DIGITAL ROADMAP FOR DISTRICT HEATING & COOLING

DHC+ Technology Platform c/o Euroheat & Power

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Disclaimer

The opinions and views expressed in this document do not necessarily represent the views of all DHC+ Technology Platform and/or Euroheat & Power members. The present document may be updated.

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Foreword

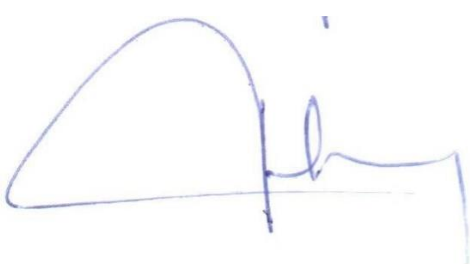
The heating and cooling sector, which makes up more than 50% of the whole energy demand, is currently under transformation because of digital technologies. This is why the DHC+ Technology Platform has initiated a thinking process on the future of the energy system and the role of digitalisation for different parts of the district heating and cooling system.

Digital technologies are believed to make the whole energy system smarter, more efficient, and reliable and to boost the integration of more renewables into the system. In the future, digital energy systems will enable district energy systems to fully optimise their plant and network operation while empowering the end consumer. We will be able to use the connected infrastructures as efficiently as possible, time their production according to forecasted demand and, enhance the usage of renewables. Yet how will we get to this future scenario?

IoT, automation, AI, and big data hold big promises. Nonetheless, they also come with pitfalls and raise new challenges, such as security and privacy as well as questions about data ownership. Additionally, new business models and policy interventions require market actors to adapt. The pace of change is fast and it is challenging both industry players and regulators.

The Digital Roadmap for District Heating & Cooling offers insights on how digitalisation impacts the industry, showcases the current state of the art, identifies barriers and presents objectives, targets and recommendations for each of the topics: Production Level, Distribution Level, Building Level, Consumption Level, Design & Planning and Sector Coupling & Integration of Multiple Sources. The idea for this Roadmap emerged from a series of discussions with DHC+ members and was driven by the H2020 research and innovation project STORM.

We hope you enjoy the reading and we look forward to keep exploring with you how the future of our energy system will look like!



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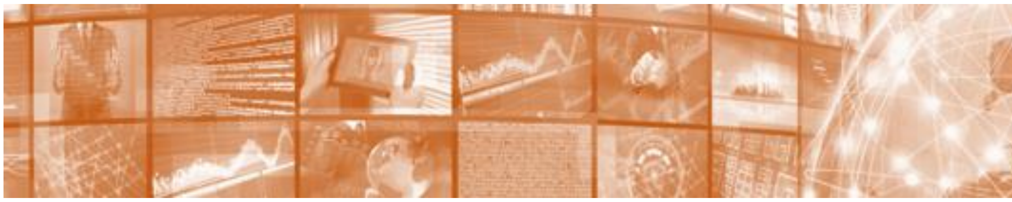

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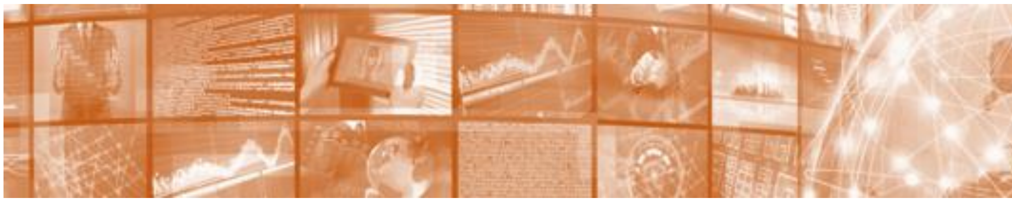


1) PRODUCTION LEVEL

Introduction

The main objectives of the transition to 4th generation district heating systems, are the increase of efficiency of these systems and the maximization of the integration of sustainable heat production sources, i.e. renewables and excess heat from industry.

Moreover, compared to traditional networks, 4th generation networks are becoming increasingly complex, with multiple smaller heat production sources and even prosumers. Finally, 4th generation networks tend to be coupled with other energy sectors, like gas, electricity or district cooling networks.

Digitalisation is a prerequisite to achieve the objectives of 4th generation networks. On the production level, without digitalisation in the form of smart control, the maximization of sustainable sources will never be possible. Indeed, sustainable energy sources are often uncontrollable and even partly unpredictable, leading to the need for new types of heat network controllers.

How and to which extent will it affect and transform the district energy industry (and other sectors)?

Renewable energy sources are often highly fluctuating; think of solar thermal energy which is heavily influenced by sudden cloudiness of the sky. While excess heat from industry might be more controllable, it is unlikely that companies want to adjust their production process to optimize the heat delivery to the heat networks. After all, excess heat is a by-product. It is through smart control of the controllable heat sources (like CHPs, boilers, heat pumps…), that those sustainable uncontrollable sources can be maximally utilised.

Often, the sustainable energy source of heat networks is not dimensioned on the peak demand of the heat network, since it does not pay off to design a rather expensive heat source for a limited number of operational hours. The peaks are often covered by cheap, often fossil fuelled boilers. Peak shaving, a form of smart control, can however maximise the operation of the sustainable source,

Furthermore, smart control is necessary for plant scheduling, i.e. between which heat plants to switch at what time? Since more and more heat sources are integrated in 4th generation networks, scheduling and operation of heat plants will become increasingly challenging, and new control systems will have to be developed.

, Smart control can also play a very important role in sector coupling. It can be especially beneficial in coupling between district heating networks and electricity grids. In current smart electricity grids more and more fluctuating energy sources, like solar or wind power, are being integrated. However, the electricity grids possess only very limited flexibility (energy storage) . Therefore, the integration of renewable sources in the electricity grids cause balancing problems and volatile market prices. District heating networks on the other hand contain a lot of flexibility (the water in the pipes, thermal storage buffers, the buildings coupled to the network). By switching heat production devices that have a connection to the electrical grid like CHP, heat pumps, ORCs… at appropriate moments, the flexibility in heat networks can be utilised as a balancing service to the electrical grids and the curtailment of renewable electricity can be reduced.

To conclude, smart control will lead to more efficient heat networks, and will decarbonise the heating sector through the maximised integration of renewable and excess heat sources. Furthermore, through sector coupling, digital heat networks can also contribute to cleaner electricity networks.

State of the art

Controlling of district heating networks consists of a number of decentralised control systems at production and consumer level. There is, however, no interaction between them. Since each control system as such has an individual control objective, this does not lead to an optimized control at system level. These controls at system level are not commercially available yet.

Production plant optimizers, however, are commercially available these days. Nevertheless, they are tailored to traditional district heating networks, using predefined scenario templates. For the complex 4th generation networks with multiple, unpredictable heat sources, these products are not yet compatible.

When it comes to peak shaving, the state of the art is central storage tanks, placed next to the heat production plants. In addition, demand side management solutions are promising since they require none or very little investments.

Technical, economic, societal & regulatory barriers

Technical barriers

- The lack of control systems for DHC networks able to deal with fluctuating sustainable energy sources.

Organisational barriers

- Integrated control systems require the ability to take control actions on the building substations. These often belong to the building owner without whose agreement, no action can be taken.

Economic barriers

- The current business models do not provide give incentives to building owners to allow their buildings to act as sources for thermal flexibility (which consequently can be used for peak load management).
- User-investor dilemma: investments are required to enable the building to shift its load (e.g. smart heat meters, additional storage…), but the benefits (e.g. cheaper heat price) are passed on to the user → the investor has no motivation to invest.
- Pricing models for heat are not adjusted to stimulate smart control.

	Hourly pricing or similar behaviour regulatory models could be useful to steer the customer demand and production loads. Regulatory barriers - Regulations with respect to data security and protection of private data might hinder the roll out of digital heat networks. Societal barriers - Consumers are used to control their heating system substation themselves. For smart control applications, consumers should allow the network operator to manage their substation, with the consumer just setting the comfort requirements.
Objectives & targets	- For the next generation of DHC systems, it is important that the production and consumption control systems become integrated. - Furthermore, intelligent control algorithms should be developed, preferably based on data driven models rather than real physical models of the network. Machine learning approaches are very interesting in this context to build heat load and flexibility forecast models in the network. - There is a need for business models and tariffs that benefit consumers who want to contribute to demand side management. - Network operators should have the “power to operate” (cf. underlying contract) the substations themselves, so that they can control the demand side as an extra degree of freedom to optimize the efficiency at system level.
Actions, Priorities & Recommendations	Actions and priorities - To develop design and performance assessment tools for a multiple-sourced, intelligent and low carbon district heating and cooling system, thus establishing the methodological base for the DHC design and performance assessment. This could be done by developing tools which model the network in a detailed but easy way (creation of “digital twins”). - To carry out case studies on how to integrate multiple heat (cool) sources and internet-based intelligent control into the DHC systems. - To showcase the actual performance of multiple-sourced, intelligent and low carbon DHC system, thus examining whether or not the expected impact can be achieved and determining the relevant contiguous plans by means of lighthouse/pilot projects. - By developing a dedicated socio-technical performance assessment system, the economic, environmental, business, marketing and social impacts of the DHC developments could be properly evaluated. This would help accelerate the transformation process towards 4th generation district heating.

Recommendations	- Learn from the experience of the demand side management in electric grids (tariff models, privacy and security issues, standards…). - Regulatory roll-out of smart heat meters

2) DISTRIBUTION LEVEL

Introduction

The distribution network ties the energy chain together by connecting the generation of energy with its consumption and is, therefore, a vital part of the overall system. This especially applies when considering the thermal characteristics of a district heating and cooling system, where the operations of the distribution network set vital constraints on the overall performance of the system.

However, most traditional distribution networks are treated as a "black box", where the grid operator knows what is put into it and what comes out but not much in between. Simply put, the traditional way to manage the distribution is simply by keeping the pressure head and not much else. This does indeed keep the system going in most situations, but it will invariably lead to suboptimal efficiency. This will increasingly become an issue as the district heating industry moves towards low-temperature networks where the operations have to be controlled more efficiently.

Digitalisation can enable so much more on the distribution level: Cost efficient, robust and scalable data collection and communication systems will enable the management of real-time data, which in turn will fuel machine learning and data mining technologies. This plays a key role in optimising the energy distribution and in maximising the performance in relation to temperatures, flow, pressure levels, thermal demand and leakage situations throughout the grid.

How and to which extent will it affect and transform the district energy industry (and other sectors)?

There are several benefits in digitalising the distribution system, relating to operational analysis, real-time control and overall efficiency of the system. Digitalising the distribution system will facilitate a more balanced energy distribution and minimise heat losses.

Operational analysis and predictive maintenance
The most immediate benefit of digitalising the distribution system is the ability for data collection and management. This will enable more in-depth analysis of the operational characteristics of each grid and introduce the ability for predictive maintenance to a higher degree. It will also form the basis for more advanced technologies relating to active control and operational optimisation.
More mature digitalisation efforts in the distribution grid will enable data management relating to temperatures, flows and pressure heads. This will help to identify bottle necks in the network or sections with over-capacity, which, in turn, will contribute to more efficient control.
Digitalisation can also play an important role in more efficient leakage detection. There are district heating systems that replace the equivalent of their total water mass each year. Leaks are a not uncommon and a recurring issue. The main challenge is to identify them as soon as possible. Improved measurement and analysis ability will greatly contribute to this end.
Managing under-dimensioned piping systems and narrow sections

Many district heating networks have been around for some time. As more and more customers are connected, the original distribution system can become under-dimensioned for the increasing demand and, narrow sections appear. Modern solutions based on digitalisation can balance and smooth the demand if introduced into a network. This prolongs the lifetime of the existing piping by facilitating the addition of new customers within the same distribution constraints. This is an important benefit of digitalisation since it benefits CAPEX as well as OPEX. As a result expensive infrastructure investments can be avoided or minimised.

Controlling the demand

Traditionally, operational distribution focuses on keeping the pressure high and questions relating to long-term work focus on insulating the pipes, hence the traditional system is about *satisfying* demand. However, by using solutions based on digitalisation, such as smart grid controllers, it is possible to also *manage* the demand, which provides several benefits for the distribution grid. By refining the control of the demand, it is possible to lower the system temperatures and create smoother hydraulic operations.

Pressure optimisation

Currently the majority of district heating and cooling distribution systems use a limited amount of critical-point measurements in a network (usually the most distant/elevated network point), as a set-point reference for the pumping station. This set-point is usually adjusted only between the winter and summer operating regime. In modern, complex district heating and cooling systems, the shifting of critical point is relevant as hydraulic conditions change. This becomes increasingly important as flexible heat sources are distributed in the network, in which the network is used as a thermal infrastructure where sources change over time in capacity and location. A more flexible system will also facilitate more dynamic operations over both daily demand change-overs as well as more long-term and seasonal change-overs. The benefits of operational pressure optimisation are not only technical, but also relate to reduced pumping costs and improved leakage management.

Operational thermal optimisation

In traditional networks the supply temperature is defined by a production curve relating it with the current outdoor temperature. Most of the time there is a safety margin factored into the curve or manually added by the network operator. By using digitalisation solutions it is possible to use a more dynamic approach regarding supply temperatures, especially when combined with other digitalisation solutions relating to the other parts of the energy chain. This facilitates lower system temperatures, which, in turn, decreases heat loss and consequently primary energy consumption. It also benefits renewable sources as lower system temperatures make it possible to utilise them more efficiently. This has a great effect on economic savings as well as environmental impact.

State of the art	Modern network controllers based on demand side management are emerging in both research and commercial applications. Current research see these being integrated more closely with buildings as well as the production side. Ways to combine such systems with thermal management are also currently being developed, based on the application of machine learning technology. Similar techniques are used to drive the development of pressure optimisation solutions, enabling pumping stations to work at optimal levels. Several ways to develop better and more cost efficient solutions for leakage detection are being investigated.
Technical, economic, societal & regulatory barriers	There are a number of barriers for the widespread adoption of digitalisation solutions in distribution systems, ranging from technical to financial and societal. Some barriers relate to regulatory constraints, e.g. contracts including certain temperature levels at supply level which hinder system wide optimisation in the operation. Related to this, the ability to coordinate the operational behaviour of a large set of buildings and the operational constrains of the grid. This requires, or at least implies, some agreement between grid operators and building owners. The complexity of the process of landing such agreements are normally underestimated. One of the primary barriers relate the fact that lowered distribution temperatures will invariably need to account for infrastructure and demand limitations (the demands of the consumer installations, which can be adjusted over time, e.g. in relation to renovation, e.g. uninsulated objects , objects under architectural protection).
Actions, Priorities & Recommendations	Several of the challenges and opportunities mentioned in this section are being addressed in on-going innovation projects, including efforts to improve technology for merging thermal and hydraulic operational optimisation as well as developing business models that include the benefit for distribution systems in the overall offering related to demand side management. Such efforts are on-going and results are expected to emerge within the near future.
Recommendations	The general urge is to put more effort into business development related to these questions and to address barriers relating to regulations and markets. Technological development is in progress, including research addressing the following questions: Development of artificial neural networks / thermo-hydraulic network hybrid model (self-learning digital twin). ● Development of automated fault detection supervision systems to detect anomalies in the networks and the building's substations. ● Technological investments into district heating systems (remote control, monitoring). ● Development of software. ● Pilot/lighthouse project. ● Updating building installations for low temperature operation, e.g. Domestic hot water, heating can still be seasonally operated at higher temperatures if needed. For new building floor heating adapts well to low temperature DH supply. Technological investments in district

heating systems (intelligent field devices, remote control & monitoring).

- Algorithm and software development.
- Pilot/lighthouse projects

3) Building level

Introduction

Modern district energy systems are demand driven. The building level, manifested by the substation, establishes this demand. At the same time, building and apartment level solutions can help mitigate supply side challenges such as the case of intermittent production. From a technical point of view, a holistic building approach is the single most important point of interest in the energy chain as it acts as the mediator between the grid (satisfying demand) and the indoor climate (creating demand).

By using smart meter technologies and remote control devices, high temporal resolution of data is possible. Bi-directional data flow between the district heating operator and customers is key to operational excellence and facilitates reaching the next level of comfort for the end consumer.

Real-time operation and prediction of demands allows for identifying usage patterns as well as for correcting periods of inefficient use of thermal energy (faulty installations, building side leakages, anomalous consumption etc.) or moments of demand resulting in an inefficient use of resources (peak loads). This can be achieved by analysing the heat consumption and temperatures from individual heating substations using pattern analysis (automated using machine learning) as well as by shifting demand patterns where necessary and possible. Root cause analysis can be performed in order to clarify the underlying issues e.g. a high return temperature.

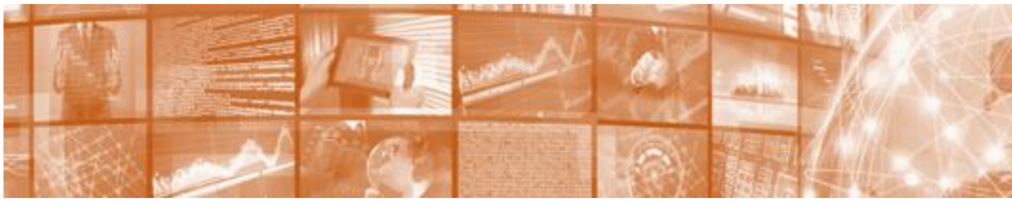
Since especially older systems in some Member States operate in a supply driven mode, digitalisation also needs to provide solutions to modernise these systems.

Moreover, digital solutions will facilitate the operation of hybrid solutions, e.g. low-temperature District Heating combined with individual heat pumps.

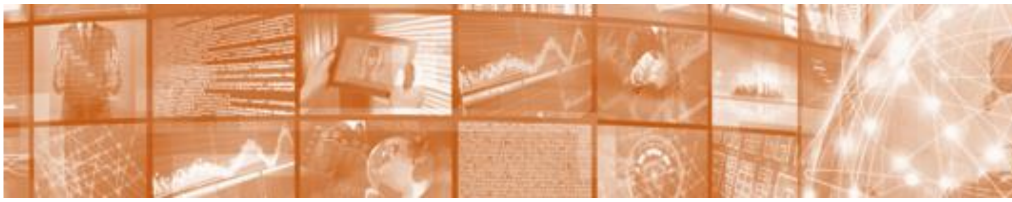
How and to which extent will it affect and transform the district energy industry (and other sectors)?

Bi-directional data flow between the district heating operator and customers is key to operational excellence. By using smart meter technologies as well as remote control devices and indoor climate data (e.g. collected by smart thermostats), the next level of comfort for the end consumer will be reached.

Using smart meter technologies and remote control devices makes high temporal data resolution possible. Bi-directional data flow is the basis for a holistic real-time overview of heat demand. This overview supports the cost optimal heat system operation and, in parallel, enables access to heat controllers in the substation in case of disruption. An automatic alert function triggers those countermeasures (e.g. enable the district heating operator to have access to the actual data of the heat controller and to send a signal to the heat controller to open the heat supply valve), before end consumers realise the indoor temperature drop.
The knowledge of the indoor climate data collected e.g. by mould meters or smart thermostats, as well as e.g. temperature data of the tap water system



	are key to avoid neurological problems caused by mould and to prevent legionella by automatically activating real-time countermeasures by the heat supply. This way the end consumer benefits from an increased level of health care. The substation is the gatekeeper between the grid and the building. As such, its digitalisation will provide benefits for the whole energy chain. A fully digitalised substation will facilitate demand side management, transparent pricing, improved energy efficiency, fault detection and more. Digital solutions at the consumer side level do not only allow for consumers to 'respond' to price signals, they also allow for peak shaving and demand shifting and, therefore, a more efficient use of generation capacities. By shifting loads, operators are able to seize the benefits of intermittent supply solutions while avoiding the use and maybe even the availability of expensive and often fossil peak load supply capacity. Also, digital solutions on the consumer side may allow for lower return temperatures as well as for lower supply temperatures which increase the efficiency of the network. Overall, consumers enjoy higher levels of comfort and often lower prices, networks can be operated in a more efficient way integrating more decarbonised sources, which results in societal effects mitigating climate change.
State of the art	A number of promising types of schemes are identified for specific situations. The last few years have seen substantial innovation, mostly based on digitalisation efforts providing increased computational and communication capacity. Functional control systems for energy efficiency schemes, including adapting to indoor temperature sensor data, outside weather and heating system constraints are now available. Furthermore, systems that allow substations to be part of demand side management schemes are available and innovative work on added functionality for predictive maintenance is on-going. So far, the process of analysing and monitoring consumption on building level is, to a high degree, a manual process carried out by the utility or a contractor (or the consumers themselves), and performed on a non-continuous basis but in regular intervals or, in case of a detected fault, either by the consumer or on the network side. Automating and sophisticating this analysis by deploying existing solutions and, for example, by using pattern recognizing algorithms (e.g. machine learning) has great potential in improving the system. Nonetheless, solutions beyond the state of the art promise even greater benefits.
Technical, economic, societal & regulatory barriers	A first barrier is the question of ownership of the substations. In cases where they are owned by DHC customers, these need to be convinced of the benefits of smart solutions where applicable. Moreover, customers and consumers are often, and especially in apartment buildings, not the same person. Building owners do not benefit from demand response induced cost improvements



and have therefore, no direct interest in corresponding solutions.

In all cases, (i.e. substations owned by the building owner, substations owned by building owners but fully operated by the utility, and substations owned by the utility,) the secondary side needs to approve any function, e.g. data usage, demand response or changed secondary temperatures.

Especially matters of data protection play a key role in the roll-out of smart technologies. Having said this, many other matters are of contractual nature. Lower (or, in the case of DC, higher) temperatures on the secondary side that are needed to adjust the grid temperature or that are a consequence of smart network management often conflict with contractually guaranteed temperatures.

To create a reliable smart meter rollout business case is a challenge for energy utilities as it has to be built on many soft factors but, the investment needed for hardware components like sensors, gateways, smart controllers, smart heat meters is high.

Smart heat meters and gateways so far do not support a standardised data transfer (e.g. support of different protocols). Replacements of heat meters from different suppliers often causes need for trouble shouting to receive data from the site as long as the suppliers of heat meters and suppliers of gateways have not agreed on a certain level of standardisation.

Actions, Priorities & Recommendations

Actions and priorities:

- Further develop the connection between operational grid optimisation and efficient heating controllers.
- Increase the digitalisation ability of the substation, with cost effective communication and data management hardware/software.
- Business models enabling grid operators to manage, and possibly own, the substation. This will provide ways to develop the offer to building owners and tenants, as well as to integrate the substation into the energy system of the grid.
- Develop integrated control solutions allowing for the efficient operation of hybrid solutions combining DHC and individual heat pumps

Recommendations:

- suppliers of heat meters and suppliers of gateways have to agree on a certain level of standardisation.
- Heat meters should be connected to the heating controller.
- Supported roll-out of smart meters (financial support of investments for gateways and smart heat meters).
- Change of contractual temperature guarantees that are no longer appropriate.
- Substations should be open to connection to the grid.
- Business models and offerings need to be innovated so that building owners become more inclined to allow their buildings to participate in making the energy grid work better.

	• Development and roll-out of integrated control solutions while ensuring inter-operability and communication standards between heat and electricity grids.

4) CONSUMPTION LEVEL

Introduction	Digitalisation gives an opportunity to engage end-users in the awareness of their energy use. By means of visualisation tools using real data on e.g. hourly interval, they get an insight into their energy use, benchmarking to other consumers becomes possible and energy savings can be suggested. Tools for customers helping to control and monitor energy usage may streamline and help the customers to make district heating much more efficient and allow 4th generation DH. Nevertheless, it can be hard to engage end-users in energy related issues. Data can also empower the energy provider to take more responsibility and action towards the end-users and offer services like monitoring the heat system. Energy providers can also develop new billing models and could ultimately sell comfort and 21°C in the living room instead of kWh of energy. For the building owners/managers and utilities, tools for energy rating, based on smart meter data, also suggesting improvements for buildings and heat system installations have a great potential for an energy efficiency perspective.
How and to which extent will it affect and transform the district energy industry (and other sectors)?	● Services for end-users are important to position district heating as an attractive product against individual heating ● In district heating, end-user behaviour and building/heating systems have a very strong impact on the operation and distribution efficiency. Engaging end-users is necessary to enable energy efficient 4th generation DH where a large extend of the energy demand for heating buildings can be covered by surplus heat and renewables. ● 80% of the buildings that will be supplied by district heating in 2050 are already built. Not all building will be new energy efficient buildings supporting LTDH. Pinpointing potential improvements for these existing buildings (data-driven) is key to enable 4th generation DH.
State of the art	● Standardisation and regulation of remote metering in the electricity sector is far ahead compared to the heat sector – still not mandatory rollout for remote metering within heating (having said that, this will probably come as part of the new EED directive) ● Fixed network data collection (hourly or daily basis) from smart meters is still in the early stages outside Scandinavia. ● End-user engagement through digital tools, including visualisation, is happening on a small scale and several studies have shown that it is hard to engage end-users in energy related issues. An alternative approach in needed ● Still only a few data driven tools on the market that do the more

	advanced analytics on buildings and heating systems compared to just visualising the data for the end-user
Technical, economic, societal & regulatory barriers	● Missing standards for heat meter interfaces hamper the remote reading of data ● A proven business case for hourly meter readings in fixed network. We all believe it is there, but we need to see tangible results compared to the cost for a smart metering solution ● Innovative low-cost data transfer infrastructure (e.g. LoRa, NB IoT) not fully rolled out EU-wide and energy providers are forced to build their own communication infrastructure for meter reading ● Smart meter data is an essential part of the digitalization process. However, in light of the General Data Protection Regulation (GDPR) the frequent collection of smart meter data raises the issue of how it is processed and protected – and whether it violates the rights of the individual consumer.
Actions, Priorities & Recommendations	**Actions and Priorities:** ● Enable consumers and buildings to behave better and more efficiently in the DH network ● Standardizing the communication / smart metering solutions, at least the connectivity part of it. **Recommendations:** Focus more on empowering energy providers to take more responsibility instead of just visualising the data for the end-user and trust that they will change and improve. This will not happen due to low interest in energy Make sure the GDPR regulation will not limit the access to data or require end-user consent. Smart meter data that is collected more frequently than what is used for billing purposes is considered personal data and is therefore covered by data protection regulation, including the GDPR. This conclusion has been reached by the Article 29 Working Party. Because frequent smart meter data is personal data, it raises the question of the need for individual consent from all customers. In addition to being an insurmountable administrative burden for most energy suppliers, this also means a considerable risk that some customers will be unwilling to give that consent. If you only have data from half of the buildings in a given area, it is all but impossible to perform an accurate forecast, which will have a negative effect on the possibilities for data-based optimisation – not just in the buildings themselves but also in the distribution network. In relation to smart meter data, points (e) and (f) of GDPR, Article 6 are relevant, as they state that processing of personal data is legal to the extent that:

(e) processing is necessary for the performance of a task **carried out in the public interest** or in the exercise of official authority vested in the controller;
(f) processing is necessary **for the purposes of the legitimate interests** pursued by the controller or by a third party (…)

We need to ensure a national implementation of the GDPR that allows that the frequent data collection from heat meters can be done without customer consent as long as the energy supplier uses that data either in the interest of the public to save energy and minimise energy losses, or for the legitimate purpose of improving the energy efficiency of its operations.

5) DESIGN AND PLANNING

Introduction

Areas for new urban developments or district retrofitting usually have high ambitions for their energy efficiency and share of renewables/ CO_2 emissions (e.g. net zero energy, plus energy districts etc.). However, the decision on the appropriate systems for energy supply distribution and consumption is often not straightforward, since it depends on many technical and non-technical conditions, as well as the individual behaviour of the relevant stakeholders.

The planning process of those systems (i.e. evaluation of the status-quo, development of technology scenarios and final decision making) is challenged by the fragmented and not consistent planning processes of the individual stakeholders and the various tools used. Furthermore, the required data is often fragmented, inconsistent or not available at all and, in addition, hereto data protection issues must also be considered. Due to the individual interests of the relevant stakeholders, it is often difficult to reach an overall "optimum" with regards to the targets.

As a consequence, the "optimum" planning, design or adaptation of (existing) thermal networks (district energy (DE)/ district heating and cooling (DHC)) in those areas is challenging, especially for innovative concepts such as low or ultra-low temperature networks or hybrid energy systems. The specific questions are related to the type and dimensioning of the networks (heating, cooling) and the system temperatures, the use of renewable gas, which buildings to connect, prosumer-integration, and application of central or decentralized supply systems (such as solar thermal energy or Photovoltaics (PV), (micro-) combined heat and power (CHP) plants, heat pumps (HP), waste heat, thermal storage, batteries etc.).

The decision making requires the use of various data sources (existing and new buildings, underground structure and barriers for pipes (e.g. streets, rivers, property lines), existing and potential new renewable energy sources and waste heat, other energy infrastructure (e.g. gas networks), storage options …). Moreover, the different planning processes need to be aligned (e.g. construction of new buildings and network expansion) and simulation/ optimization tools should be used appropriately.

The planning process of DHC networks can be optimized through development and application of different digital solutions, including big data approaches for data analysis (e.g. utilization of metering data for design processes), mapping algorithm (e.g. renewables, retrofitting potential), process planning tools, sophisticated optimization and co-simulation methods etc. Such solutions will be needed to overcome the challenge of traditional methods when designing DH systems – including scenario verification / iteration approach to development, maximizing the share of renewables and energy efficiency, risk management, avoiding bottlenecks and over-dimensioned systems, lower safety coefficients, reducing heat loss etc. In return, the investment and operation costs can be reduced and

	customer satisfaction increased.
How and to which extent will it affect and transform the district energy industry (and other sectors)?	Benefits for: - **The end consumer:** optimum planning leads to a higher supply security , e.g., environment-friendly heat supply even during exceptionally cold periods, moreover, the increased cost-efficiency due to synergies might be passed on to customers. - **The energy sector:** Increasing the economic and ecologic performance of their systems by reducing the investment and operation costs for exploitation of renewables and increasing the energy efficiency. Although only representing a rather small share of 5-15% of the overall costs over the lifetime of a DH network, the distribution infrastructure represents 60-80 of the value of the infrastructure as such. Investments into expansion and refurbishments mean substantial efforts for utilities and by that also have a significant impact on the assessment of investment feasibility. With a more accurate design (e.g. utilizing calibrated thermo-hydraulic network model and network measurements), a significant optimization of investments can be achieved. Additionally, customer satisfaction can be increased (see above) leading to higher connection rates. - **Society at large:** Reduction of the socio-economic costs for achieving the energy related targets of urban developments or district retrofitting usually (e.g. energy efficiency and share of renewables/ CO2 emissions. New business models should also be enabled, e.g. prosumer integration.
State of the art	Often, decisions on the heat (and cold) supply systems (DH, gas, individual heating/ cooling systems) for a new or retrofitted district are done by individual stakeholders based on personal preferences and targets and are sometimes influenced by general political tendencies and boundary conditions. DH networks are planned as standard 3rd generation networks, often using an extension of the existing network. Decentralised sources, storage or low temperature networks are usually not taken into consideration. The systems as such are designed traditionally by “rules of thumb” without any sophisticated scenario evaluation or the use of all available data sources. The individual tools for each component of the energy systems (buildings, heat supply, and renewable sources), have none or very few interfaces and are used in parallel.

Technical, economic, societal & regulatory barriers	The challenges for an integrated planning of energy infrastructure in cities and districts are: - Planning processes are fragmented within the municipality and related units; Planning and communication processes are not consistent, continuity is also required, after the project is finished. - The coordination of all stakeholders (utilities, network operators, city planners, architects ...). - The numerous data sources to be considered and the consistency of the data as well as processes for enabling a continuous exchange of data - Low availability of data (e.g. Complete digital GIS models of the pipe networks and other infrastructure, waste heat potential, rooftop areas for solar energy) and limited willingness of the data owner to share data. - Data protection regulation - privacy issues are important if one would like to consider citizen behaviour related to the use of heating and cooling. - Various tools are used in different departments, different stakeholders need to be involved. - The development of accurate energy system models (digital twin) requires accurate snapshots (due diligence) of existing infrastructure (lack of documentation on existing infrastructure). - Digitalization of complete system can be financially burdensome. - Complex relationship between energy demand (heat, cold, electricity), storage, mobility, supply options (PV, ST, WP, waste heat…) and networks including various coupling points (power-to-heat, power-to-gas, gas-to-power) – see also chapter on Sector Coupling and Integration of Multiple Sources. - The integration of additional simulation/ planning tools into the existing tools and processes. The relevant stakeholders have various tools they are using for planning and design processes of their individual systems. It is hard to motivate them to use “another tool”.
Objectives and targets	Development and application of new methodologies, tools and processes allowing for an integrated energy infrastructure planning, supporting the day-to-day decision making process in cities, energy utilities and other decision makers (e.g. property developers) and finally leading to a socio-economic optimum and at the same time allowing for new business models (e.g. prosumer integration)

Actions, priorities & recommendations	● State of the art assessment and collection of best practice examples, Identification of barriers and gaps for using/ integrating tools/ methodologies/ data. ● (Further) development of interfaces between existing tools in order to make them applicable for co-simulation approaches and integrated planning processes. ● (Further) development of multi-functional GIS databases that are secure and build on existing standards (e.g. City-GML) and is able to include various data sets. ● Establish integrated planning processes involving all relevant stakeholders and enabling to reach socio-economic optimum parameters. ● Technological investments into digitalization of energy infrastructures, i.e. district heating (and cooling) systems (remote control & monitoring, mapping, fault detection). ● Development of DH System modelling and simulation tools with interface to different data sources, (self)calibration functionality, potential mapping, scenario evaluation including risk management etc. ● Involvement and communication of the developments to various stakeholders, especially city planning offices, energy utilities and other decision makers (e.g. property developers) ● Pilot project: Demonstration of (economic) advantages of the integrated, data-based planning process on one or more concrete examples: reaching an overall optimum, lower total investment and operational costs

6) Sector Coupling and Integration of Multiple Sources

Introduction

Traditionally electricity, heat/cold, transport and industry are treated as individual sectors. The ongoing decentralisation trend leads communities to consider their territory as an entity to be optimized as such. Local networks and energy sources can therefore now be considered as building blocks of a different business model, with new opportunities for local stakeholders and evolving at the pace of the territory planning.

A second effect of this trend is the drive of massive investments into decentralized technologies that quickly improve their competitiveness, such as PV, heat pumps, smart electric boilers, demand response systems, electrolysis processes, hybrid gas turbines, chemical and heat storage as well as traditional CHP plants.

As the focus of the overall energy transition perspective has shifted to local systems over the last 5 years, DHC grids, together with associated production and service activities, are gradually perceived as the backbone of this local energy transition, thanks to their sector coupling abilities.

- They enable, on a large scale, the use of the full scope of local energies:
    - Biomass, sludge, waste, geothermal
    - Waste heat and recycled heat form the industry, data centres or buildings themselves
- They are closely connected to energy management in buildings, and integrate sub-systems such as private or micro-grids, CHP and heat pumps into an optimised, energy exchange driven, architecture
- They provide cheap, market efficient solutions to deeply decarbonise local energy supply

From a DHC operator point of view, these "coupling points" between energies can be located at four main levels that will require both technical and economic coordination:

1. DHC customers, with their private installations
2. DHC distribution substations, with the various heat and cold sources and storage
3. DHC generation units, mainly with electricity grids
4. DHC from waste heat with electricity as input and DHC at the bottom of the process

This particularity opens a new field of optimisation by coupling heat consumers to both local hybrid generation sources and national or regional electricity markets. Sector coupling can be seen as a way to dynamically adapt the competitiveness of DHC networks on the long run, while improving their openness to competition and ability to develop circular economy around them.

How and to which extent will it affect and transform the district energy industry

Sector coupling applied to DHC could bring benefits for DHC stakeholders and communities.
Sector coupling opens a wide field of transformation for DHC networks refurbishment and new designs.
The versatile architecture of DHC infrastructure allows many configurations that may provide significant benefits to a variety of stakeholders.

For DHC customers: better prices and quality of service
As sector coupling requires a precise management of supply and demand, and multiply generation sources, DHC operators will benefit from synergies in generation, storage and consumption. This results in a higher reliability, flexibility, supply safety and efficiency of their services that may be passed to the customers. For them, in addition to this improved quality of service, there arises an opportunity to benefit from dynamic and competitive pricing, energy efficiency services and access to decarbonized energy for the heat and cold appliances.

For local communities: relocate energy production and optimise investments
Sector coupling allows local communities to leverage the DHC network as a local energy transition backbone, improve local self-consumption rate and reduce territory CO2 intensity. As DHC may provide an efficient source of local flexibility it may also help to reduce local need for electrical grid capacity, reduce voltage congestion and loss of transmissions, accelerate connection capacity for other electric usage such as EVs and production.
Considering a DHC network as a local energy backbone makes it possible to locally improve energy production competitiveness and therefore attract new projects, employment, investments and turn-over.

For the larger community: Enable global energy transition and develop new services
The intrinsic flexibility of thermal networks can support the balance in electric grids, which typically have limited flexible resources but growing needs for both very short-term and long-term flexibility. By doing so, curtailment of renewable energy can be avoided, their share in the energy mix can grow while security of the system is preserved. Coupling DHC flexibility potential to electrical grids will improve decentralized energy producers as well as virtual power plants operators (VPP) and aggregators' role.
The large flexibility in DHC networks will be essential in the large-scale roll-out of smart electrical grids. Therefore, smart controlled DHC networks are indispensable systems in the transition towards zero carbon solutions.

Sector coupling benefits are pushing for a larger adoption of ICT technologies in DHC.
This trend is pushing the demand for ICT solutions offering innovative system configurations and control strategies. Digital solutions will need to support operators in managing multi-level optimisation across heat, gas and electricity networks and enable business beyond the traditional borders of single-carrier networks, e.g. through the ability to sell or buy energy across

	multiple networks and open access to their customers to new entrants. ICT solutions are a pre-requisite to build efficient sector coupling applications. These include: sensors, actuators, dynamic demand, storage and production forecasts, flexibility planning and operation, D-1 and intraday merit-order or market systems, transactional platforms and connection with other energy network mechanisms and markets and their participant's trading platform (e.g. aggregators systems). For most of the existing networks, this ICT system is either non-existing or not planned. However, there is a growing number of pilot DHC networks that demonstrate the interest of such designs and allows to benefit from their case studies and key success factors. Such evolution can be a solution to modernize the existing DHC networks in Europe, especially in Eastern Europe, and to develop modern ones to accelerate energy transition in Western Europe. For Northern Europe DHC intraday systems may bring an additional source of competitiveness to fight against the erosion of electricity-based costs.
State of the art	District heating and cooling (DHC) networks have traditionally strong links to electricity and gas networks via combined heat and power (CHP) processes. However, sector coupling is meant to be a more decentralised, integrated, multi-directional, multi-layer process at district level including multiple generation sources in one bigger system. Digital solutions ensure governance of such systems exist but their widespread application and roll-out are not envisaged in the near future.
Technical, economic, societal & regulatory barriers	**Technical barriers** ICT for system automation is expected to expand rapidly. Nevertheless, their presence in the energy sector is still limited and the adaptation of services and platforms it not ensured. Furthermore, data quality and cyber security concerns will be major challenges to further enhance interoperability of network operation and information exchange among actors. The integration with existing equipment, the interoperability of different applications, the harmonisation and optimisation of communications protocols are challenging. The high number of power-to-heat and power-to-cooling appliances have a great, yet unexploited potential for flexibility and storage service. A crucial technical barrier, is that demand side units (e.g. heat pumps or boilers) are still denominated by "ripple control", which does not support remote control nor on-line measurements (service clearing, as in most EU countries, is done based on standardized load profiles). **Non-technical barriers** The state of regulation toward DHC and sector coupling application is not the same everywhere in Europe. No stable trend has emerged so far in favour of the development of dedicated and incentive regulation for modern DHC, but interesting initiatives are emerging in many countries. Without precise regulations and adaptation of market designs and

mechanisms, designing sector coupling and ICT systems remains a challenge with high entry costs and associated risks.

As an example, sector coupling rules and technical requirements for national balancing, wholesale and capacity market participation still prevent flexibility solutions from entering the market. A generalization of lower thresholds for entering member states markets would be beneficial.

As CHPs/HPs can't play on the energy market today since their individual capacity is too small, they need to be added to a portfolio of an aggregator, and this also reflects a potential evolution of how stakeholders may have to collaborate with new contract frameworks and integrate their ICT systems.

Next steps for a greater development of sector coupling digital applications:
The overall objective is to improve flexibility of both heat and electricity network and build transactional systems that allow value to flow between the stakeholders of a more integrated energy system.

Despite the great potential, much still needs to be done to ensure that all heat production systems, distribution networks, storage and demand are duly interconnected in order to exchange real-time data, quantify the availability of each equipment and the demand at any time and part of the network, in order to exploit the flexibility potential that such infrastructure offers.

Objectives and targets

Further research and testing of technical and operational modelling, simulation and optimization of multi energy technologies and system is required to identify the technological and systemic constraints, such as the maximal ramping speed of a storage system connected to heat pumps or the speed of temperature drops in a district heating system after the deactivation of the heat pumps.

Globally, ICT systems for DH sector coupling should improve in the following fields:

- Real time supervision of energy flows at building and system level.
- Intraday forecasting for demand, source prices and flexibility potential.
- Power dispatch control and management, algorithms able to deal with an increased number of more complex boundary conditions.
- Cost competitive deployment using cloud-based systems and configuration templates.
- Strengthening AI smart algorithms and operational specifications.
- Financial and transactional systems with merit order connected with multiple consumers, prosumers and suppliers.
- Virtual power plant aggregation systems adapted to DHC stakeholders.

	• Technical interoperability between DHC technologies, automation and electricity market standards to enable private equipment that contributes to sector coupling (e.g. heat pumps, EV loading stations, etc.) to be seamlessly integrated into a wider system of systems.
Actions, priorities & recommendations	• Promote the development of industrial pilots in various regions and configurations to review the real flexibility options that these technologies and system can provide to the electricity sector, compatibly with the current regulation and market design. • Facilitate R&D programs to further simulate and optimise the control strategy to improve the operations of such technology systems. This will, in turn, maximise the flexibility provision. • Collaborate with regulators, associations and other sectors to propose improved market designs to maximise synergies that will be modelled in a market simulation platform for the project case study countries. • Exploit the results achieved by developing policy strategy and recommendations. • Actively participate in existing ICT standardisation and interoperability working groups to leverage their experience and promote DHC sector coupling use cases.