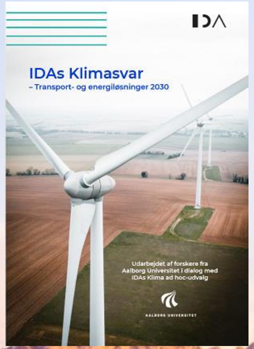
XV KONFERENCJA
PROBLEMY BADAWCZE ENERGETYKI CIEPLNEJ
30 października - 3 grudnia 2021

XV CONFERENCE ON
RESEARCH & DEVELOPMENT IN POWER ENGINEERING
30 November - 3 December 2021



Smart Energy Systems and 4th Generation District Heating

Professor Henrik Lund
Aalborg Universitet

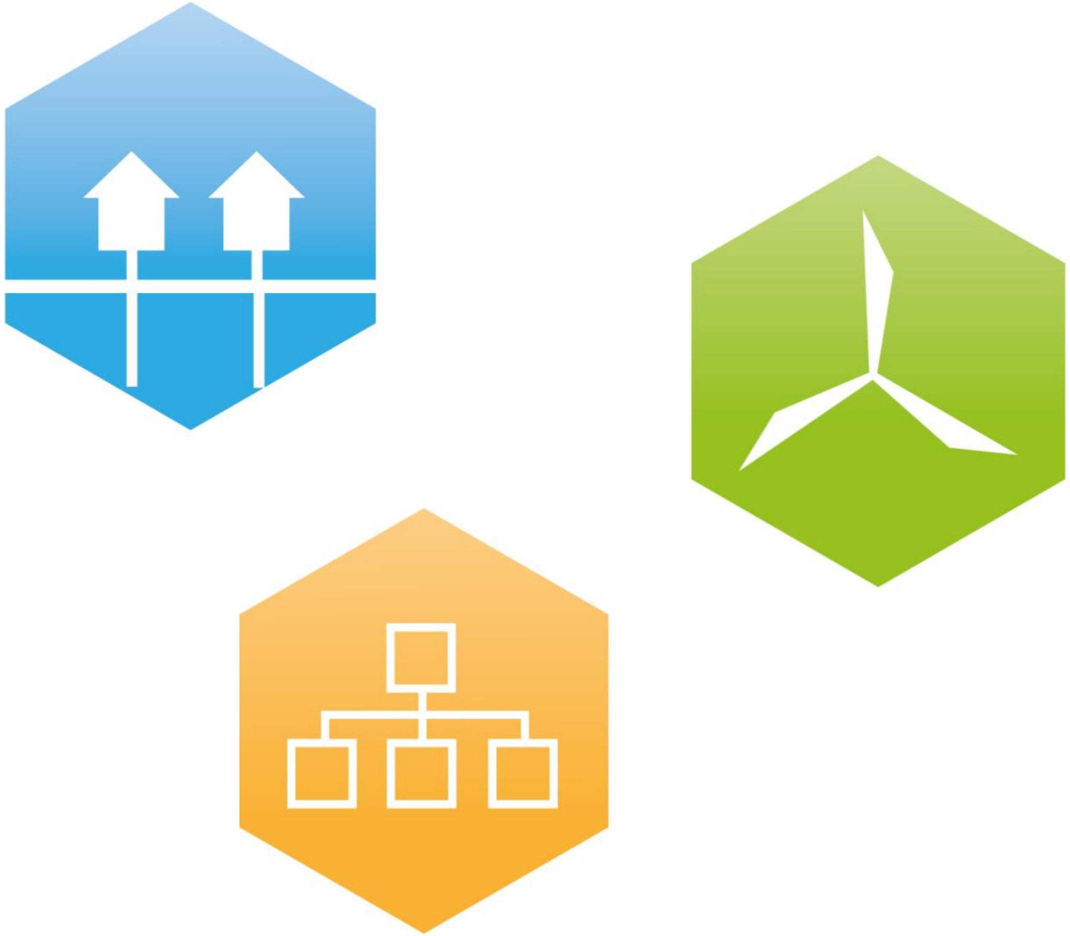
4DH
4th Generation District Heating
Technologies and Systems

Purpose

To investigate the future of District Heating and Cooling

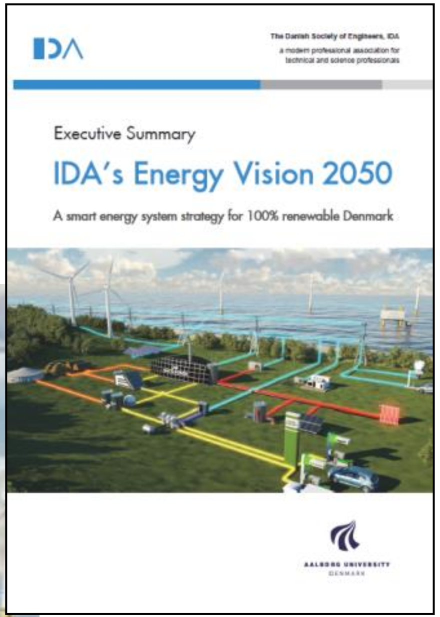
What is the role of district heating in
future energy systems..?

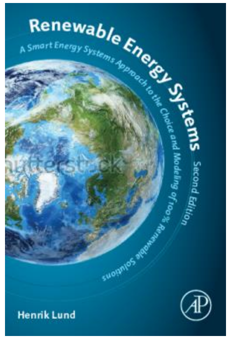
How should the technology develop
in order to fulfil such role..?



Smart Energy Systems

With the purpose of fully decarbonized societies

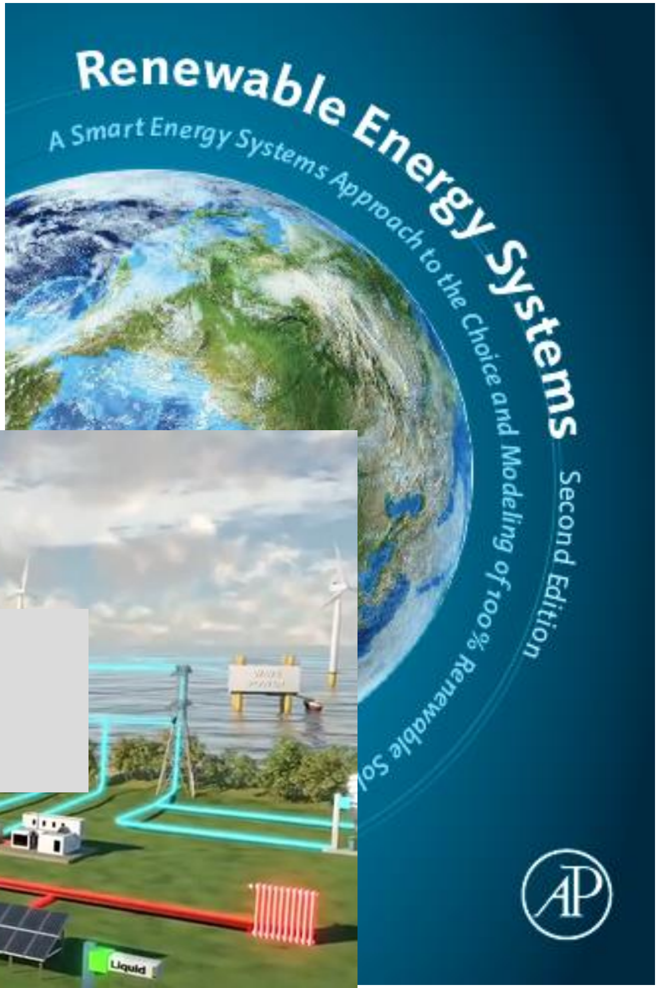




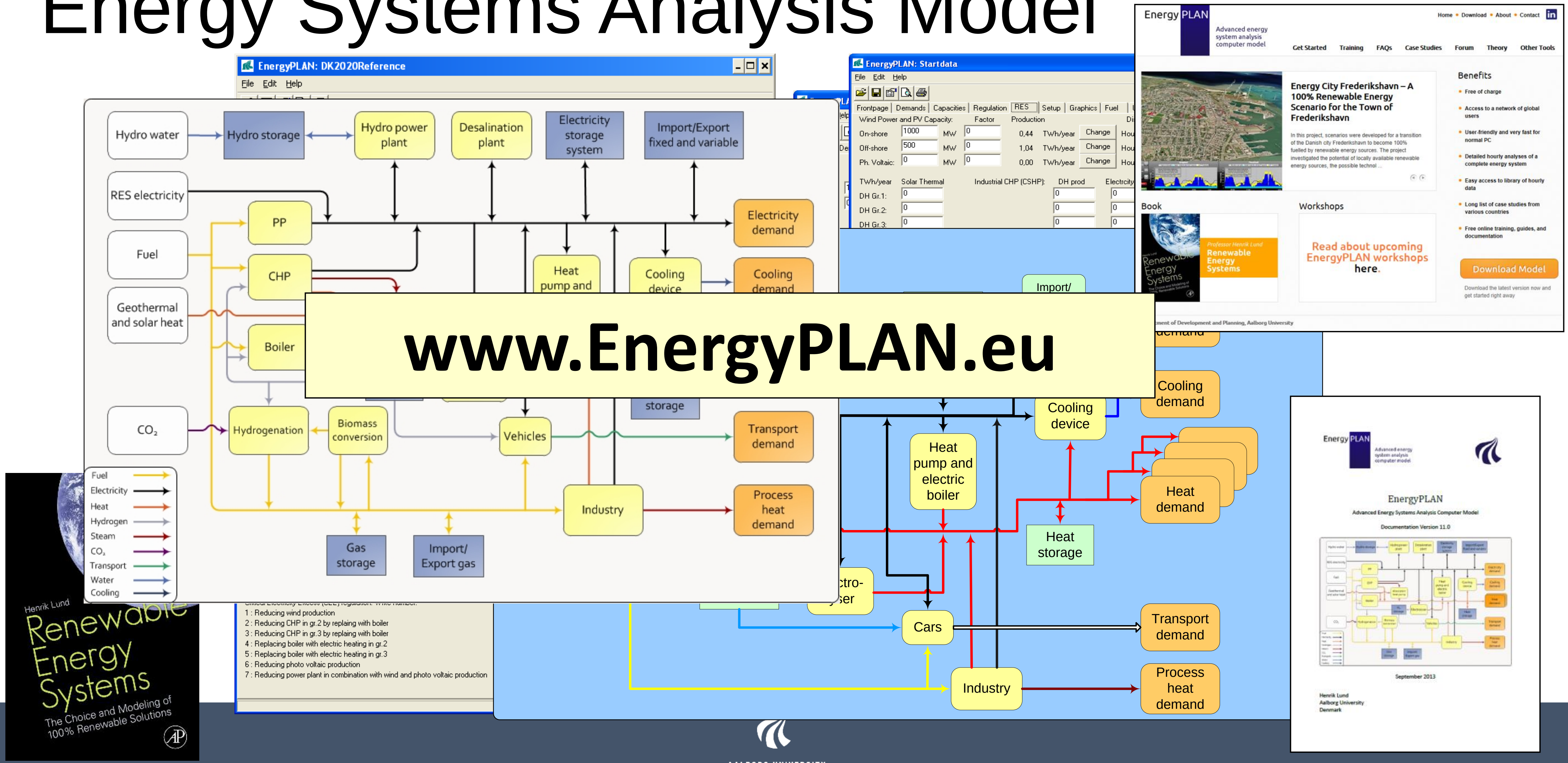
Smart Energy Systems

YouTube

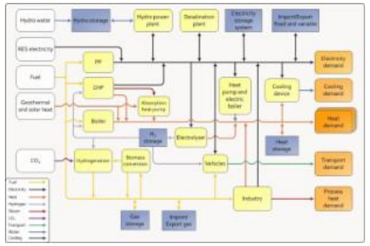
www.energyplan.eu/smartenergysystems/



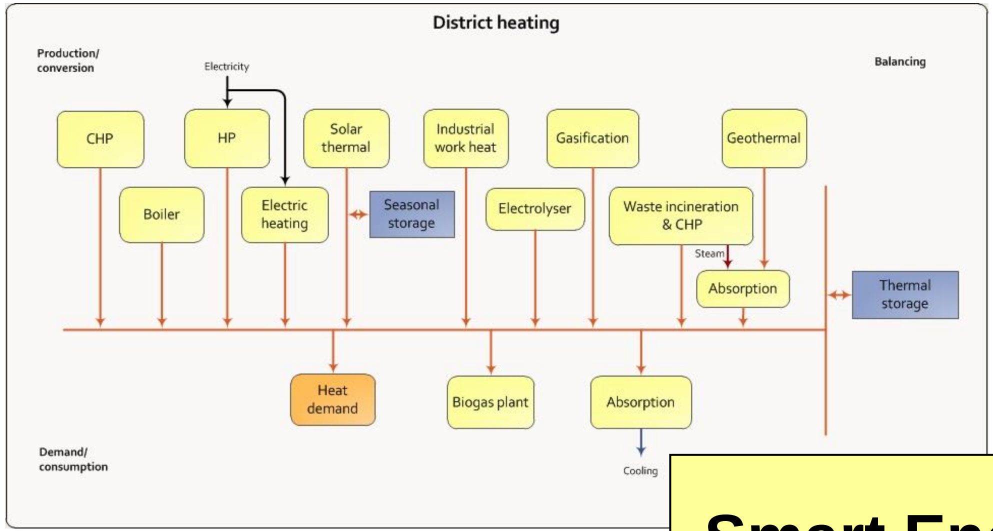
Energy Systems Analysis Model

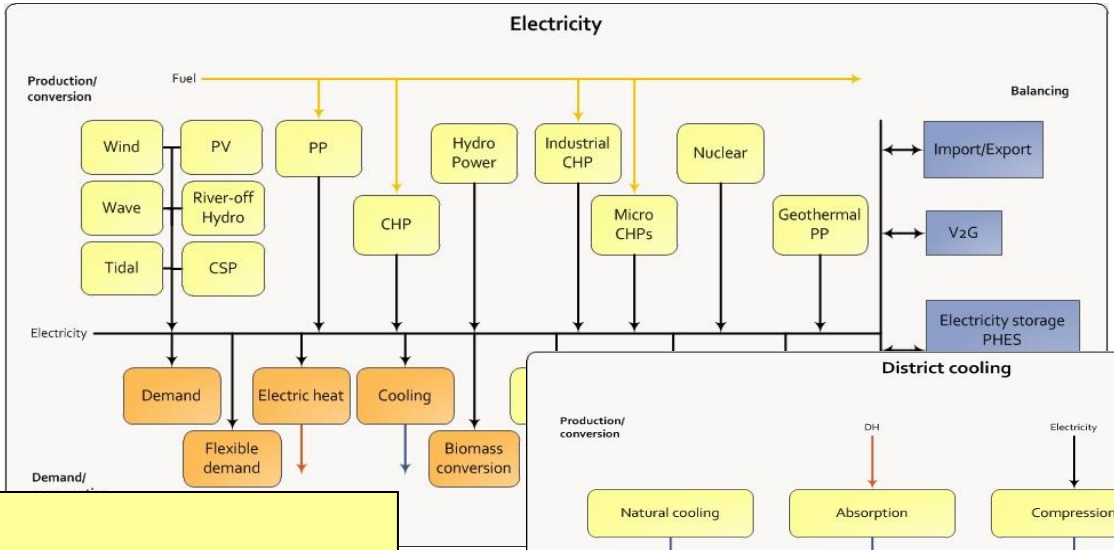


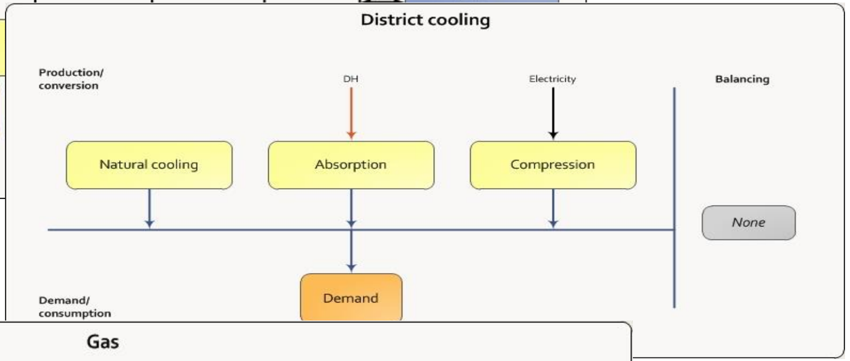
EnergyPLAN



- ***Replicable by other researchers***. (Freeware, User-friendly, normal PC, No solvers or similar. Data-sharing)
- ***Credibility***. Documentation, many users, 5000+ downloads, used in 200+ scientific paper.
- ***Smart Energy Systems:*** Sectors (Buildings, Industry, Transportation etc.) and relevant grid and storage options (Electricity, District Heating and Cooling, Hydrogen, Green gas, solid biomass and synthetic green liquid fuels).
- ***High time resolution and chronological calculations of storage and grid infrastructures.*** (In all relevant sectors)

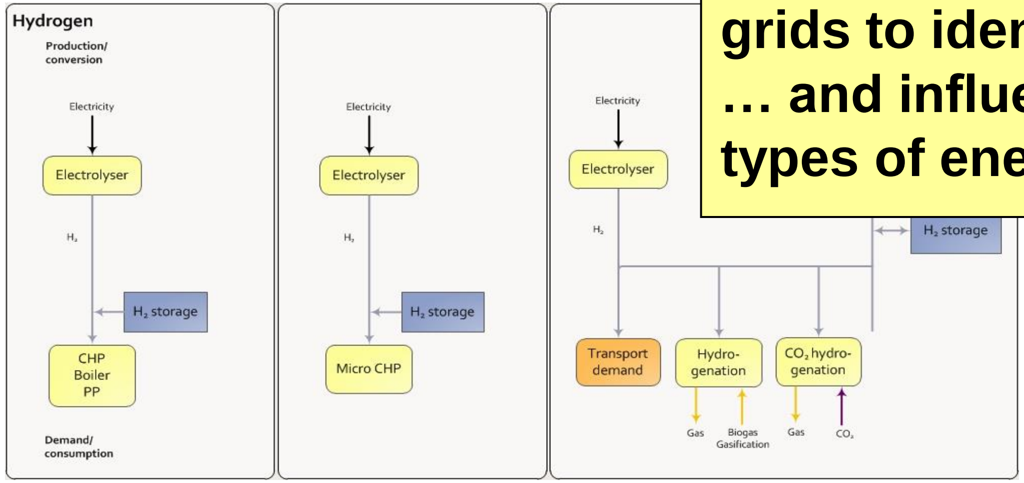


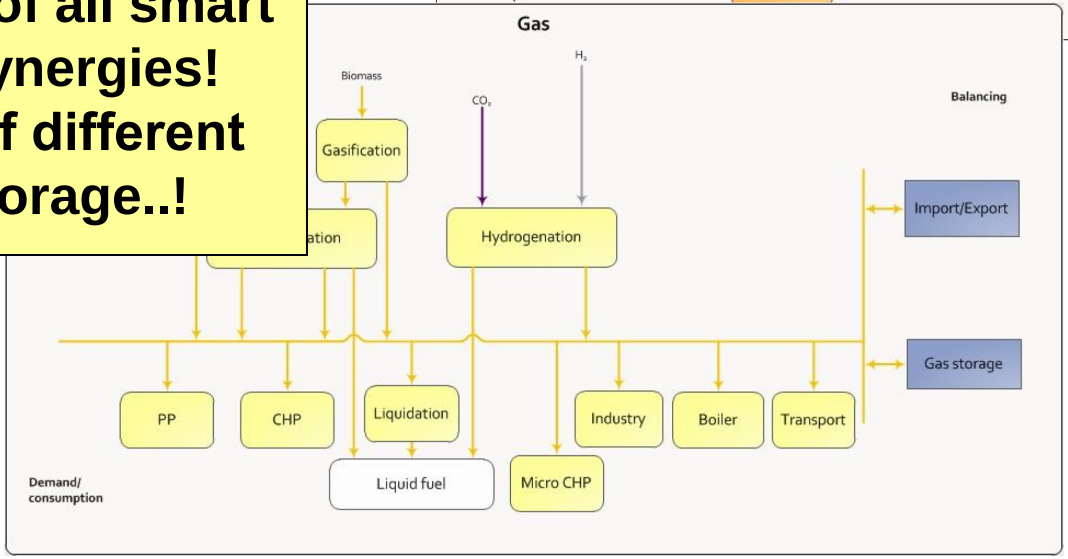




Smart Energy Systems:

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



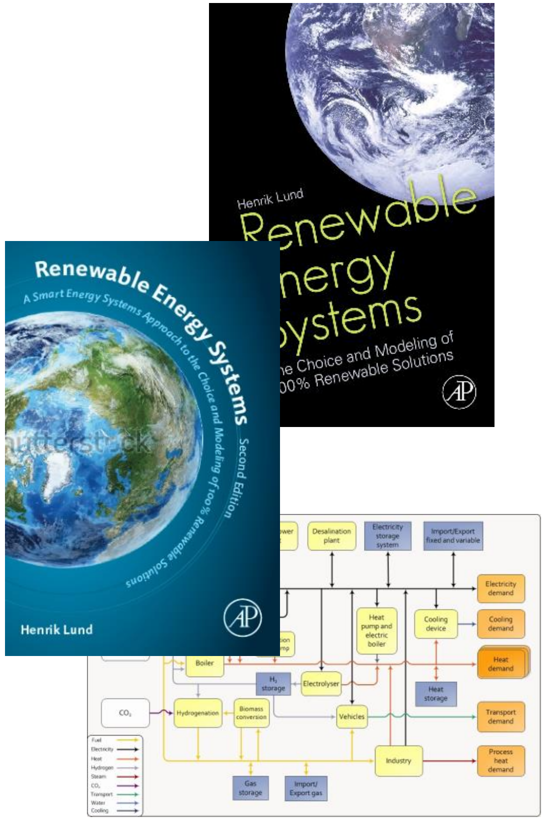


Smart Energy Systems

The key to cost-efficient 100% Renewable Energy

- A sole focus on renewable **electricity (smart grid)** production leads to electricity storage and flexible demand solutions!

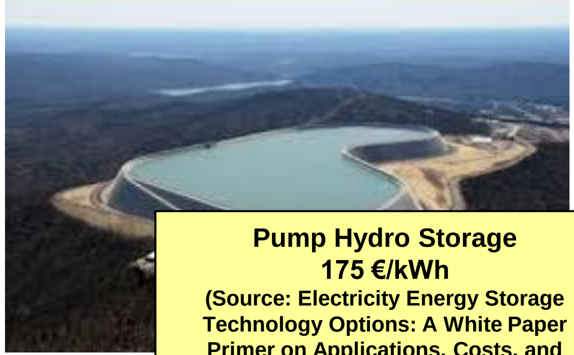
- Looking at renewable electricity as a part **smart energy systems** including heating, industry, gas and transportation opens for cheaper and better solutions…



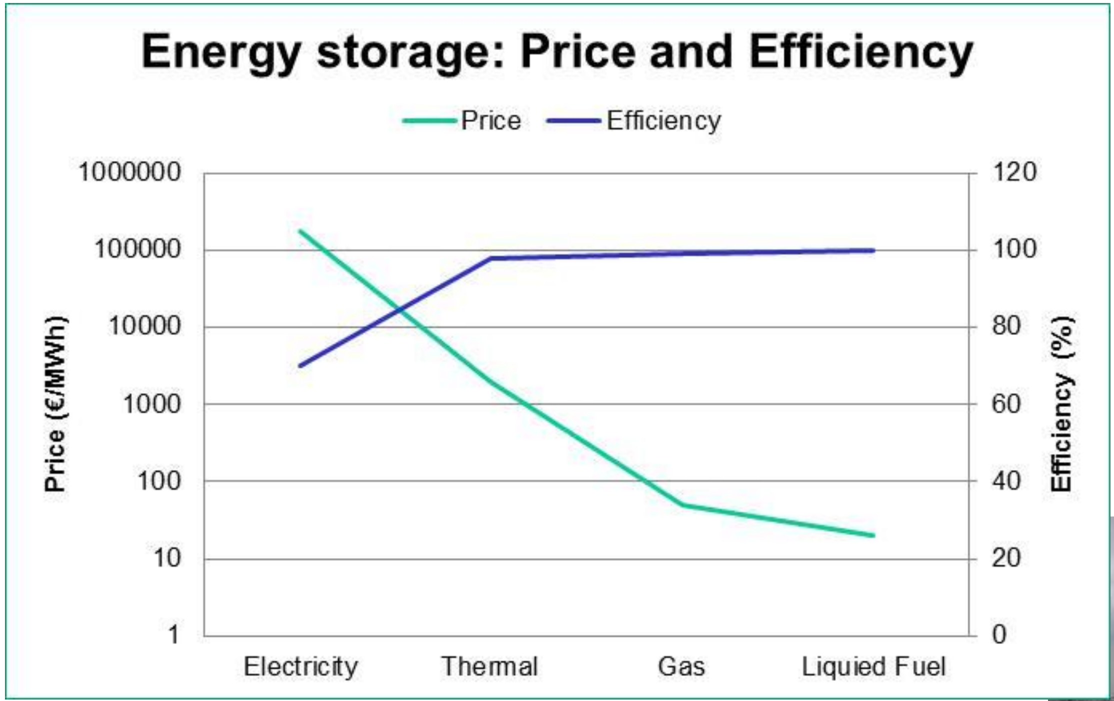
Power-to-Heat

Power-to-Gas
Power-to-Transport

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)

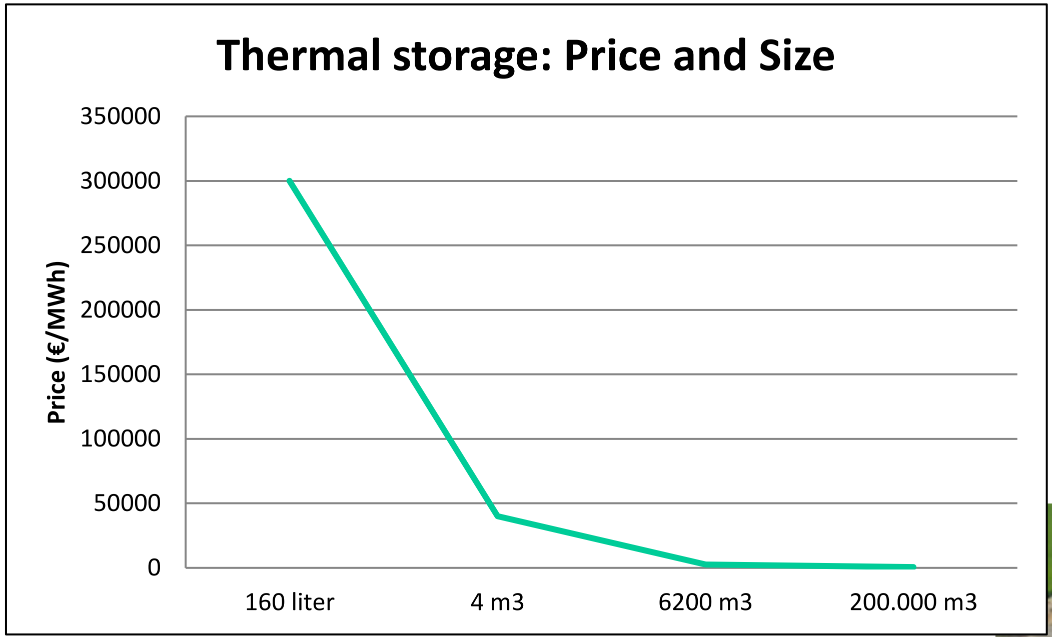
Natural Gas Underground Storage
0.05 €/kWh
(Source: Current State Of and Issues Concerning Underground Natural Gas Storage. Federal Energy Regulatory Commission, 2004)

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

Thermal Storage

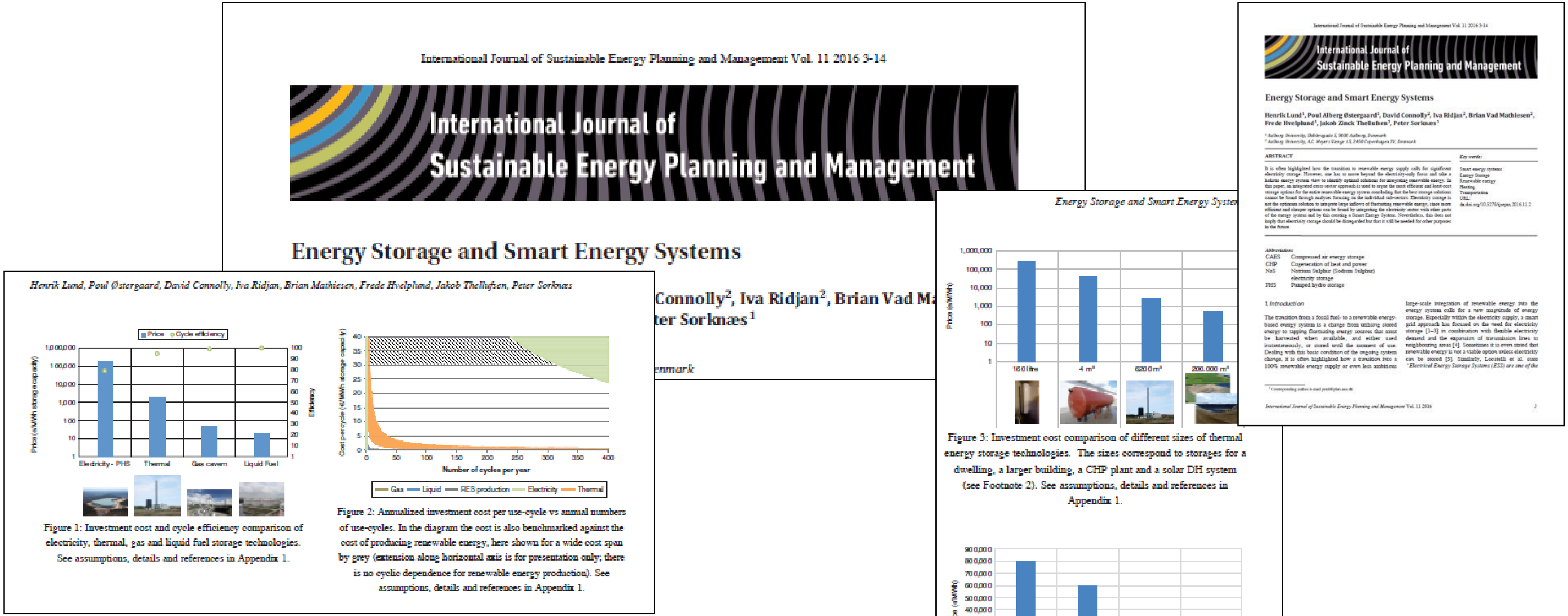
6200 m3 Thermal Storage
2500 €/MWh
(Skagen: 6200 m3 for 5.4 mio. DKK)

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)

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



International Journal of Sustainable Energy Planning and Management Vol. 11 2016 3-14

Energy Storage and Smart Energy Systems

Henrik Lund, Poul Østergaard, David Connolly, Iva Ridjan, Brian Mathiesen, Frede Hvelplund, Jakob Thellufsen, Peter Sorknæs

Figure 1: Investment cost and cycle efficiency comparison of electricity, thermal, gas and liquid fuel storage technologies. See assumptions, details and references in Appendix 1.

Figure 2: Annualized investment cost per use-cycle vs annual numbers of use-cycles. In the diagram the cost is also benchmarked against the cost of producing renewable energy, here shown for a wide cost span by grey (extension along horizontal axis is for presentation only; there is no cyclic dependence for renewable energy production). See assumptions, details and references in Appendix 1.

Energy Storage and Smart Energy Systems

Figure 3: Investment cost comparison of different sizes of thermal energy storage technologies. The sizes correspond to storages for a dwelling, a larger building, a CHP plant and a solar DH system (see Footnote 2). See assumptions, details and references in Appendix 1.

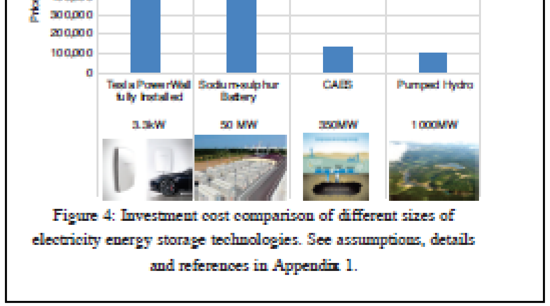


Figure 4: Investment cost comparison of different sizes of electricity energy storage technologies. See assumptions, details and references in Appendix 1.

www.journals.aau.dk/index.php/sepm

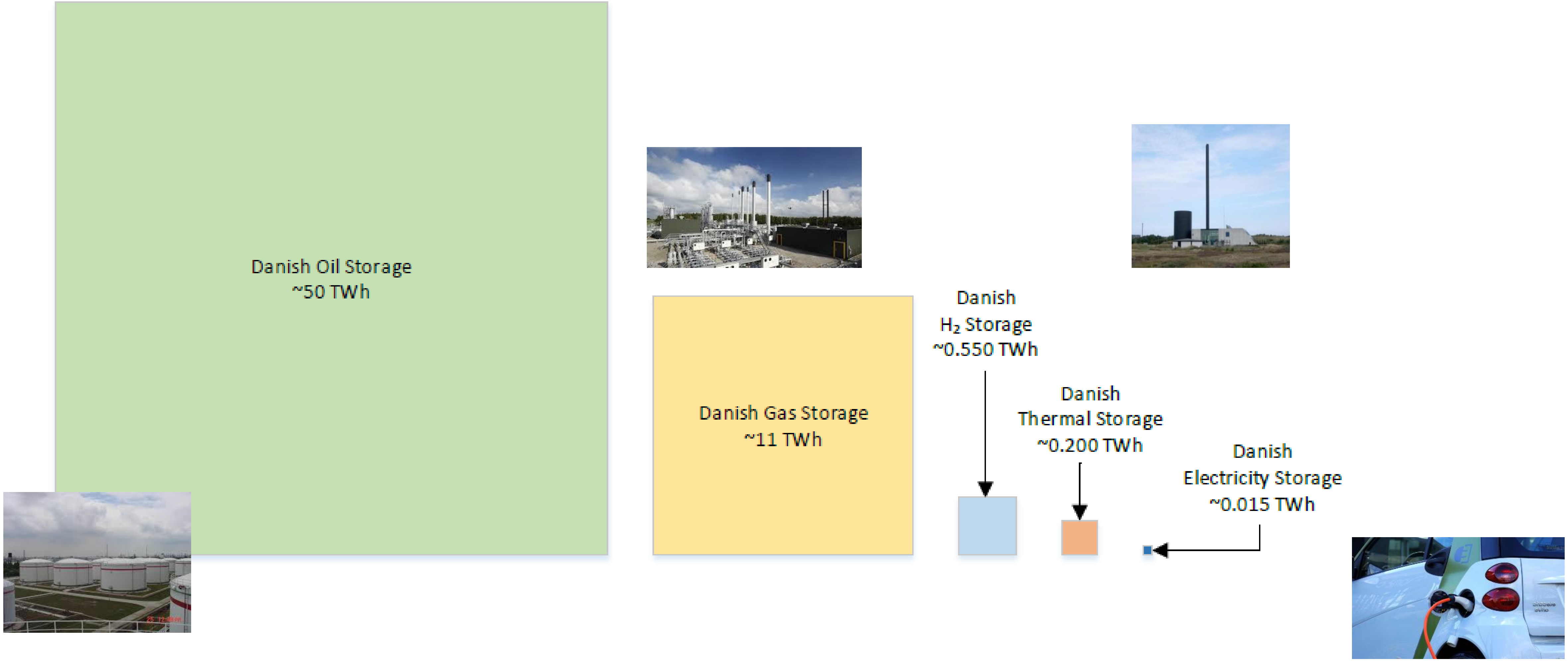
Energy Storage Capacities in Denmark

Danish Oil Storage
~50 TWh

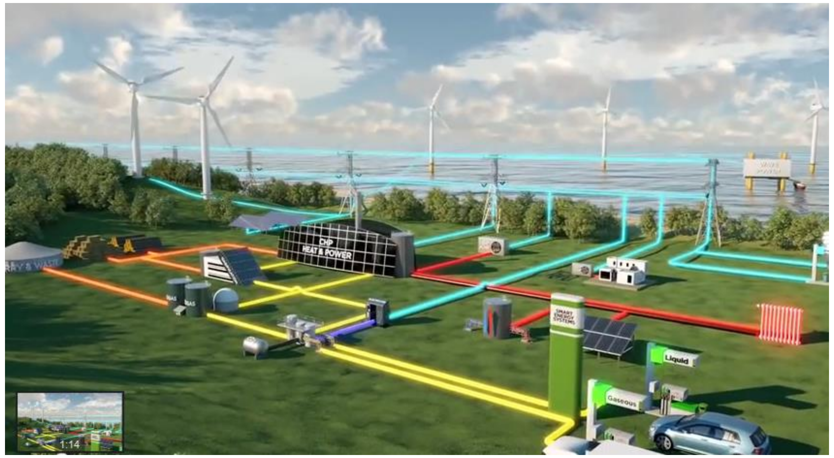
Danish Gas Storage
~11 TWh

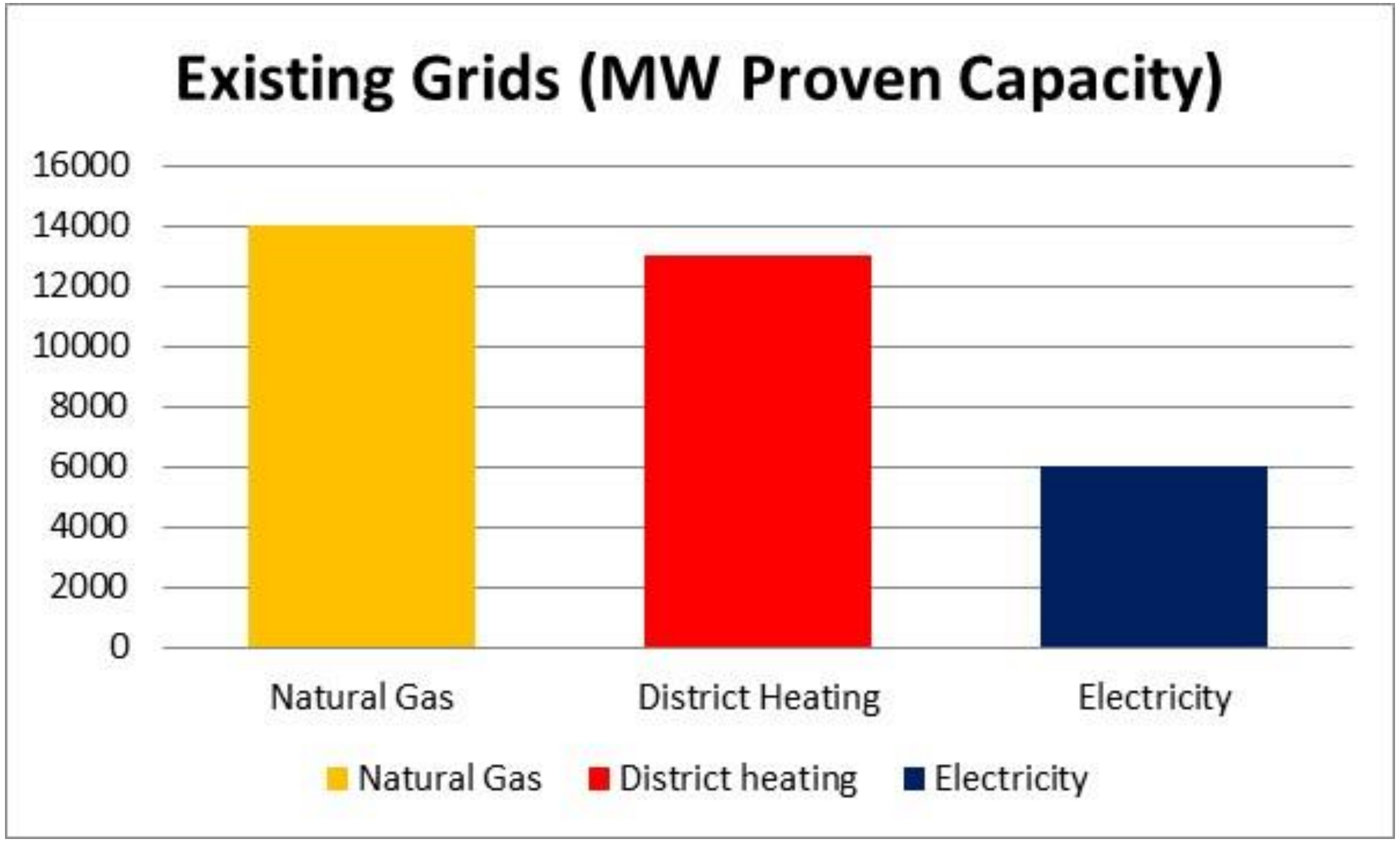
Danish
Thermal Storage
~0.090 TWh

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



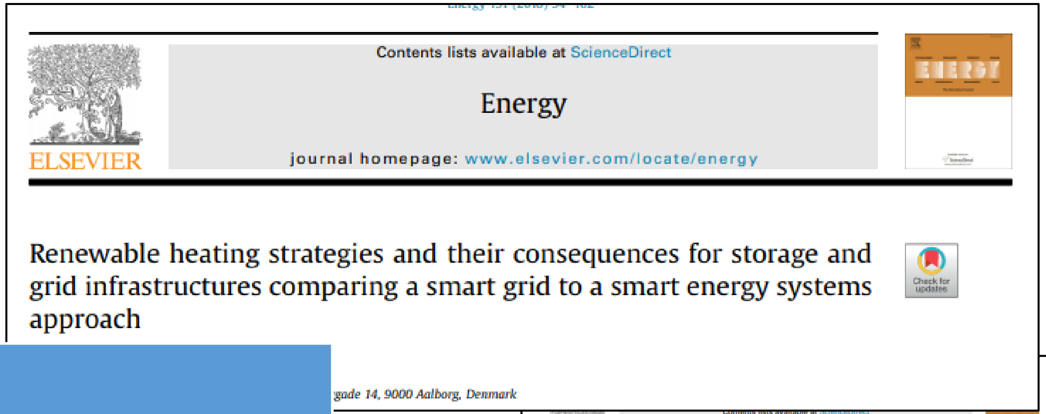
Existing distribution grids

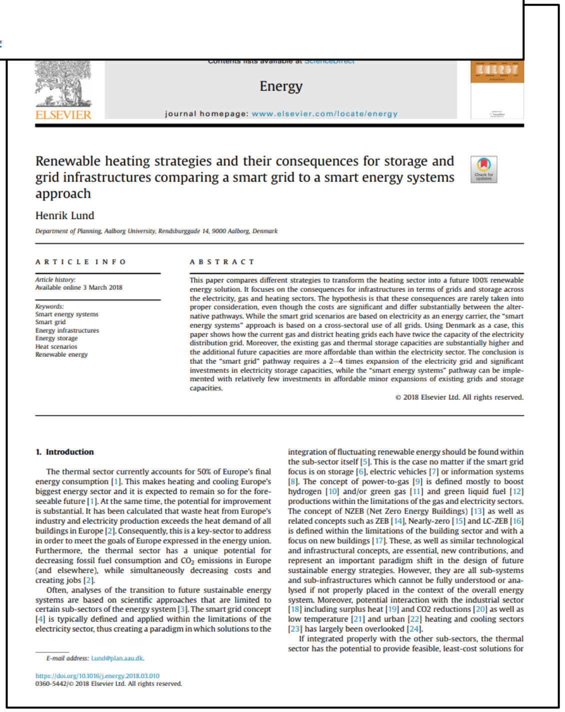




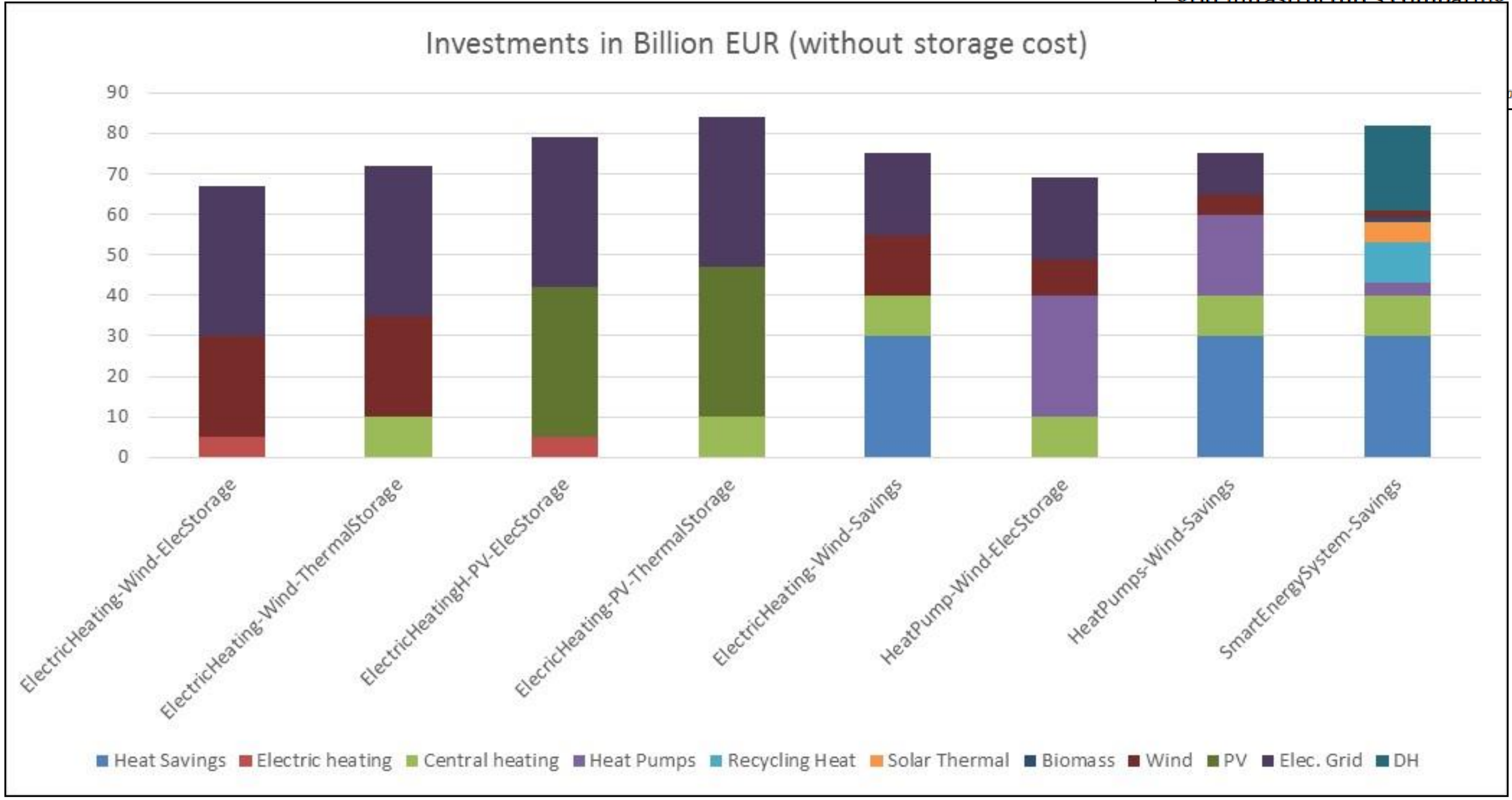
Heating solutions and storage and grid infrastructures

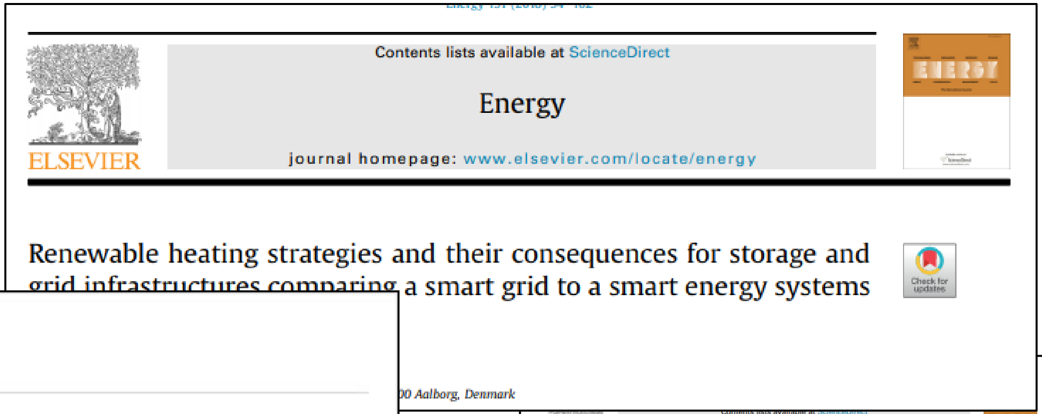
Scenario	Without Savings 47 TWh/year	With Savings 28 TWh/year
Electric Hating (Smart Grid..!!?)	13,000 MW Wind (25 GEUR) 24,000 MW hour peak 10 TWh Storage (2,000 GEUR)	8,000 MW wind 15,000 MW hour peak 5 TWh storage (900 GEUR)
Individual Heat Pumps (Smart Grid..!)	5,000 MW Wind 17,000 MW hour peak 3.7 TWh storage (750 GEUR)	2,500 MW Wind 12,000 MW hour peak 2 TWh Storage (400 GEUR) ..or heat storage 20-30 m3/household
District Heating Indv. Heat Pumps (Smart Energy System)	2,600 MW Wind (plus biomass) hour peak < 8300 MW Storage…!!??	1,500 MW wind (plus recycling etc.) Hour peak < 7,500 MW Heat storage < 1 GEUR





Investment costs NOT including the storage

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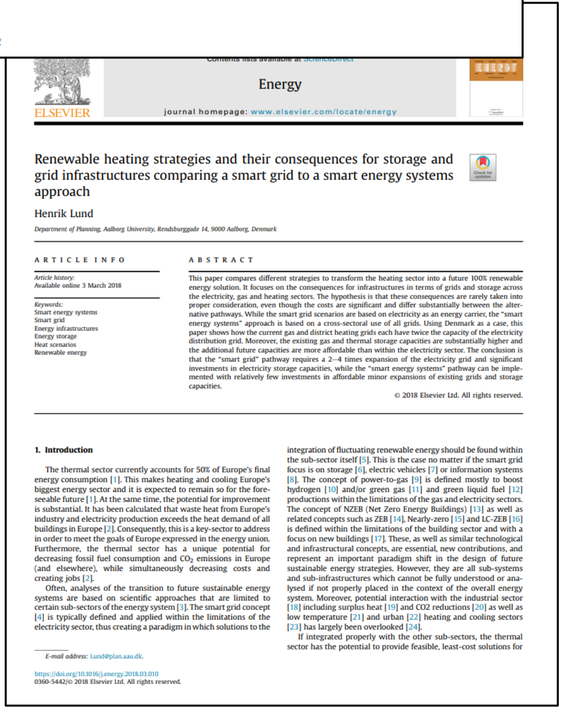
Renewable heating strategies and their consequences for storage and grid infrastructures comparing a smart grid to a smart energy systems

00 Aalborg, Denmark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Renewable heating strategies and their consequences for storage and grid infrastructures comparing a smart grid to a smart energy systems approach

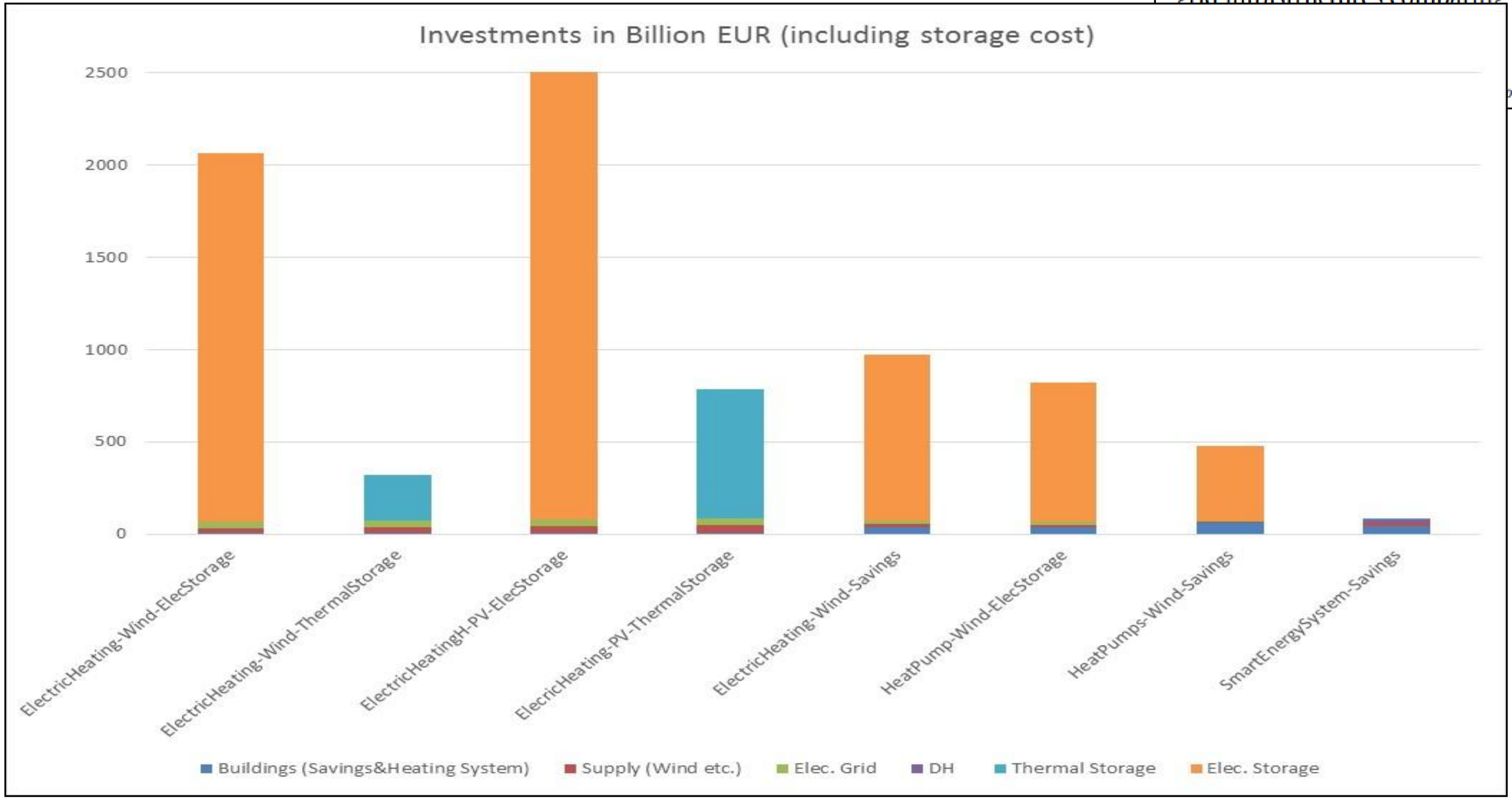
Henrik Lund

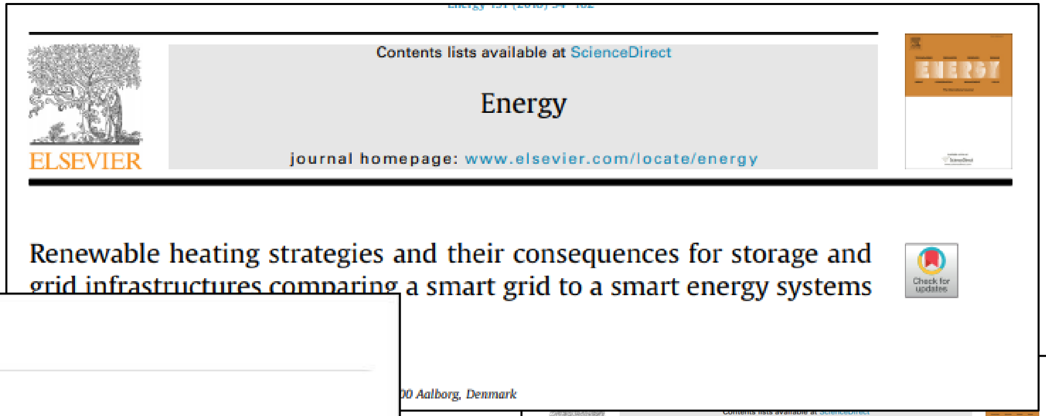
ARTICLE INFO

ABSTRACT

1. Introduction

Investment costs INCLUDING the storage

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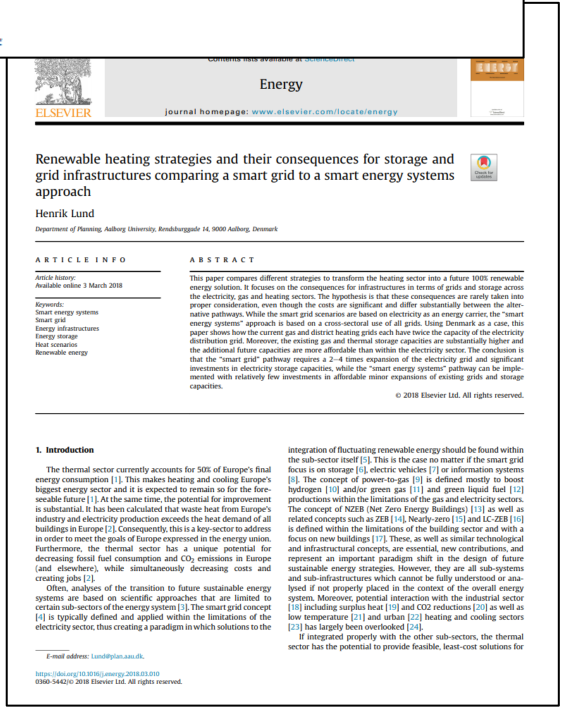
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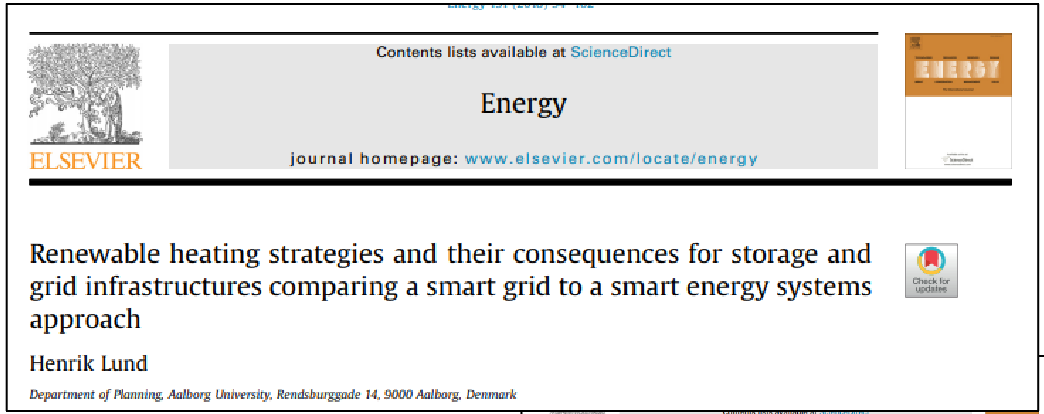
ABSTRACT

1. Introduction

Conclusions

- The need for grid and storage infrastructures differ significantly between different scenarios.
- The cost of grids and storage infrastructures may significantly exceed the cost of the renewable energy sources themselves.
- An integrated “Smart Energy Systems” approach seems to be essential in the design of suitable least cost solutions.
- Savings (in this paper heat savings) have a significant influence on the need for grid and storage infrastructures.



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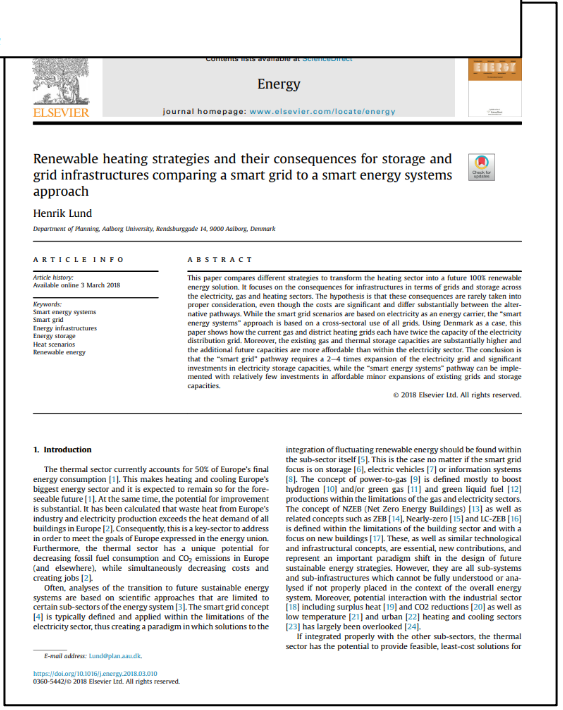
Renewable heating strategies and their consequences for storage and grid infrastructures comparing a smart grid to a smart energy systems approach

Henrik Lund

Department of Planning, Aalborg University, Rendsburggade 14, 9000 Aalborg, Denmark



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Renewable heating strategies and their consequences for storage and grid infrastructures comparing a smart grid to a smart energy systems approach

Henrik Lund

Department of Planning, Aalborg University, Rendsburggade 14, 9000 Aalborg, Denmark

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Energy infrastructures
Energy storage
Heat scenarios
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ABSTRACT

This paper compares different strategies to transform the heating sector into a future 100% renewable energy solution. It focuses on the consequences for infrastructures in terms of grids and storage across the electricity, gas and heating sectors. The hypothesis is that these consequences are rarely taken into proper consideration, even though the costs are significant and differ substantially between the alternative pathways. While the smart grid scenarios are based on electricity as an energy carrier, the “smart energy systems” approach is based on a cross-sectoral use of all grids. Using Denmark as a case, this paper shows how the current gas and district heating grids each have twice the capacity of the electricity distribution grid. Moreover, the existing gas and thermal storage capacities are substantially higher and the additional future capacities are more affordable than within the electricity sector. The conclusion is that the “smart grid” pathway requires a 2–4 times expansion of the electricity grid and significant investments in electricity storage capacities, while the “smart energy systems” pathway can be implemented with relatively few investments in affordable minor expansions of existing grids and storage capacities.

1. **Introduction**

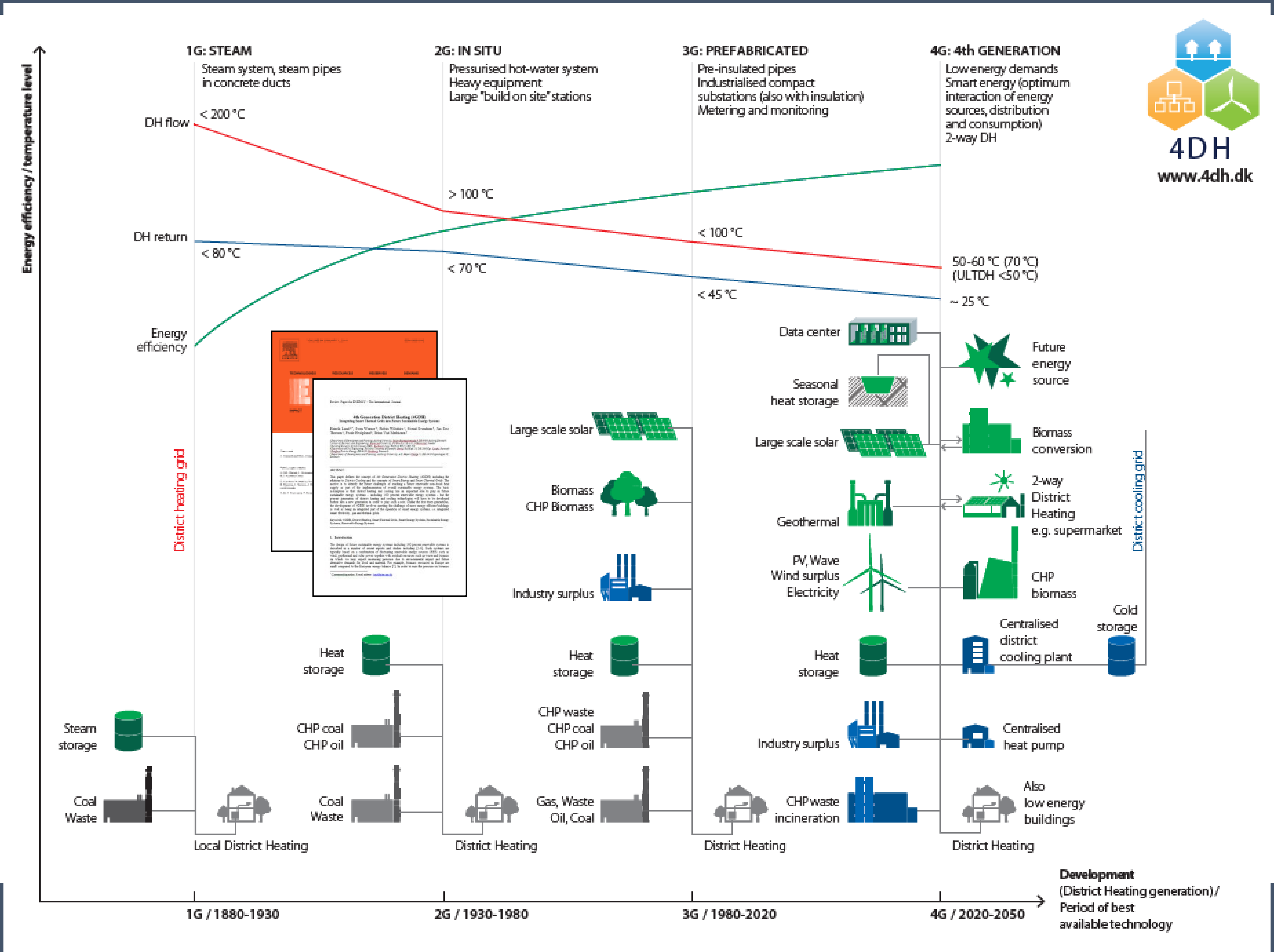
The thermal sector currently accounts for 50% of Europe’s final energy consumption [1]. This makes heating and cooling Europe’s biggest energy sector and it is expected to remain so for the foreseeable future [1]. At the same time, the potential for improvement is substantial. It has been calculated that waste heat from Europe’s industry and electricity production exceeds the heat demand of all buildings in Europe [2]. Consequently, this is a key-sector to address in order to meet the goals of Europe expressed in the energy union. Furthermore, the thermal sector has a unique potential for decreasing fossil fuel consumption and CO_2 emissions in Europe (and elsewhere), while simultaneously decreasing costs and creating jobs [2].

Often, analyses of the transition to future sustainable energy systems are based on scientific approaches that are limited to certain sub-sectors of the energy system [3]. The smart grid concept [4] is typically defined and applied within the limitations of the electricity sector, thus creating a paradigm in which solutions to the integration of fluctuating renewable energy should be found within the sub-sector itself [5]. This is the case no matter if the smart grid focus is on storage [6], electric vehicles [7] or information systems [8]. The concept of power-to-gas [9] is defined mostly to boost hydrogen [10] and/or green gas [11] and green liquid fuel [12] productions within the limitations of the gas and electricity sectors. The concept of NZEB (Net Zero Energy Buildings) [13] as well as related concepts such as ZEB [14], Nearly-zero [15] and LC-ZEB [16] is defined within the limitations of the building sector and with a focus on new buildings [17]. These, as well as similar technological and infrastructural concepts, are essential, new contributions, and represent an important paradigm shift in the design of future sustainable energy strategies. However, they are all sub-systems and sub-infrastructures which cannot be fully understood or analysed if not properly placed in the context of the overall energy system. Moreover, potential interaction with the industrial sector [18] including surplus heat [19] and CO2 reductions [20] as well as low temperature [21] and urban [22] heating and cooling sectors [23] has largely been overlooked [24].

If integrated properly with the other sub-sectors, the thermal sector has the potential to provide feasible, least-cost solutions for

E-mail address: Lund@plan.aau.dk.

https://doi.org/10.1016/j.energy.2018.03.010


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
Large scale solar
Biomass
CHP Biomass
Geothermal
2-way
District
Heating
e.g. supermarket
Industry surplus
PV, Wave
Wind surplus
Electricity
CHP
biomass
Heat
storage
Heat
storage
Heat
storage
Centralised
district
cooling plant
Cold
storage
Steam
storage
CHP coal
CHP oil
CHP waste
CHP coal
CHP oil
Industry surplus
Centralised
heat pump
Coal
Waste
Coal
Waste
Gas, Waste
Oil, Coal
CHP waste
incineration
Also
low energy
buildings
Local District Heating
District Heating
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

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

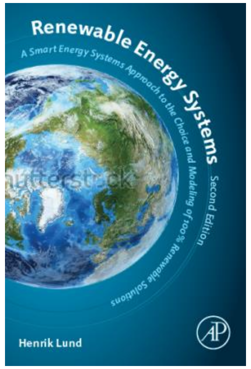
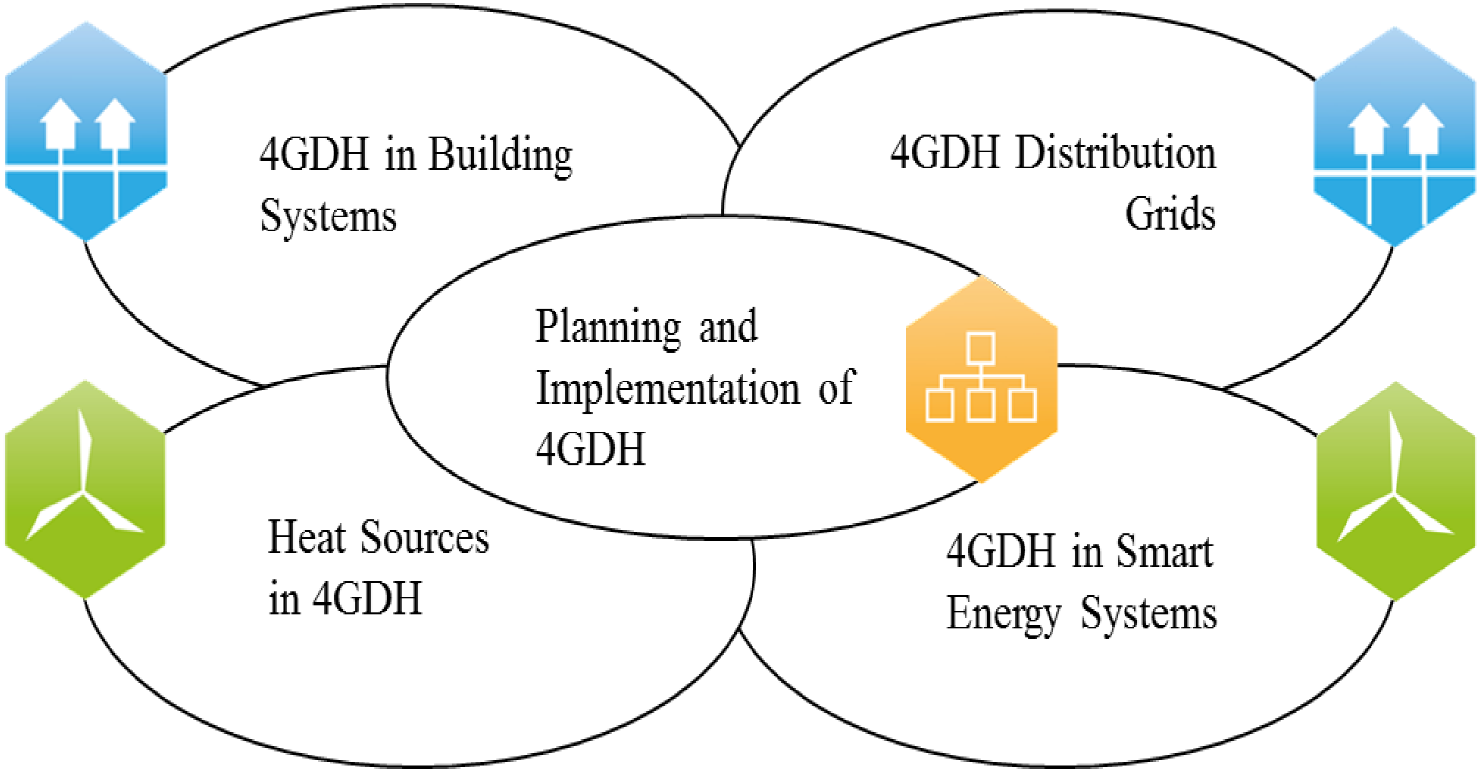


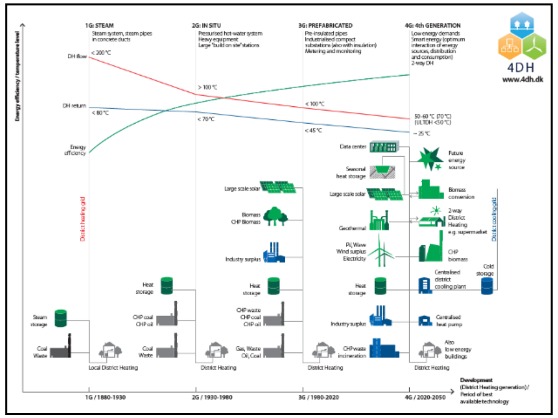
Figure 1: Illustration of the concept of 4^{th} Generation District Heating



4DH
4th Generation District Heating Technologies and Systems

4GDH

1. The ability to supply existing, renovated, and new buildings with low-temperature DH for space heating and domestic hot water.
2. The ability to distribute heat in DH networks with low grid losses.
3. The ability to recycle heat from low-temperature waste sources and integrate renewable heat sources, such as solar and geothermal heat.
4. The ability to be an integrated part of smart energy systems and thereby helping to solve the task of integrating fluctuating renewable energy sources and proving energy conservation into the smart energy system.
5. The ability to ensure suitable planning, cost and incentive structures in relation to the operation as well as to strategic investments related to the transformation into future sustainable energy systems.



Energy 164 (2018) 147–159

Contents lists available at ScienceDirect

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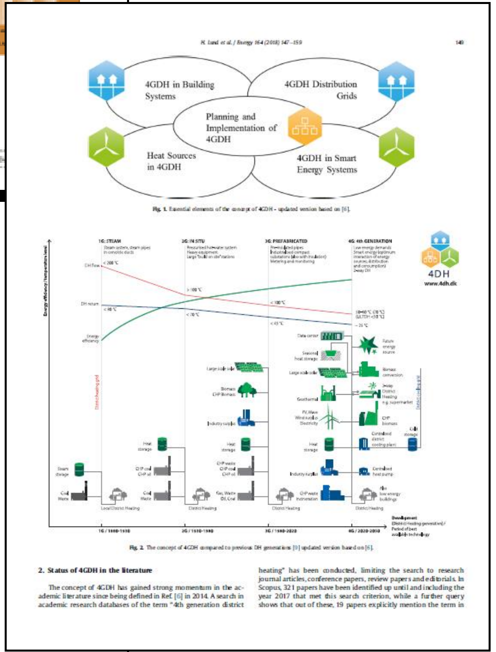
Review

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

Henrik Lund [a,*], Poul Alberg Østergaard [a], Miguel Chang [a], Sven Werner [b],



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.

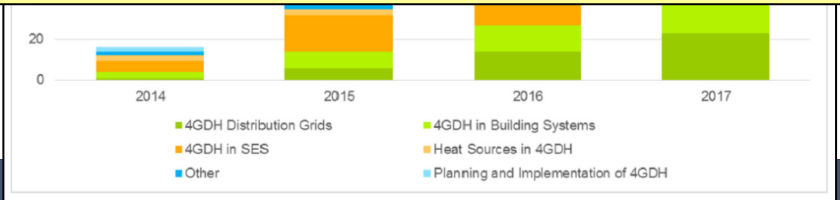
4GDH Distribution Grids
4GDH in Building Systems
4GDH in SES
Heat Sources in 4GDH
Other
Planning and Implementation of 4GDH

Energy 164 (2018) 147–159

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.

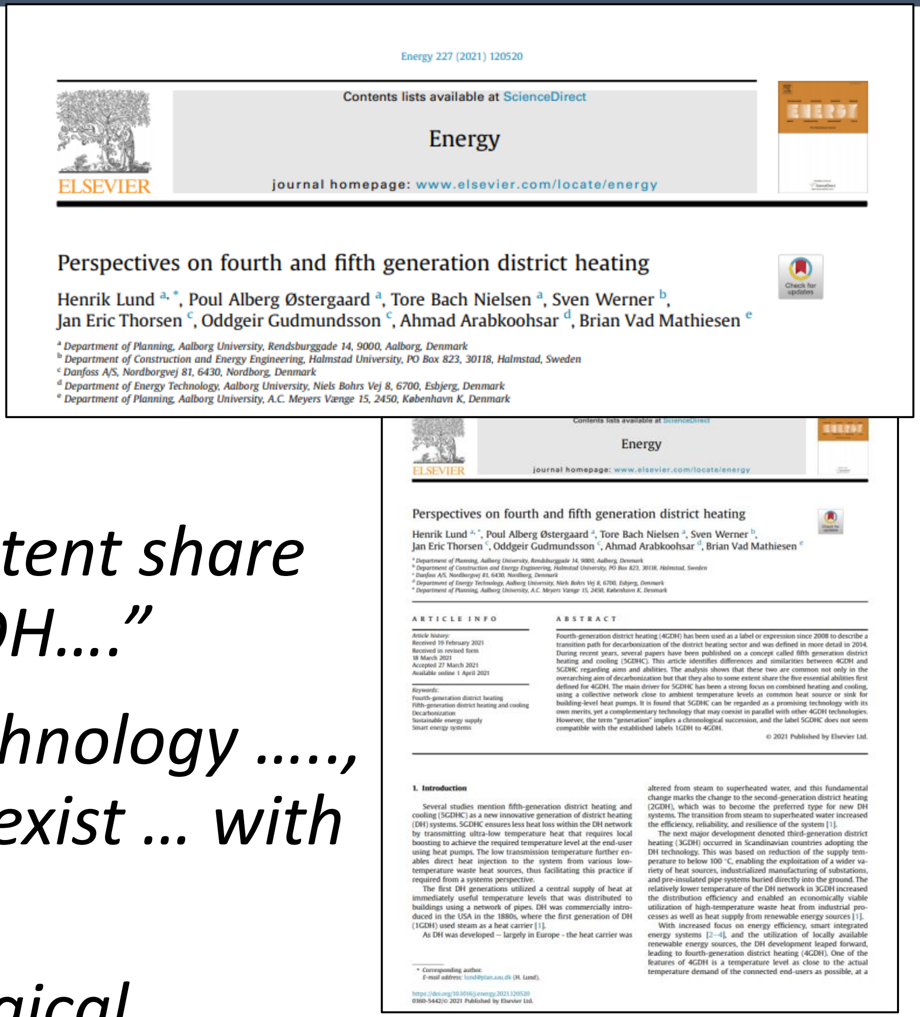
Elements of implementing 4GDH instead of 3GDH	Annualized cost MEUR/year
Additional cost within the buildings (investment in equipment)	50–100
Additional cost in the DH grid (operation costs)	0–10
Savings in investments and operation of the DH grid and in the production (system costs) due to lower temperatures.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



4GDH and 5GDHC

- 4GDH and 5GDHC .. *"….these two are common not only in the overarching aim of decarbonization but that they also to some extent share the five essential abilities first defined for 4GDH…."*
- *"…5GDHC can be regarded as a promising technology ….., yet a complementary technology that may coexist … with other 4GDH technologies…"*
- *"…. The term "generation" implies a chronological succession, and the label 5GDHC does not seem compatible with the established labels 1GDH to 4GDH…"*



Energy 227 (2021) 120520

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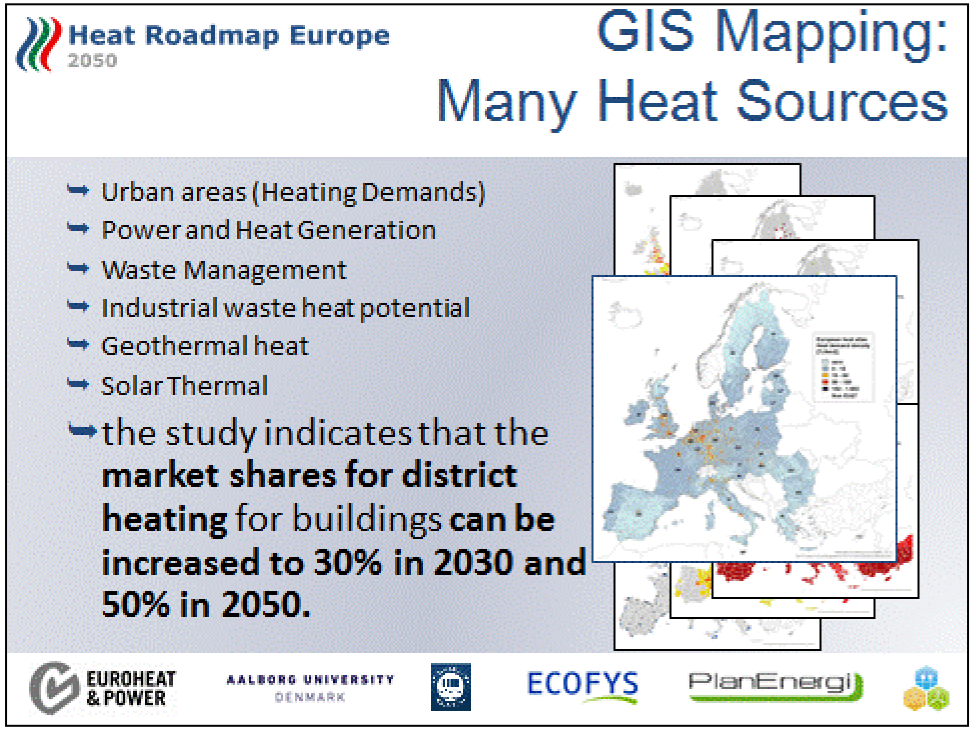
Perspectives on fourth and fifth generation district heating

Henrik Lund [a, *], Poul Alberg Østergaard [a], Tore Bach Nielsen [a], Sven Werner [b], Jan Eric Thorsen [c], Oddgeir Gudmundsson [c], Ahmad Arabkoohsar [d], Brian Vad Mathiesen [e]

[a] Department of Planning, Aalborg University, Rendsburggade 14, 9000, Aalborg, Denmark
[b] Department of Construction and Energy Engineering, Halmstad University, PO Box 823, 30118, Halmstad, Sweden
[c] Danfoss A/S, Nordborgvej 81, 6430, Nordborg, Denmark
[d] Department of Energy Technology, Aalborg University, Niels Bohrs Vej 8, 6700, Esbjerg, Denmark
[e] Department of Planning, Aalborg University, A.C. Meyers Vænge 15, 2450, København K, Denmark

Heat Roadmap Europe



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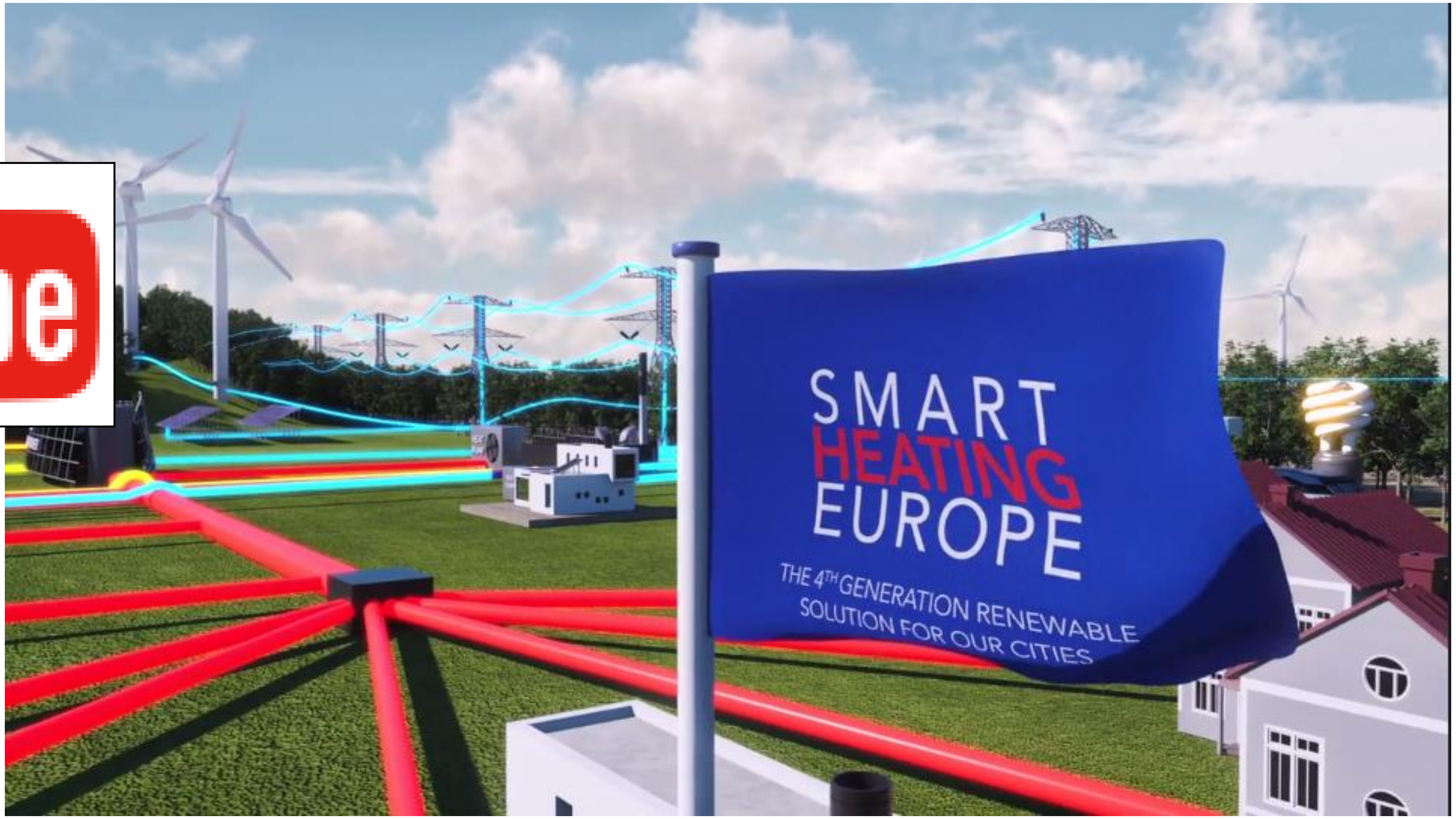
Smart Heating Europe



Smart Energy Europe

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

D. Connolly[a,*], H. Lund[b], B.V. Mathiesen[a]

[a] Department of Development and Planning, Aalborg University, A.C. Meyers Vænge 15, 2450 Copenhagen SV, Denmark
[b] Department of Development and Planning, Aalborg University, Vestre Havnepromenade 9, 9000 Aalborg, Denmark

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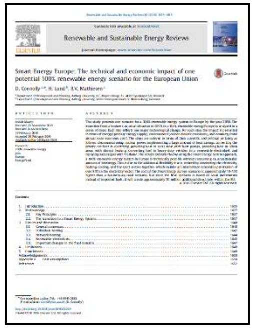
ABSTRACT

This study presents one scenario for a 100% renewable energy system
transition from a business-as-usual situation in 2050, to a 100% renew



www.EnergyPLAN.eu/SmartEnergyEurope

- Report Online
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A Clean Planet for all

A European long-term strategic vision
for a prosperous, modern, competitive and climate neutral economy

Table 1: Overview of main scenario building blocks

Long Term Strategy Options	Electrification (ELEC)	Hydrogen (H2)	Power-to-X (P2X)	Energy Efficiency (EE)	Circular Economy (CIRC)	Combination (COMBO)	1.5°C Technical (1.5TECH)	1.5°C Sustainable Lifestyles (1.5LIFE)
Main Drivers	Electrification in all sectors	Hydrogen in industry, transport and buildings	E-fuels in industry, transport and buildings	Pursuing deep energy efficiency in all sectors	Increased resource and material efficiency	Cost-efficient combination of options from 2°C scenarios	Based on COMBO with more BECCS, CCS	Based on COMBO and CIRC with lifestyle changes
GHG target in 2050	-80% GHG (excluding sinks) ["well below 2°C" ambition]					-90% GHG (incl. sinks)	-100% GHG (incl. sinks) ["1.5°C" ambition]	
Major Common Assumptions	• Higher energy efficiency post 2030 • Deployment of sustainable, advanced biofuels • Moderate circular economy measures • Digitilisation • Market coordination for infrastructure deployment • BECCS present only post-2050 in 2°C scenarios • Significant learning by doing for low carbon technologies • Significant improvements in the efficiency of the transport system.							
Power sector	Power is nearly decarbonised by 2050. Strong penetration of RES facilitated by system optimization (demand-side response, storage, interconnections, role of prosumers). Nuclear still plays a role in the power sector and CCS deployment faces limitations.							
Industry	Electrification of processes	Use of H2 in targeted applications	Use of e-gas in targeted applications	Reducing energy demand via Energy Efficiency	Higher recycling rates, material substitution, circular measures	Combination of most Cost-efficient options from "well below 2°C" scenarios with targeted application (excluding CIRC)	COMBO but stronger	CIRC+COMBO but stronger
Buildings	Increased deployment of heat pumps	Deployment of H2 for heating	Deployment of e-gas for heating	Increased renovation rates and depth	Sustainable buildings			CIRC+COMBO but stronger
Transport sector	Faster electrification for all transport modes	H2 deployment for HDVs and some for LDVs	E-fuels deployment for all modes	Increased modal shift	Mobility as a service			• CIRC+COMBO but stronger • Alternatives to air travel
Other Drivers		H2 in gas distribution grid	E-gas in gas distribution grid				Limited enhancement natural sink	• Dietary changes • Enhancement natural sink

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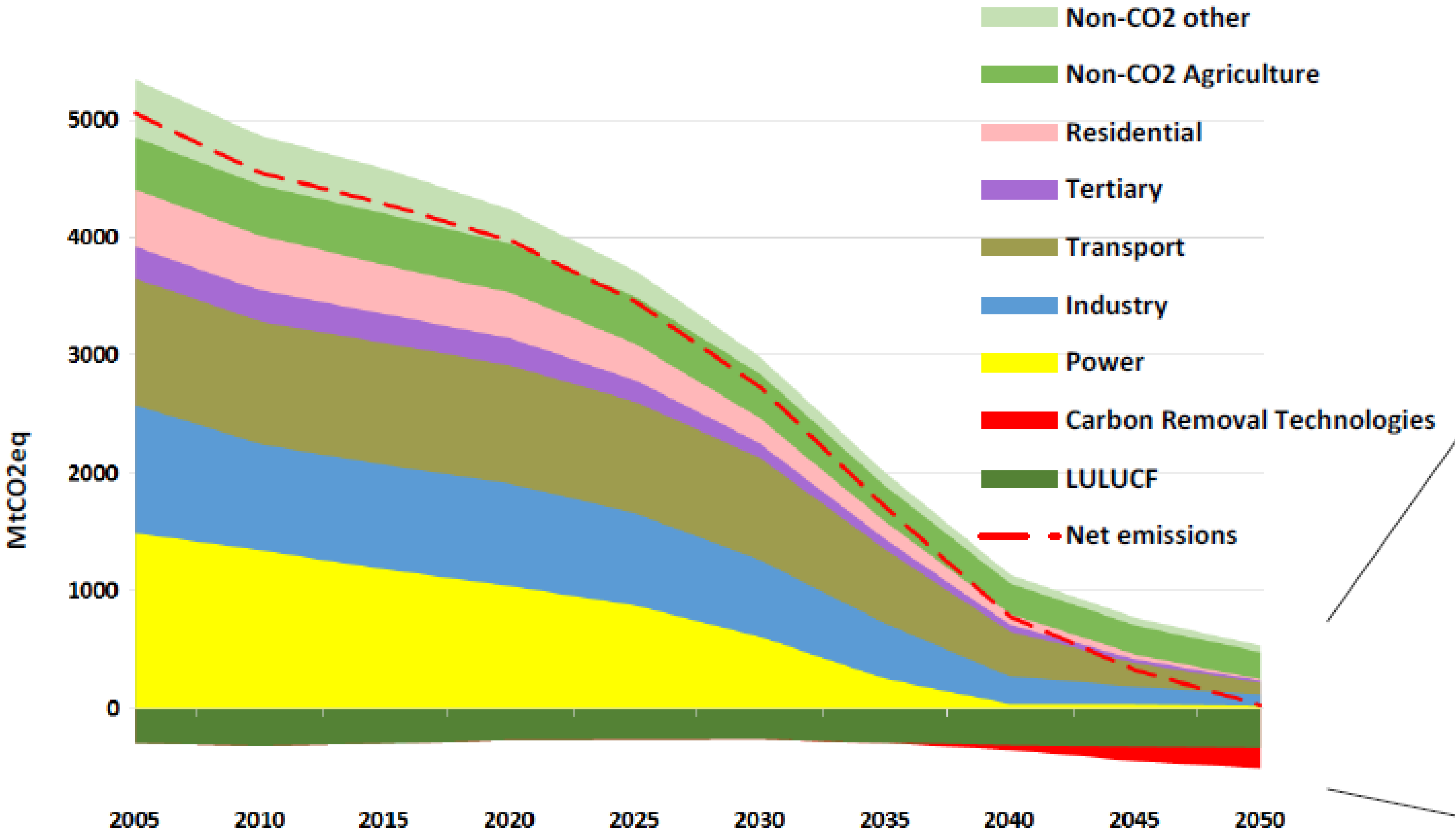
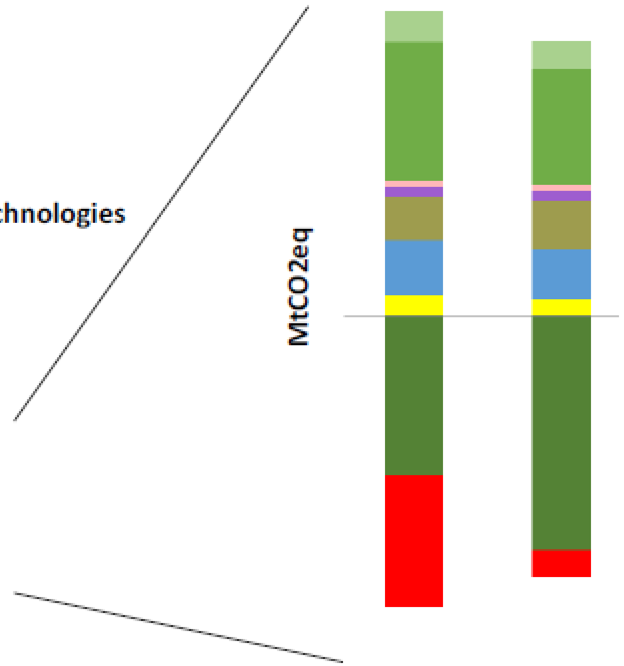
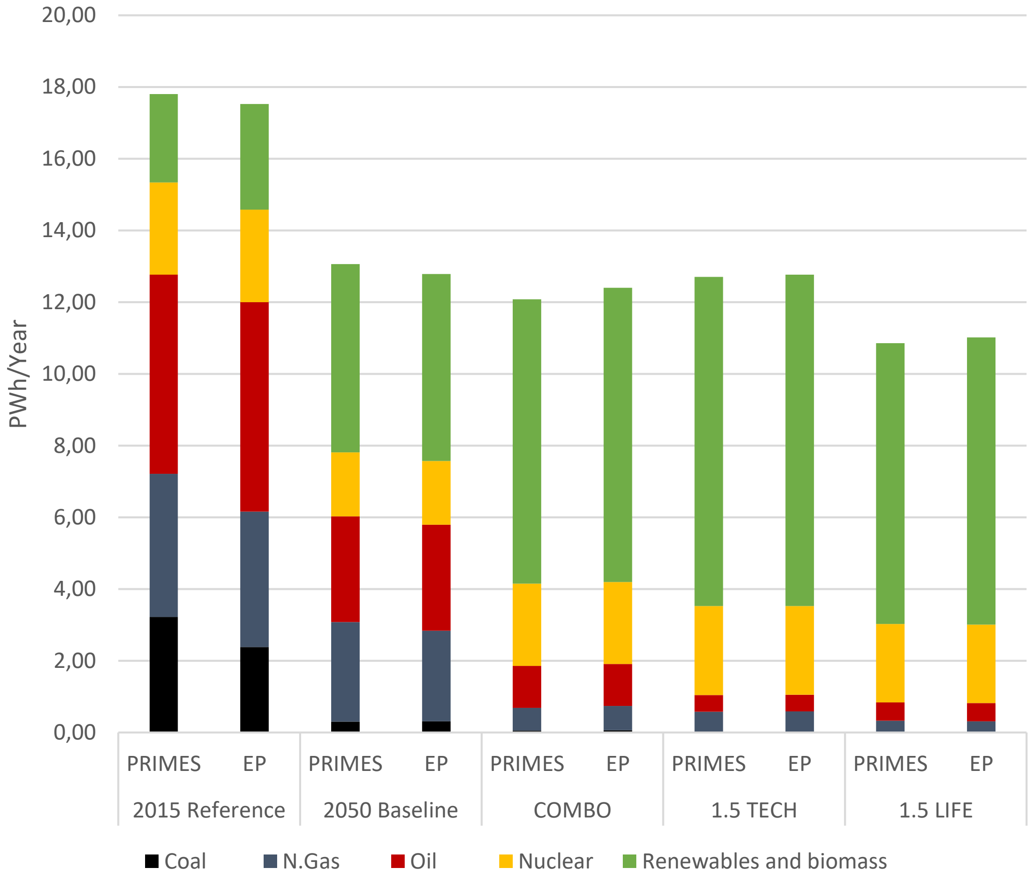
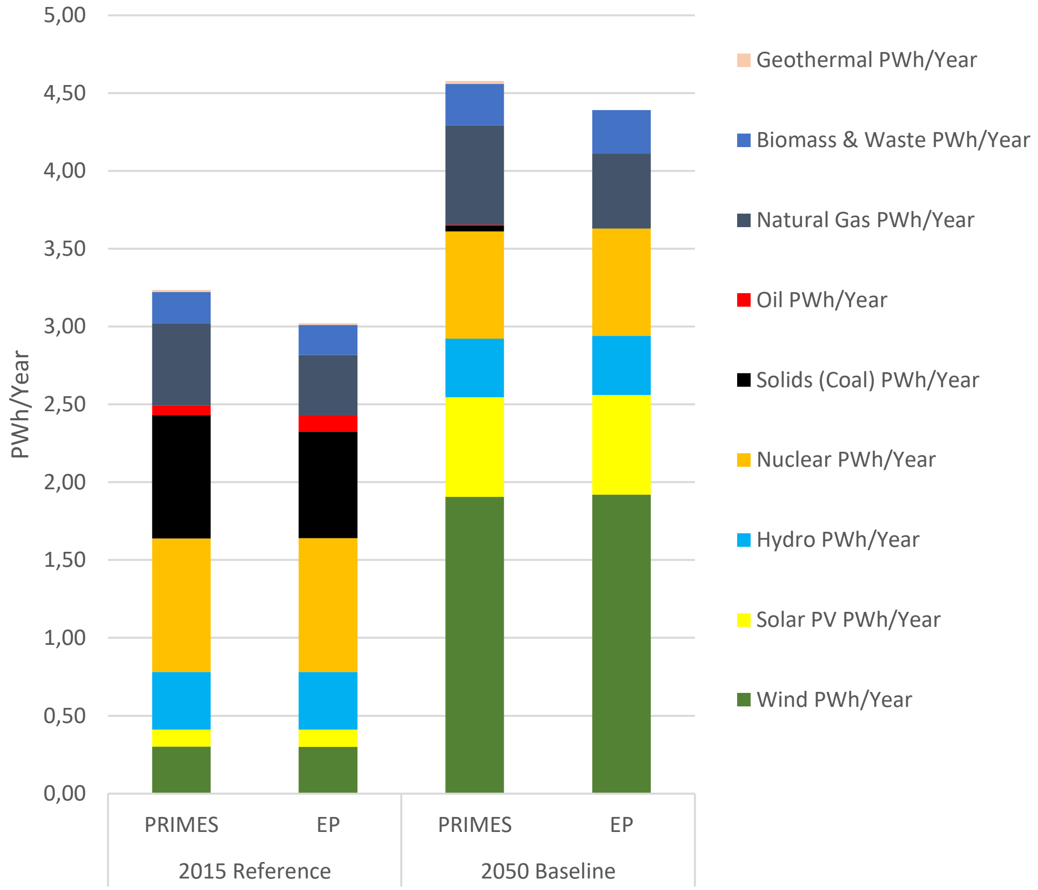


Different zero GHG pathways lead to different levels of remaining emissions and absorption of GHG emissions



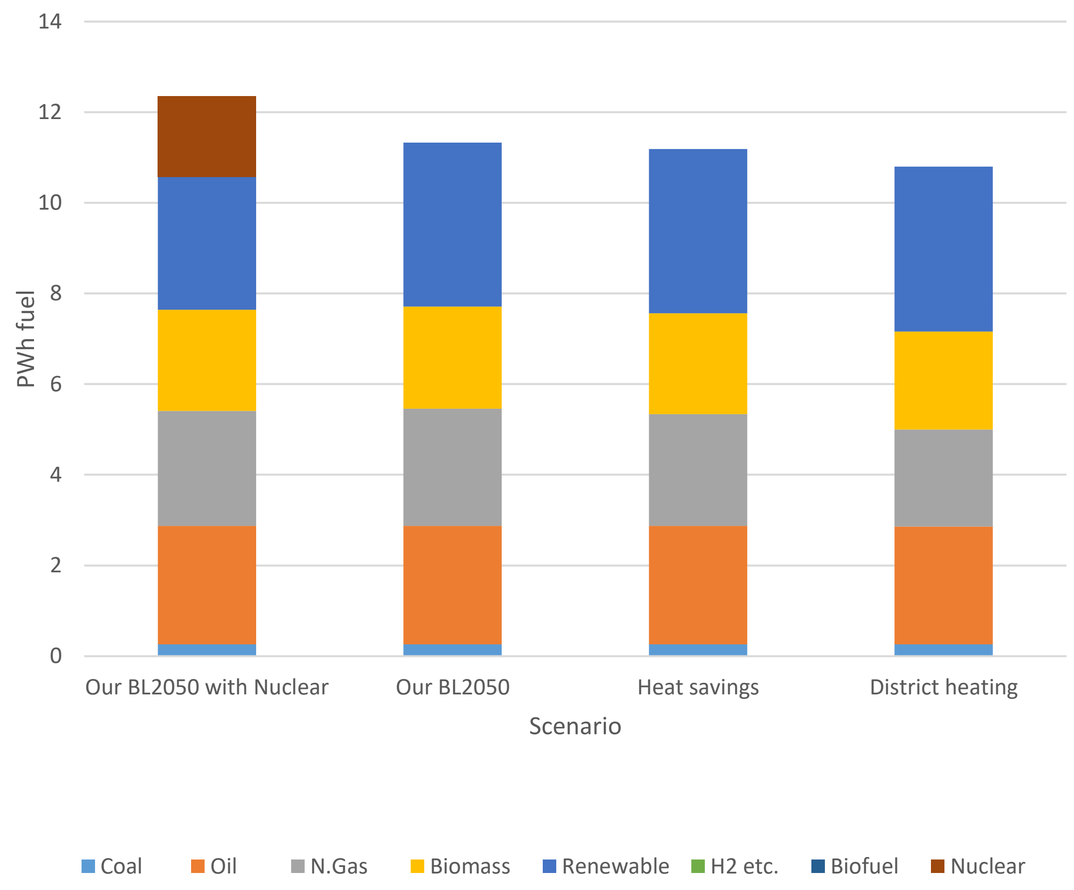
Our replication





Step 2: Implementing district heating

- Converting to district heating based on Heat Roadmap Europe
- Implementing CHP, HP and boilers based on average and peak heat demands
- Increase PP capacity to be sufficient



More information:

www.henriklund.eu

www.4DH.dk

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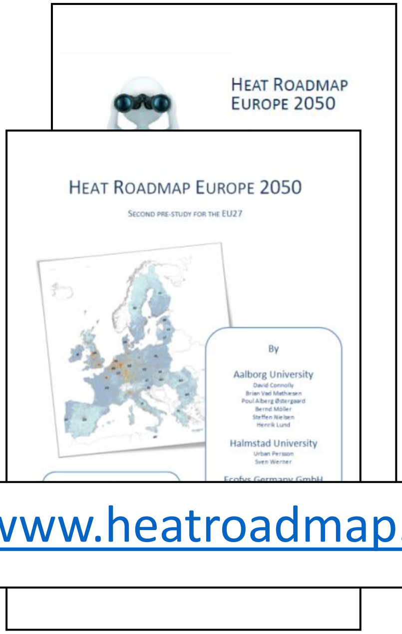

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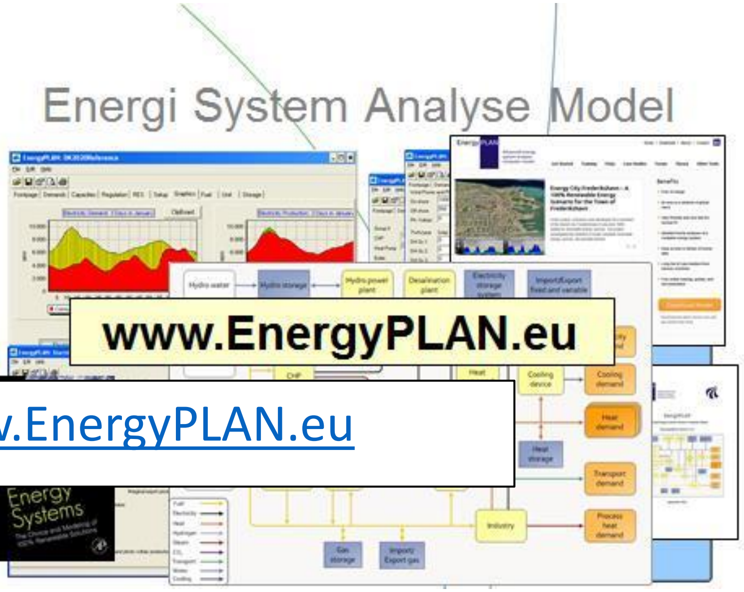

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