



DIGITAL ROADMAP FOR DISTRICT HEATING & COOLING

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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 exploring how the future of our energy system will evolve!

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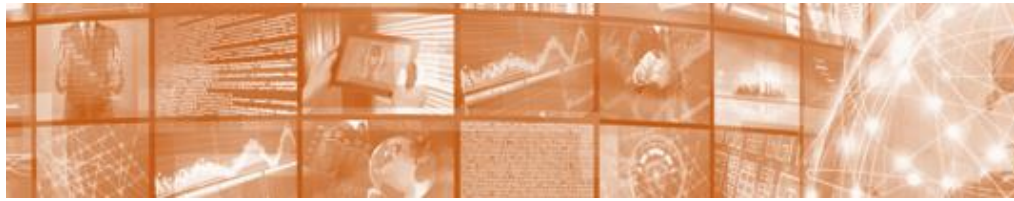
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CONTENTS

1) Production level.....	4
2) Distribution level	10
3) Building level	15
4) Consumption level.....	19
5) Design and Planning	22
6) Asset Management	28
7) Sector Coupling and Integration of Multiple Sources	30
8) Horizontal Topics.....	36
A) Big Data	36
B) Artificial Intelligence	37
C) Blockchain.....	38



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 added considerations including multiple heat production sources and 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 maximisation of sustainable sources will never be possible. Sustainable energy sources are often uncontrollable and sometimes unpredictable, leading to the need for new types of heat network controllers.

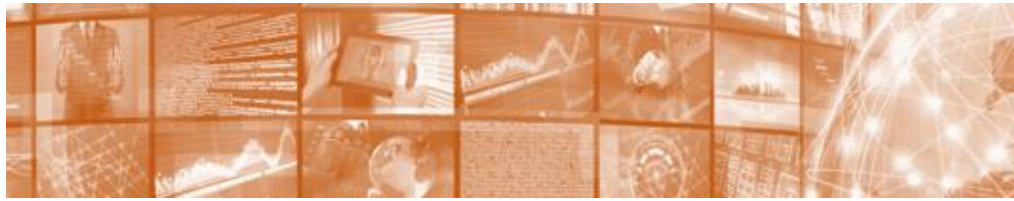
How and to what extent will it affect and transform the district energy industry (and other sectors)?

Renewable energy sources are often highly fluctuating; think of solar thermal energy which is heavily influenced by the 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 optimise 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 fully utilised.

Often, the sustainable energy source of heat networks is not utilised for the peak demand of the heat network, since it does not make financial sense to use a rather expensive heat source for a limited number of operational hours. The peaks are usually covered by cheap, often fossil fuelled boilers. However, peak shaving, a form of smart control, can be implemented to maximise the operation of a 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 operating heat plants will become increasingly challenging, and new control systems will need to be developed.

Smart control can also play a key role in sector coupling, especially between district heating networks and electricity grids. In current smart electricity



grids more and more fluctuating energy sources such as, solar or wind power, are being integrated. This poses a challenge because electricity grids have very limited flexibility (energy storage). As a result, the integration of renewable sources into electricity grids can 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 linked to the network). By switching heat production devices that have a connection to the electrical grid (i.e. 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.

Test Case: Optit smart energy planning system

Gruppo Hera, one of the major multi-utility companies in Italy, runs a dozen district heating networks in the Emilia Romagna region, ranging from the relatively large, high efficiency system in Ferrara (fuelled by WTE and geothermal energy across a network exceeding 50km) to smaller systems with CHP plants, boilers, thermal storage and cooling services.



CHPC energy production of such (generally unsupervised) systems requires a smart energy planning system capable of meeting the following requirements: Configuring the plant's features, integrating with field data, forecasting demand curves based on historical data and weather forecast and, providing hourly dispatching patterns that optimise the plant's operating margin (taking into account multiple revenue and cost drivers, as well as operating and regulatory constraints).

The system, fully integrated with the company's SCADA system, was provided by Optit srl, allowing progressive improvement up to semi-automation of the daily process and effective management of year-long strategic operations planning, with significant benefits both in terms of ROI and digitalisation of a previously manual process.

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

Currently, managing district heating networks involves a number of decentralised control systems at production and consumer level, there is no interaction between them. Because each of these controls has a targeted, independent focus, the management at a system level is not optimised. A system level approach is not commercially available yet, but some market



players have started to address this.

Production plant optimisers, however, are commercially available now, allowing production optimisation in relatively complex scenarios, mostly relating to traditional district heating networks (boilers, CHP, heat storage). For the complex 4th generation networks with multiple, unpredictable heat sources, these optimisation products are only just starting to integrate more complex elements (e.g. waste heat) and they are generally not yet compatible with temperature-dependent sources such as complex heat pumps.

When it comes to peak shaving, the most effective current approach is central storage tanks, placed next to the heat production plants. In addition, demand side management solutions are promising as they require very little or no investment.

Technical, economic,
societal & regulatory
barriers

Technical barriers

- The lack of DHC network control systems capable of dealing with fluctuating sustainable energy sources.

Organisational barriers

- Integrated management systems require the ability to take control actions on the building substations which often belong to the building owner. Without their agreement, no action can be taken.

Economic barriers

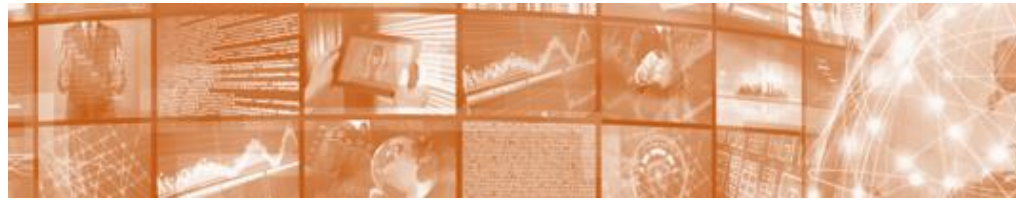
- The current business models do not provide incentives to building owners to allow their property to act as sources for thermal flexibility (which consequently can also be used for peak load management).
- User-investor dilemma: investments are required to enable the building to shift its load (e.g. 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 accustomed to having control over their heating system. For smart control applications, consumers should allow the network operator to manage their substation, with the consumer setting the comfort requirements.



Test Case: Energiforsk Digitalisation Project

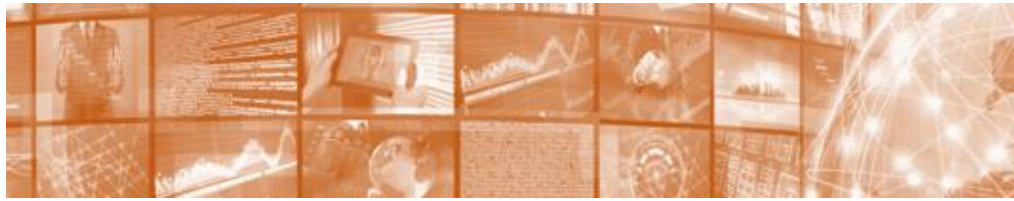
Energiforsk is currently implementing a project on the theme of digitalisation in the energy sector. The project aims to give a thorough review of the ongoing digitalisation and technology status within areas such as artificial intelligence, advanced automation and robotization, Internet of Things, blockchain, etc. In addition to increasing the general knowledge within the energy sector the project also analyses how digitalization may affect and transform the sector. The overall aim of the project is to lay the foundation for an upcoming research platform on future ventures in this field among energy companies and the academy.

The most crucial challenges and opportunities linked to digitalization are about its effects and consequences rather than the technologies themselves. The digital transformation may lead to radical changes in society, not least in changing the prerequisites and the criteria for a large number of sectors and companies.

The ongoing transformation of the energy system, with an increasingly distributed and variable electricity production, leads to a growing challenge to balance supply and demand. In this context, digitalization offers new means for increasing the interconnection of the future energy system which can lead to more grid service opportunities and may act as a means to further advance the disintegration of the traditional boundaries of supply and demand in the energy system. Beside the potential it offers when it comes to catalysing the change towards a more interconnected system, digitalization can also enable both lower energy consumption and increased customer value. This means that digitalization, among other things, can become an important tool for meeting today's ambitious energy and climate targets within the energy sector.

The project gives some examples of how digitalization and its different technology areas could affect the energy sector. In particular, the project has illuminated the potential for predictive maintenance and advanced optimization and control systems as well as the opportunities and challenges offered by blockchain technology. On the basis of the interviews and discussions undertaken with those companies and organizations that participate in the project, we conclude that, the energy sector in Sweden is in a phase of orientation when it comes to digitalization. The knowledge about the second wave of digitalization seems to have come about rather late to the energy sector, and the general level of knowledge varies considerably between different companies. Some have just begun their digitalization journey, while others have reached a phase where they have started applying the techniques in real case studies.

What distinguishes those companies that have come further in their digitalisation process and are more active in testing different technologies is their willingness to share data and cooperate with other actors. They highlight the necessity and a will to create common initiatives and form partnership projects, not just between energy companies, suppliers and customers but also among competitors.



Many of the energy companies participating in the project talk about digitalization first and foremost in terms of the increased potential benefit for the customers. The increased benefit to the customers is described as one of the major incentives for testing the different digitalization technologies, not least due to the large potential for more individualized offers for customers. New digital platforms also enable closer contact with customers and therefore create opportunities to form closer relationships with them.

The benefits of making use of the opportunities offered by digitalization could indeed be substantial. There is, however, a number of challenges that companies and organizations need to be aware of and be able to handle. This concerns issues of responsibility, ownership and necessary changes in legislation as well as IT security and a general lack of knowledge within organizations and lack of competence and workforce in this field.

To avoid lagging behind and instead make use of the large potential offered by the ongoing digitalisation, companies should start testing the technologies to some extent, learn from it and collaborate with both customers and other actors.

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 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” the substations themselves, so that they can control the demand side as an extra degree of freedom to optimise the efficiency at system level.

Actions & Priorities

- To develop assessment tools for a multi-source, intelligent and low carbon district heating and cooling system, thus establishing the methodological base for DHC design and performance assessment. This could be achieved by developing tools which model the network in a clear and detailed way (creation of “digital twins”).
- To carry out case studies on how to integrate multiple heat (cool) sources and internet-based intelligent control into DHC systems.



- To showcase the actual performance of multi-sourced, intelligent and low carbon DHC systems, thus examining whether 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 to accelerate the transformation towards 4th generation district heating.

Test Case: Digitalisation in practice

Karlshamn Energi operates the district heating grid in the municipality of Karlshamn in the South of Sweden. This grid is nearly fully based on renewable sources with the primary source of energy in the form of excess heat from a nearby industry. The grid has a length of about 125 km with peak demands around 60 MW during colder periods and about 170 GWh in yearly delivery.

Karlshamn Energi has long been involved in the innovation of district heating, and were, for many years, active as domain experts in The Swedish District Heating Association. They were the first in Sweden to adopt operational demand-side management on a larger scale through smart grid technology. This effort was later evaluated in a study funded by The Swedish Energy Agency and concluded a return of investment between 3-5 years on this type of technology in the case of Karlshamn.

In the last few years Karlshamn Energi has continued to push the boundaries of innovative district heating, participating in several research projects at national and international scale. The primary on-going project is the FHP Horizon 2020 project, focusing on thermal flexibility for the power grid through smart grid technology. Several recent research projects have been using data provided by Karlshamn Energi, resulting in published research relating to advances in demand-forecasting and machine learning based data analytics for fault detection.

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 links 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. The traditional way to manage distribution is by focusing on maintaining pressure, and not much else. This does indeed keep the system going in most situations, but it will invariably lead to suboptimal efficiency. This issue will become increasingly significant as the district heating industry moves towards low-temperature networks, where the operations must be controlled more efficiently.

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

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

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

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 a more in-depth analysis of the operational characteristics of each grid and introduce the ability for a higher degree of predictive maintenance. It will also form a basis for more advanced technologies related to active control and operational optimisation. More mature digitalisation efforts in the distribution grid will enable data management related to temperature, flow and pressure. This will help 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. Many district heating systems replace the equivalent of their total water mass each year. Leaks are a common and recurring issue in most district heating systems. Improved measurement and analysis tools will help identify problems quickly.

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 out demand if introduced into a network. This prolongs the usage of the existing piping by facilitating the addition of new customers within the same distribution constraints. This is an important advantage of digitalisation which 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 points is relevant as hydraulic conditions change. This becomes increasingly important as flexible heat sources are distributed in a network which is used as a thermal infrastructure where sources change over time in terms of 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 to 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 implementing digital solutions it is possible to use a more dynamic approach regarding supply temperatures, especially when applying digital solutions to several 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 because lower system temperatures make it possible to utilise them more efficiently. This has a positive effect on economic savings as well as environmental impact.

State of the art

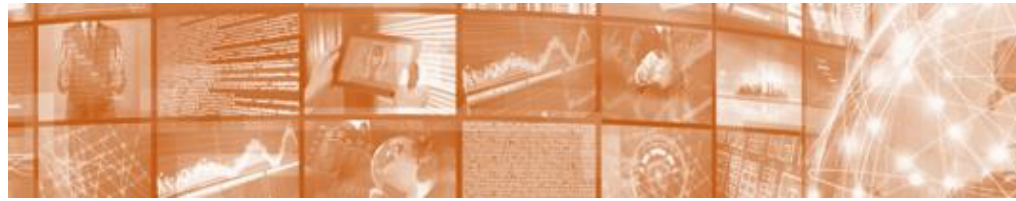
Modern network controllers based on demand side management are emerging in both research and commercial applications. Current research sees these being integrated more closely with buildings as well as the production side. Methods to combine such systems with thermal management are also currently being developed, based both on network dynamic modelling as well as on the application of machine learning technology. Similar techniques are used to drive the development of pressure optimisation solutions, enabling smart pumping stations to work at optimal levels. Several ways of developing improved and more cost efficient solutions for leakage detection are also being investigated.

Technical, economic, societal & regulatory barriers

There are a number of barriers to 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 temperatures at supply level which hinder system wide optimisation of the operation. Related to this, the ability to coordinate the operational behaviour of a large set of buildings and the operational constraints of the grid. This requires, or at least implies, some agreement between grid operators and building owners. The complexity of the process to negotiate such agreements is normally underestimated. One of the primary barriers is the reality that lowered distribution temperatures will invariably need to account for infrastructure and demand limitations (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 by on-going innovation projects. These include efforts to improve technology to merge thermal and hydraulic operational optimisation as well as developing business models that include benefits for distribution systems in the overall offering related to demand side management. Such efforts are on-going and results are expected to emerge in the near future.

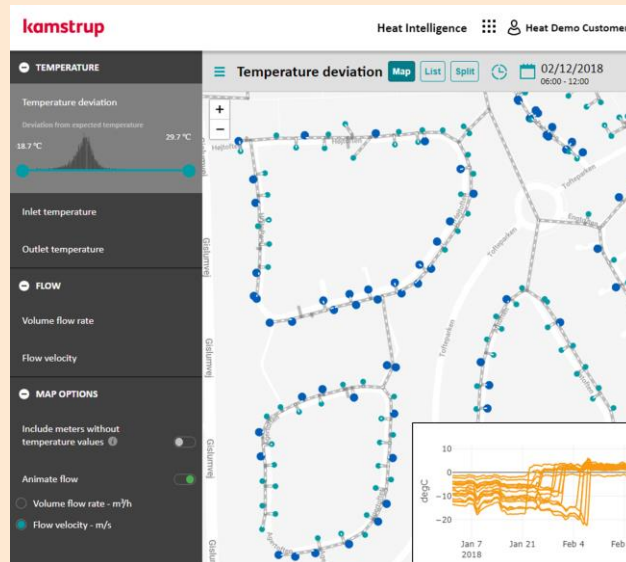


Test Case: SCADA for heat distribution, locating high heat loss in the distribution network, Kamstrup Heat Intelligence:

Heat Intelligence continuously aggregates data from all meters located in the distribution network. Data from thousands of meters placed at the network end points, is used to back propagate flow, pressure, forward and return temperature in order to estimate these at all positions in the network. The measurements from the individual meters can then be compared to these network estimates to identify consumers that may act as outliers. In this way e.g. high heat losses in the distribution grid can be identified as illustrated in the figure below.

Where to renovate next?

In addition to identifying regions with higher heat loss, Heat Intelligence also provides valuable insight into ways to design and dimension new pipe sections. With Heat Intelligence you can easily get an overview of the actual consumption in the different regions of the network. That is, finding out what the typically consumption of a given branch is and whether there are any bottlenecks in the system which generate high pressure loss. Moreover, Heat Intelligence can be used to identify circulation and estimate its influence, identify regions in network cycles with a high risk of stagnating flow and identify leakage, (to mention but a few examples).



Kamstrup Heat Intelligence: Here used to identify service connections with a high heat loss (large blue circles). Embedded line plot at the bottom right: timeseries plot showing how the heat loss (calculated in °C) changes for selected end users during a period where worn-out service connections are replaced. One service connection is replaced per day, explaining why the heat loss signatures “jump” from a negative value (heat loss of up to 15 °C) to approximately zero over the renovation period. It is evident from the plot that, one service connection is replaced every day.



Recommendations

A stronger focus on business development is required and further action to address barriers related to regulations and markets.

Technological development is in progress, including research in the following areas:

- Development of artificial neural networks / thermo-hydraulic network hybrid model (self-learning digital twin).
 - Development of automated fault detection supervision systems to recognise anomalies in the networks' and the building's substations.
 - Technological investments in district heating systems (remote control, monitoring).
 - Software and algorithm development.
 - Pilot/lighthouse projects.
 - Updating building installations for low temperature operation.
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3) BUILDING LEVEL

Introduction

Modern district energy systems are demand-driven. The building level, guided by the substation, establishes this demand. At the same time, building and apartment level solutions can help mitigate supply side challenges such as 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, a 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 demand allows for the identification of usage patterns, periods of inefficient thermal energy use (faulty installations, building side leakage, anomalous consumption etc.) and 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) and by shifting demand patterns where necessary and possible. Root cause analysis can also be performed in order to clarify the underlying issues e.g. a high return temperature.

Since older systems in some Member States operate in a supply driven mode, digitalisation must also provide solutions to modernise their processes.

Digital solutions will also support the operation of hybrid solutions, e.g. low-temperature District Heating combined with individual heat pumps.

How and to what 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. information collected by smart thermostats), the next level of comfort for the end consumer can be achieved.

Implementing new monitoring technologies will make high temporal data resolution possible. Bi-directional data flow is the basis of a holistic real-time overview of heat demand. This overview supports a cost optimal heat system operation and, in parallel, provides access to heat controllers in the substation to manage cases of disruption. An automatic alert function triggers those



counter measures (e.g. enabling a district heating operator to access data from a heat controller and deliver a signal to open a heat supply valve if necessary), before end consumers experience a drop in temperature.

The knowledge of the indoor climate data collected (e.g. by mould meters, smart thermostats or temperature data from the tap water system) are key to avoid neurological problems caused by mould and to prevent legionella by automatically activating real-time counter measures from the heat system. This provides an increased level of health care to the end consumer.

The substation is a gatekeeper between the grid and the building. As such, its digitalisation will provide benefits across 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 level allow an active response to price signals, peak shaving and demand shifting measures and 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 perhaps even the availability of expensive and often fossil peak load supply capacity. In addition, digital solutions on the consumer level may allow for lower return and supply temperatures, providing a more efficient network.

Overall, consumers will enjoy higher levels of comfort and often lower prices, networks will be operated in a more efficient way and integrate more decarbonised sources.

State of the art

The last few years have seen a substantial number of research and innovation projects at the building level, many focused on increasing computational and communication capacity through digitalisation. Functional control systems for energy efficiency schemes have emerged, including indoor temperature sensor data which also monitors external weather conditions and heating system constraints. Additionally, systems that allow substations to be part of demand side management schemes are now available and innovative work to provide added functionality for predictive maintenance is on-going.

So far, the process of analysing and monitoring consumption at the 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 the 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 to improve current systems.



Technical, economic, societal & regulatory barriers

An initial barrier is the varied ownership of substations. In cases where they are owned by DHC customers, this market needs to be convinced of the benefits of smart solutions. An additional challenge is that 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 therefore have no direct interest in implementing these 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 a change to secondary temperatures.

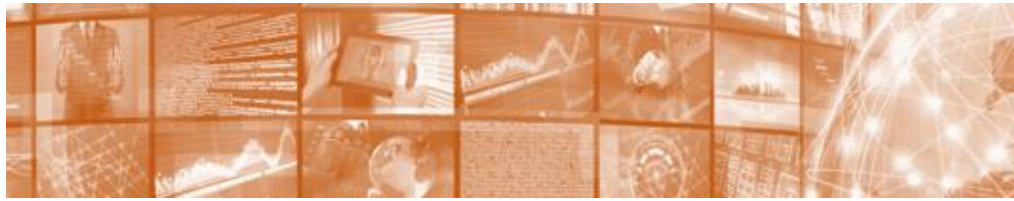
Considerations of data protection play a key role in the roll-out of smart technologies and many other concerns are of contractual nature. Lower (or, in the case of DC, higher) temperatures on the secondary side that are needed to adjust the grid temperature or that are a consequence of smart network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

Creating a reliable smart meter rollout business case is a challenge for energy utilities as it must be built on many soft factors. However, the investment needed for hardware components like sensors, gateways, smart controllers and smart heat meters is high. So far, these technologies do not support a standardised data transfer (e.g. support of different protocols). As a result, replacement hardware from different suppliers often requires complicated troubleshooting to receive relevant data.

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 connecting 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.
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4) CONSUMPTION LEVEL

Introduction	<p>Digitalisation gives an opportunity to raise end-users' 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 to help customers control and monitor energy usage may streamline and help them make district heating much more efficient and allow 4th generation DH.</p> <p>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 such as monitoring the heat system. Energy providers can also develop new billing models and could ultimately sell comfort (e.g. 21°C in the living room) instead of kWh of energy.</p> <p>For building owners/managers and utilities, energy rating tools, based on smart meter data, which also suggest improvements for buildings and heat system installations have a great potential from an energy efficiency perspective.</p>
How and to what extent will it affect and transform the district energy industry (and other sectors)?	<ul style="list-style-type: none">- 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 volume 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. Thus, not all buildings will be new, energy-efficient buildings that support LTDH. Pinpointing potential improvements for these existing buildings (data-driven) is key to enabling 4th generation DH.
State of the art	<ul style="list-style-type: none">- Standardisation and regulation of remote metering in the electricity sector is far ahead compared to the heat sector.- 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 is needed.- There are still only a few data-driven tools on the market that perform advanced analytics on buildings and heating systems compared to just visualising 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. There is general acceptance that it exists, but tangible results are needed in order to compare to the cost of a smart metering solution.
- Innovative low-cost data transfer infrastructure (e.g. LoRa, NB IoT) not fully rolled out at EU level. Furthermore, energy providers are forced to build their own communication infrastructure for meter reading.
- Smart meter data is an essential part of the digitalisation 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.
- Standardising the communication / smart metering solutions, at least the connectivity part of it.

Recommendations:

Greater focus on empowering energy providers to take more responsibility instead of just visualising 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 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 was reached by the Article 29 Working Party.

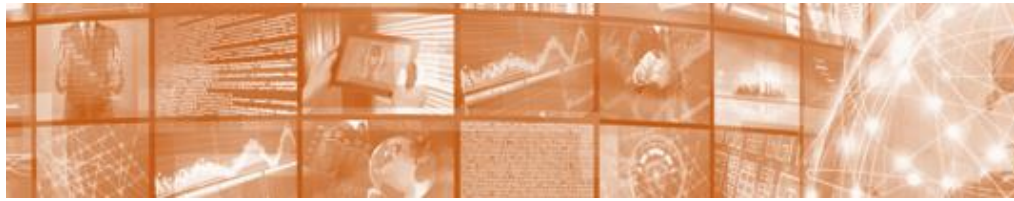
Because frequent smart meter data is personal data, it raises the question of the need for individual consent from all customers. In addition to being an insurmountable administrative burden for most energy suppliers, this also means a considerable risk that some customers will be unwilling to consent. If there is only data from half of the buildings in a given area, it is all but impossible to perform an accurate forecast. This, in turn, 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, paragraphs (e) and (f) of Article 6 of the GDPR regulation are relevant, as they state that processing 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 (...)

It is vital to ensure a national implementation of the GDPR that allows the frequent data collection from heat meters without customer consent as long as energy suppliers use that data either in the interest of the public (to save energy and minimise energy loss), or for the legitimate purpose of improving the energy efficiency of its operations.



5) DESIGN AND PLANNING

Introduction

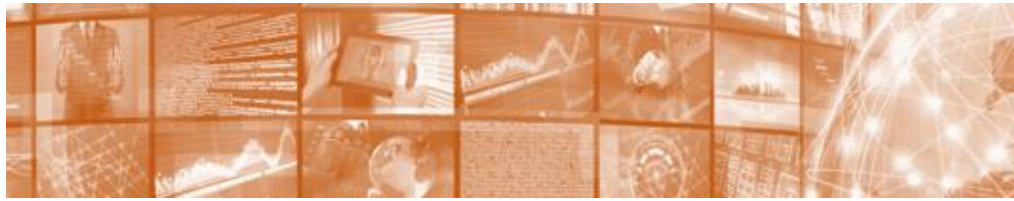
Areas for new urban developments or district retrofiting usually have high ambitions for their energy efficiency and share of renewables/ CO₂ emissions (e.g. net zero energy, plus energy districts etc.). However, the decision on the appropriate systems for energy supply distribution and consumption is rarely 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, 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 dimension 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 process 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 infrastructures (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 the 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, retrofiting 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 oversized 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 what 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 can potentially be passed on to customers.
- **The energy sector:** Increasing the economic and ecologic performance of their systems by reducing investment and operation costs associated with the exploitation of renewables and, increasing energy efficiency. Distribution infrastructure (pipes) represents, on average, 60 to 80% of the value of the entire DE system infrastructure. Investments in the expansion and refurbishments of utilities are financially highly burdensome and, as such, it also has 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 optimisation 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 retrofiting (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



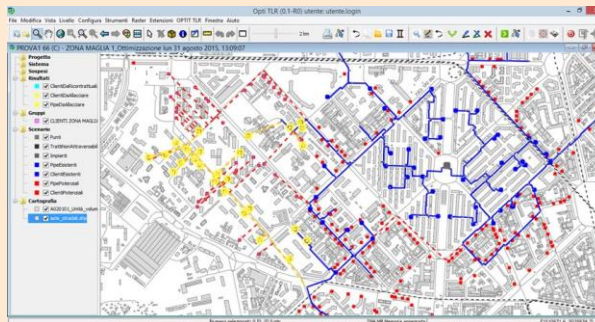
“rules of thumb” without any sophisticated scenario evaluation or the use of all available data sources, even though a few rather sophisticated Decision Support Systems for strategic and commercial development of district heating and cooling networks are starting to emerge in the market.

Test Case: Optit Decision Support Tool

The Italian company Optit s.r.l. has developed an innovative solution to support optimal decision making in District Heating network development, both at strategic (e.g. where to expand the network) and tactical (e.g. what set of customers to address first) level. By means of state-of-the-art integer programming modelling and metaheuristic approaches embedded in an opensource GIS environment, the solution proposes a development scenario that maximises Net Present Value (NPV), given a set of network expansion configurations (e.g., new backbones) and a set of potential customers (prospects), taking into account the full thermo-hydraulic constraints.

The tool has been successfully adopted by the leading Italian district heating company A2A Calore e Servizi (ACS), part of the multi-utility group A2A, to evaluate how best to saturate its heat capacity in a densely populated urban area following the construction of a large interconnection pipeline. Key success factors have proved to be:

- Significant number of decision variables managed by the model allow decision makers to perform many kinds of “what-if” analyses;
- Quick generation of results comparing a large number of potential options, as opposed to simulating approaches where each scenario needs to be configured specifically. Supports search for real optimization;
- Integration of the perspectives of commercial and engineering departments in a single tool reduces organisational conflicts and speeds up decision making.



Development scenario: blue = existing assets, red = potential assets, yellow= optimal subset

What is still missing are integrated solutions capable of handling each component of the energy systems (buildings, heat supply, and renewable sources) as a whole and at once.



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 it.
- Data protection regulation - privacy issues are important in order 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 the existing infrastructure (lack of documentation on existing infrastructure).
- Digitalisation of the 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 Asset Management
- The integration of additional simulation/planning tools into the existing tools and processes. The relevant stakeholders have various tools they use for the planning and design processes of their individual systems. It is hard to motivate them to use “another tool”.

Objectives and targets

The 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)



Test Case: Flexible heat demand - a model to estimate the value

Budget: approx. 150 € from Energiforsk R&D program FutureHeat and 4 Swedish district heating companies and the Swedish Energy Agency.

Flexible heat demand through e.g. thermal storage in buildings or load shifting between district heating and heat pumps can be effective methods for reducing costs and environmental impact associated with heat generation. The value created by flexible demand is complex to quantify and strongly dependent on local conditions. This project aims to quantify value created by flexible heat demand under a broad set of conditions so that all district heating companies will understand and respond positively to the question: "What is the value of flexible heat demand with the conditions that apply in our specific district heating network?"

The fact that almost all district heating companies lack a good answer to this question is a major obstacle for large investments in flexible heat demand. The results of the project will create conditions for: profitable investments, correct technology choices, successful procurement and enabling business models.

A flexibility resource in district heating is any component that can provide heat and/or electricity generation with a degree of freedom in time, quantity and/or source. To enable district heating companies to reduce their operational cost and act in a balancing role on the electricity grid, the following flexibility resources are considered in the project:

- hot water storage tank (time)
- thermal inertia in connected buildings (time)
- choice between multiple heat sources in connected buildings (source)
- borehole thermal storage (time)

A new application based on an existing cloud-based platform will be developed in order to calculate the value of this flexibility in a single network. Different configurations of flexible heat demand are modelled in several DH grids and the output compared. Seven different general DH-networks as well as 4 real networks are modelled.

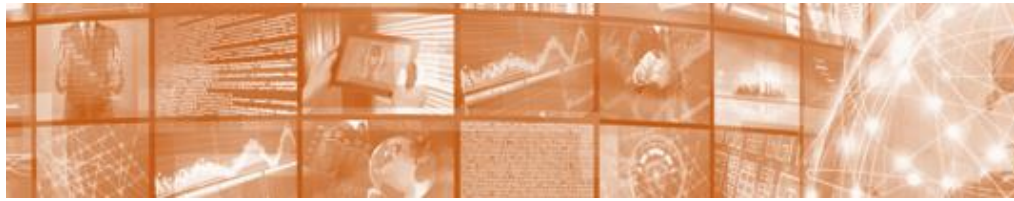
Results:

Preliminary results show that the savings on the systems running costs and avoided CO₂-emissions are highly dependent on the local conditions of the DH-system (such as fuel mix) and on the type of flexibility used. Another important factor is whether an accumulator already exists in the system.

The running cost savings ranged from 4-14 % depending on the factors mentioned. It should be noted that this does not take into account savings from avoided investments in peak capacity and distribution capacity for satellites. These savings from avoided investments in new peak capacity can, for example, cost as much as 8 000 € per building, in a case where 33 % of the heat load is connected as flexible demand and can contribute with 19 MW of capacity.

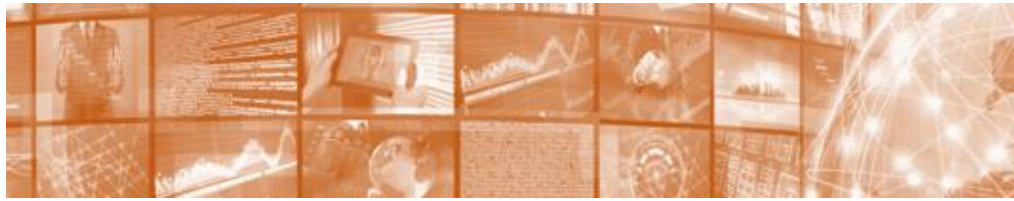
More information:

<https://energiforskmedia.blob.core.windows.net/media/26034/the-value-of-flexible-heat-demand-2019-565.pdf>



Actions, priorities &
recommendations

- State of the art assessment and collection of best practice examples, identification of barriers and gaps in using or integrating tools, methodologies and 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 can include various data sets.
- Establish integrated planning processes involving all relevant stakeholders and enabling to reach socio-economic optimum parameters.
- Technological investments in the digitalisation 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 an 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) ASSET MANAGEMENT

Introduction	Currently, asset management is based on age and life expectancy. Asset management can be made data-driven so that the condition of a given asset is calculated based on the actual use, rather than time. Improved asset management will assist energy providers to target investments where they make most sense.
How and to what extent will it affect and transform the district energy industry	<ul style="list-style-type: none">- Data driven asset management has the potential to guide investment for the energy system, reducing variations and fixed costs.- When supplier costs are lowered, it's also possible to reduce the price for the customer.- Digitalisation will further enable technology for predictive maintenance and automated decision support systems. These areas are important in making the asset management process more efficient in terms of cost and functionality.- Increased competitiveness through targeted investments.- Deferring or avoiding investments that tie up capital for several years.- Avoid disturbing consumers with unnecessary pipe replacements.
State of the art	<ul style="list-style-type: none">- A tool which can evaluate and propose the best possible investments to the right location.- There are several ongoing research projects concerned with predictive maintenance. They all apply digitalisation solutions in the form of machine learning and large scale data management.- A tool that can pinpoint the weakest spots and propose the best investments,- A tool that, based on data, can tell the actual state of an asset,- A tool that proposes the best pipe replacement program.
Technical, economic, societal & regulatory barriers	<p>The complexity of modern H&C networks provides a barrier, as does gaining access to data that is "good enough" for automated machine learning analysis. Additional challenges include:</p> <ul style="list-style-type: none">- Coordinating/implementing the roll out of smart meters,- Completing digital GIS models of the pipe networks,- Implementation of advanced data analysis in user friendly applications is generally lacking,- Smart meters collecting data with high temporal resolution is, in some countries, somewhat widespread. Nevertheless, clean and processed data sets are not easily accessible, and is generally not available to the operating personnel.



Test Case: OPTi project

District heating and cooling (DHC) systems play a vital role in many cities and facilities, and their establishment is also motivated to achieve climate targets. Achieving operational efficiency is difficult since the transfer of thermal energy requires the transport of large amounts of a medium, usually hot or cold water, over long distances from production sites to consumers. Optimizing DHC systems in terms of energy efficiency, therefore, requires not only an understanding of future heat or cold consumer demands but also an understanding of the flexibility of those demands. Such understanding aids in planning, scheduling, and controlling both production and distribution in an optimal way to achieve energy efficiency while satisfying consumers' demands.

The OPTi project aims to create a long-lasting impact by rethinking the way DHC systems are designed and controlled. The overarching goal is to create business benefit for the industry as well as to ensure optimal end-consumer satisfaction. OPTi will deliver methodologies and tools that will enable accurate modelling, analysis and control of current and envisioned DHC systems. The methodology is tested and validated both on a complete system level, and on the level of a building(s).

OPTi considers the dynamic behaviour of the DHC system, and will treat the stored thermal energy and consumer flexibility as a resource to save energy and reduce peak loads. For this end, learning mechanisms are used to understand consumption patterns. A consumer interaction device called the Virtual Knob is proposed to assess the user comfort zone and, automated modelling mechanisms for the production of the digital twin of a DHC system are used to optimise the operation, control and demand management of the DHC system. This will lead to a more environmentally-friendly way of utilising different energy sources and, in turn, providing an overall socio-economically sustainable environment.”

Actions, priorities & recommendations

- Investments to improve/create rich data sources such as GIS-data, clean meter data etc. needs to be made.
- Investments in the development of better data infrastructure, in order to make data more easily available to simulation software, data dashboards, and analysis applications at large.
- A lot of research, projects and studies are available. However, the work is complex and hard-to-reach, especially for small to medium sized utility companies. More effort should be put into identifying useful business cases and implementing already established knowledge.



7) SECTOR COUPLING AND INTEGRATION OF MULTIPLE SOURCES

Introduction

Traditionally electricity, heat/cold, transport and industry are treated as individual sectors. This ongoing decentralisation trend leads communities to consider their territory as a collection of separate entities to be optimised individually. Local networks and energy sources are considered the building blocks of an updated business model, with new planning opportunities evolving for local stakeholders.

A second effect of this trend is the drive of large investments into decentralised 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 from 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 and provide cheap, market efficient solutions to deeply decarbonise local energy supplies.

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

1. Customers, with their private installations.
2. Distribution substations, with the various heat and cold sources and storage.
3. Generation units, mainly with electricity grids.
4. 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 with 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 over an extended period and to develop



the circular economy around them.

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

Sector coupling applied to DHC could bring benefits for stakeholders and communities. It opens a wide field of transformation for network refurbishment and new designs.

The versatile architecture of DHC infrastructure allows for 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 the multiplication of generation sources, DHC operators will benefit from synergies in generation, storage and consumption. This results in higher reliability, flexibility, supply safety and efficiency of their services that may be passed to customers. 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 decarbonised energy for 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 rates and reduce territory CO2 intensity. Because DHC can provide an efficient source of local flexibility it may also help to reduce a local need for electrical grid capacity, reducing voltage congestion and loss of transmissions and accelerating connection capacity for other electric usage such as EVs and production.

Considering a DHC network as a local energy backbone makes it possible to improve energy production competitiveness at local level and, therefore, attract new projects, employment, investments and turn-over.

For the larger community: Enable global energy transition and development of new services. The intrinsic flexibility of thermal networks can support the balance in electric grids, which typically have limited flexible resources but a growing need for both very short and long term flexibility. In doing so, restrictions on renewable energy can be avoided, their share in the energy mix can grow and the security of the system is preserved. Coupling the flexibility potential of DHC with electrical grids will improve the role of the decentralised energy producers, virtual power plant operators (VPP) and aggregators.



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.

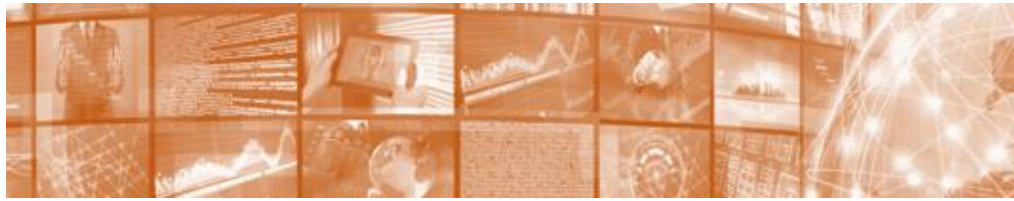
Sector coupling benefits are pushing for a larger adoption of ICT technologies in DHC. This trend is driving the demand for ICT solutions offering innovative system configurations and control strategies. Digital solutions will need to support operators in managing multi-level optimisation across heat, 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 by providing new participants with open access to their customers.

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 trading platform (e.g. aggregators' systems).

For most of the existing networks, this ICT system is either non-existent or not planned. However, there is a growing number of pilot DHC networks that demonstrate the interest of such designs which present case studies and key success factors others can benefit from. Such evolution can be a solution to modernising the existing DHC networks in Europe (especially in Eastern Europe) and, to accelerate energy transition in Western Europe. For Northern Europe DHC systems may bring an additional source of competitiveness to fight against the erosion of electricity-based costs.

State of the art

Traditionally, District heating and cooling (DHC) networks have had 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.



Test Case: STORM project

The STORM controller is a state-of-the-art smart district heating and cooling grid management system, based on self-learning algorithms. It includes modules for forecasting, planning and dispatching heating and cooling management actions. The control strategies benefit the whole energy chain, spanning from energy generation and distribution to end-user consumption.

The STORM controller can be applied in different settings and contexts, using three different kinds of control strategies.

Peak heat reduction tests in the Swedish demonstration site led to a long-term peak heat reduction of 12.75% on average compared to the reference scenario without the STORM controller active. It should be noted that even during months with low heat demand reductions of up to 57% were achieved.

The Market Interaction strategy is a strategy that uses both charging and discharging capabilities to adapt to a set of electricity spot prices. Based on these prices, the STORM controller moves heat demand to match spot prices, thereby ensuring heat delivery and comfort. This strategy resulted in a 15% reduction on the electricity purchase price and an overall electricity procurement costs reduction by 6%. This option of the controller is beneficial for electric systems such as heat pumps and cogeneration units, especially when sufficient thermal buffering is provided in the system, making it possible to charge energy independently of the energy demand at times when the electricity price is most favourable.

For the cell balancing strategy in the Dutch Mijwater system the controller was able to reduce the flow over the entire test period without jeopardising the energy delivery to customers. A peak shaving potential of 17.3% could be determined here. Furthermore, an improved capacity could be derived ranging from 37% up to 49% (median value 42.1%) which corresponds to a total of 48,200 normative Home Equivalentents (nHE) that can be additionally connected to the existing system.

In each of the demo sites a CO₂ emission reduction of around 11,000 ton/year was achieved, which is equivalent to the CO₂ emissions of 600 flights from Barcelona to Madrid.

Technical, economic,
societal & regulatory
barriers

Technical Barriers

ICT for system automation is expected to expand rapidly. Nevertheless, a digital presence in the energy sector is still limited and the adaptation of services and platforms is not guaranteed. Furthermore, data quality and cyber security concerns will be major challenges to further enhance the interoperability of network operation and information exchange among actors.

The integration with existing equipment, the inter-operability of different applications, the harmonisation and optimisation of communication protocols are challenging.



The large 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 standardised load profiles).

Non-technical barriers

The state of regulation of DHC and sector coupling application is not the same across 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 generalisation of lower thresholds for entering member states’ markets would be beneficial.

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

Next steps for further development of sector coupling digital applications:

The overall objective is to improve flexibility of both heat and electricity networks 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 optimisation of multi energy technologies and systems 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 flow at building and system level.
- 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 inter-operability 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.) being 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 systems 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 inter-operability working groups to leverage their experience and promote DHC sector coupling use cases.



8) HORIZONTAL TOPICS

A) BIG DATA

In 2011, McKinsey & Company published a report stating that Big Data is the next frontier in innovation, competition and productivity. Years later, data is all around us and the cost for storing massive amounts of data has tumbled. In many areas of business, analysis of large data sets has become a commodity and has proven itself beneficial in many different use cases. Despite these developments, the expected ROI by companies that heavily invest in Big Data and analytics is falling short in relation to expectation, according to a recent report by McKinsey & Company entitled 'Analytics comes of age'.

A key priority should therefore be a broadened exchange of data beyond traditional industry boundaries, which requires the development of proper governance structures, enabling exchange of data while preserving considerations such as security and privacy. The resulting digital ecosystems with massive decentralised storages will in turn provide the required propellant for the development of solutions based on artificial intelligence and particularly machine learning with its subset deep learning. An important aspect is also the characteristics of data which can be from the design domain and the operation domain, spanning update cycles from less than seconds to years. Joining such diverse sources will enable a more systematic approach to the design-operation continuum.

One of the main issues is the dependency of the solution on the quality of the whole chain, which involves data, analytics, IT, people and processes, where the latter two are from the business domain while the first are from technology domain. The effects of the quality are multiplicative, which implies that the whole chain is as good as the weakest link. Here efforts need to be placed on processes like collecting, linking, cleaning, enriching and augmentation. In a further step, when it comes to AI and machine learning, the labelling is a critical aspect which requires more consideration.

As for DHC, data has traditionally not been a focus, but with the emergence of IoT and non-intrusive measurement technologies, the access to data has become easy, at least from the consumer side with smart meters. Access to data from the infrastructure side, which is usually more costly due to installation costs and the higher costs for the hardware, is becoming increasingly critical. Energy efficiency improvements are largely depending on the capability to optimise, which depends on data and system models, both dynamic and static.



B) ARTIFICIAL INTELLIGENCE

Industry 4.0 has brought a lot of benefits not just in the manufacturing industry, but also outside, including the (district) energy sector. Especially in the process industry, concepts like identification of devices, connectivity of devices into cloud systems, and combining the devices into some level of artificially intelligent (AI) systems offer substantial benefits to utilities as well as to end users, with the goal of improving energy- / cost-efficiency and the quality of supply & service.

In computer science AI is defined as the study of "intelligent agents": any device that perceives its environment and takes actions that maximize its chance of successfully achieving its goals. Colloquially, the term "artificial intelligence" is applied when a machine mimics "cognitive" functions that humans associate with other human minds, such as "learning" and "problem solving".

In general, we talk about three (sometimes four) levels of AI:

- a. Narrow (or weak) AI: artificial intelligence focused on specific task and able to solve problems related only to this task, with goal of successfully completing the task.
- b. General AI: artificial intelligence on level of human intelligence, meaning it can perform any task humans can perform. AI on this level could autonomously write and improve its code, learning and constantly improving (optimizing) execution of its task and processes in operates.
- c. Super AI (superintelligence): artificial intelligence that is self-aware and able to "greatly exceed the cognitive performance of humans in virtually all domains of interest".

Most digital solutions described in this "Digital Roadmap for District Heating & Cooling" already require the introduction of narrow or weak AI to District Energy.

As an example "Operational thermal optimization" is a process where an artificial intelligence is in charge of specific task, with a specific goal. In this case to find optimum balance of supply temperature and flow in a District Energy distribution system, with the goal of minimizing production and distribution costs, while still ensuring quality of supply. In this process the AI requires various data, including:

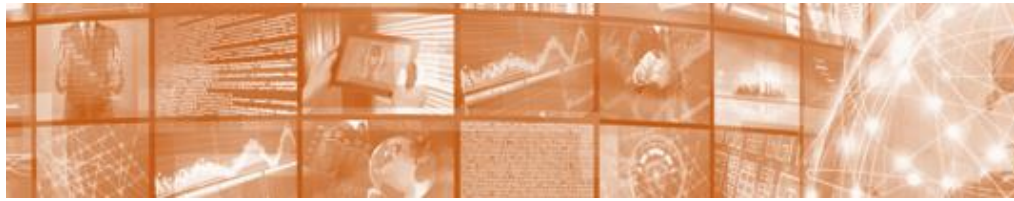
- Historic and real-time demand, in relation to time of day and weather data,
- economic data for energy production and distribution - fuel prices and electricity prices,
- network physical characteristics - transport times and network losses.

Based on this data, AI driven software solutions are able to predict future demand and prescribe optimal techno-economic operational parameters.

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Bolstrom, N., *Superintelligence*, 2014, p. 22

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C) BLOCKCHAIN

Although it is mainly known for its use in cryptocurrencies and often confused with Bitcoin, Blockchain is a very basic, underlying distributed database (or technically correct: “distributed ledger”) and can be applied in many different areas. The energy sector is in the focus of some recent investigations and implementation projects.

Blockchain is a “Distributed Ledger Technology” enabling a database to be shared and synchronized across a network (Gupta). What makes blockchain special is the fact that it is not owned or controlled by one central authority or company (Underwood). Every participating computer in the network has access to the most recent version of the database, thus creating a peer-to-peer decentralized system where trust does not need to be placed on one central node. The ledger is collecting all transactions made on the blockchain and the shared ledger is the single source of truth, meaning that the records of the transactions in the blockchain are always considered true.

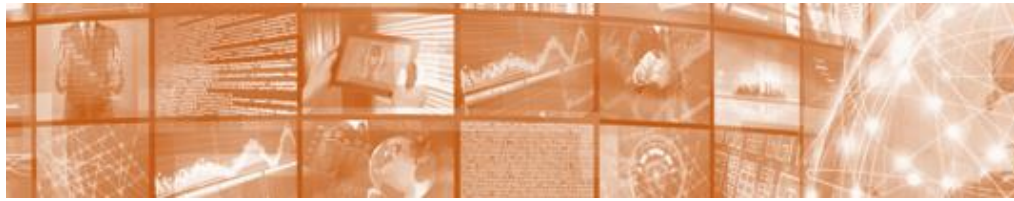
Although there are a large number companies and start-ups working in the field of energy and blockchain, a systematic review of challenges and opportunities of Blockchain technology in the energy sector concluded, that “most projects are in an early development phase and face a large variety of challenges to achieve market penetration, including legal, regulatory and competition barriers” (Andoni).

Although there are no known examples of Blockchain use in district heating, some of the applications in the energy sector are transferable in principle. Oluwole highlighted the possible application for easy reconciliation of contracts between generators, transmitters, distributors and their customers. More importantly, customers will have the option to switch between generators thereby making the market more competitive and fair (see also Cole).

An investigation of possible blockchain applications for a Swedish district heating company by Gunnarson and Hamber results in seven areas with a “high priority application”:

- Trace the origin of the fuel and track the fuel along the supply chain,
- Create a shared fuel procurement program with other district heating companies,
- Create a common heat production system between district heating companies with aim to optimise the district heating network,
- Ensure quality of the metering and maintenance tasks,
- Simplify collaboration between involved parties in the construction process of new properties by creating one unified system for communication, agreements and permit management,
- Simplify machine-to-machine (M2M) communication between the production, distribution and customers,
- Facilitate an open marketplace where heat is traded.

This study, however, recommends to “wait one to two years before blockchain is implemented in the organisation to see how the technology will develop”. This concept when analysed with regards to investments in district heating network infrastructures – i.e. crowdfunding, has been seen as “one possible answer to the challenges as well as the opportunities that the district heating sector is facing as alternative source of finance for new projects and business ventures; Additionally, to allow the general public easier, disintermediated access and participation to investments, from which they would most likely left apart” (Candelise).



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