The Status of 4th Generation District Heating: Research and Results.
Review
The status of 4th generation district heating: Research and results
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Reference to the 4th Generation District Heating concept in Scientific Publications

District Heating: A viable solution – requiring change
The Renewable Future of District Heating and Cooling: Research and results from the 4G District Heating and Cooling Centre

AALBORG UNIVERSITY DENMARK
Purpose
To investigate the future of District Heating and Cooling

What is the role of district heating in future energy systems? How should the technology develop in order to fulfil such role?
Smart Grid (2005)

No definition.

However it can be understood from the context that a *smart grid* is a power network using modern computer and communication technology to achieve a network which can better deal with potential failures.
Smart Grid - definitions

“A smart grid is an electricity grid that uses information and communications technology to gather and act on information, such as information about the behaviors of suppliers and consumers, in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity.” (U.S. Department of Energy)

“Smart Grids … concerns an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both - in order to efficiently deliver sustainable, economic and secure electricity supplies.” (SmartGrids European Technology Platform, 2006).

“A Smart Grid is an electricity network that can cost efficiently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety.” (European Commission, 2011)

“Smart grids are networks that monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end users” …. “The widespread deployment of smart grids is crucial to achieving a more secure and sustainable energy future.” (International Energy Agency 2013).
Smart heating and cooling grids

- In the European Commission’s strategy [7] for a competitive, sustainable and secure “Energy 2020”, the need for “high efficiency cogeneration, district heating and cooling” is highlighted (page 8). The paper launches projects to promote, among others, “smart electricity grids” along with “smart heating and cooling grids” (page 16).
Smart Energy Systems

- **Smart Electricity Grids** are electricity infrastructures that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both - in order to efficiently deliver sustainable, economic and secure electricity supplies.

- **Smart Thermal Grids** are a network of pipes connecting the buildings in a neighbourhood, town centre or whole city, so that they can be served from centralised plants as well as from a number of distributed heating or cooling production units including individual contributions from the connected buildings.

- **Smart Gas Grids** are gas infrastructures that can intelligently integrate the actions of all users connected to it - supplies, consumers and those that do both - in order to efficiently deliver sustainable, economic and secure gas supplies and storage.

**Smart Energy System** is defined as an approach in which smart Electricity, Thermal and Gas Grids are combined and coordinated to identify synergies between them in order to achieve an optimal solution for each individual sector as well as for the overall energy system.
Smart Energy Systems
Energy Storage

- **Pump Hydro Storage**
  - 175 €/kWh

- **Natural Gas Underground Storage**
  - 0.05 €/kWh

- **Thermal Storage**
  - 1-4 €/kWh
  - (Source: Danish Technology Catalogue, 2012)

- **Oil Tank**
  - 0.02 €/kWh
  - (Source: Dahl KH, Oil tanking Copenhagen A/S, 2013: Oil Storage Tank. 2013)
Thermal Storage

0.16 m³ Thermal Storage
300,000 €/MWh
(Private house: 160 liter for 15000 DKK)

4 m³ Thermal Storage
40,000 €/MWh
(Private outdoor: 4000 m³ for 50,000 DKK)

6200 m³ Thermal Storage
2500 €/MWh
(Skagen: 6200 m³ for 5.4 mio. DKK)

200,000 m³ Thermal Storage
500 €/MWh
(Vojens: 200,000 m³ for 30 mio. DKK)
Energy Storage Capacities in Denmark

Danish Oil Storage
~50 TWh

Danish Gas Storage
~11 TWh

Danish Thermal Storage
~0.090 TWh
Eksisterende distributionsnet
Energy System Analysis Model

www.EnergyPLAN.eu
Smart Energy Systems:
Hourly modelling of all smart grids to identify synergies! … and influence of different types of energy storage..!
IDA Energiplan 2030
Smart Energy Europe: The technical and economic impact of one potential 100% renewable energy scenario for the European Union

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ARTICLE INFO

Article history:
Received 29 September 2015
Revision received 10 February 2016

ABSTRACT

Smart Energy Europe: The technical and economic impact of one potential 100% renewable energy scenario for the European Union

www.EnergyPLAN.eu/SmartEnergyEurope

○ Report Online
○ Paper Published
Energy Storage Capacities in 100 % RES Denmark 2050 (IDA)

Danish Oil Storage
≈ 50 TWh

Danish Gas Storage
≈ 11 TWh

Danish H₂ Storage
≈ 0.550 TWh

Danish Thermal Storage
≈ 0.200 TWh

Danish Electricity Storage
≈ 0.015 TWh
4th Generation District Heating (4GDH) system is defined as a coherent technological and institutional concept, which by means of smart thermal grids assists the appropriate development of sustainable energy systems. 4GDH systems provide the heat supply of low-energy buildings with low grid losses in a way in which the use of low-temperature heat sources is integrated with the operation of smart energy systems. The concept involves the development of an institutional and organisational framework to facilitate suitable cost and motivation structures.
Figure 1: Illustration of the concept of 4\textsuperscript{th} Generation District Heating

- 4GDH in Building Systems
- 4GDH Distribution Grids
- Planning and Implementation of 4GDH
- Heat Sources in 4GDH
- 4GDH in Smart Energy Systems
Three pillars

WP1: Supply
Low temperature District heating

WP2: Production
Renewable Systems Integration

WP3: Organisation
Planning and Implementation
Review

4th Generation District Heating (4GDH)
Integrating smart thermal grids into future sustainable energy systems

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ABSTRACT

This paper defines the concept of 4th Generation District Heating (4GDH) including the elements of District Cooling and the concept of smart energy and smart thermal grids. The objective is to identify the future challenges of reaching a future sustainable non-fossil heat supply as part of the implementation of overall sustainable energy systems. The basic assumption is that district heating and cooling has an important role to play in future sustainable energy systems – including 100% renewable energy systems – but the present generation of district heating and cooling technologies will have to be developed further into a new generation in order to play such a role. Unlike the first three generations, the development of 4GDH is driven by the challenges of future energy systems – including smart energy systems, i.e., integrated smart electricity, gas and thermal grids.

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1. Introduction

The design of future sustainable energy systems including 100% renewable systems is described in a number of recent reports and studies including [1–6]. Such systems are typically based on a combination of fluctuating renewable energy sources (RES) such as wind, geothermal and solar power together with residual resources such as waste and biomass on which we may expect increasing pressure due to environmental impact and future alternative demands for food and material. For example, biomass resources in Europe are small compared to the European energy balance [7]. In order to ease the pressure on biomass resources and investments in renewable energy, feasible solutions to future sustainable energy systems must involve a substantial focus on energy conservation and energy efficiency measures.

District heating infrastructures have an important role to play in the task of increasing energy efficiency and reducing these resources most efficient demands. District heating comprises a network of pipes connecting the buildings in a neighborhood, town center or whole city, so that they can be served from centralised plants or a number of decentralised heat production units. This approach allows any available source of heat to be used. The inclusion of district heating in future sustainable cities allows for the wide use of combined heat and power (CHP) together with the utilization of heat from waste energy, and various industrial surplus heat sources as well as the inclusion of geothermal and solar thermal heat [8–16]. In the future, such industrial processes may involve indirect processes of transferring solid biomass fractions into bioenergy gas and/or different forms of liquid biofuels for transportation fuel purposes, among others [17–19].

Future district heating infrastructures should, however, not be designed for the present energy systems but for the future system. One of the future challenges will be to integrate district heating with the electricity sector as well as the transport sector [20]. In the following, such a future system will be referred to as a smart energy system, i.e., an energy system in which smart electricity, thermal and gas grids are combined and coordinated to identify synergies between them in order to achieve an optimal solution for each
Impact on science

Reference to the 4th Generation District Heating concept in Scientific Publications

- 4GDH Distribution Grids
- 4GDH in Building Systems
- 4GDH in SES
- Heat Sources in 4GDH
- Other
- Planning and Implementation of 4GDH
The 4DH conferences

"The conference on Smart Energy Systems and 4th Generation District Heating presents a lot of knowhow and research about district heating and the advanced technology in Denmark and Europe."

"I have chosen to attend this conference because it is one of the greatest conferences on district heating in the World, actually."

"I am attending the Conference on Smart Energy Systems and 4th Generation District Heating because I would like to contribute in my home country to improve district heating and go towards a more sustainable energy system."
Partners

District heating part of energy strategy

The Energy2020 Strategy
Self-sufficiency in renewable energy was approximately 56.2% in 2015. The following nine initiatives will increase the current level of renewable energy by approximately 44.2%, bringing Energy2020 to its full objective of 100% in 2020.

<table>
<thead>
<tr>
<th>Initiative</th>
<th>Impact</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction in required heat consumption</td>
<td>0.2</td>
<td>10% reduction in housing heat consumption, 296 T/year</td>
</tr>
<tr>
<td>Renewable energy in businesses</td>
<td>1.0</td>
<td>29% of the total consumption from renewable energy</td>
</tr>
<tr>
<td>Less energy consumption for road transport</td>
<td>0.0</td>
<td>19% reduction in consumption for 177 T/year</td>
</tr>
<tr>
<td>More renewable energy in district heating</td>
<td>4.8</td>
<td>Increased from renewable energy heating</td>
</tr>
<tr>
<td>Change of boiler to renewable energy</td>
<td>1.9</td>
<td>2/3 of boilers changed to renewable energy</td>
</tr>
<tr>
<td>New wind turbines</td>
<td>22.0</td>
<td>Wind power is 4,000 T/year</td>
</tr>
</tbody>
</table>

"We chose to participate in the 4DH work and we have had a lot of very good analysis and inputs from the whole group, so thank you!"  
- Morten Abildgaard, CEO of Viborg Fjernvarme, during the third International Conference on Smart Energy Systems and 4th Generation District Heating, 2017
Outreach

4DH Forum in Japan

"The work of the 4DH Research Centre has been inspiring for district heating systems in Slovakia. It contributes to a new perspective on the role of district heating in Slovak cities, clearly showing the prospective paths of further development."

- Ivan Ďuďák - Slovak Association of Heat Producers

Stockholm

Belgium

Slovakia
Heat Roadmap Europe

GIS Mapping: Many Heat Sources

- Urban areas (Heating Demands)
- Power and Heat Generation
- Waste Management
- Industrial waste heat potential
- Geothermal heat
- Solar Thermal

The study indicates that the market shares for district heating for buildings can be

“Heat Roadmap Europe is the most advanced study on the EU’s heating and cooling sector as a whole.”

- Paul Hodson, Head of the Energy Efficiency Unit in the European Commission’s DG Energy
District Heating on the first page of the Commission’s Vision for Heating and Cooling

1. INTRODUCTION
Heating and cooling consume half of the EU’s energy and much of it is wasted. Developing a strategy to make heating and cooling more efficient and sustainable is a priority for the Energy Union. It should help to reduce energy imports and dependency, to cut costs for households and businesses, and to deliver the EU's greenhouse gas emission reduction goal and meet its commitment under the climate agreement reached at the COP21 climate conference in Paris.

Although the heating and cooling sector is moving to clean low carbon energy, 75% of the fuel it uses still comes from fossil fuels (nearly half from gas). While this strategy will contribute to reducing import dependency, security of supply remains a priority, especially in Member States that rely on a single supplier.

Heating and cooling and the electricity system can support each other in the effort to decarbonise. It is essential to recognise the links between them and exploit synergies.

This strategy provides a framework for integrating efficient heating and cooling into EU energy policies by focusing action on stopping the energy leakage from buildings, maximising the efficiency and sustainability of heating and cooling systems, supporting efficiency in industry and reaping the benefits of integrating heating and cooling into the electricity system. It is accompanied by a Staff Working Document giving an overview of this complex sector. The solutions will be examined in the ongoing reviews of legislation under the Energy Union.

A smarter and more sustainable use of heating and cooling is within reach as the technology is available. Actions can be deployed rapidly, without prior investment in new infrastructure, and with substantial benefits for both the economy and individual consumers, provided that (household) consumers can afford to invest or have access to the finance needed to do so.

2. VISION AND GOALS
To achieve our decarbonisation objectives, buildings must be decarbonized. This entails renovating the existing building stock, along with intensified efforts in energy efficiency and renewable energy, supported by decarbonized electricity and district heating. Buildings can use automation and controls to serve their occupants better, and to provide flexibility for the electricity system through reducing and shifting demand, and thermal storage.

Industry can move in the same direction, taking advantage of the economic case for efficiency and new technical solutions to use more renewable energy. In this sector, however, some fossil fuel demand can be expected for very high temperature processes. Industrial processes will continue to produce waste heat and cold, as well infrastructure. Much of it

"I believe that Heat Roadmap Europe is a cornerstone for changing heating and cooling practices in the EU."
- Morten Bæk, director of the Danish Energy Agency
EU Strategy on Heating and Cooling

“Linking heating and cooling with electricity networks will reduce the cost of the energy system – to the benefit of consumers.”

“District heating can integrate renewable electricity (through heat pumps)....

...It can offer flexibility to the energy system by cheaply storing thermal energy, for instance in hot water tanks or underground.”

“We are taking an integrated holistic approach, which we have never done before. We now look at heating and cooling as a part of energy systems and hopefully this will help us discover synergies that will make the systems more energy efficient.”

- Eva Hoos, Policy Officer at the European Commission’s DG Energy, during the First International Conference on Smart Energy Systems and 4th Generation District Heating, 2015
Smart Heating Europe

“4DH is very much defining and establishing the future within district heating and cooling. The Research Centre has given the industry a community and a structure to refer to, and internationally we can also see that people are beginning to reflect on the different generations of district heating.

Danfoss is proud to be a part of 4DH.”

- Jan Eric Thorsen, Director of Danfoss District Heating Application Centre and partner in 4DH
Quantifies the **costs** and **benefits** of 4GDH in future sustainable energy systems.

- **Costs** involve an upgrade of heating systems and of the operation of the distribution grids.
- **Benefits** are lower grid losses, a better utilization of low-temperature heat sources and improved efficiency in the production compared to previous district heating systems.
### Table 2
Electricity, heat and fuel demands. The electricity demand is the sum of exogenously given demands and does not include energy sector internal demands for DH heat pumps, electrolyzers or electric boilers.

<table>
<thead>
<tr>
<th></th>
<th>3GDH</th>
<th>4GDH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity demand [TWh]</td>
<td>36.64</td>
<td>36.64</td>
</tr>
<tr>
<td>DH supply [TWh]</td>
<td>39.16</td>
<td>34.80</td>
</tr>
<tr>
<td>Final individual heating demand [TWh]</td>
<td>14.51</td>
<td>14.51</td>
</tr>
<tr>
<td>Transport fuel demand [TWh]</td>
<td>40.23 (Total)</td>
<td>40.23 (Total)</td>
</tr>
<tr>
<td>Electrofuels</td>
<td>31.13</td>
<td>31.13</td>
</tr>
<tr>
<td>Electricity</td>
<td>9.1</td>
<td>9.1</td>
</tr>
<tr>
<td>Gas</td>
<td>8.41</td>
<td>8.41</td>
</tr>
<tr>
<td>Biomass</td>
<td>3.41</td>
<td>3.41</td>
</tr>
</tbody>
</table>

### Table 3
System configuration with 3GDH and 4GDH.

<table>
<thead>
<tr>
<th></th>
<th>3GDH</th>
<th>4GDH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onshore wind power [MW]</td>
<td>5000</td>
<td>5000</td>
</tr>
<tr>
<td>Off-shore Wind power [MW]</td>
<td>14000</td>
<td>12520</td>
</tr>
<tr>
<td>PV [MW]</td>
<td>5000</td>
<td>5000</td>
</tr>
<tr>
<td>CHP (electric/heat) [MW]</td>
<td>5000/3750</td>
<td>5000/4231</td>
</tr>
<tr>
<td>Electrolyser [MW]</td>
<td>9009</td>
<td>7975</td>
</tr>
</tbody>
</table>

### Table 4
Aggregated system parameters.

<table>
<thead>
<tr>
<th></th>
<th>3GDH</th>
<th>4GDH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total annual cost [M EUR]</td>
<td>22,373</td>
<td>22,047</td>
</tr>
<tr>
<td>Biomass demand [TWh]</td>
<td>52.50</td>
<td>52.51</td>
</tr>
<tr>
<td>Critical excess electricity [TWh]</td>
<td>2.47</td>
<td>2.47</td>
</tr>
</tbody>
</table>
WP1 Supply: Low temperature District heating

For DHW, it is expected that a new control system is needed for all building types with an estimated cost of 1.7 EUR/MWh DHW. With an assumed distribution between space heating and DHW of 70/30, the annual cost for reducing the return temperature is assumed to be in the range of 0.7–1.3 EUR/MWh of end-user consumption. Using the data from the 100% RE-based energy scenario described in [61], where the total end-user consumption of DH is 28.2 TWh/year, this cost will total around 19–38 M EUR/year.

While the reduction in return temperature can be made already now in existing buildings, it is expected that lowering the supply temperature will take general retrofit of the new building stock in the existing buildings. The new generation of low-temperature district heating systems requires lower temperature levels, and it is expected that the investment cost of such a system will be around 8000 EUR. With an assumed average DHW consumption per average DHW consumption per legionella removal system of 30 MWh/year and a lifetime of 20 years, this adds an extra cost for larger buildings of 13.4 EUR/MWh of DHW consumption. Using the data from the 100% RE-based energy scenario, and assuming the same distribution between single-family houses and larger buildings in the district heating sector [109], the extra cost for also reducing the supply temperature in the Danish case equals 59 M EUR/year.

In conclusion, the overall costs of a full implementation of 4G DH compared to 3G DH results in a cost range of 78–97 MEUR/year. Since this is an estimate, a reasonable result would be to conclude on a range of 50–100 MEUR/year.

Since this is a rough estimate, we express the cost difference in the range of 0–10 MEUR/year.

- In accordance with Danish district heating statistics, pumping in average uses approx. 6 kWh electricity in DH plants per MWh of heat supply. A similar figure of 5 kWh/MWh is used in Ref. [110]. This figure may of course be lower in the future due to more efficient pumping technologies.
- The electricity demand is approx. proportional to the flow cubed. When assuming the same network, a flow reduction of 16% – (1–30 k(35 K)) will give an electricity reduction of 37% –

Assuming an electricity production cost of 50–100 EUR/MWh, the additional pumping cost of operating 4G DH is in the order of magnitude of 3–6 MEUR/year.
WP 2 Production: Renewable Systems Integration

Production and system integration:
- the development of energy systems analysis tools, methodologies and theories
- scenario building of future sustainable energy systems.
- The aim is to identify the role of district heating systems in various countries.

| Table 1 Modelling assumptions for the comparison between 3GDH and 4GDH. |
|-----------------------------------------------|------------------|
|                                             | 3GDH system      | 4GDH             |
| Yearly average supply/return temperatures at DH plant | 80 °C/45 °C      | 55 °C/25 °C      |
| ΔT = 35 K                                      | ΔT = 30 K        |                  |
| DH Grid losses                                 | 28%              | 19%              |
| DH heat pump COP (resource temp. 5 °C; yearly average) | 2.9              | 3.9              |
| DH heat pump COP (resource temp. 35 °C; yearly average) | 4.2              | 7.1              |
| Waste heat sources for direct DH application  | 0.83 TWh +2.28 TWh from district cooling | 2.4 TWh +2.28 TWh from district cooling |
| Waste heat sources for indirect DH application through heat pumps | 1.67 TWh         | 2 TWh            |
| Added 0.4 TWh to electricity demand           |                  | Added 0.28 TWh to electricity demand |
| CHP (Combined cycle)                          | η_e = 52% & η_t = 39% | η_e = 52% & η_t = 44% |
| DH Biomass boilers with condensation          | 95%              | 105%             |
| Thermal storage                               | 3.17 M€/GWh      | 3.70 M€/GWh      |
| Solar thermal                                 | 544 €/MWh        | 382 €/MWh        |
WP3 Organisation: Planning and Implementation

Planning and implementation:

- further development of the planning and management systems
- spatial analysis and geographical information systems (GIS) as a tool for planners and decision-makers.
- organisation and design of specific public regulation measures including ownership, tariffs, reforms etc.

7. Planning and implementation of 4GDH

The transition towards 4GDH and smart energy systems requires innovative planning practices, support tools, policies facilitating the transformation, as well as changes in economic calculation practices. These include conducting strategic and innovative energy planning considering legal perspectives and socio-economic development, energy atlases to support the planning process, and the proposal of new price regulations and tariffs [6,84,85]. This section details some of these general public regulation, planning and framework conditions that will further 4GDH.

7.1. Public regulation and 4GDH

The implementation of 4GDH systems represents a paradigmatic shift in terms of public regulation in various aspects. With
It is quantified how **benefits** exceed **costs** by a safe margin with the benefits of systems integration being the most important.
Thank you..!
4th International Conference on Smart Energy Systems and 4th Generation District Heating
13-14 November 2018 in Aalborg, Denmark.

Thank you