4th International Conference on

Smart Energy Systems and 4th Generation District Heating

13-14 November 2018 in Aalborg, Denmark.

The Status of 4th Generation District Heating: Research and Results.

4DH

4th Generation District Heating Technologies and Systems

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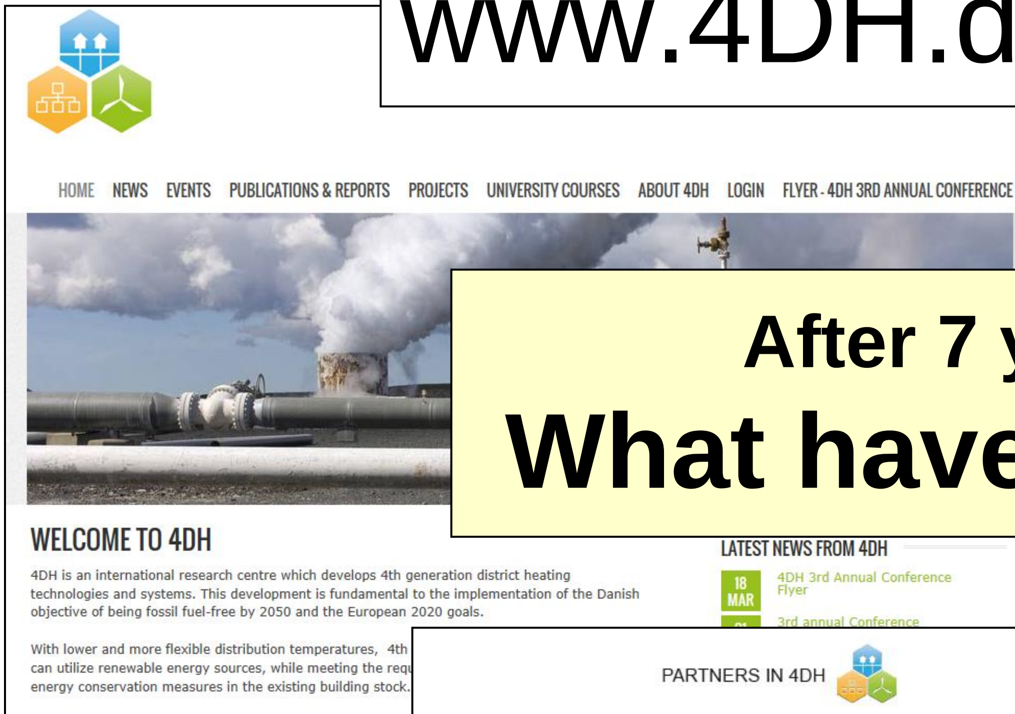
Innovation Fund Denmark

www.4DH.dk

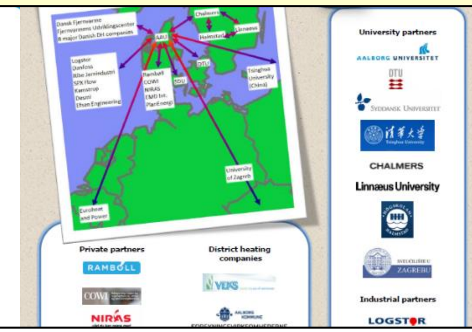
4DH

4th Generation District Heating Technologies and Systems



After 7 years of work:

What have we learned..?



Outreach numbers in 4DH:

250	150	50	12
Presentations	Publications	Times in the press	PhD Fellows

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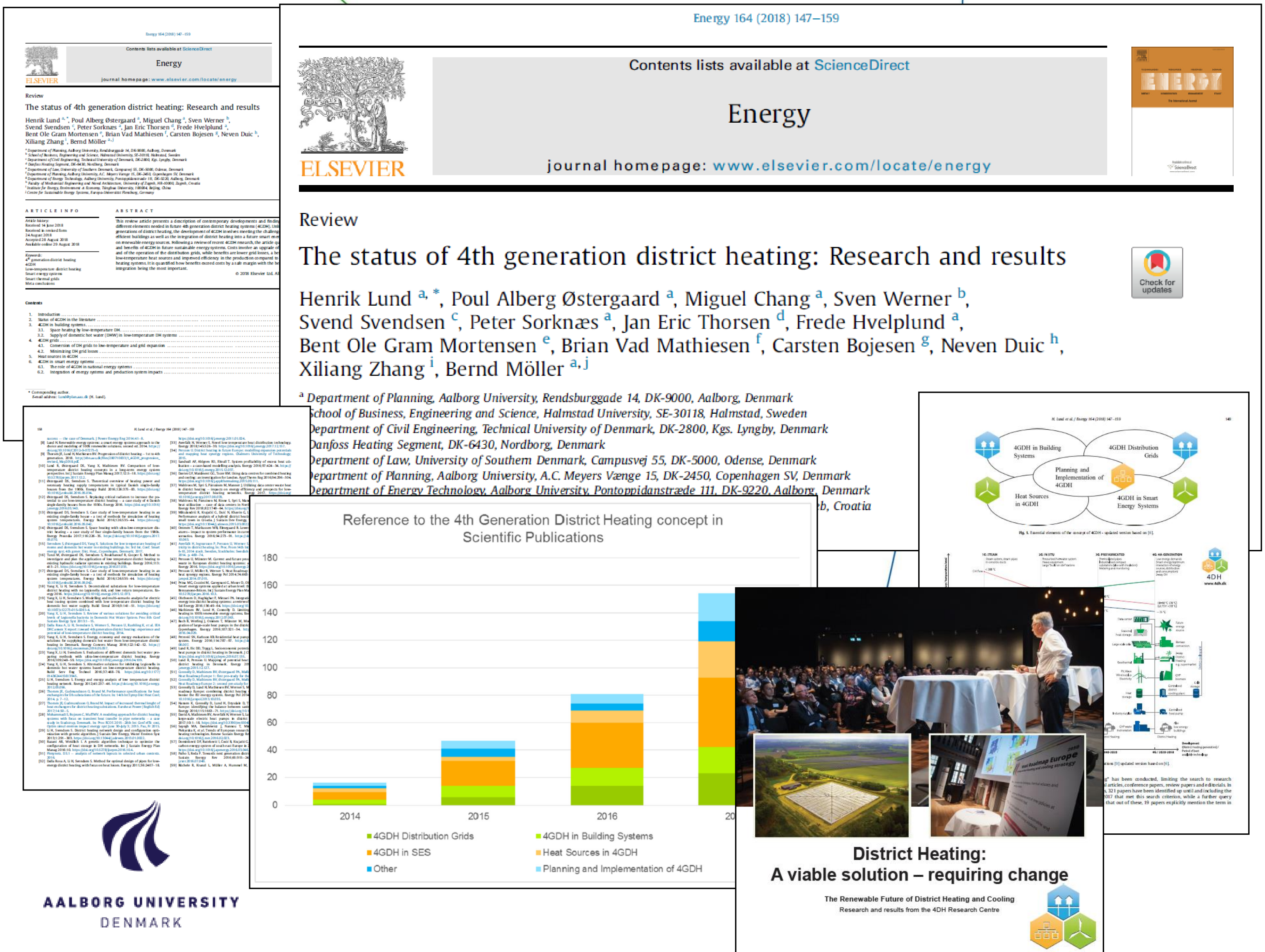
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Review
The status of 4th generation district heating: Research and results
Check for updates
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Reference to the 4th Generation District Heating concept in Scientific Publications
180
160
140
120
100
80
60
40
20
0
2014
2015
2016
4GDH Distribution Grids
4GDH in Building Systems
4GDH in SES
Heat Sources in 4GDH
Other
Planning and Implementation of 4GDH
4GDH in Building Systems
4GDH Distribution Grids
Planning and Implementation of 4GDH
Heat Sources in 4GDH
4GDH in Smart Energy Systems
District Heating:
A viable solution – requiring change
The Renewable Future of District Heating and Cooling
Research and results from the 4DH Research Centre
AALBORG UNIVERSITY
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4DH

4th Generation District Heating Technologies and Systems

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..?

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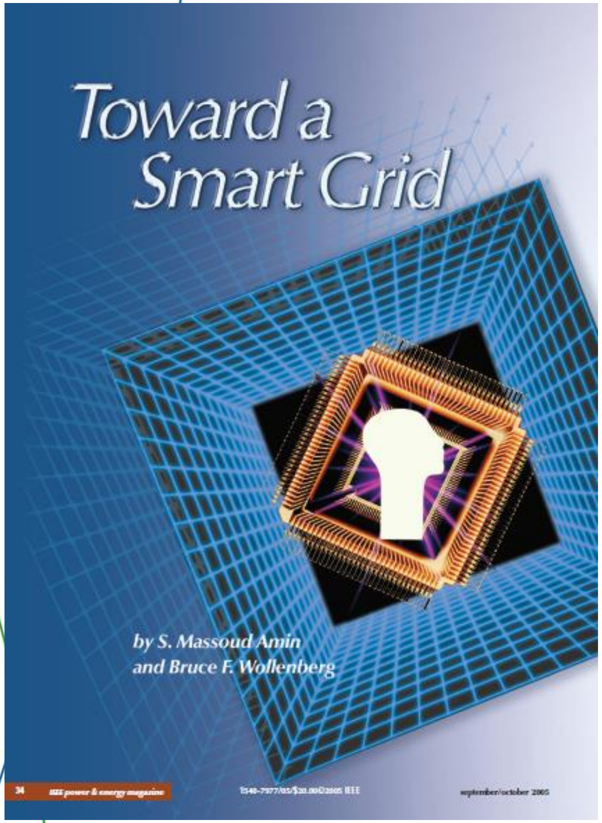
Smart Grid (2005)

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.



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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).

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Smart heating and cooling grids

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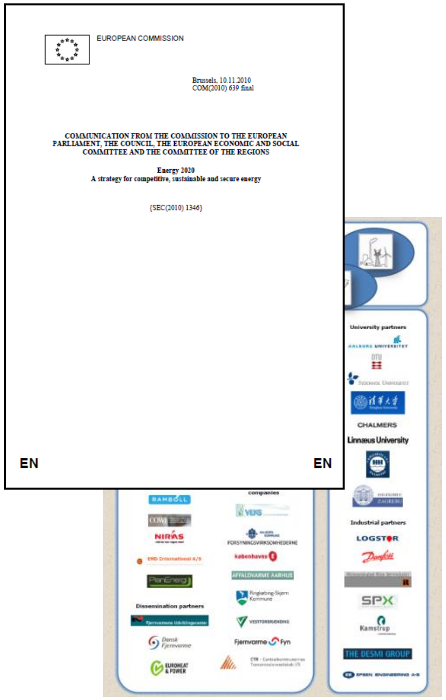
4th Generation District Heating Technologies and Systems

- 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).



EUROPEAN COMMISSION

Brussels, 10.11.2010
COM(2010) 639 final

COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

Energy 2020
A strategy for competitive, sustainable and secure energy

{SEC(2010) 1346}

EN EN

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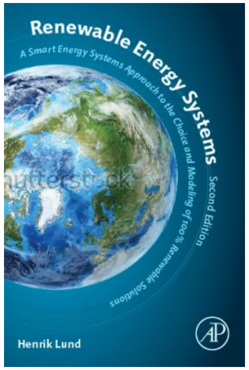
Smart Energy Systems



- **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

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 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.

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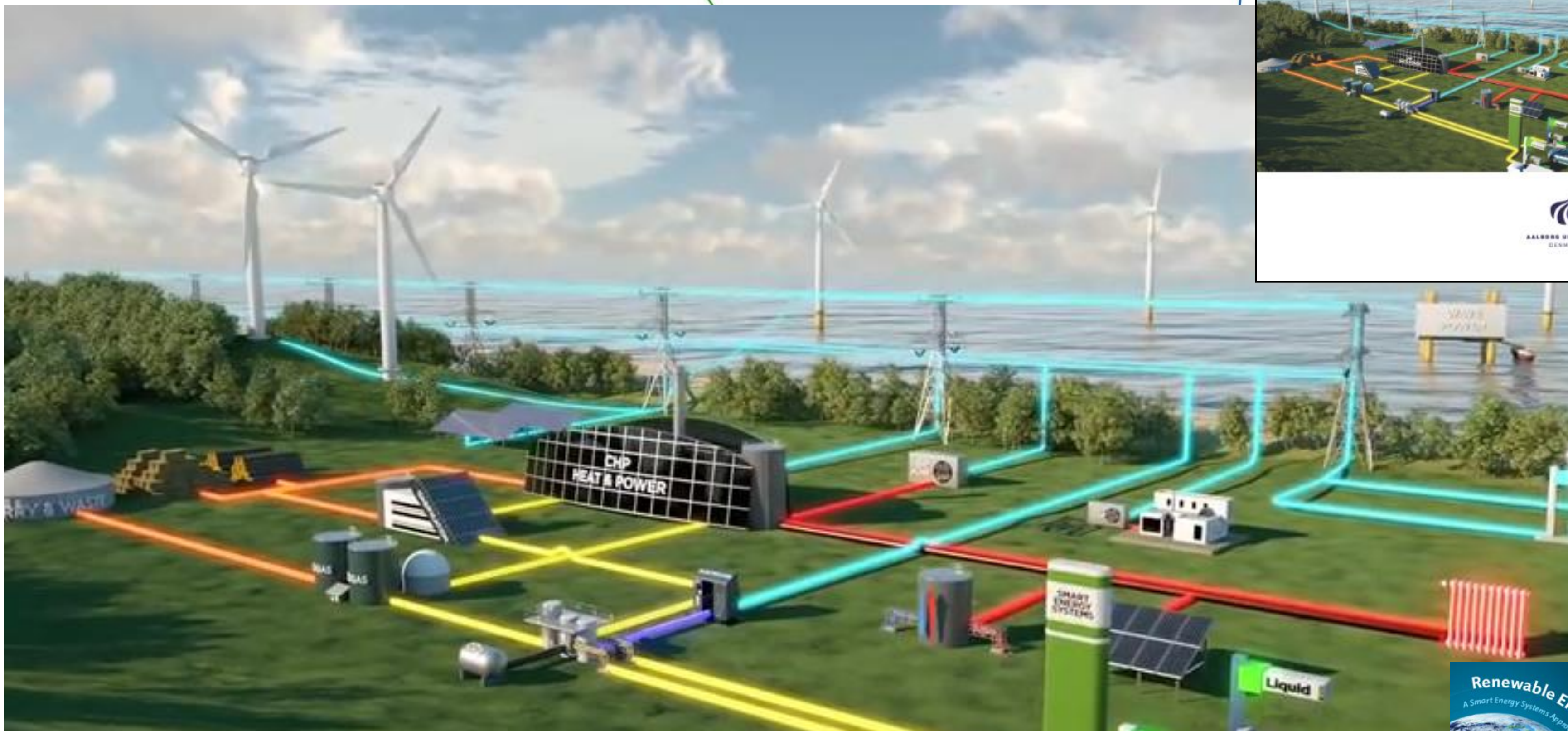
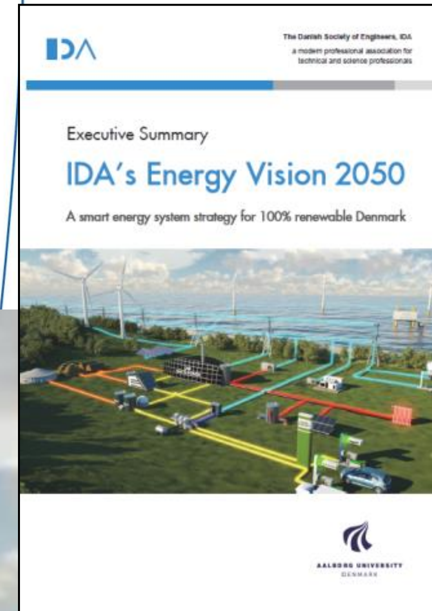
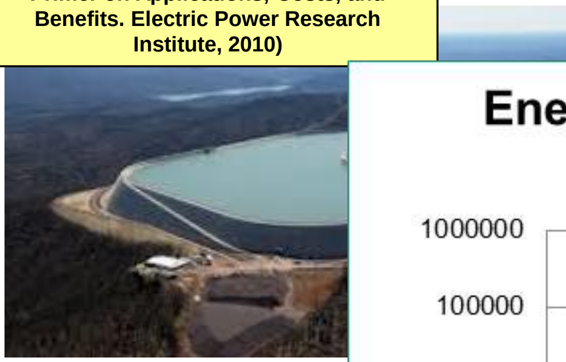
Smart Energy Systems



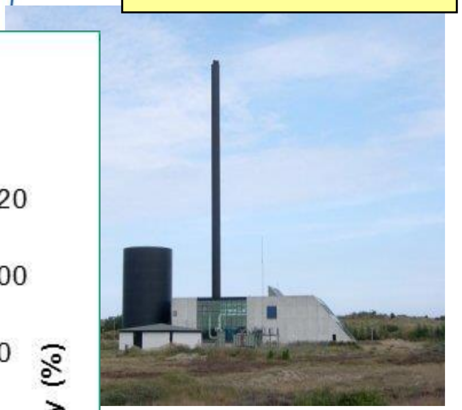


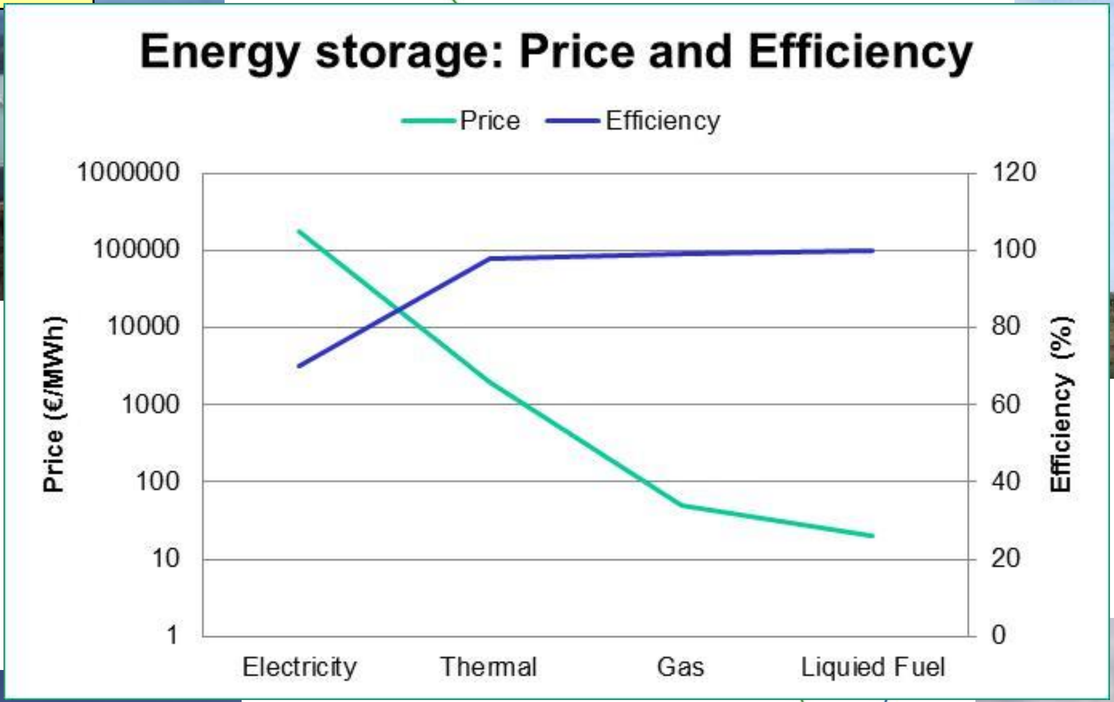
Energy Storage

Pump Hydro Storage
175 €/kWh
(Source: Electricity Energy Storage Technology Options: A White Paper Primer on Applications, Costs, and Benefits. Electric Power Research Institute, 2010)



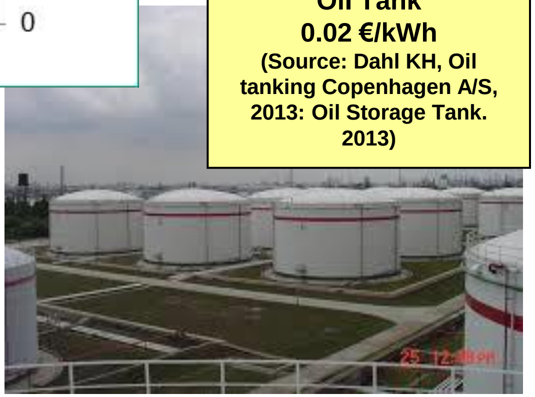
Thermal Storage
1-4 €/kWh
(Source: Danish Technology Catalogue, 2012)





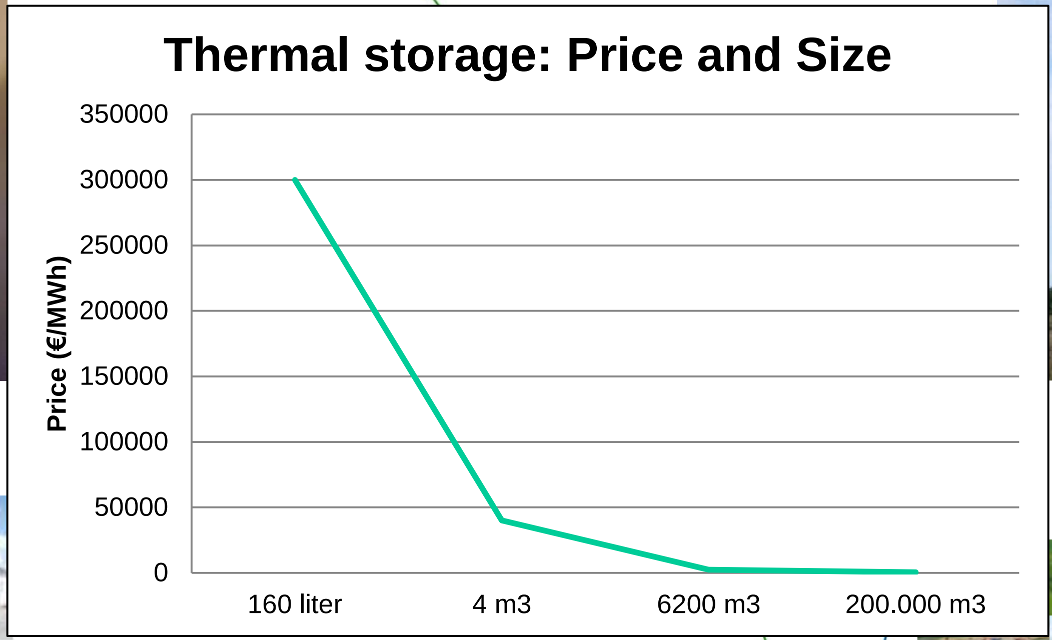
Natural Gas Underground Storage
0.05 €/kWh
(Source: Current State Of and Issues Concerning Underground Natural Gas Storage. Federal Energy Regulatory Commission, 2004)

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

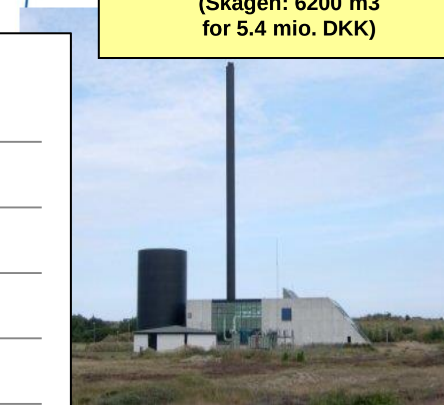


Thermal Storage

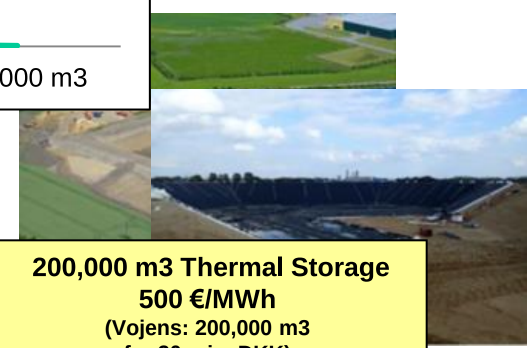
0.16 m3 Thermal Storage
300.000 €/MWh
(Private house: 160 liter for 15000 DKK)



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



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



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

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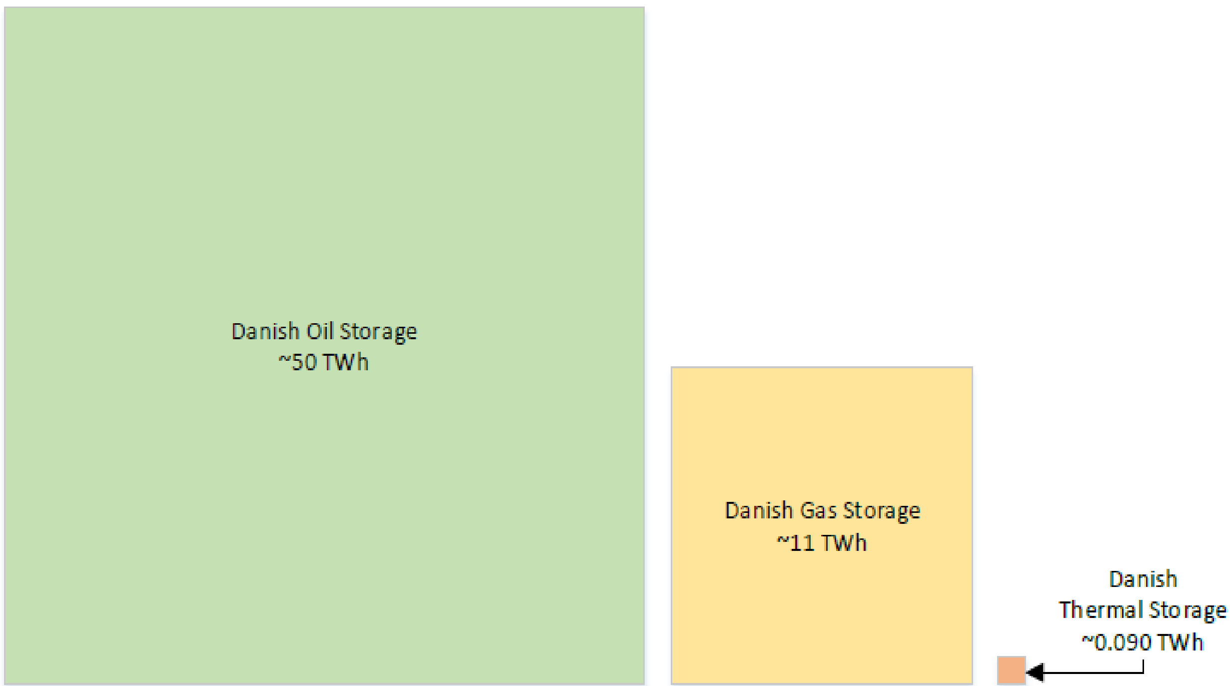
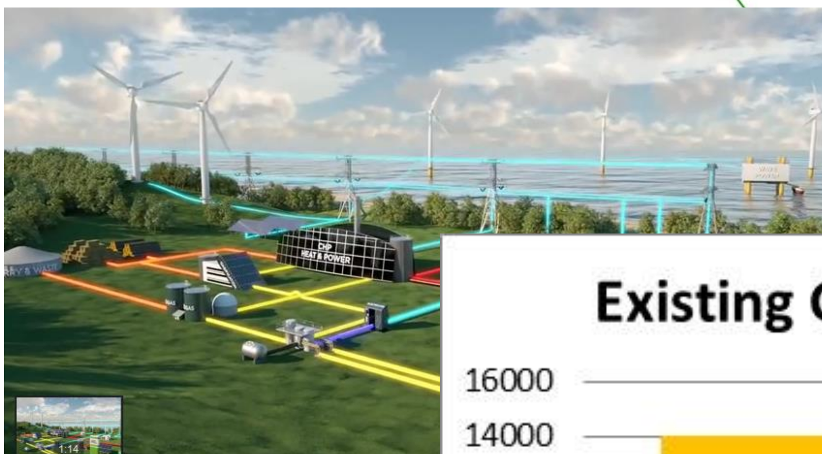
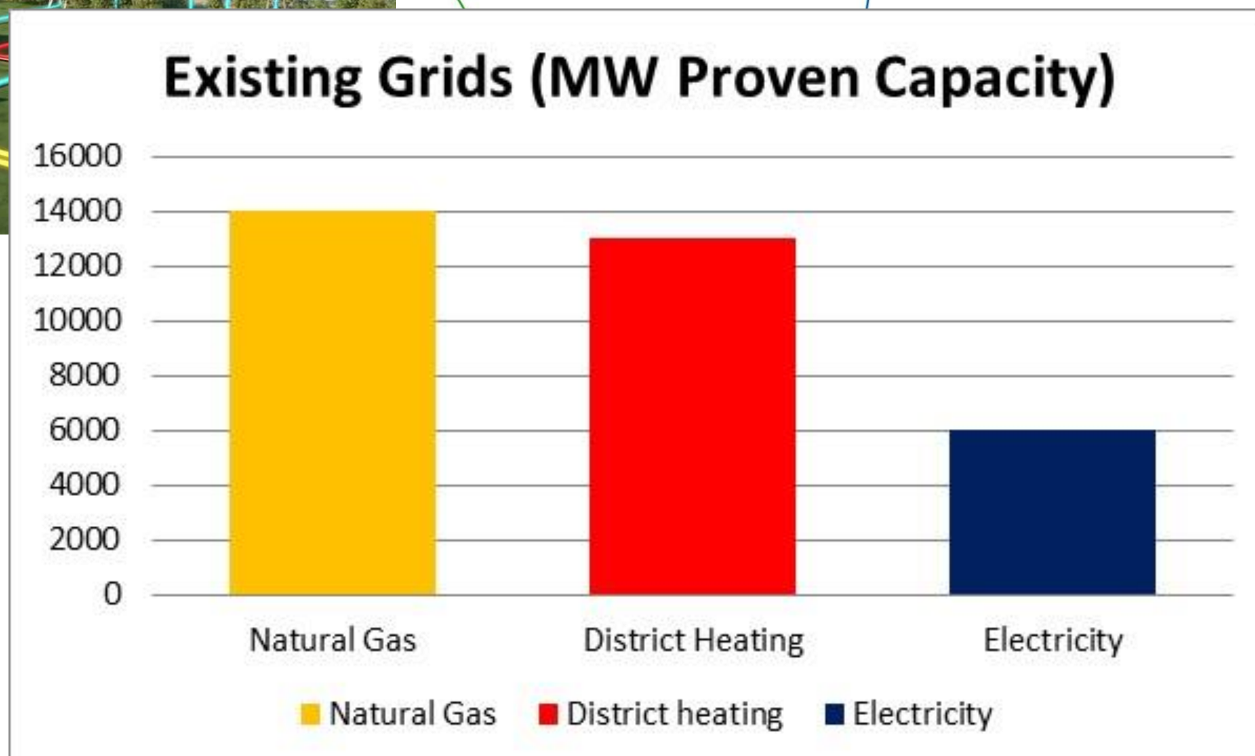
Energy Storage Capacities in Denmark



Eksisterende distributionsnet





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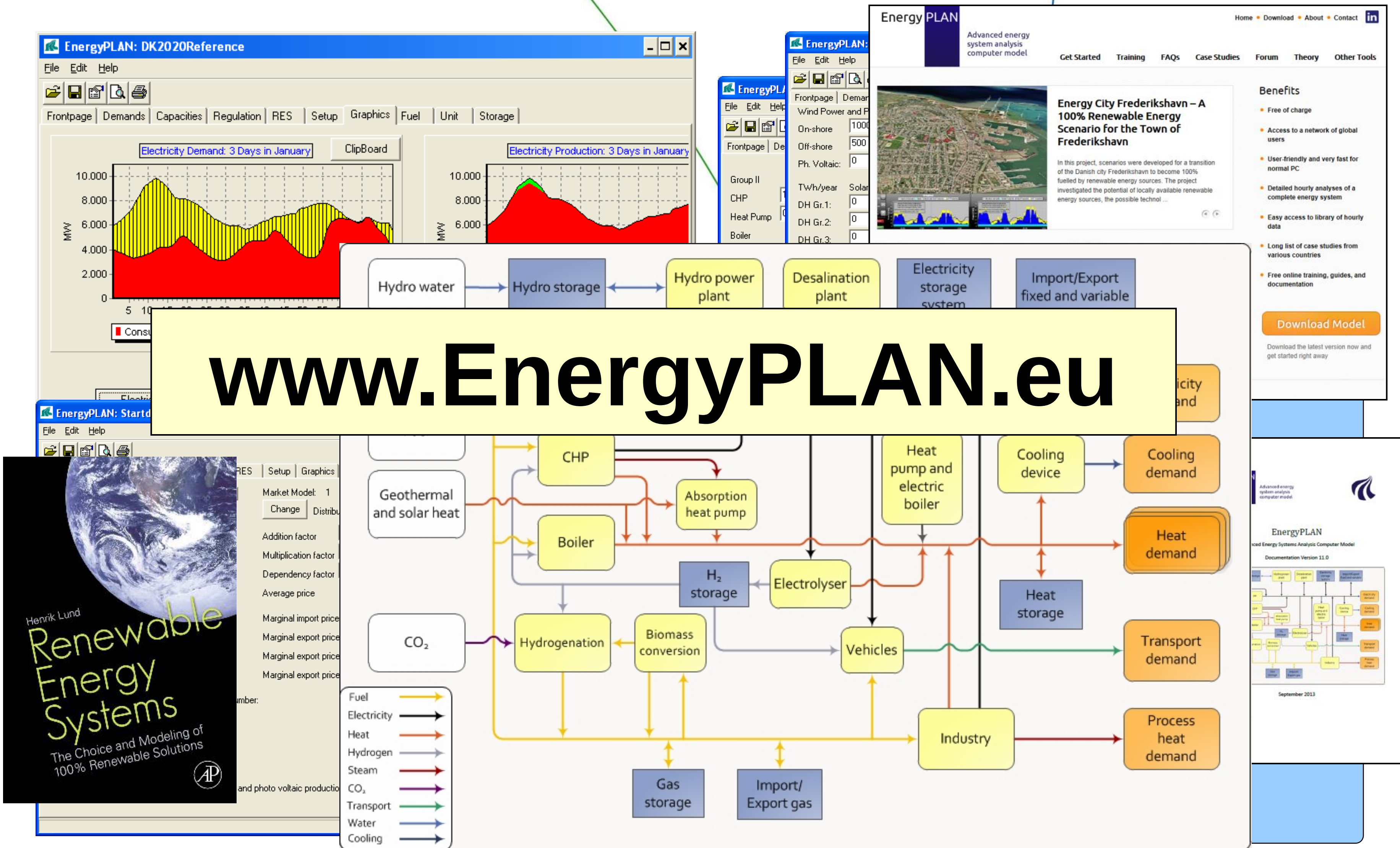
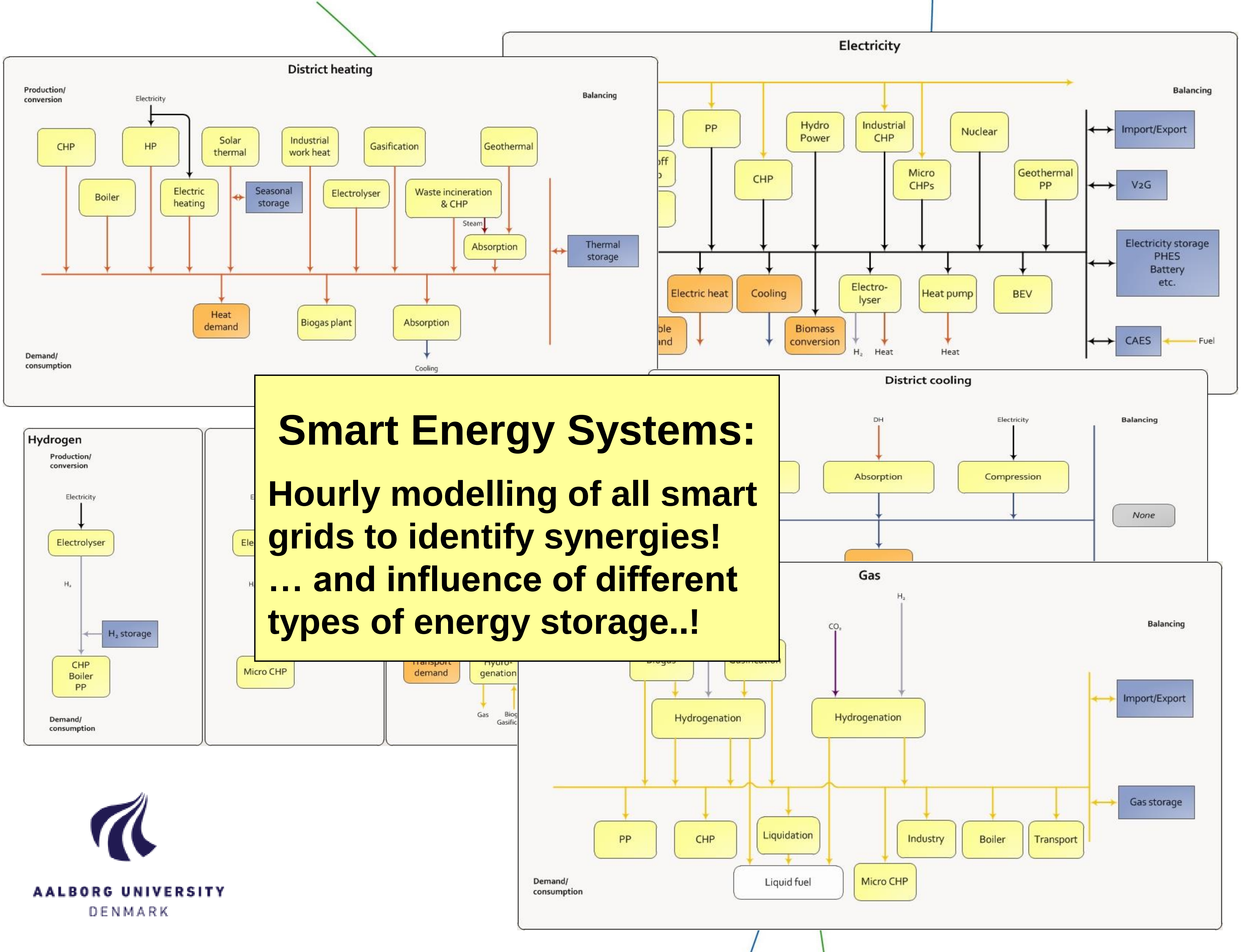
Energy System Analysis Model





Smart Energy Systems:

Hourly modelling of all smart grids to identify synergies!
… and influence of different types of energy storage..!

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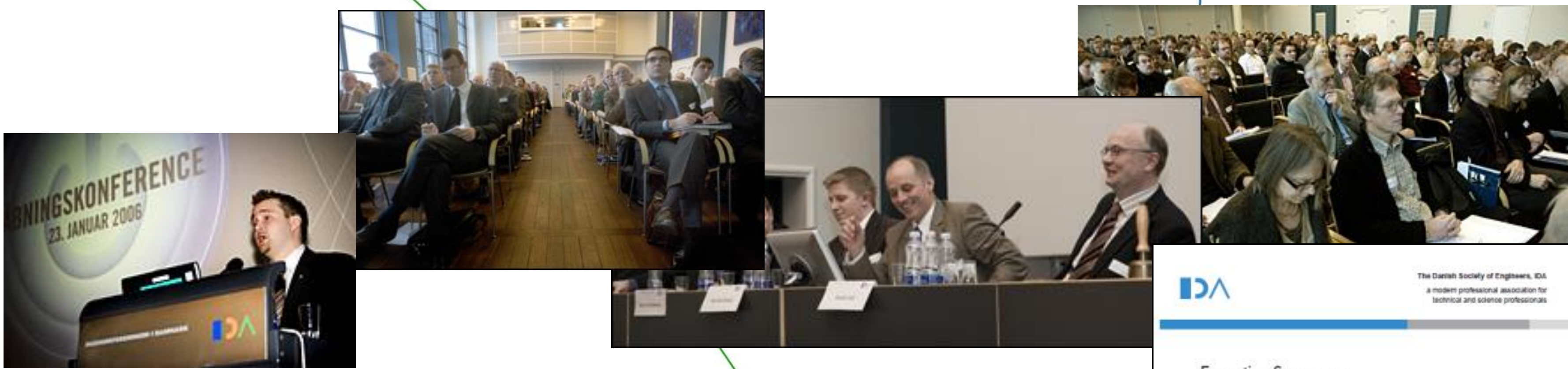
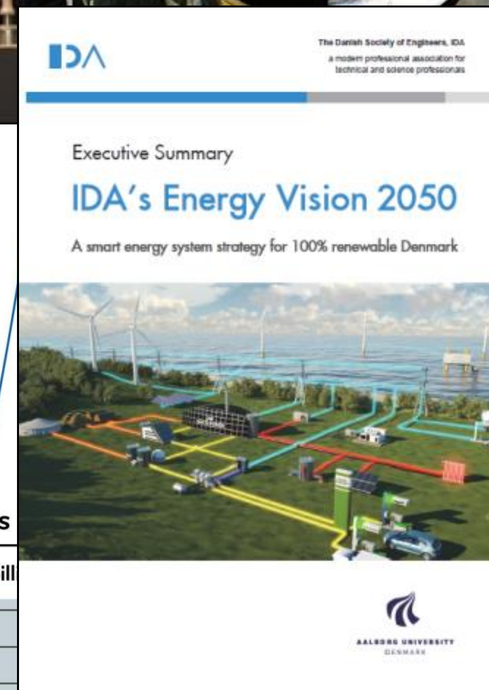
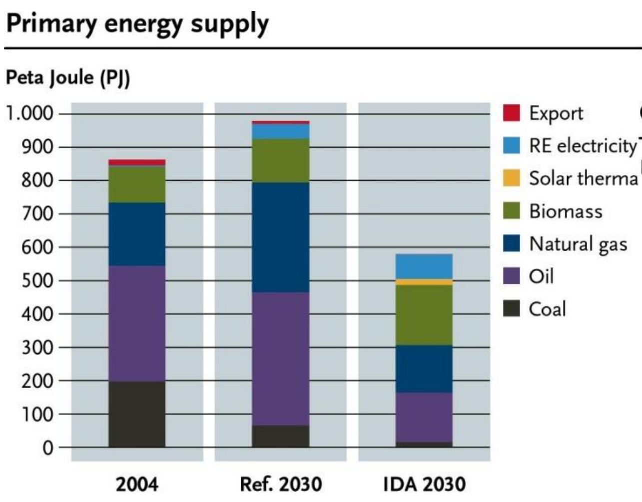
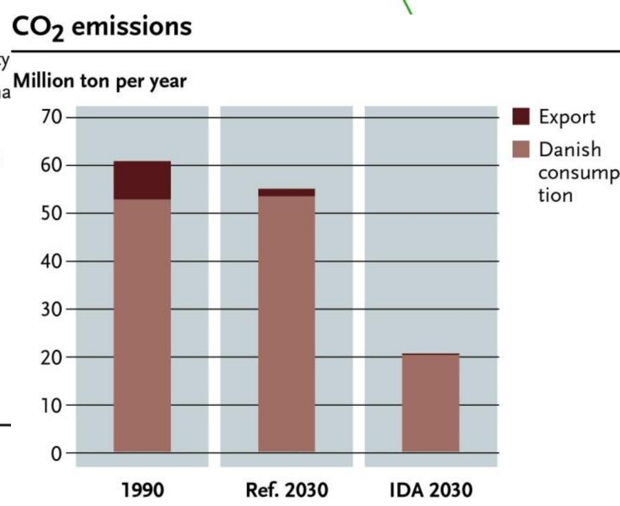
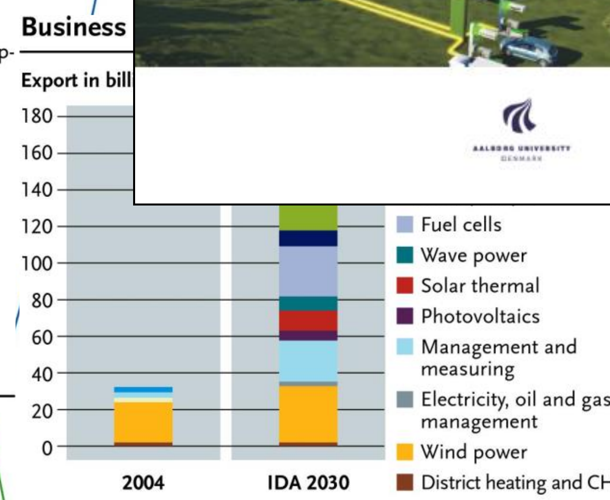




IDA Energiplan 2030







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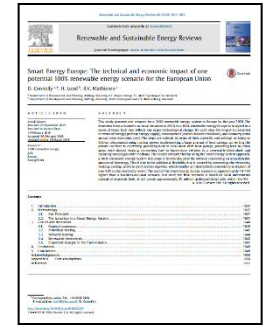
Smart Energy Europe



Renewable and Sustainable Energy Reviews 60 (2016) 1634–1653

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

ELSEVIER

CrossMark

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

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ABSTRACT

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- Paper Published

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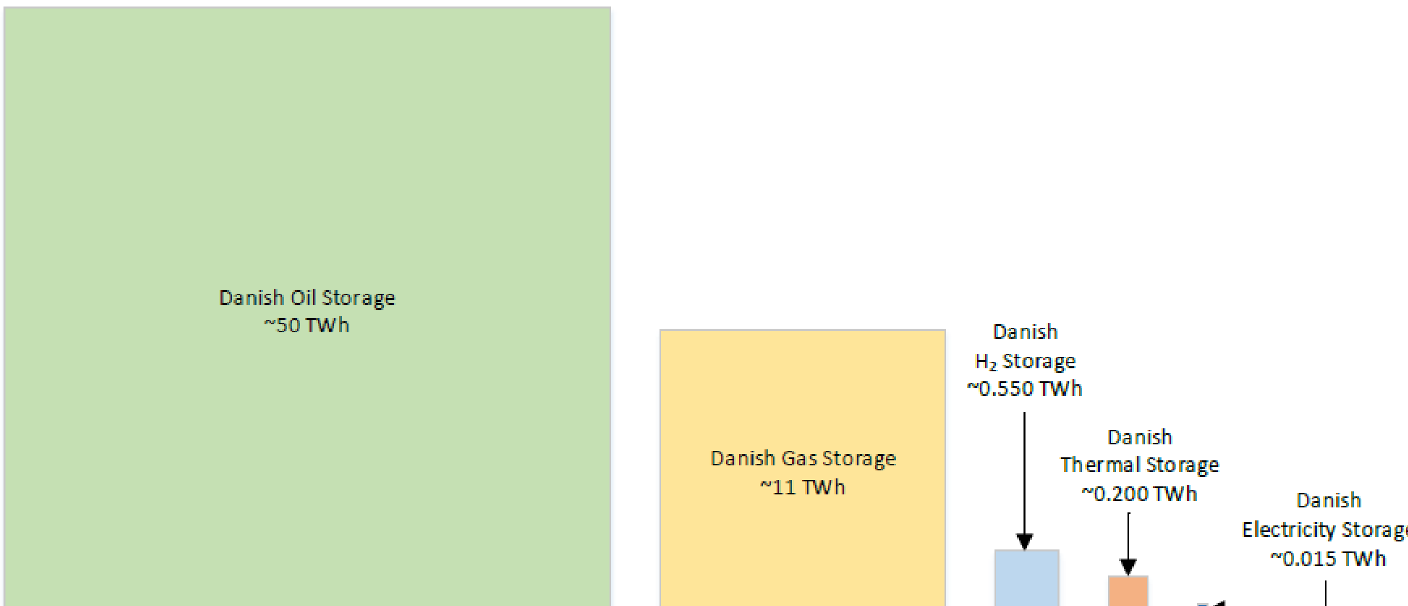
4DH
4th Generation District Heating Technologies and Systems

reINVEST

Innovation Fund Denmark

Energy Storage Capacities in 100 % RES Denmark 2050 (IDA)



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4th Generation District Heating

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.

4DH
4th Generation District Heating
Technologies and Systems

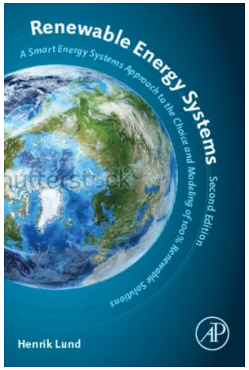

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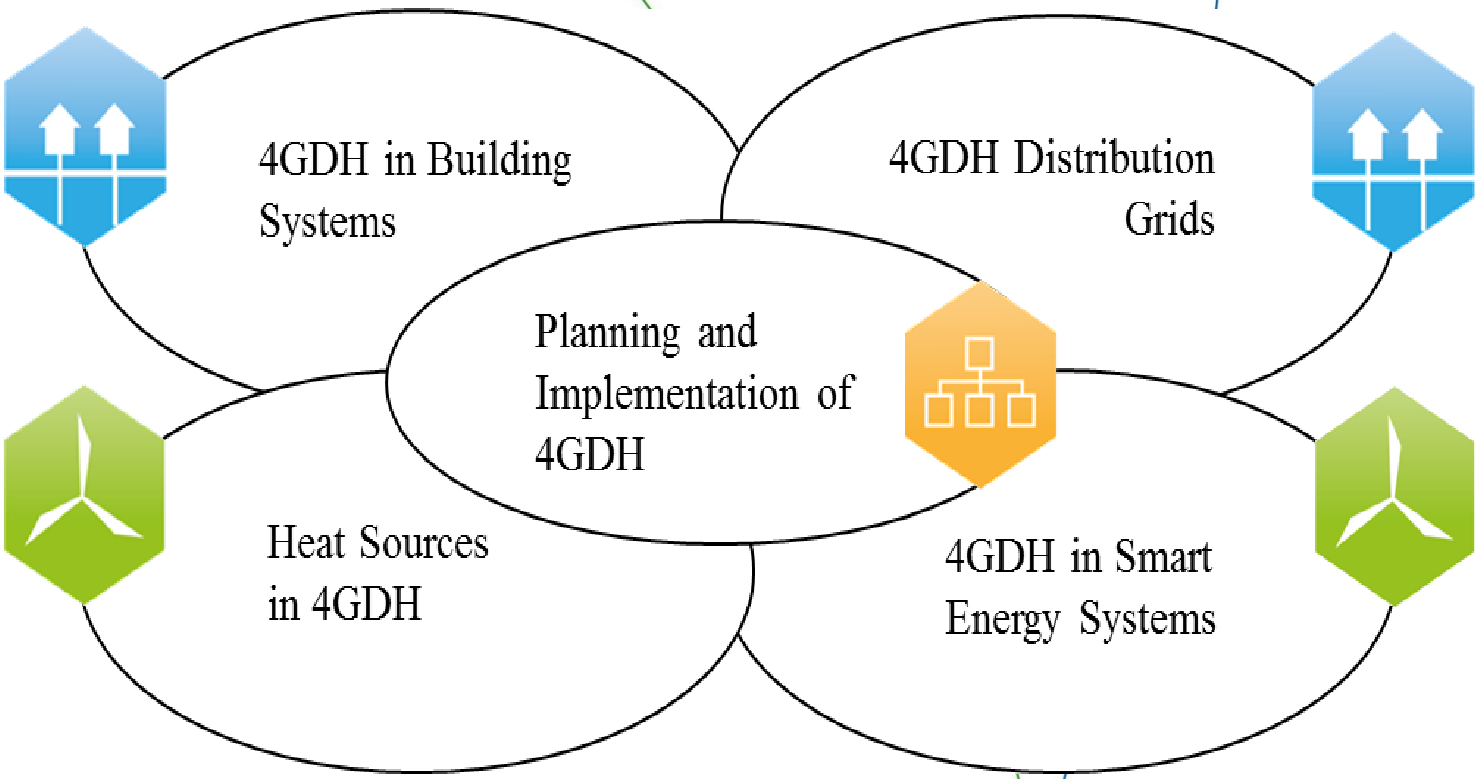
Figure 1: Illustration of the concept of 4th Generation District Heating



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4DH
4th Generation District Heating
Technologies and Systems

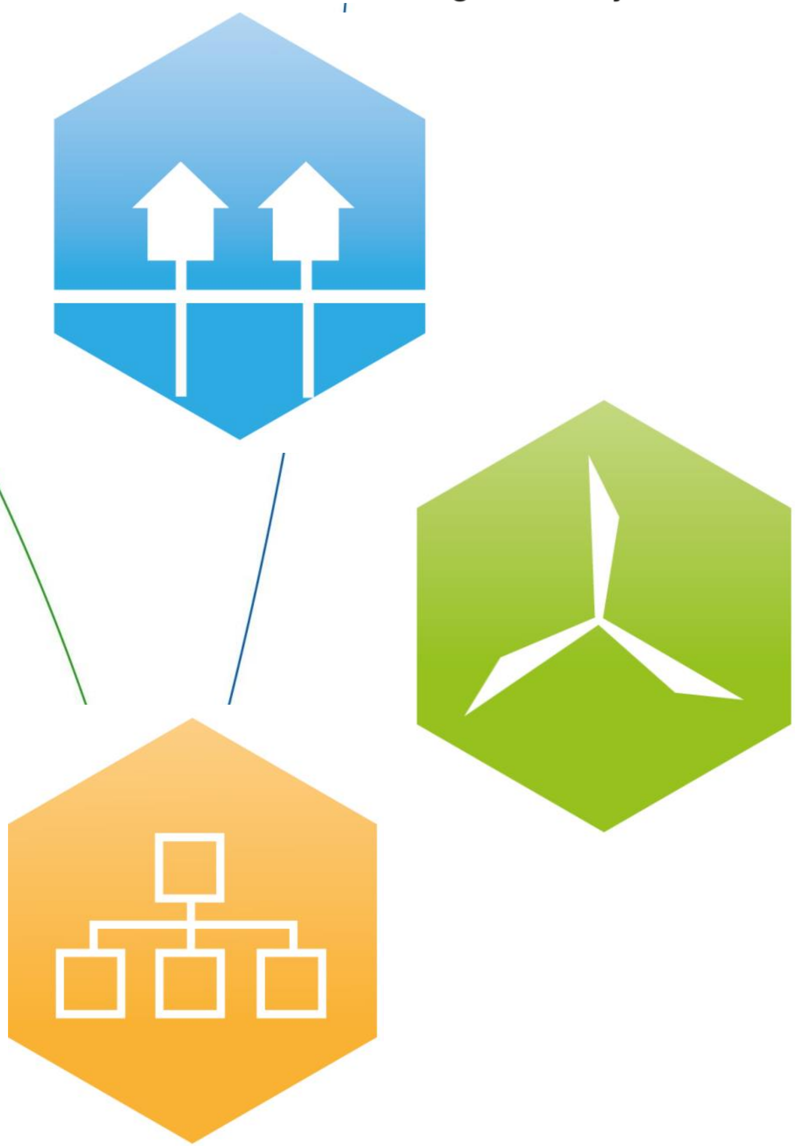
4DH
4th Generation District Heating
Technologies and Systems

Three pillars

WP1: Supply
Low temperature District heating

WP2: Production
Renewable Systems Integration

WP3: Organisation
Planning and Implementation



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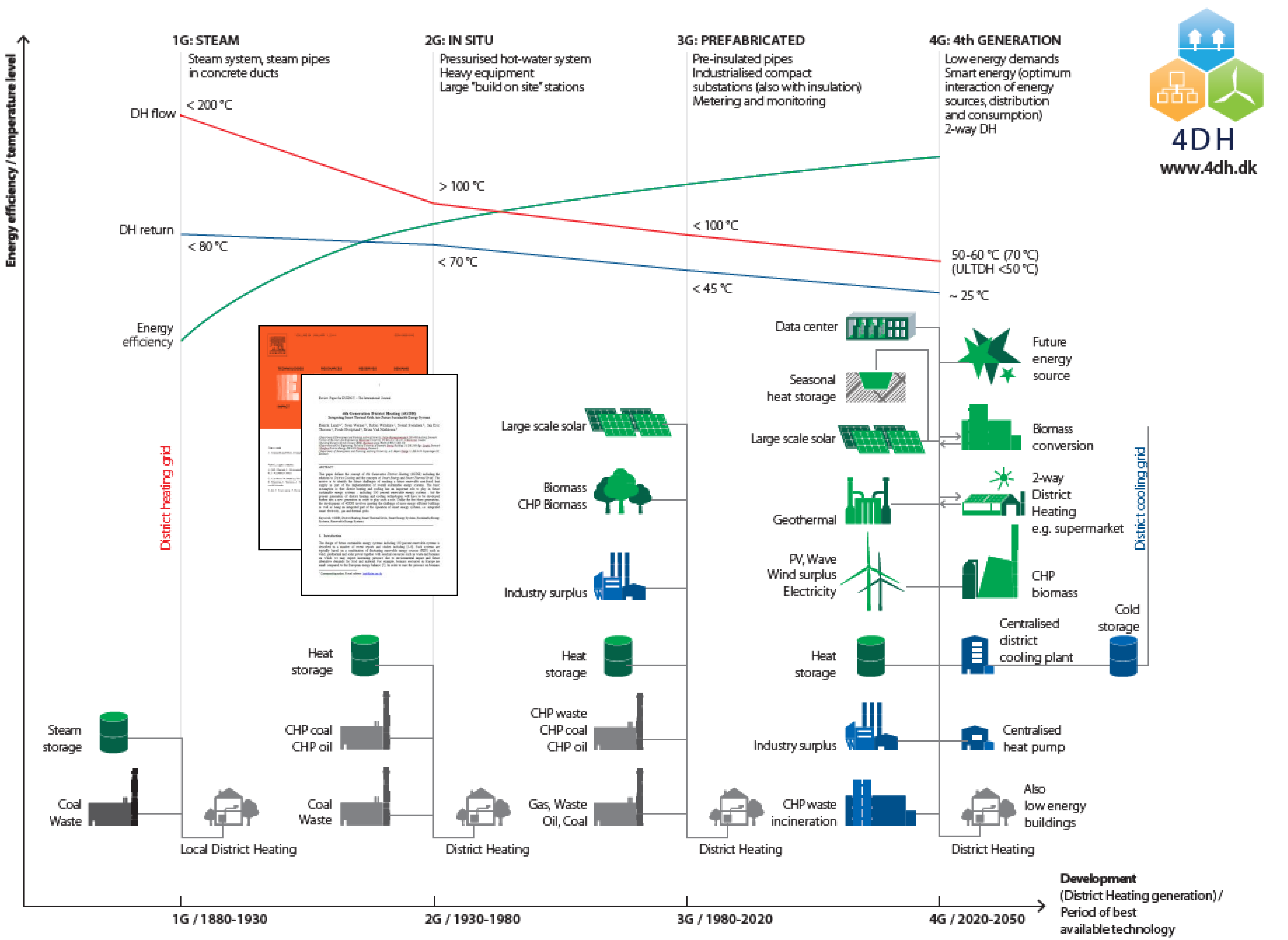

Energy efficiency / temperature level
1G: STEAM
Steam system, steam pipes in concrete ducts
2G: IN SITU
Pressurised hot-water system
Heavy equipment
Large "build on site" stations
3G: PREFABRICATED
Pre-insulated pipes
Industrialised compact substations (also with insulation)
Metering and monitoring
4G: 4th GENERATION
Low energy demands
Smart energy (optimum interaction of energy sources, distribution and consumption)
2-way DH
4DH
www.4dh.dk
DH flow
< 200 °C
> 100 °C
< 100 °C
50-60 °C (70 °C)
(ULTDH <50 °C)
DH return
< 80 °C
< 70 °C
< 45 °C
~ 25 °C
Energy efficiency
District heating grid
District cooling grid
Data center
Future energy source
Seasonal heat storage
Large scale solar
Biomass conversion
Biomass CHP Biomass
2-way District Heating e.g. supermarket
Geothermal
PV, Wave Wind surplus Electricity
CHP biomass
Industry surplus
Heat storage
Centralised district cooling plant
Cold storage
Steam storage
CHP coal CHP oil
CHP waste CHP coal CHP oil
Centralised heat pump
Coal Waste
Gas, Waste Oil, Coal
CHP waste incineration
Also low energy buildings
Local District Heating
District Heating
Development
(District Heating generation) / Period of best available technology
1G / 1880-1930
2G / 1930-1980
3G / 1980-2020
4G / 2020-2050

"We have a lot to learn from the experience here in Denmark and other leading companies in this area."

- Makato Tajima, Institute for Sustainable Energy Policies, Japan, during the third International Conference on Smart Energy Systems and 4th Generation District Heating, 2017.

Energy 68 (2014) 1–11

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journal homepage: www.elsevier.com/locate/energy

Review

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

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Smart energy systems
Sustainable energy systems
Renewable energy systems

ABSTRACT

This paper defines the concept of *4th Generation District Heating* (4GDH) including the relations to *District Cooling* and the concepts of *smart energy* and *smart thermal grids*. The motive is to identify the future challenges of reaching a future renewable 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 percent 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 involves meeting the challenge of more energy efficient buildings as well as being an integrated part of the operation of smart energy systems, i.e. integrated smart electricity, gas and thermal grids.

1. Introduction

The design of future sustainable energy systems including 100 percent 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 thus making these scarce resources meet future demands. District heating comprises a network of pipes connecting the buildings in a neighbourhood, town centre or whole city, so that they can be served from centralised plants or a number of distributed heat producing 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 utilisation of heat from waste-to-energy and various industrial surplus heat sources as well as the inclusion of geothermal and solar thermal heat [8–14]. In the future, such industrial processes may involve various processes of converting solid biomass fractions into bio(syn)gas and/or different sorts of liquid biofuels for transportation fuel purposes, among others [15,16].

Future district heating infrastructures should, however, not be designed for the present energy system 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 [17]. 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

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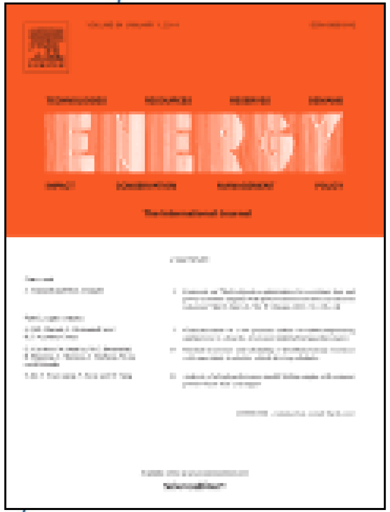

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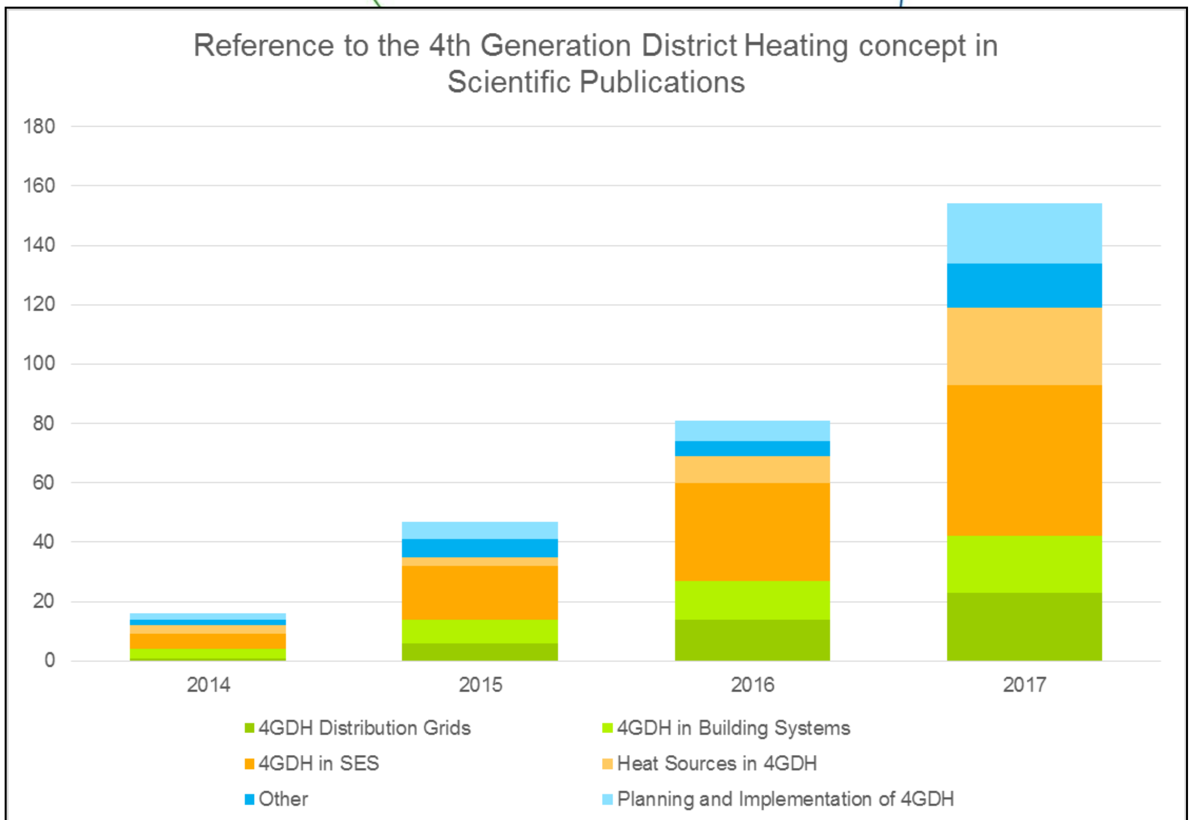
"The 4DH Research Centre is tackling key challenges of European energy systems and is thereby a strong encouragement for the prospering DHC Team at AIT. Denmark is currently a forerunner for sustainable energy concepts based on an ambitious climate protection strategy, pointing the route forward for all Europe. 4DH is one of the driving forces of this development."

- Ralf-Roman Schmidt, Engineer at the Austrian Institute of Technology

Impact on science



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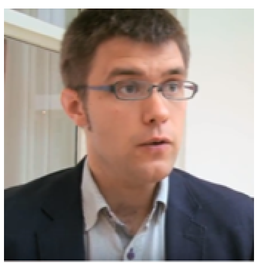
The 4DH conferences

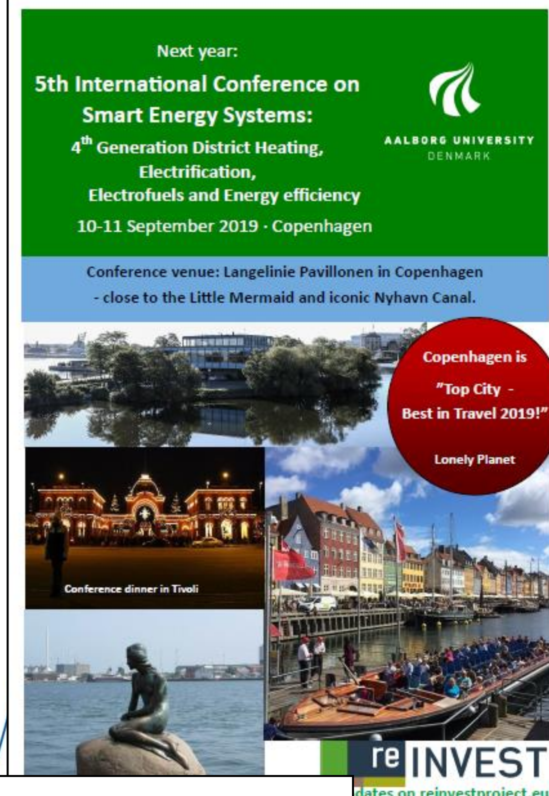
"The conference on Smart Energy Systems and 4th Generation District Heating presents a lot of knowhow and research about district heating and the advanced technology in Denmark and Europe"

- Hironao Matsubara, Institute for Sustainable Energy Policies, Japan, during the third International Conference on Smart Energy Systems and 4th Generation District Heating, 2017.



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

- Helge Averfalk, Halmstad University, Sweden, during the third International Conference on Smart Energy Systems and 4th Generation District Heating, 2017



"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."

- Olatz Terroz, AIT - Austrian Institute of Technology, GmbH, during the third International Conference on Smart Energy Systems and 4th Generation District Heating, 2017.

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"It is important for LOGSTOR to be a part of the development of the next generation of district heating in 4DH's cooperation with industries, universities and research, and utility companies. The 4DH projects are based on the Danish model in designing the future's district heating solutions and technologies that can be used by utility companies all over the world. Because of this they will have a great impact on the Danish export potential within district heating solutions."

- Peter Jorsal, Product Manager at LOGSTOR.

Partners

PARTNERS IN 4DH

Contact 4DH: Head, Professor Henrik Lund

www.4dh.eu @4DHresearch

Funded by Innovation Fund Denmark

District Heating Planning and Implementation Results

District heating part of energy strategy

The Danish municipality of **Ringkøbing-Skjern** has a 2020 plan of a self-sufficient renewable energy supply. A part of this plan is the transformation of the district heating from natural gas to renewable sources. The goal is to reach 60% renewable energy sources in the local district heating grid. Focus is mainly on integrating wind energy. Analyses conducted by 4DH show that the share of buildings with district heating connection can be increased from 50% to 70% by connecting all homes in the district heating area to the grid. The goal in the municipality's Energy2020 Strategy is to connect all homes in district heating areas by 2020. As a part of the plan, the local district heating company **Ringkøbing Fjernvarme** is installing a gas driven heat pump which will supply 30,000 MWh a year to the heating consumers, about 25% of the total supply, supplementing the existing 30,000 m2 solar heating plant and 12 MW electric boiler. Another part of the plan is to increase the energy ... eating

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:

Initiative	Impact	Target
Reduction in housing heat consumption	0.2	10% reduction in housing heat consumption: 288 TJ/year
Renewable energy in businesses	1.0	20% of the indus... consumption cha... renewable energ...
Less energy consumption for road transport	0.8	10% reduction in... consumption for... 177 TJ/year
More renewable energy in district heating	4.8	Increased from 4... renewable energ... heating
Change oil boiler to renewable energy	1.9	2/3 of individual ... changed to rene...
New wind turbines	22.0	Wind power is in... 6,000 TJ/year, 2...

Aalborg Kommune

AALBORG FORSYNING

Viborg Fjernvarme

NEMT TRYGT BILLIGT

Ringkøbing-Skjern Kommune

"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

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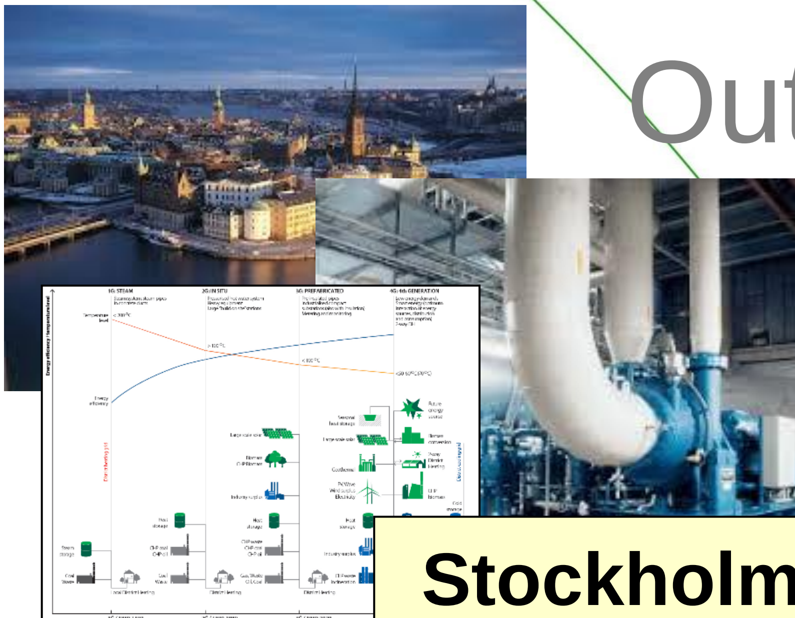
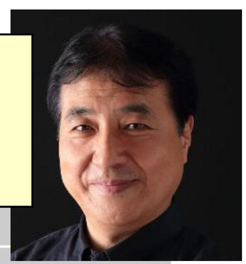
Outreach



Stockholm

Belgium

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

Slovakia

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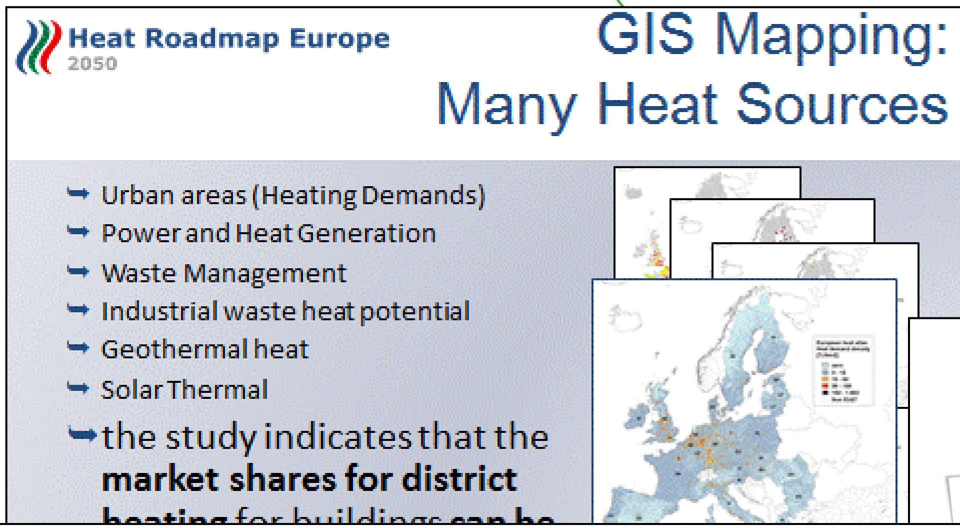
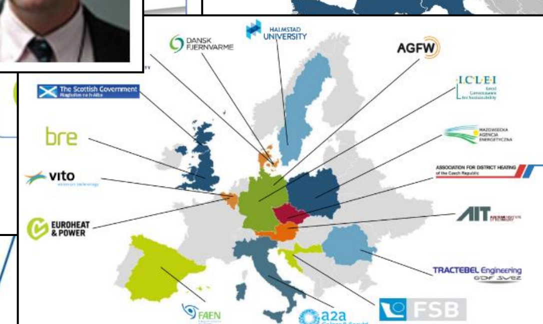
Heat Roadmap Europe



"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



Aalborg University Denmark

ECOFYS sustainable energy for everyone

PlanEnergi

Högskolan Halmstad

Euroheat & Power

4DH 4th Generation District Heating Technologies and Systems

EUROPEAN COMMISSION

Brussels, 16.2.2016
COM(2016) 51 final

COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

An EU Strategy on Heating and Cooling

{SWD(2016) 24 final}

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[1]. 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[2].

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[3]. 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 will 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

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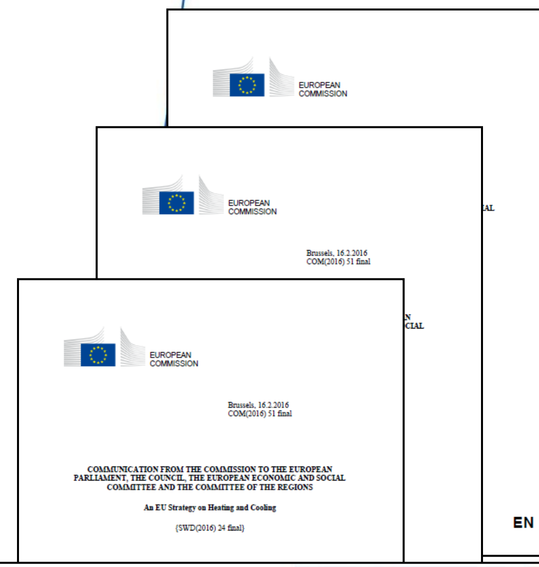
EU Strategy on Heating and Cooling

"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

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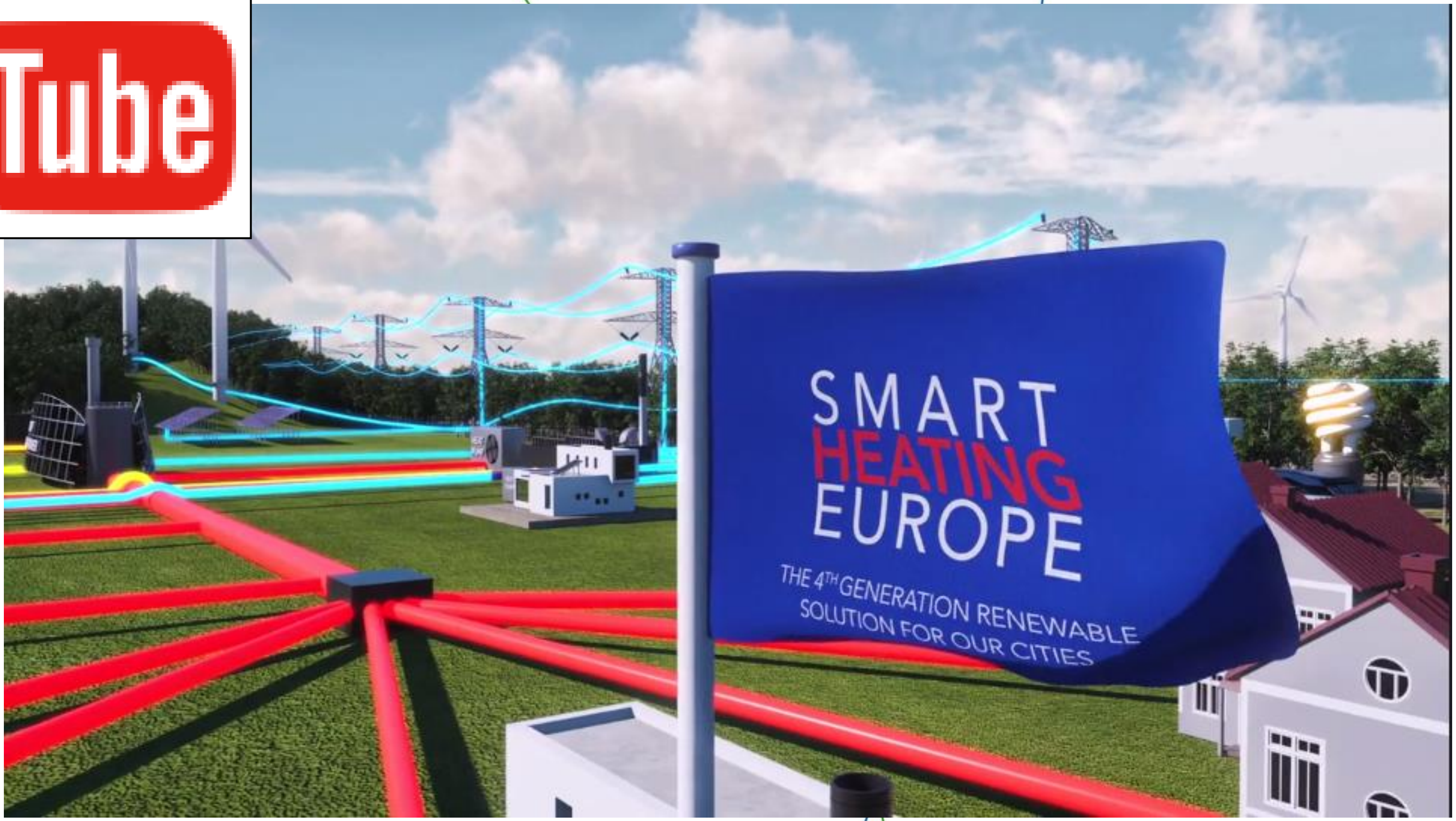
Smart Heating Europe

"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



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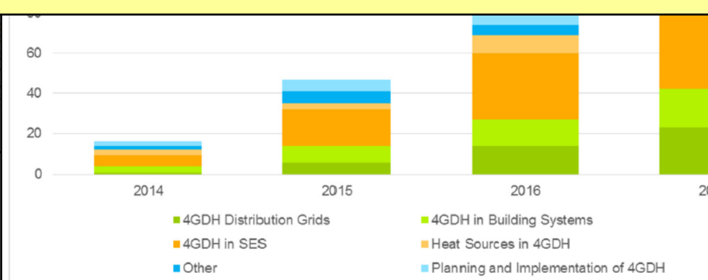
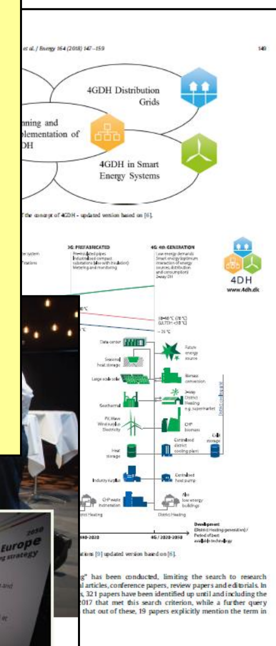
Review

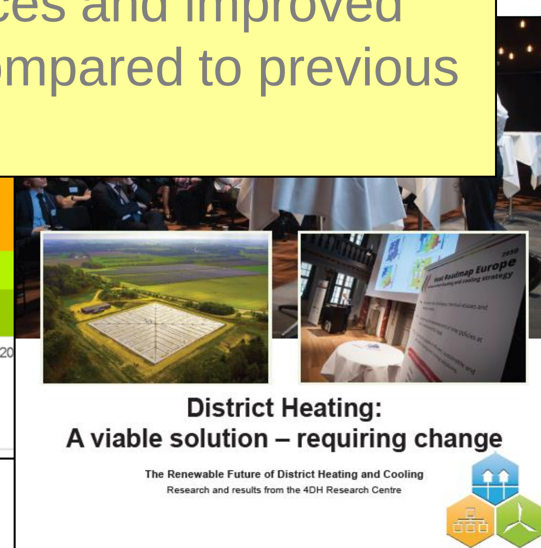
The status of 4th generation district heating: Research and results

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.







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Smart Energy 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, electrolysers or electric boilers.

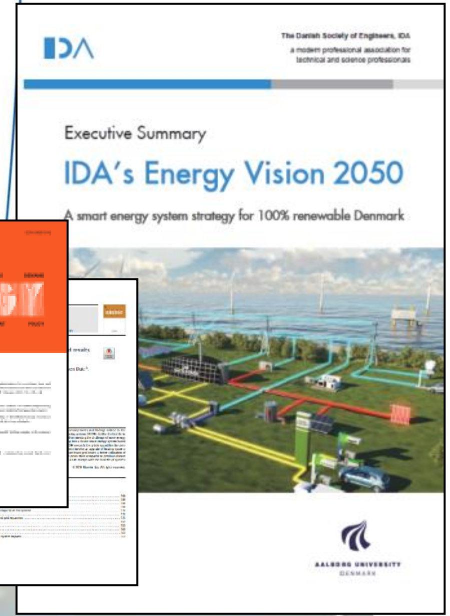
	3GDH	4GDH
Electricity demand [TWh]	36.64	36.64
DH supply [TWh]	39.16	34.80
Final individual heating demand [TWh]	14.51	14.51
Transport fuel demand [TWh]	40.23 (Total)	40.23 (Total)
	31.13 (Electrofuels)	31.13 (Electrofuels)
	9.1 (Electricity)	9.1 (Electricity)
Industrial fuel demands	11.82 (total)	11.82 (total)
	8.41 (Gas)	8.41 (Gas)
	3.41 (Biomass)	3.41 (Biomass)

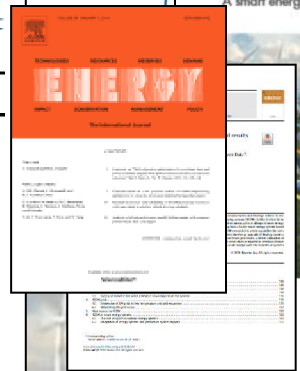
Table 3
System configuration with 3GDH and 4GDH.

	3GDH	4GDH
Onshore wind power [MW]	5000	5000
Off-shore Wind power [MW]	14000	12520
PV [MW]	5000	5000
CHP (electric/heat) [MW]	5000/3750	5000/4231
Electrolyser [MW]	9009	7975

Table 4
Aggregated system parameters.

	3GDH	4GDH
Total annual cost [M EUR]	22,373	22,047
Biomass demand [TWh]	52.50	52.51
Critical excess electricity [TWh]	2.47	2.47





4DH

4th Generation District Heating Technologies and Systems

WP1 Supply:

Low temperature District heating

Grid

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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 temperatu... will take ... general re... the new ... houses an... large buil... temperatu... systems re... buildings, and it is expected that the investment cost of such a system will be about 8000 EUR. With an assumed average DHW consumption per legionella removal system of 30 MWh/year and a lifetime of 20 years, this adds a yearly 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 4GDH compared to 3GDH results in a cost range of 78–97 MEUR/year. Since this by nature is an estimate, a reasonable result would be to conclude on a range of 50–100 MEUR/year.

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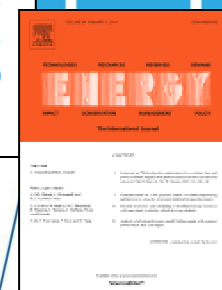
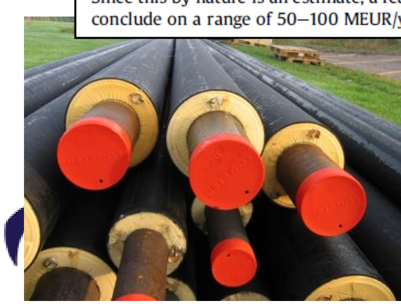


- In accordan... ng statistics, pumping in average uses approx. 6 kWh electricity in DH plants per MWh of heat supply. A similar figure of 5 kWh_e/MWh_{th} is used in Ref. [110]. This figure may of course be lower in the future due to more efficient pumping technologies.
- The electricity demand is approx. 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 4GDH is in the order of magnitude of 3–6 MEUR/year.

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



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WP 2 Production:

Renewable Systems Integration

Producti

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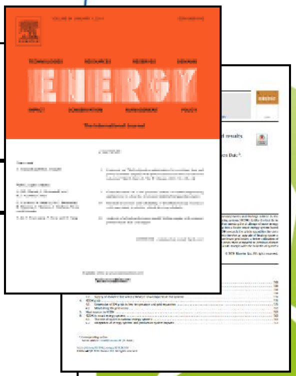
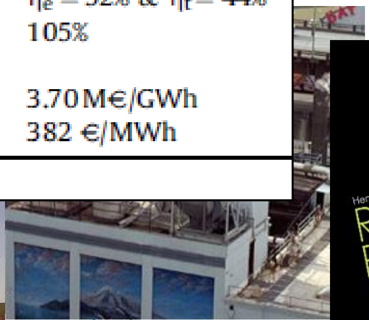
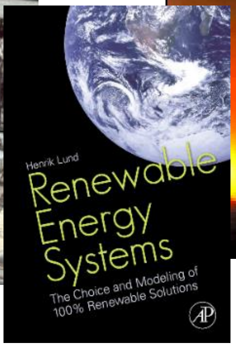
Table 1
Modelling assumptions for the comparison between 3GDH and 4GDH.

	3GDH system	4GDH
Yearly average supply/return temperatures at DH plant	80 °C/45 °C ΔT = 35 K	55 °C/25 °C 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 Added 0.4 TWh to electricity demand	2 TWh Added 0.28 TWh to electricity demand
CHP (Combined cycle)	$\eta_e = 52\%$ & $\eta_t = 39\%$	$\eta_e = 52\%$ & $\eta_t = 44\%$
DH Biomass boilers with condensation	95%	105%
Thermal storage	3.17 M€/GWh	3.70 M€/GWh
Solar thermal	544 €/MWh	382 €/MWh

4DH
4th Generation District Heating Technologies and Systems







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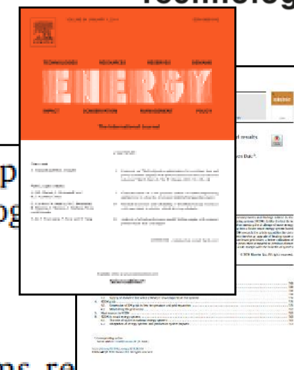
WP3 Organisation:

Planning and Implementation



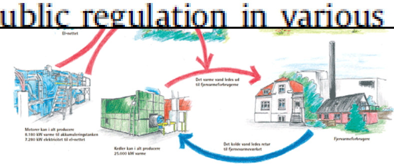
tricity systems, it becomes important that ancillary-service p
sion is distributed to other production and demand technolog

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



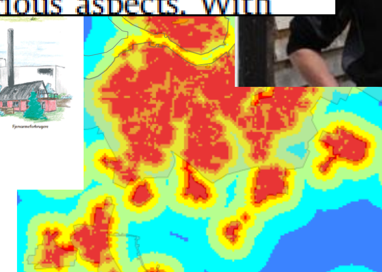
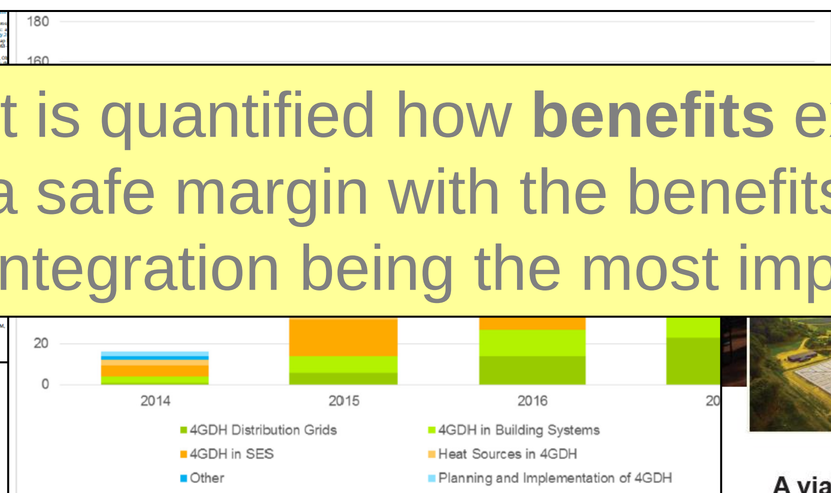


Table 5
Cost assessment of implementing 4GDH instead of 3GDH in a future sustainable energy system in the year 2050 in a country of the size of Denmark.

Elements of implementing 4GDH instead of 3GDH	Annualized cost MEUR/year
Additional cost within the buildings (investment in equipment)	50–100
Additional cost in the DH grid (operation costs)	0–10
Savings in investments and operation of the DH grid and in the production (system costs) due to lower temperatures.	300–350
Sum	200–300

It is quantified how **benefits** exceed **costs** by a safe margin with the benefits of systems integration being the most important.



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Thank you..!

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University of Zagreb
SDU
CHALMERS University of Technology
Linnaeus University
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4th International Conference on

Smart Energy Systems and 4th Generation District Heating

13-14 November 2018 in Aalborg, Denmark.

Thank you

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