introduced to the technical and economic potential of renewable energy sources for heat production, the economics of distribution network replacement and thermal storage integration.
- **Mehren** (Eifel) is a small town, located in the western part of Germany. The local biomass-fired CHP plant suffered from multiple inefficiencies. The follower case benefited from discussions on general optimisation opportunities, consultation on subsidies requirements and framework conditions, support in monitoring activities for digital control of the DH system, technical analysis of different expansion strategies.
- **Næstved** Fjernvarme a.m.b.a. is the district heating company located in Næstved Municipality (Denmark). Næstved DH has started a collaboration with the experts from Upgrade DH aiming to use the large amount of data available after the implementation of smart meters in the network. The aim of the collaboration was to develop a new heat loss calculation tool, which could estimate the losses from the pipes in the network to understand where the pipes needed to be replaced.
- KJKP Toplane – **Sarajevo** d.o.o. is the Cantonal Public Utility Company for heat production and distribution in Sarajevo (Bosnia and Herzegovina). Being the largest district heating system in Bosnia and Herzegovina, it is based on natural gas, extra light and heavy fuel oil. Through the expert support of the Upgrade DH partners, they benefited from the discussions about introducing renewable resources into district heating system.
- **Širvintai** (Lithuania) Sirvintu siluma is a municipality owned company, providing heat energy to households, state authorities and businesses in city Širvintos (Lithuania). High technological heat loss occurs due to low usage capacity and oversized and old network, as well as low heat generation flexibility, especially in summer months. The company is keen to install the same or similar digitalisation solutions as in Salcininkai. This would help the company progress towards low temperature heat network operation, reduce heat loss, increase pump efficiency, reduce CO_2 emissions and maintenance costs.
- **Verona** is a small city located in the north of Italy. A portion of the city is served by a district heating and cooling network managed by the local utility AGSM Verona. The Upgrade DH expert support helped AGSM understanding better the necessary steps to improve the operations and to reduce the implications related to a volatile heat production coming from a steel factory. Furthermore, the project gave a better idea on how to integrate different energy source and thermal storage in the system.

Further details can be found in the report of Krasatsenka et al. 2021.

8 Public image raising campaign

Upgrade DH has launched an image raising campaign to promote modern district heating networks. The campaign aimed to improve the perception of district heating at local level, thus establishing district heating as a viable solution for the energy transition, in the minds of citizens. The webpage www.dhcitizen.eu (as well as the German webpage https://www.fernwaerme-info.com/) provides information on DHC, as well as its role in decarbonising our cities; highlights examples of decarbonisation success stories thought an integrated #DHCities map; gathers DHC customer experiences and information about relevant initiatives in different countries.

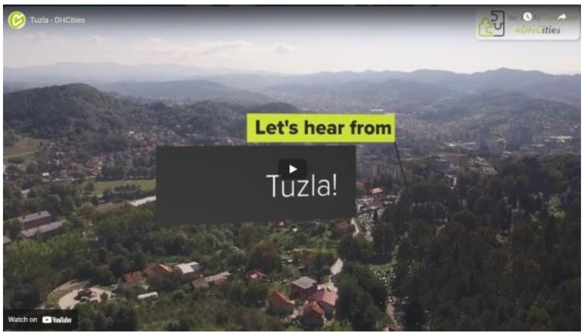

Figure 13: City decarbonisation stories

A brochure “District Heating and Cooling. A modern solution to traditional challenges” explains in simplified language, the benefits district energy delivers at all levels (i.e. local, national and global), its operating principles, and opportunities for modernisation of inefficient networks. It features selected Upgrade DH case studies that are undergoing retrofitting processes and invites citizens to engage with the heating solutions in their own homes. The brochure was made available in 6 other languages.

Figure 14: Cover page of the brochure

To strengthen the role and visually present the importance of decarbonising activities within the DHC domain, animated videos on “Decarbonising DHC for our cities” have been translated into several demo case languages and promoted across Europe.

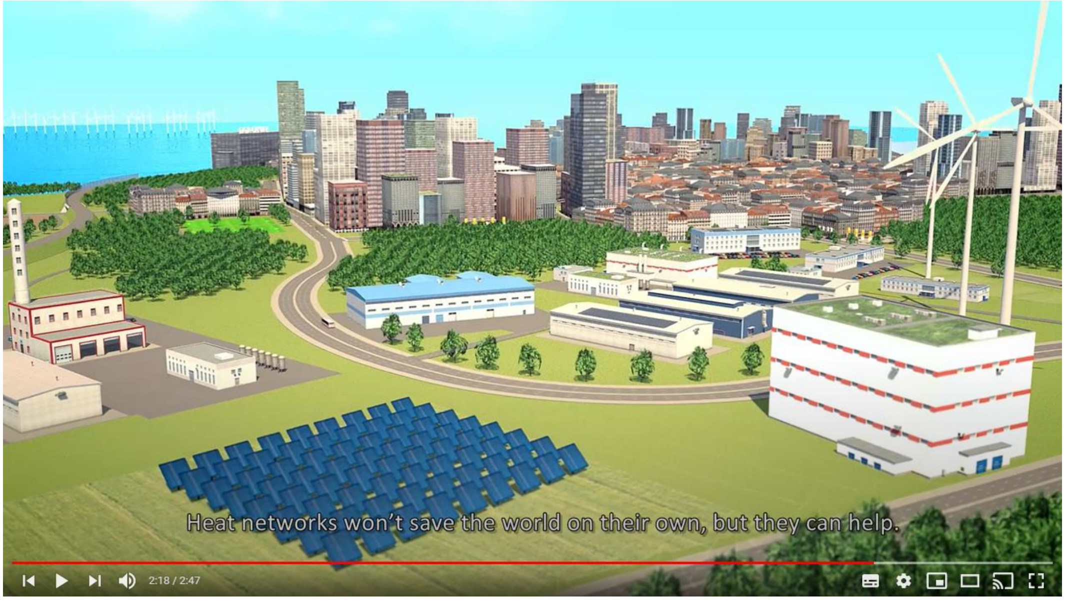

Figure 15: Screenshot of the video

Finally, a social media campaign “Become a #DHCitizen!” was carried out in order to create awareness and raise interest in the topic of modern district heating networks among the general public, showcasing best practices of retrofitting and success stories of upgrading local communities to district energy. The photo contest "Meet the ones who keep you warm!", face masks #DHCitizen, professional articles about energy transition in selected countries along with some important events made a significant impact on the promotion of DHC in Europe.

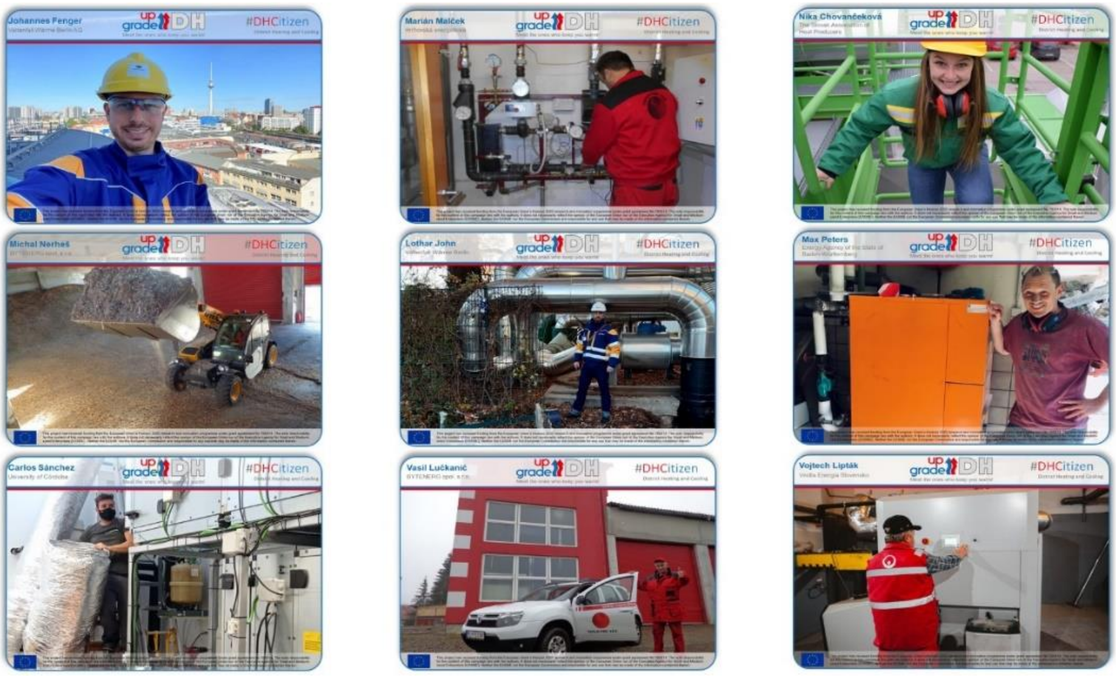

Figure 16: Photos received for the photo contest

The campaign was very successful as more than 50,000 citizens were reached. More details can be found in the report of Krasatsenka (2021).

9 National action plans

An important activity in the Upgrade DH project was the development of national action plans for the retrofitting of inefficient district heating networks in the above-mentioned target countries, including the results of the retrofitting approaches. The Upgrade DH action plans, available at the project website, include an overview of the current policy framework relevant for DH development, market analysis and challenges, as well as proposed solutions. Here are some of the main take-aways for each of the target countries:

Bosnia and Herzegovina: Due to the complex administrative structure of the country, separate laws exist at the state, federal, and canton levels. Challenges have been identified, as well as priorities for improving the market regulatory conditions in the heat sector. Policy recommendations and actions for the modernisation of inefficient district heating systems are presented in the DHC action plan including their implementation timeline.

Denmark: The report finds the situation of the DH sector in Denmark to be very satisfying from the renewable and efficiency perspective, adding only minor recommendations to the developments that are already ongoing and efforts to further decarbonise and increase efficiency. For example, removing taxation on waste heat, and instead of using CO_2 taxes to push the market, encouraging climate friendly solutions. Other recommendations focusing on production, distribution and end-use consumption are also included.

Croatia: District heating will have a significant role in the future energy system in Croatia, which is already outlined in the National Energy and Climate Plan. However, various actions and measures need to be implemented in order for district heating to achieve its potential. The proposed action plan has been developed based on the analysis of the current state of the sector and taking into account the already developed action plan of the KeepWarm project for Croatia.

Germany: Germany is characterized by numerous promotion instruments and incentive programmes for the improvement of district heating systems. Input to the DHC action plan for this country contains recommendations on large heat pumps as an important piece of the puzzle for implementing the planned coal phase-out. Other recommendations focus on funding opportunities, tax incentives, legislative framework, integrated urban planning and knowledge exchange between municipalities.

Italy: Input to the DHC action plan for Italy contains recommendations over short, medium and long timeframes. The short-term strategy mainly focuses on legislative interventions. The medium-term strategy details possible retrofitting measures on the production, distribution and consumption sides. Finally, the long-term strategy emphasises consumer empowerment, novel business models, multi-energy planning and digitalisation.

Lithuania: The Lithuanian district heating market is heavily regulated and there is a lack of investments into new efficient DH systems. International collaboration of experts as well as identification of sustainable options for DH systems is essential in this process. Therefore, a list of existing regulations, problems and proposed solutions that could support the development or retrofitting of DH networks was elaborated.

Poland: DH is already considered as a solution by the Polish Government for the green transition process. The proposed action plan provides recommendations, which can be considered in the transition process. The solutions can be divided into three main areas, where the district heating is acting: production, distribution and end-use. Furthermore, a fourth area regarding policy and regulation can be considered, which does not directly act on the district heating network but can incentivise its development.

The Netherlands: There are clear indications that district heating is going to be promoted in general. It has been stated by the Government that by 2050 natural gas shall no longer be used for heating purposes. More specifically, the Dutch Climate Agreement of 2019 covers many aspects that must be considered for the transition towards the implementation of renewable energy solution in the Netherlands. The proposed action plan suggests actions for DH that can be considered to increase the possibilities of reaching the national targets.

10 Conclusion

The overall impact of Upgrade DH is significant. The proposed measures for upgrading lead to a reduction of 16.9% of the primary energy demand and 51.9% reduction of greenhouse gases of the DH systems at the eight demo sites. In absolute numbers, this is a reduction of more than 150,000 t of CO_2 equivalent per year. Furthermore, the share of using waste heat increased by 3.3% and the share of renewable energies increased by 21.7%. Several of the upgrading measures are currently being implemented, some measures were even finalised.

Furthermore, the Upgrade DH project has managed to raise very significant interest at EU level amongst key members of the DHC industry. Whenever abstracts were submitted to important conferences (e.g. Smart Energy Systems Conference, EUBCE, IEA Symposium), they were accepted and presentations showed a high degree of participation and engagement. The potential for replication has repeatedly been highlighted as a key factor to increase impacts in the medium run and the pragmatic and holistic approach regarded by third parties as a key strength of the project.

Finally, the "Upgrade DH" brand became recognised as a best practice itself, which is obviously very beneficial to partners from the consortium to present their services. It is expected that, also due to the synergies that have been initiated with the Celsius Initiative, the capacity of the project to inform and inspire a large fraction of EU utilities undertaking upgrading measures, will live beyond the project's termination, and so will the established collaboration between many project partners, all with the aim of upgrading district heating systems towards more sustainable ones.

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