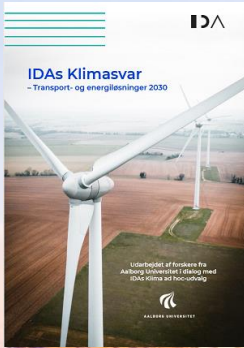


17TH CONFERENCE ON SUSTAINABLE DEVELOPMENT OF ENERGY, WATER AND ENVIRONMENT SYSTEMS

6-10 NOVEMBER, 2022
PAPHOS, CYPRUS



Smart Renewable Energy Systems and a fully decarbonized society

Professor Henrik Lund
Aalborg Universitet

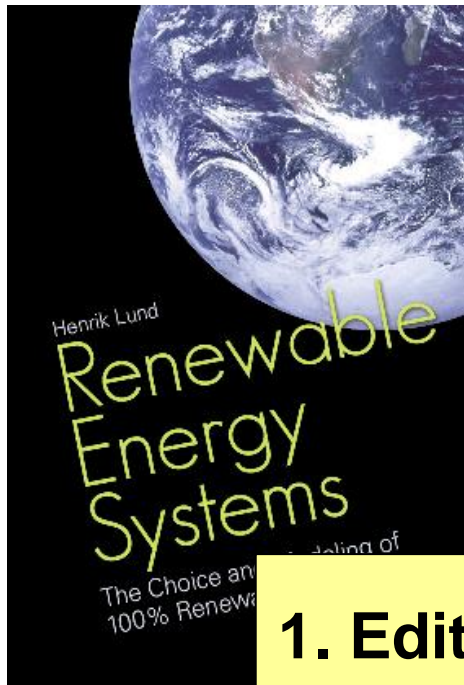


AALBORG UNIVERSITY
DENMARK

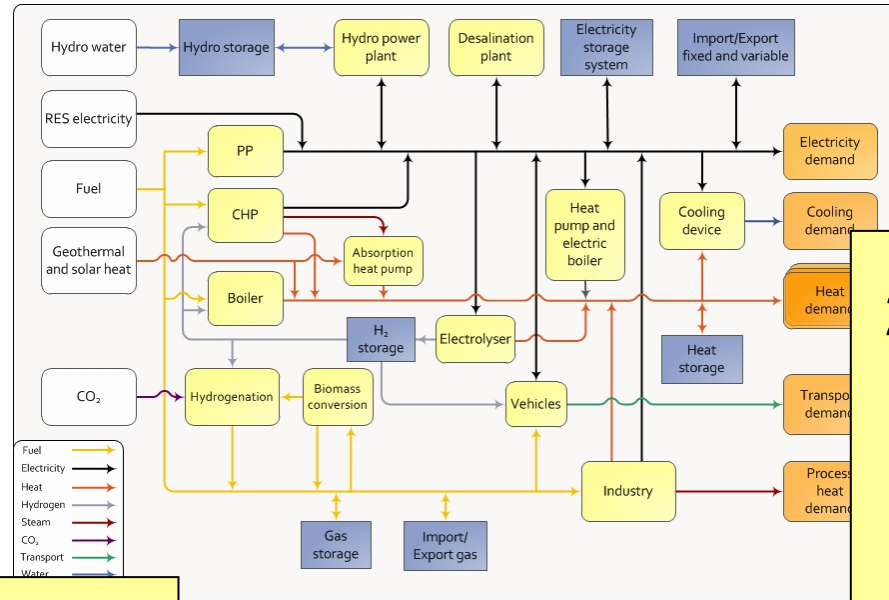


Renewable Energy Systems

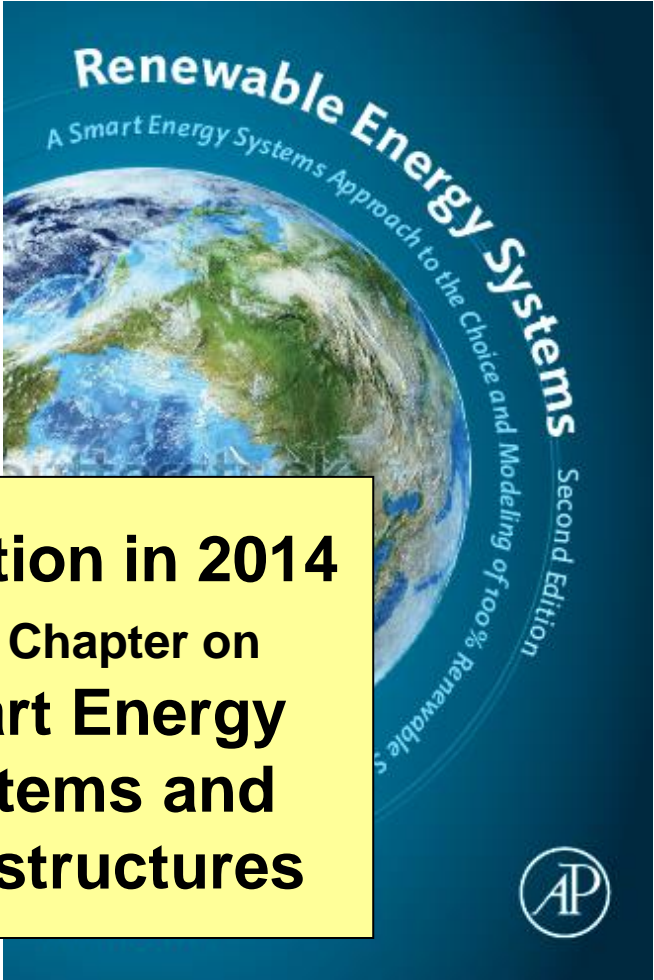
A Smart Energy Systems Approach to the
Choice and Modeling of 100% Renewable Solutions



1. Edition in 2010



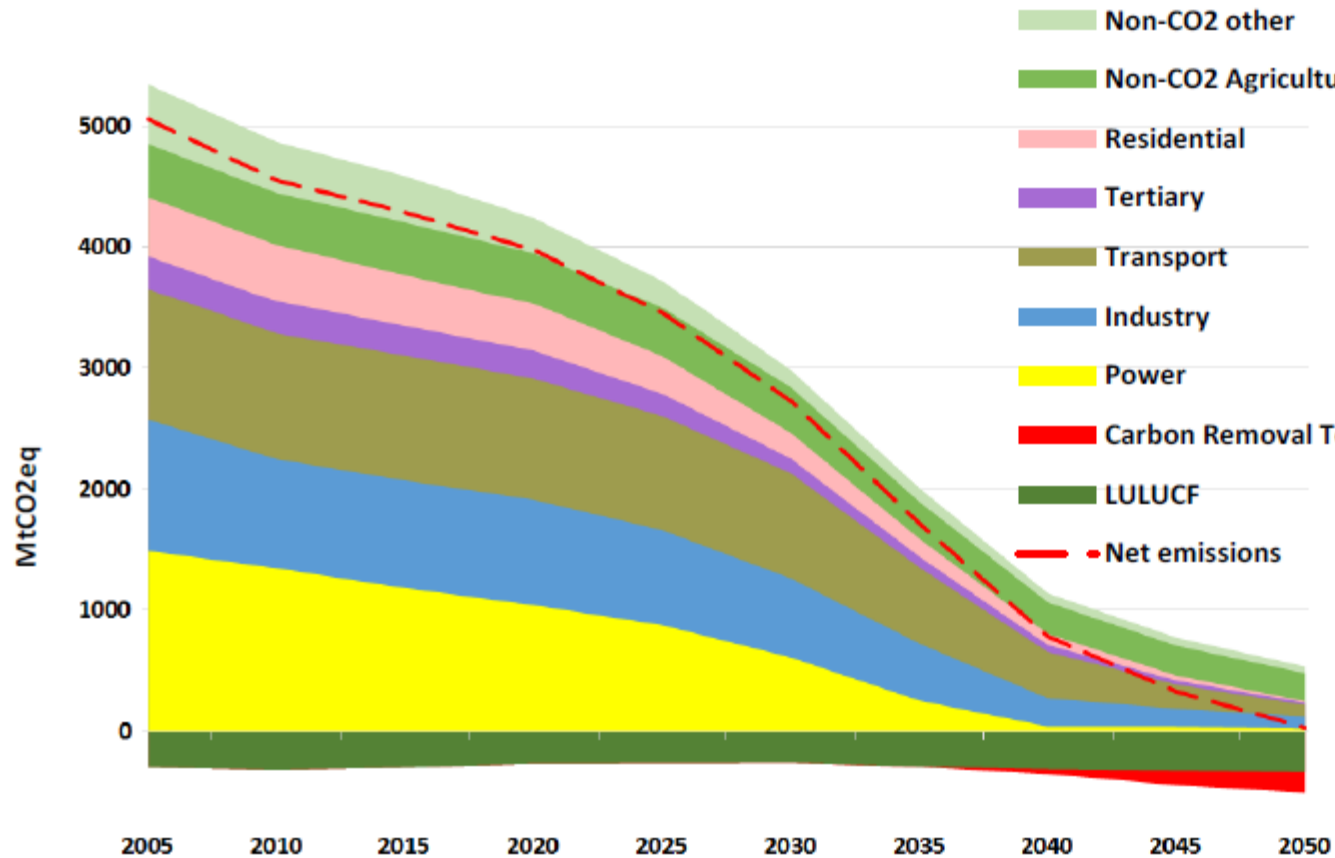
2. Edition in 2014
New Chapter on
Smart Energy
Systems and
Infrastructures



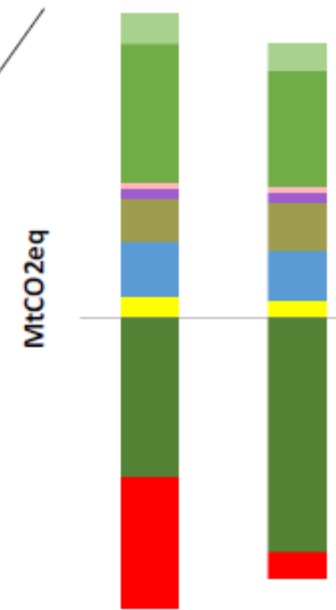
A Clean Planet for all

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

Climate Neutral



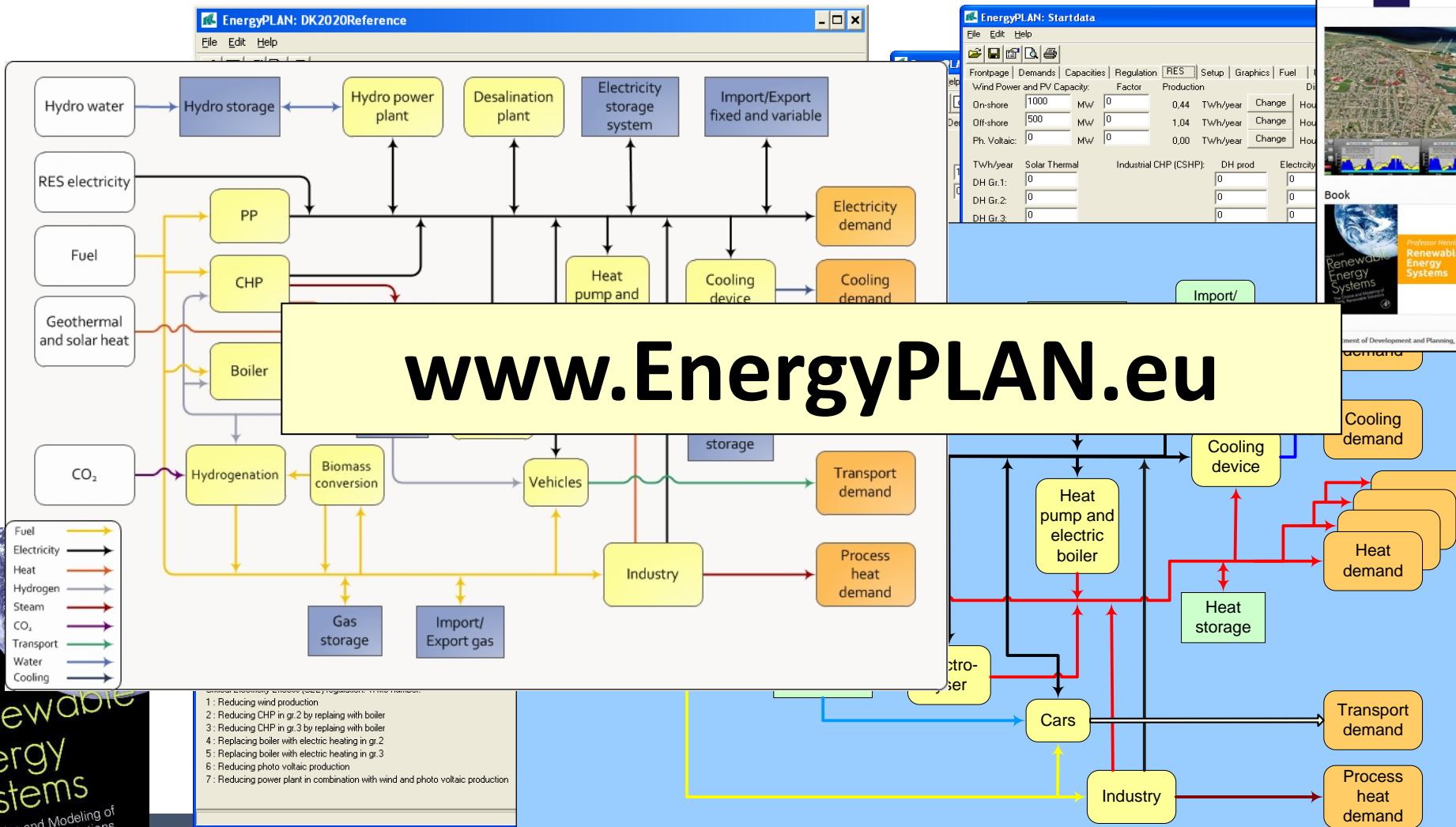
Different zero GHG pathways lead to different levels of remaining emissions and absorption of GHG emission



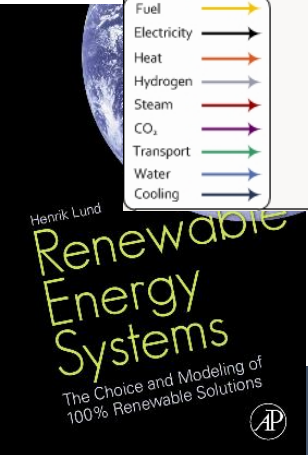
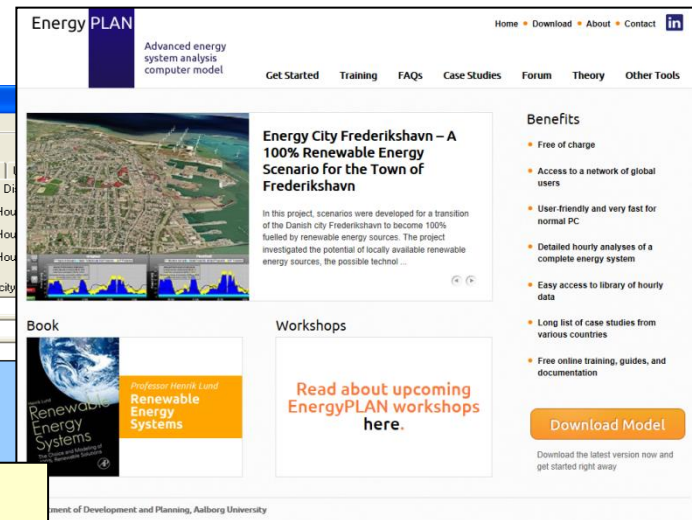
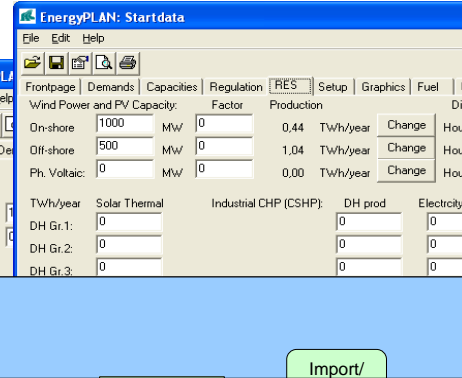
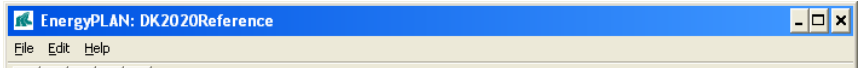
100% Renewable Energy 2050 Or a Climate Neutral Economy but how...????!!



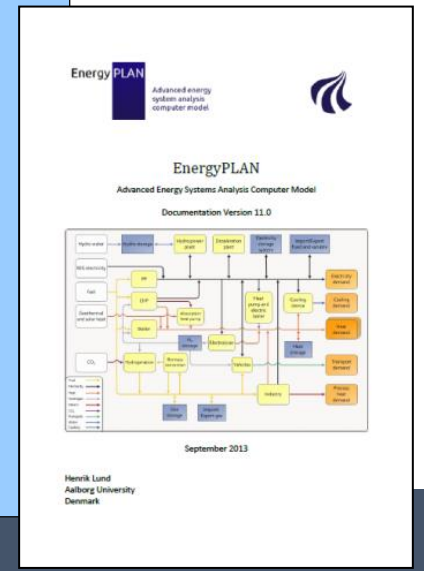
Energi System Analyse Model



www.EnergyPLAN.eu



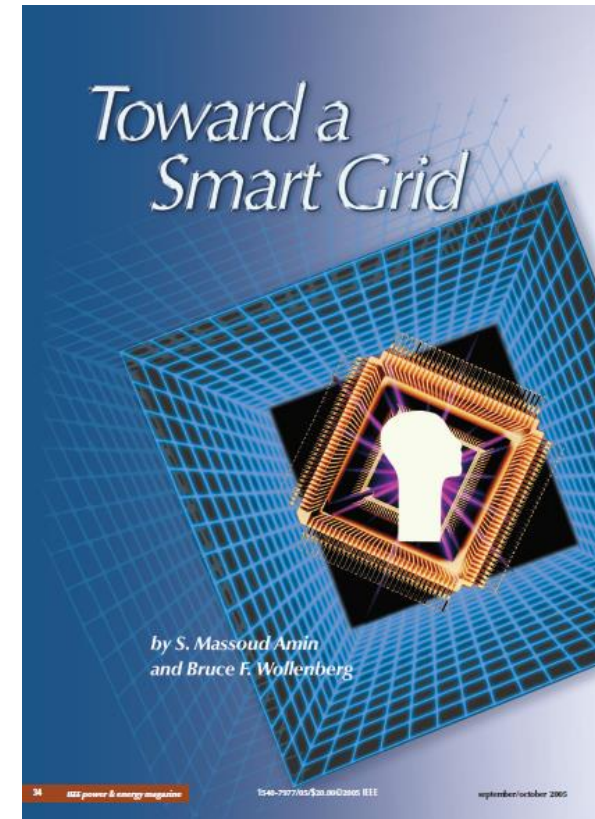
- 1: Reducing wind production
- 2: Reducing CHP in gr 2 by replacing with boiler
- 3: Reducing CHP in gr 3 by replacing with boiler
- 4: Replacing boiler with electric heating in gr.2
- 5: Replacing boiler with electric heating in gr.3
- 6: Reducing photo voltaic production
- 7: Reducing power plant in combination with wind and photo voltaic production



Smart Grid (2005)

No definition.

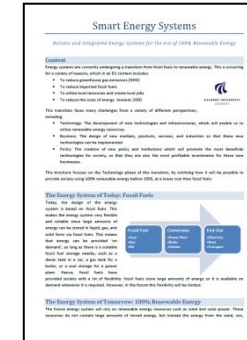
However it can be understood from the context that a *smart grid* is a power network using modern computer and communication technology to achieve a network which can better deal with potential failures.

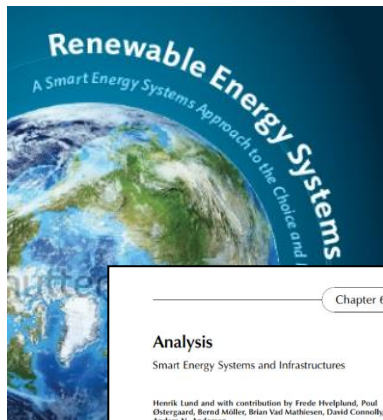


Smart Energy Systems

- **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.
- **Smart Thermal Grids** are a network of pipes that deliver heat in a neighbourhood, town centre or whole city. They can be served from centralised plants as well as from distributed heating or cooling production units and can receive contributions from the connected buildings.
- **Smart Gas Grids** are gas infrastructures that can intelligently integrate the actions of all users connected to it - 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.



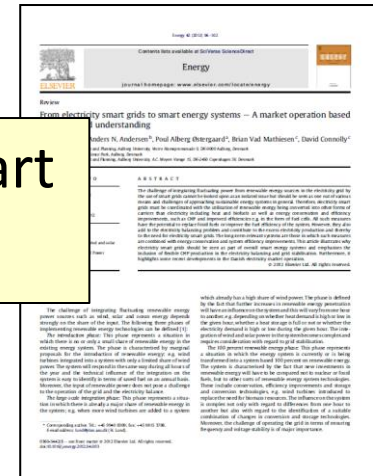


Chapter 6
Analysis
 Smart Energy Systems and Infrastructures
 Henrik Lund and with contribution by Frode Høglund, Poul Østergaard, Bernd Müller, Brian Val Mathiesen, David Connolly, and Anders N. Andersen

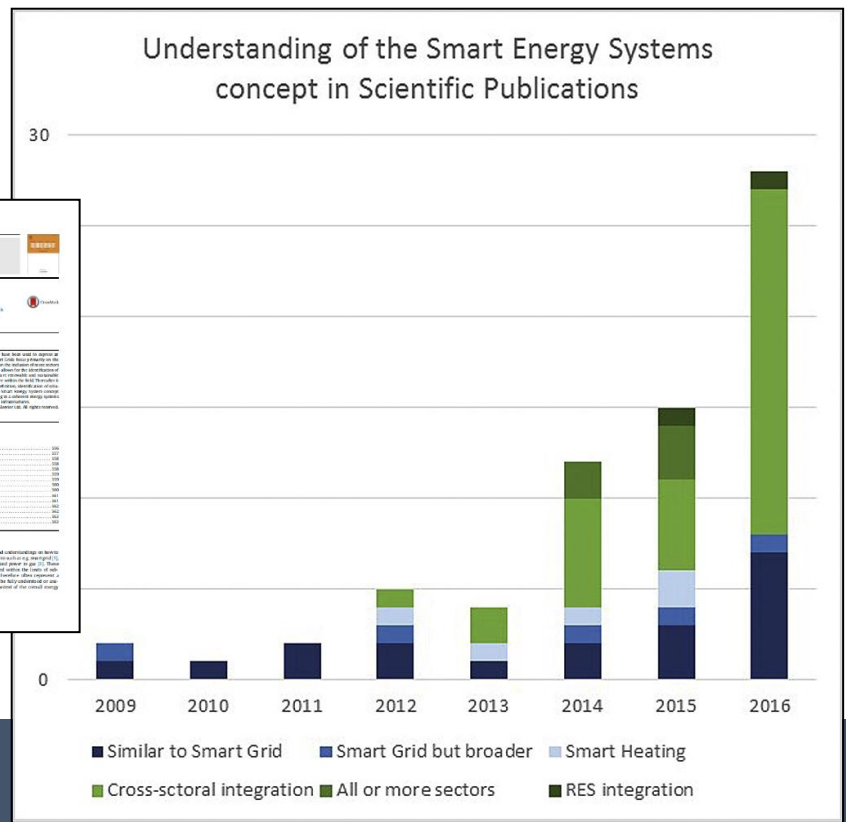
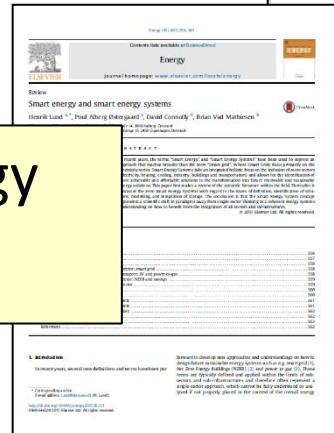
Smart Energy Systems and Infrastructures published 2014

When the electricity sector is combined with the other sectors, such as the heating sector and the transportation sector. Moreover, as will be explained in this chapter, the combination of electricity and gas infrastructures may play an important role in the design of future renewable energy systems.
 This chapter starts by discussing the challenges as well as the concepts and definitions of various smart grids and energy systems. Then it presents the results of a list of studies relevant to the understanding of the challenges of the different energy infrastructures and how to meet these. One main point is

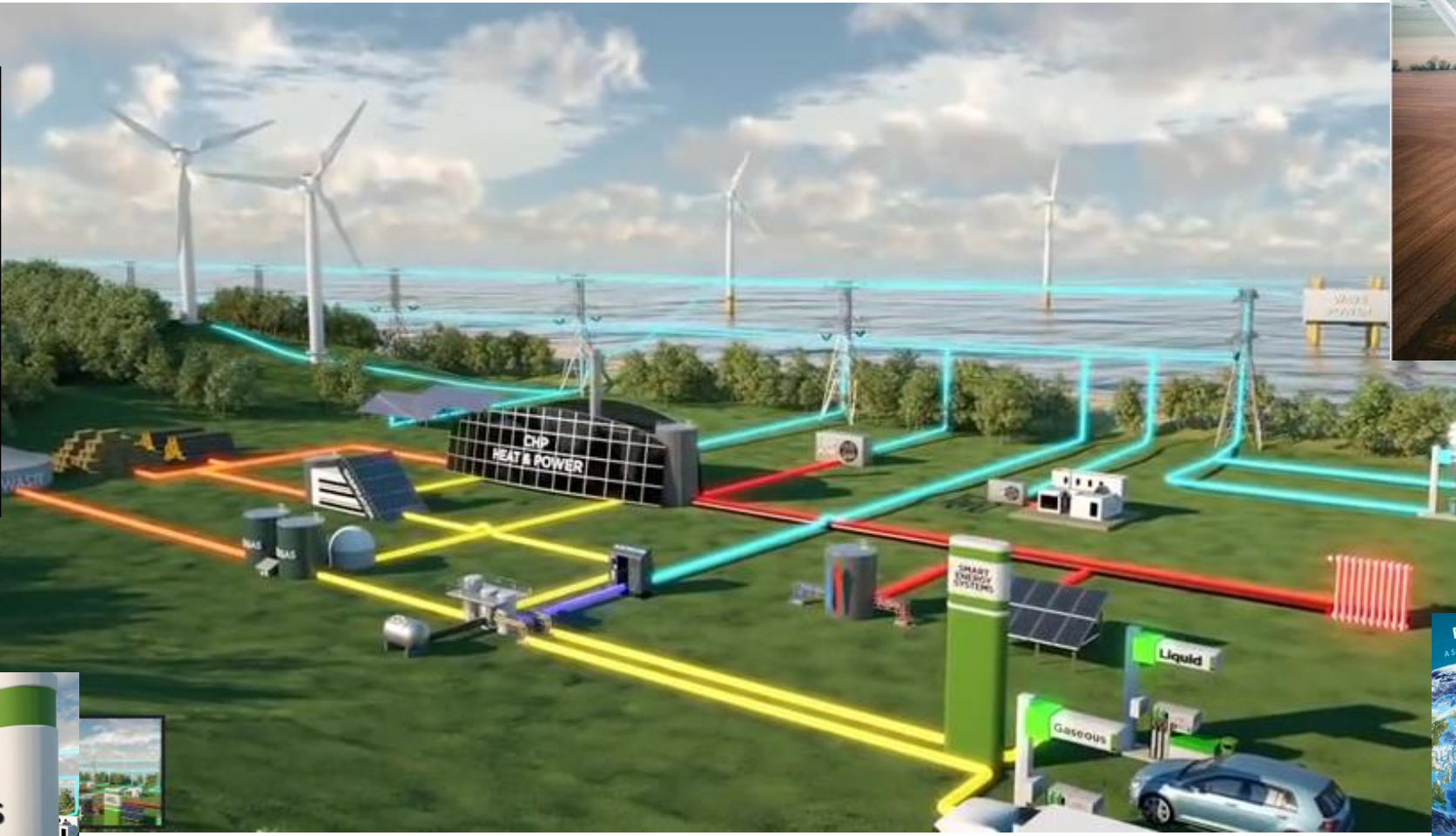
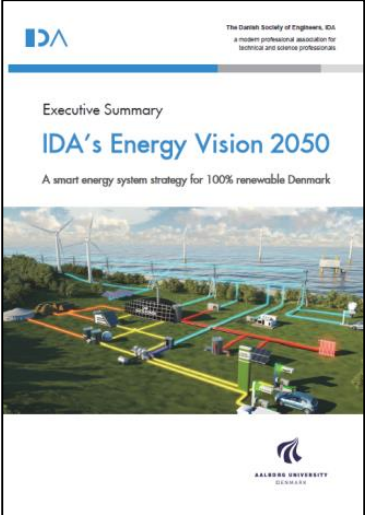
From electricity smart grids to smart energy systems published 2012

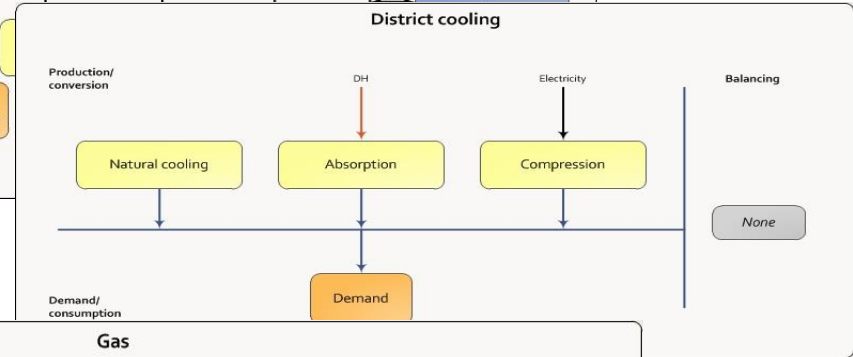
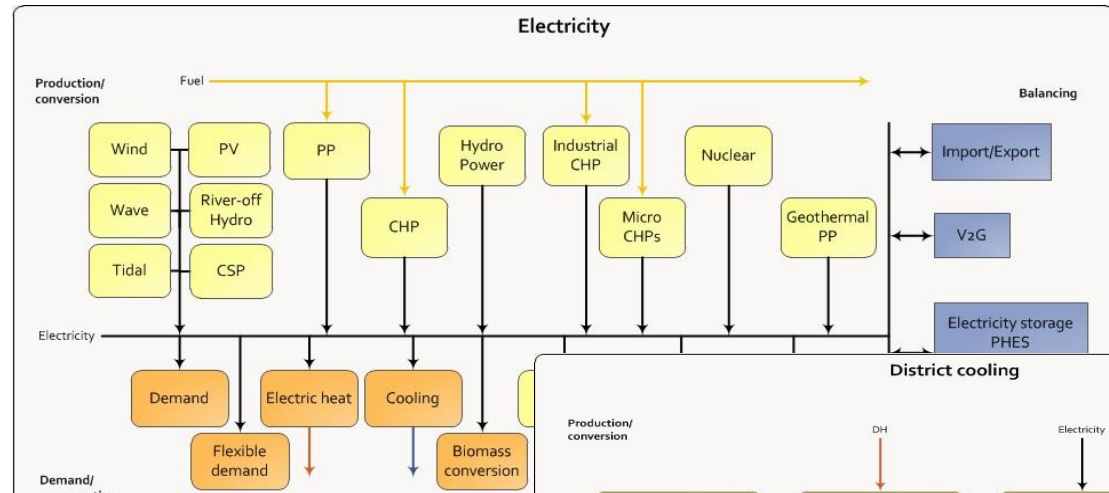
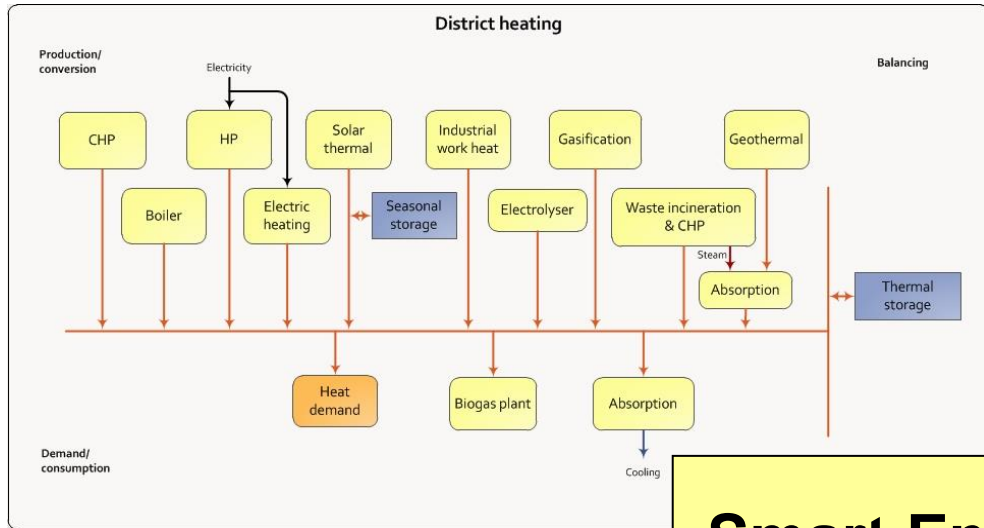


Smart Energy and Smart Energy Systems published 2017

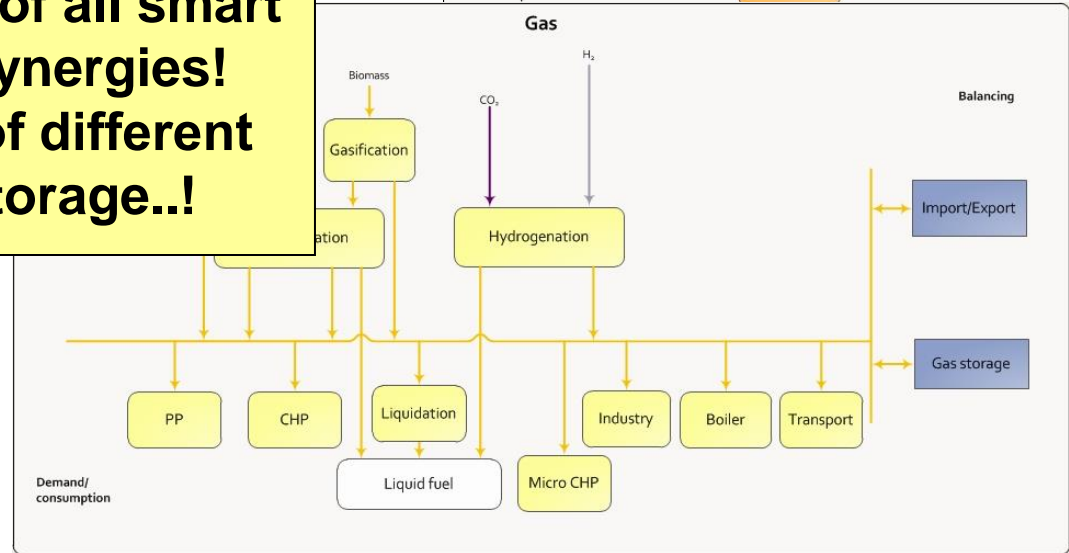
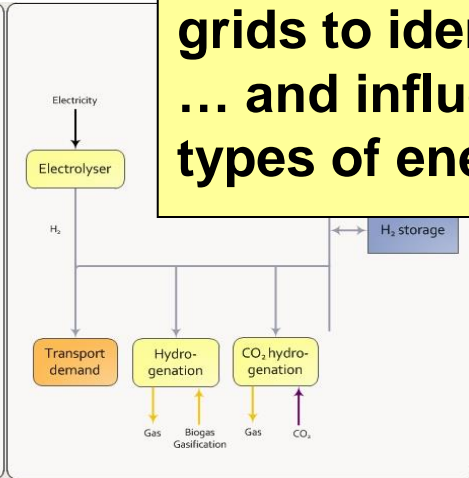
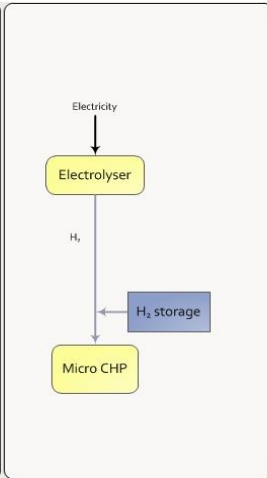
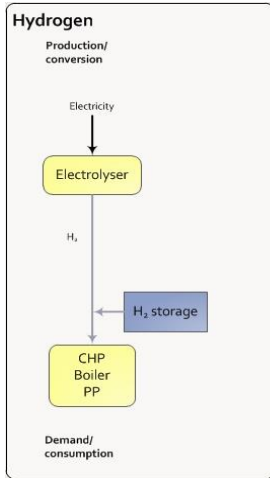


A Holistic Smart Energy Systems Approach

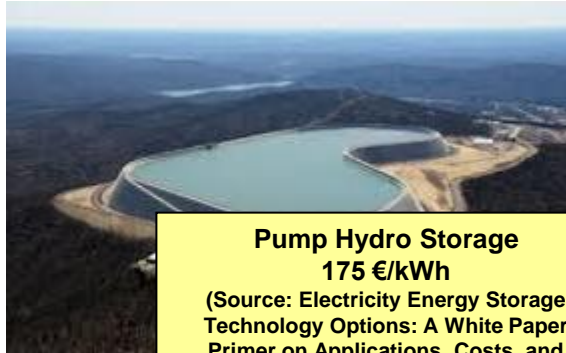




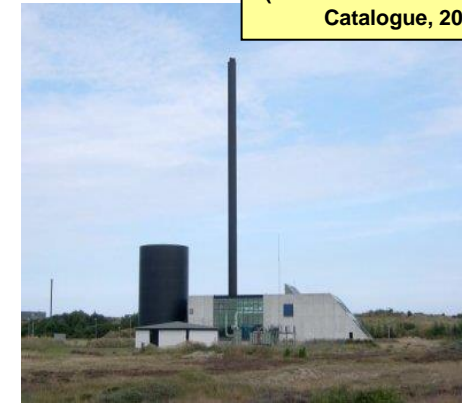
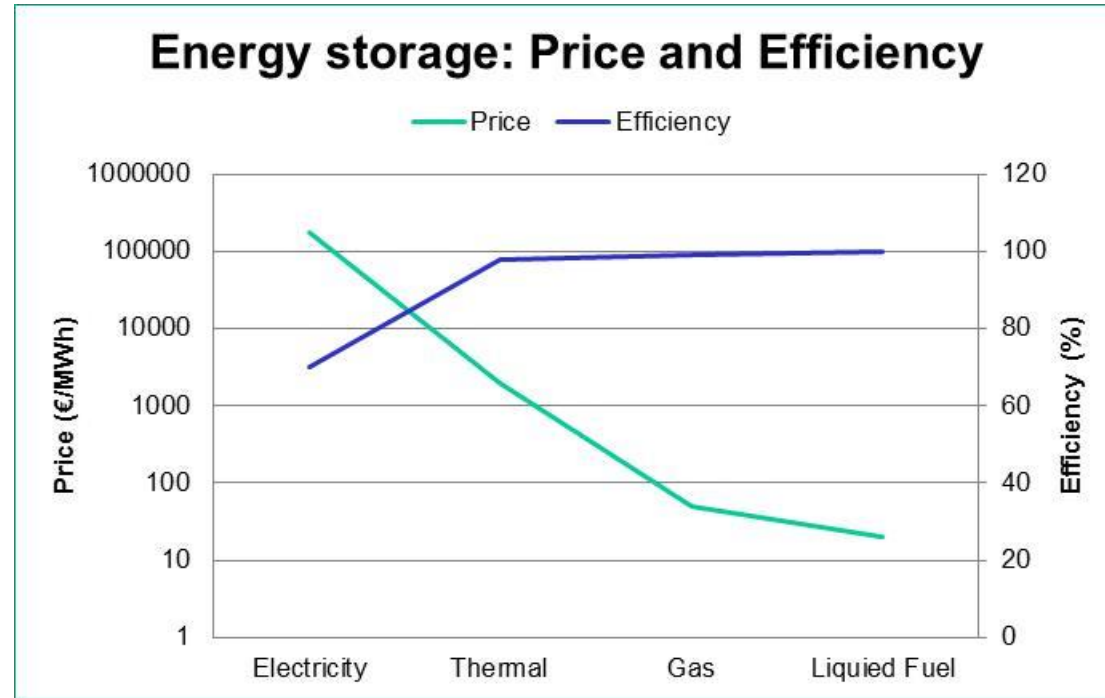
**Smart Energy Systems:
Hourly modelling of all smart
grids to identify synergies!
... and influence of different
types of energy storage..!**



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)

International Journal of Sustainable Energy Planning and Management

Energy Storage and Smart Energy Systems

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

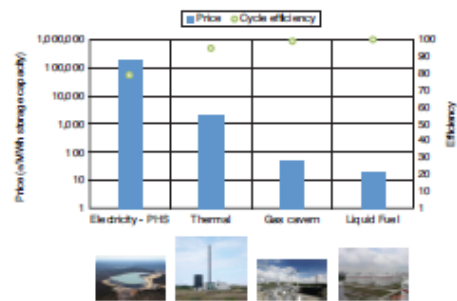


Figure 1: Investment cost and cycle efficiency comparison of electricity, thermal, gas and liquid fuel storage technologies. See assumptions, details and references in Appendix 1.

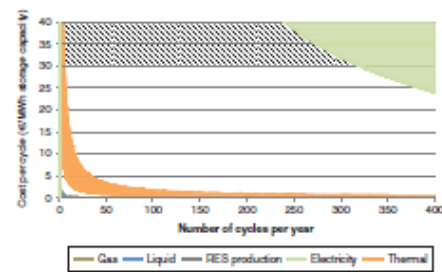


Figure 2: Annualized investment cost per use-cycle vs annual numbers of use-cycles. In the diagram the cost is also benchmarked against the cost of producing renewable energy, here shown for a wide cost span by grey (extension along horizontal axis is for presentation only; there is no cyclic dependence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

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

Connolly², Iva Ridjan², Brian Vad Mathiesen¹, Peter Sorlacius¹

Denmark

Energy Storage and Smart Energy Systems

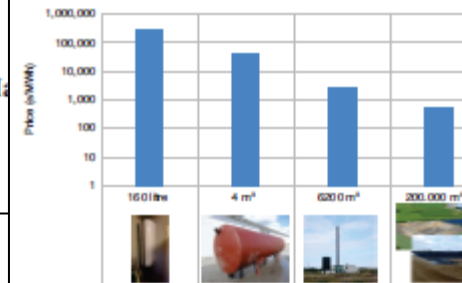


Figure 3: Investment cost comparison of different sizes of thermal energy storage technologies. The sizes correspond to storages for a dwelling, a larger building, a CHP plant and a solar DH system (see Footnote 2). See assumptions, details and references in Appendix 1.

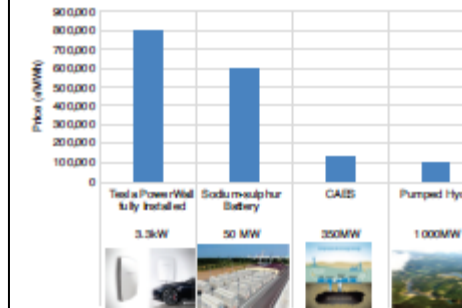


Figure 4: Investment cost comparison of different sizes of electricity energy storage technologies. See assumptions, details and references in Appendix 1.

International Journal of Sustainable Energy Planning and Management

Energy Storage and Smart Energy Systems

Henrik Lund¹, Poul Alberg Østergaard², David Connolly², Iva Ridjan², Brian Vad Mathiesen¹, Frede Hvelplund¹, Jakob Zinck Thellufsen¹, Peter Sorlacius¹

¹Aalborg University, Skovengen 5, 9000 Aalborg, Denmark
²Aalborg University, AC, Meyers Gade 15, 7400 Copenhagen NV, Denmark

ABSTRACT

It is often highlighted how the transition to renewable energy supply calls for significant electricity storage. However, one has to move beyond the electricity-only focus and take a holistic energy system view to identify optimal solutions for integrating renewable energy. In this paper, an integrated cross-sector approach is used to explore the most efficient and least cost storage options for the entire renewable energy system considering both the best storage solution, assessed by fossil-fuel dispatch, focusing on the individual sub-systems. Electricity storage is set as the system solution to integrate large volumes of fluctuating renewable energy, since more efficient and cheaper options can be found by integrating the electricity sector with other parts of the energy system and by also creating a Smart Energy System. Nevertheless, gas does not imply that electricity storage should be disregarded for that it is not needed for other purposes in the future.

Abbreviations:

CAES Compressed air energy storage
CHP Cogeneration of heat and power
NAS Sodium sulphur (Sodium sulphide) battery
PHS Pumped hydro storage

1 Introduction

The transition from a fossil fuel- to a renewable energy-based energy system is a change from utilizing stored energy to supply fluctuating energy sources that must be harvested when available, and either used instantaneously, or stored until the moment of use. Dealing with this basic condition of the ongoing system change, it is often highlighted how a transition into a 100% renewable energy supply or even less ambitious

large-scale integration of renewable energy into the energy system calls for a new magnitude of energy storage. Especially within the electricity supply, a smart grid approach has focused on the need for electricity storage [1–3] in combination with flexible electricity demand and the separation of transmission lines to neighboring areas [4]. Sometimes it is even stated that renewable energy is not a viable option unless electricity can be stored [5]. Similarly, Lorenzelli et al. state "Electrical Energy Storage Systems (ESS) are one of the

¹Corresponding author. Email: henrik.lund@aalborku.dk

Energy Storage Capacities in Denmark

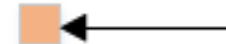
Danish Oil Storage
~50 TWh



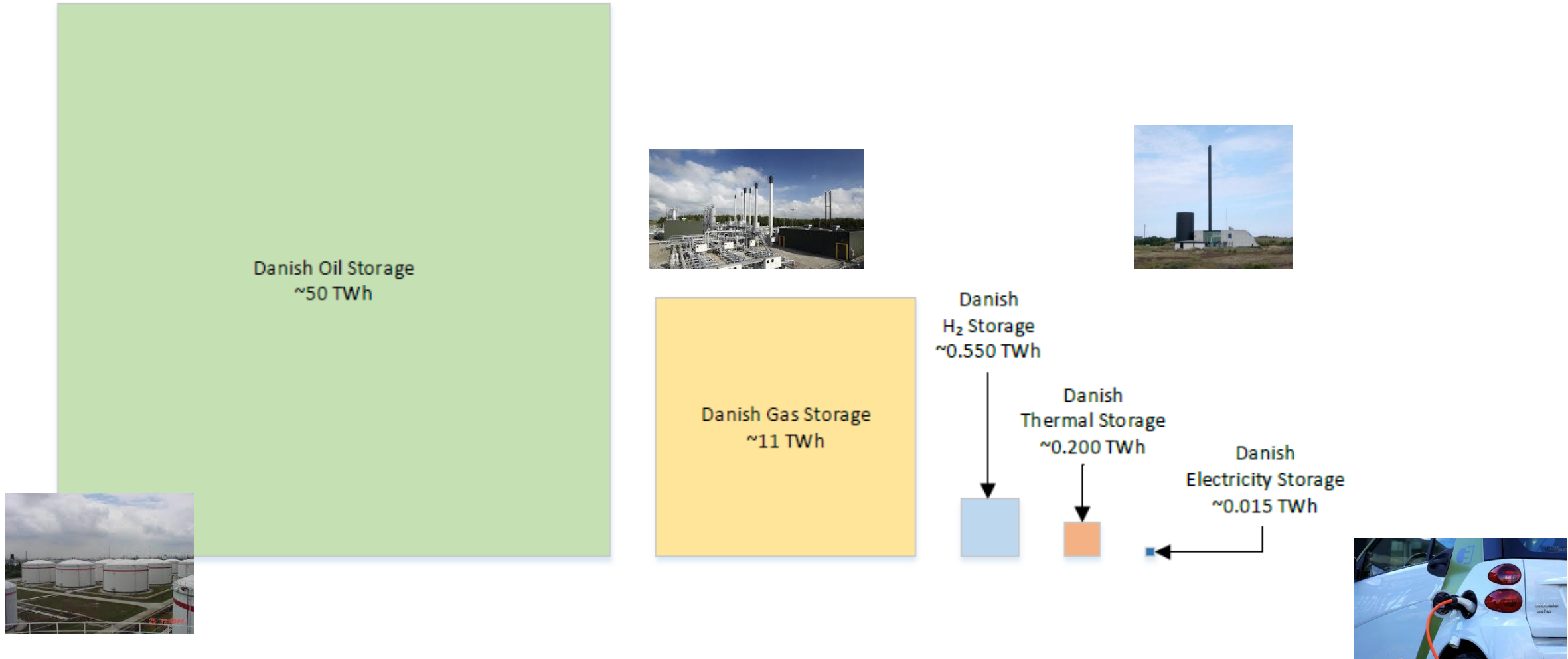
Danish Gas Storage
~11 TWh



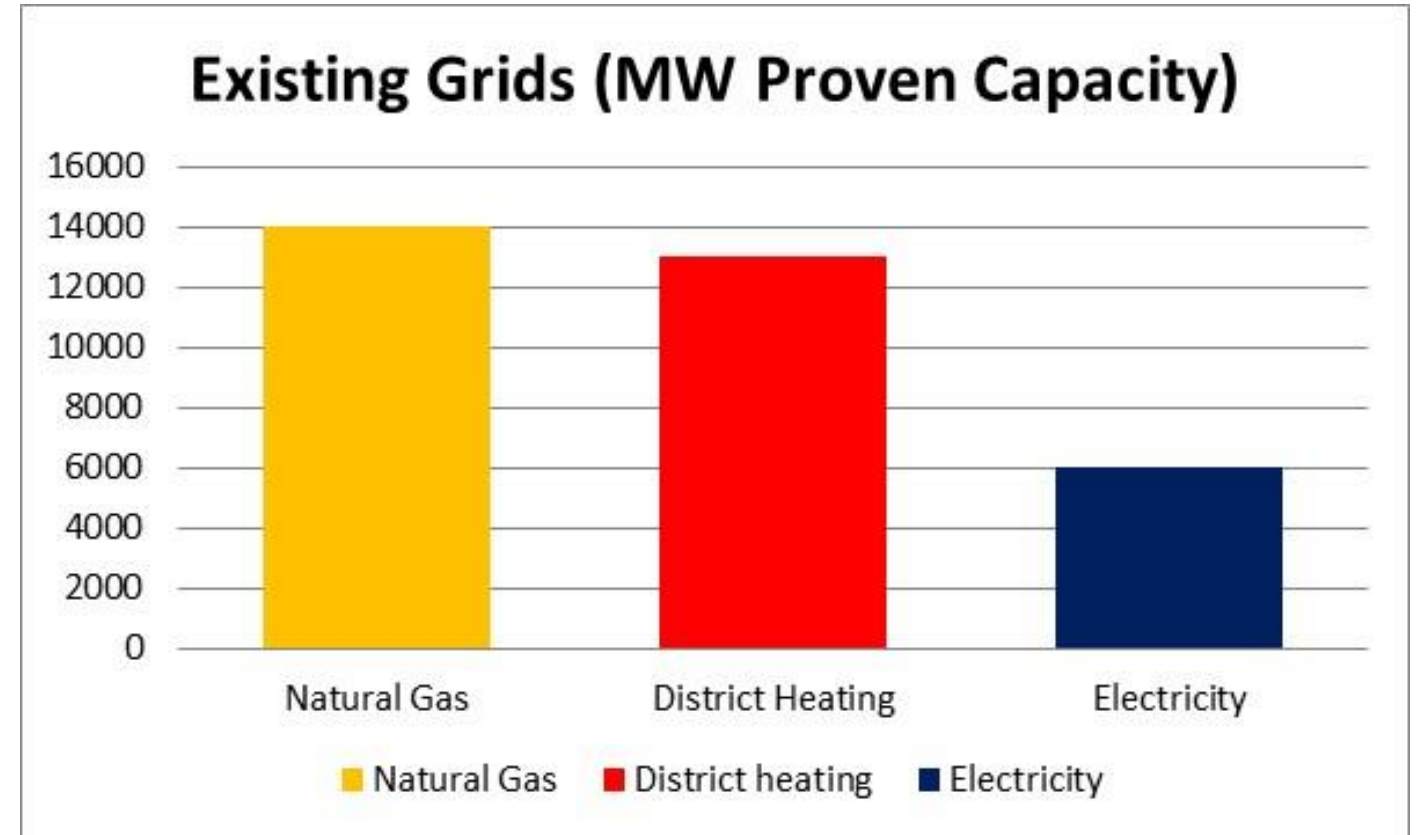
Danish
Thermal Storage
~0.090 TWh

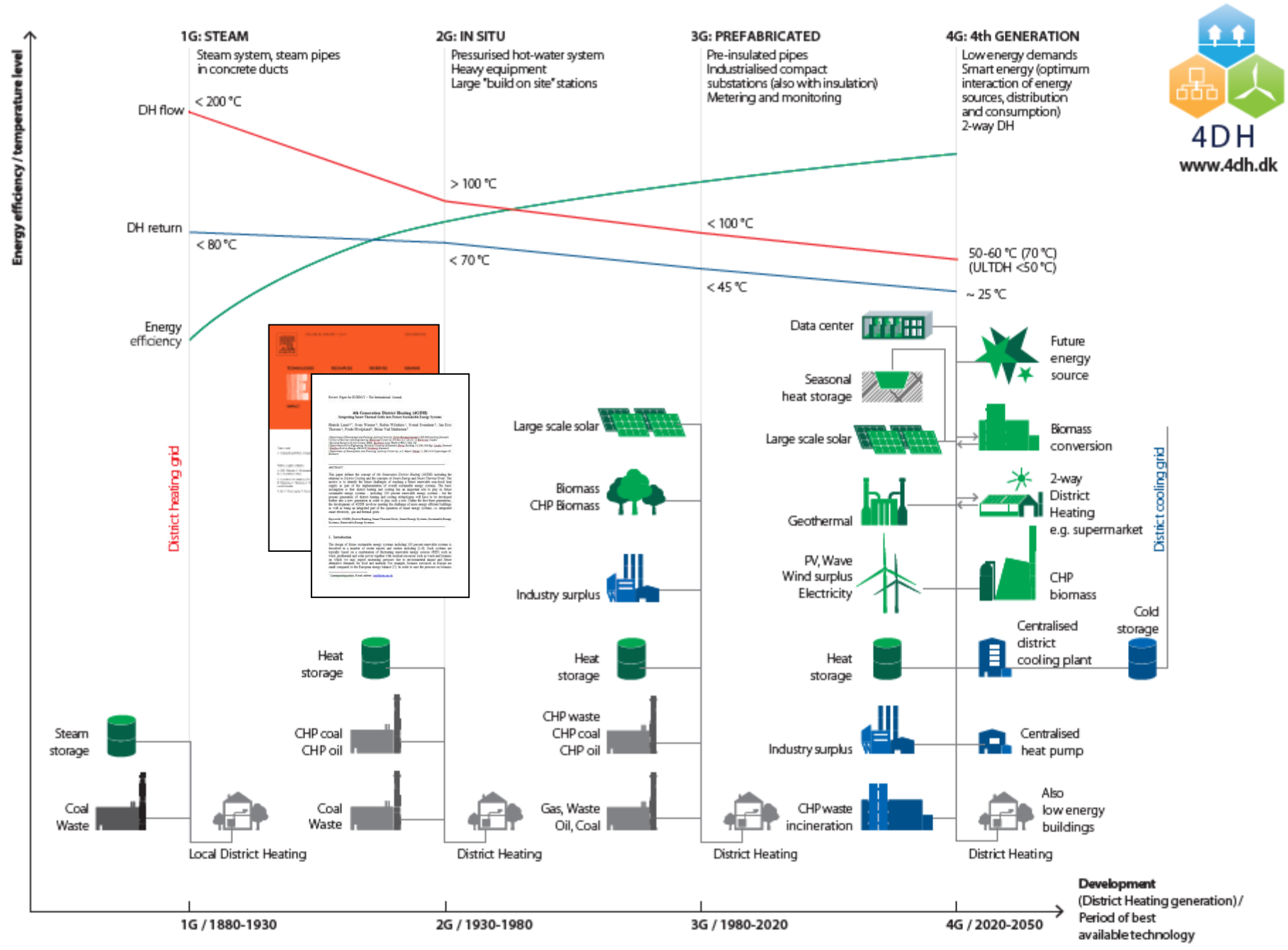


Energy Storage Capacities in 100 % RES Denmark 2050 (IDA)



Existing distribution grids





Heat Roadmap Europe



Heat Roadmap Europe 2050

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 increased to 30% in 2030 and 50% in 2050.**

Logos: EUROHEAT & POWER, AALBORG UNIVERSITY DENMARK, ECOFYS, PlanEnergi



4DH
4th Generation District Heating
Technologies and Systems



HEAT ROADMAP EUROPE 2050
FIRST PRE-STUDY FOR THE EU27

By
Aalborg University
Daniel Connolly
Brian Vaa Mathiesen
Poul Alberg Østergaard
Brend Møller
Steffen Nielsen
Henrik Lund

Halmstad
Urban Persson
Daniel Nilsson
Sven Werner

PlanEnergi
Daniel Trier

For
EUROHEAT & POWER

HEAT ROADMAP EUROPE 2050
SECOND PRE-STUDY FOR THE EU27

By
Aalborg University
Daniel Connolly
Brian Vaa Mathiesen
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Brend Møller
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Halmstad University
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Sven Werner

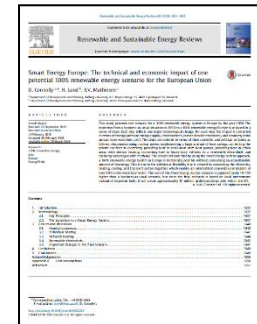
Ecofys Germany GmbH
Jan Gröninger
Thomas Boermans
Michelle Bosquet

PlanEnergi
Daniel Trier

For
EUROHEAT & POWER




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



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

 CrossMark

ARTICLE INFO **ABSTRACT**

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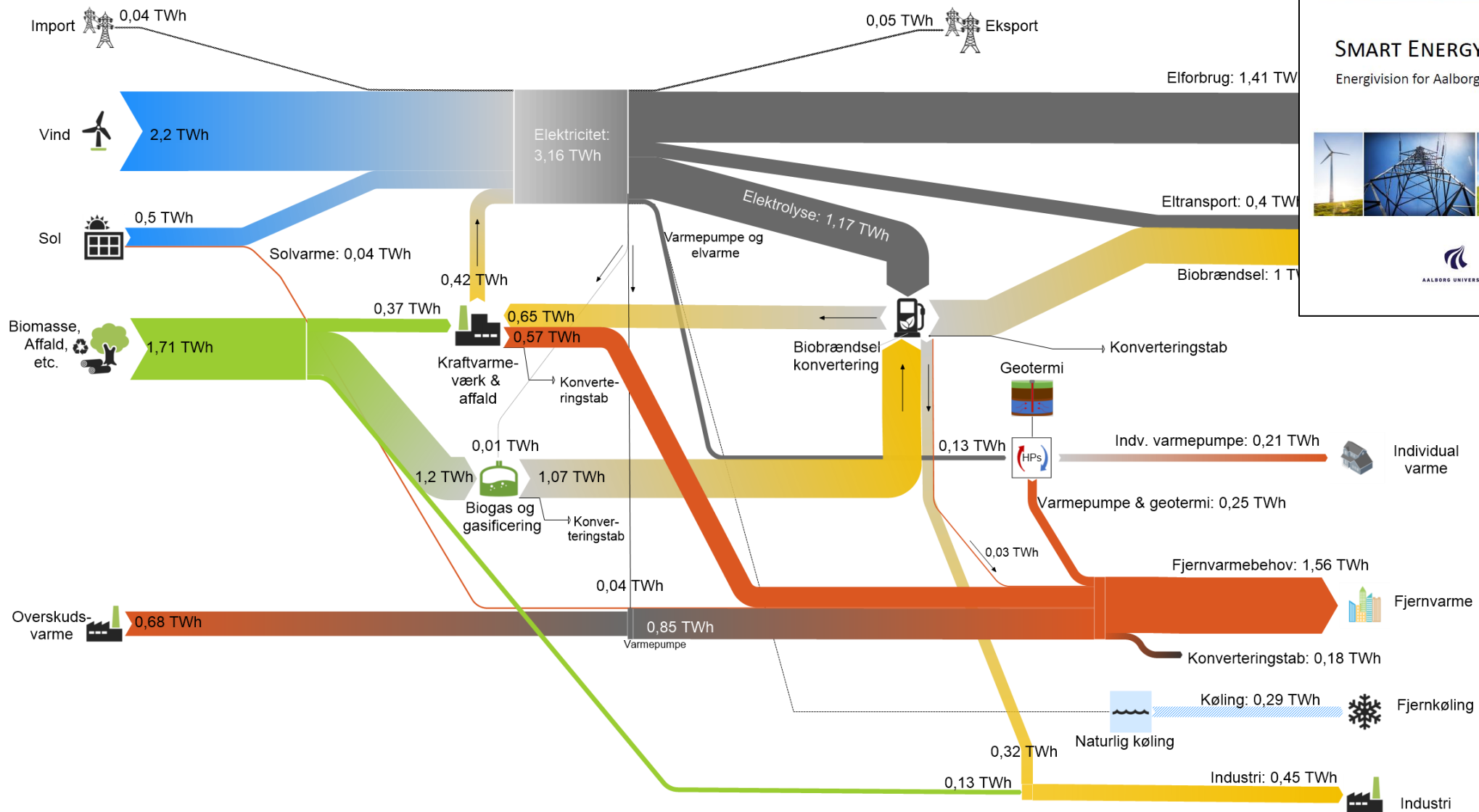
This study presents one scenario for a 100% renewable energy system transition from a business-as-usual situation in 2050, to a 100% renew

www.EnergyPLAN.eu/SmartEnergyEurope

- Report Online
- Paper Published



Vision: Smart Energy Aalborg 2050

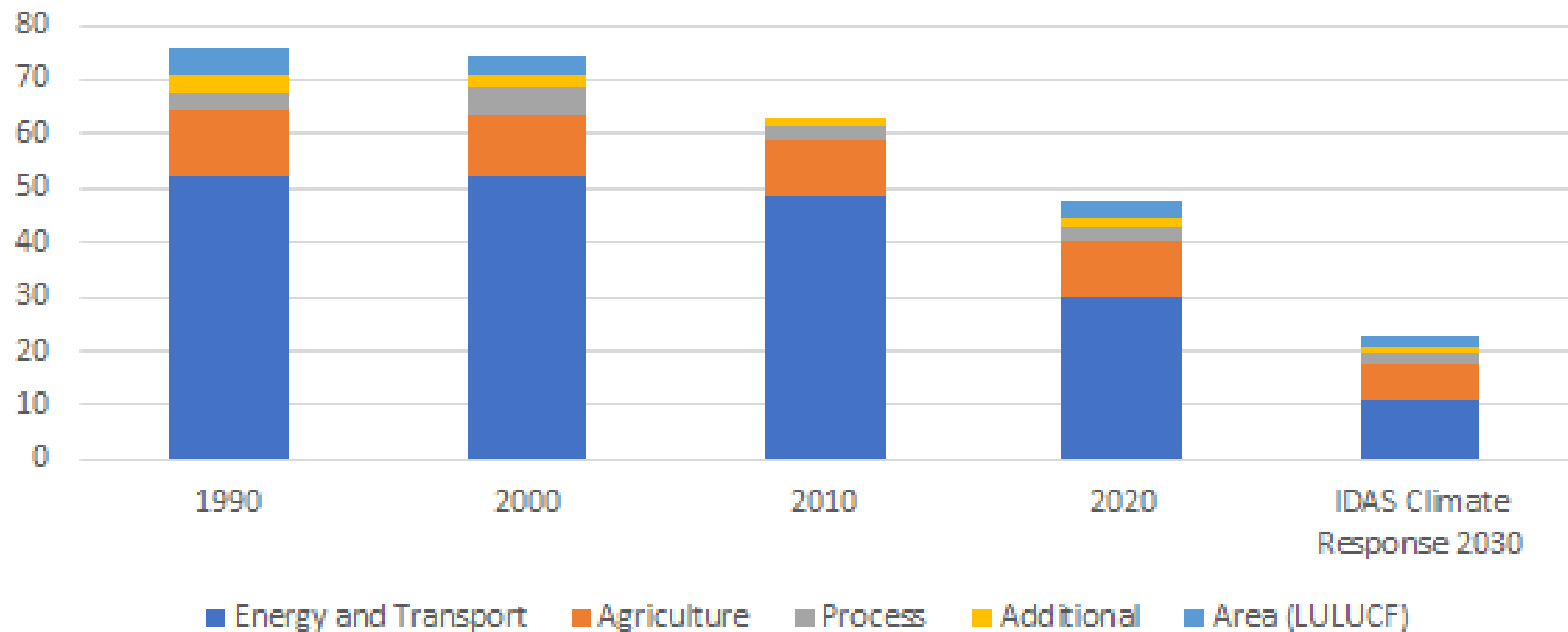


SMART ENERGY AALBORG

Energivision for Aalborg Kommune 2050



Danish CO2 emission - UN-accounting (Mt/year)

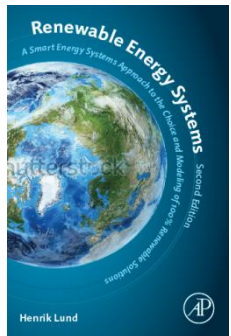
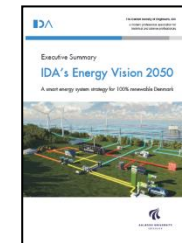


IDAs Climate Response: In a European context

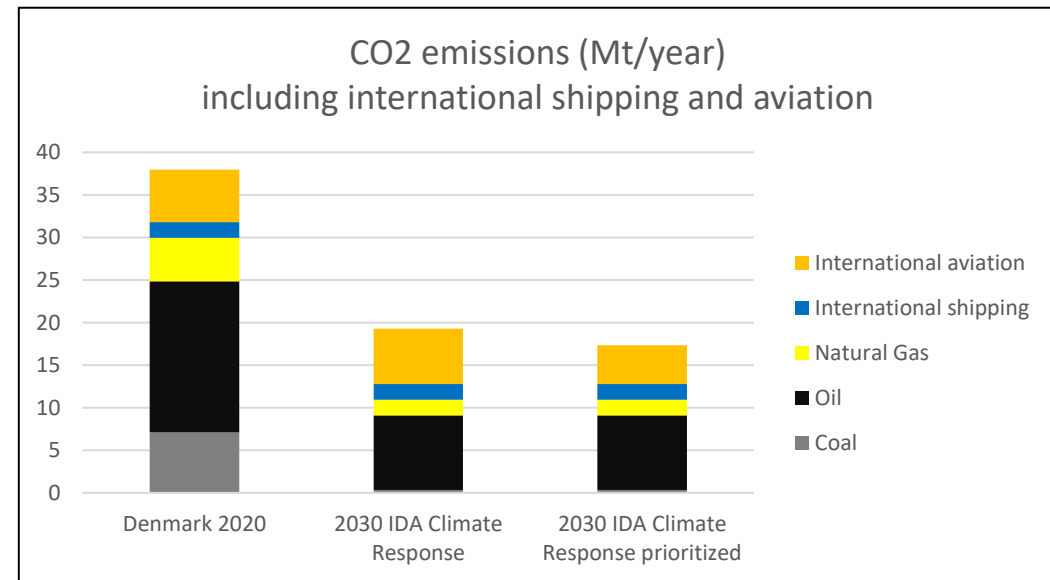
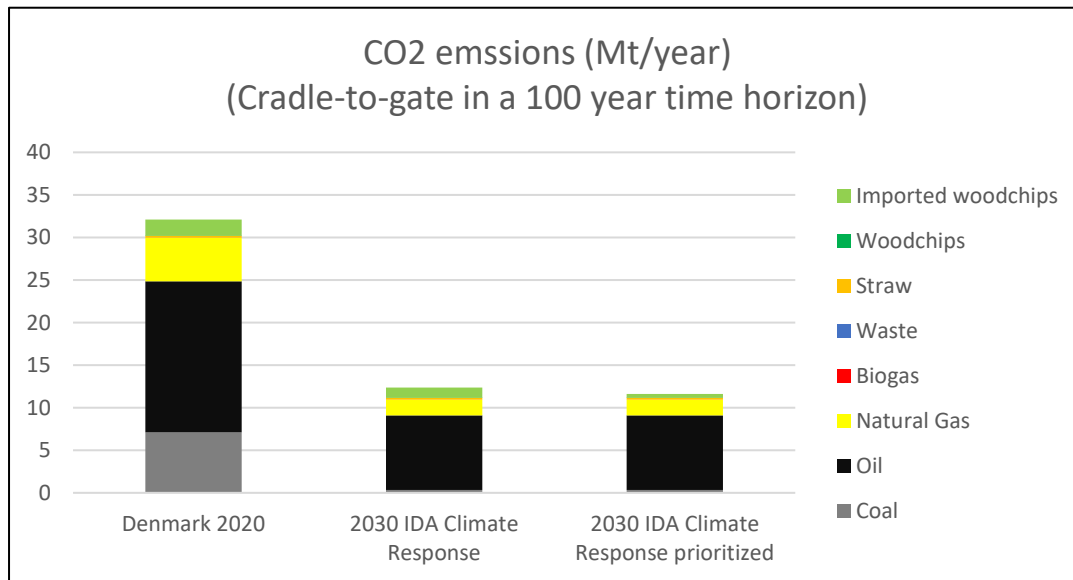
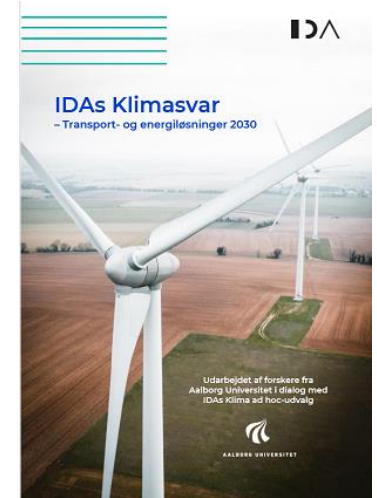
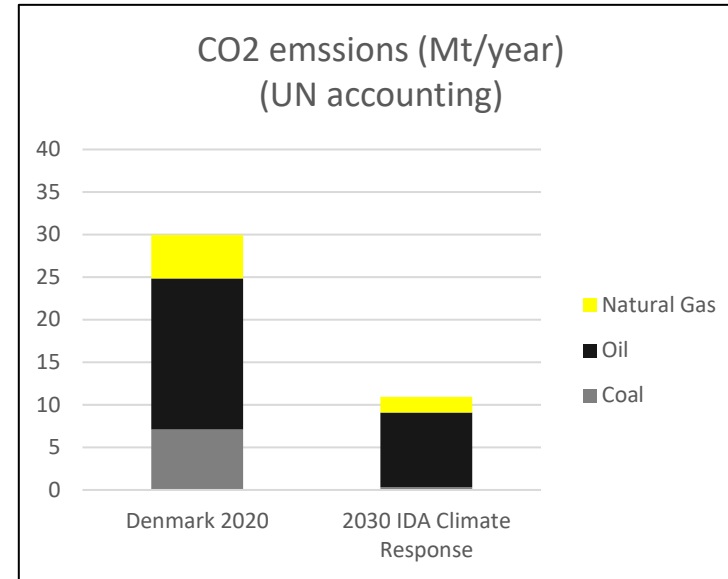
Denmark should fulfill its objective of renewable energy and CO₂-reductions in a way, so it fits well into a context in which the rest of Europe - and the world - will do the same.

Therefore:

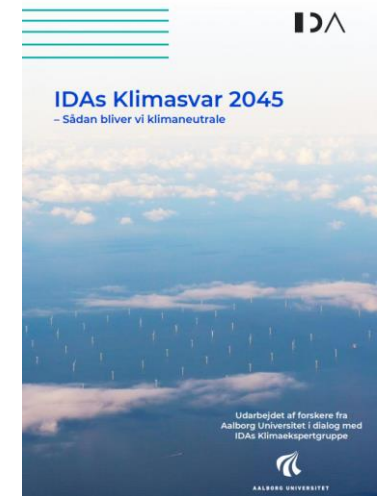
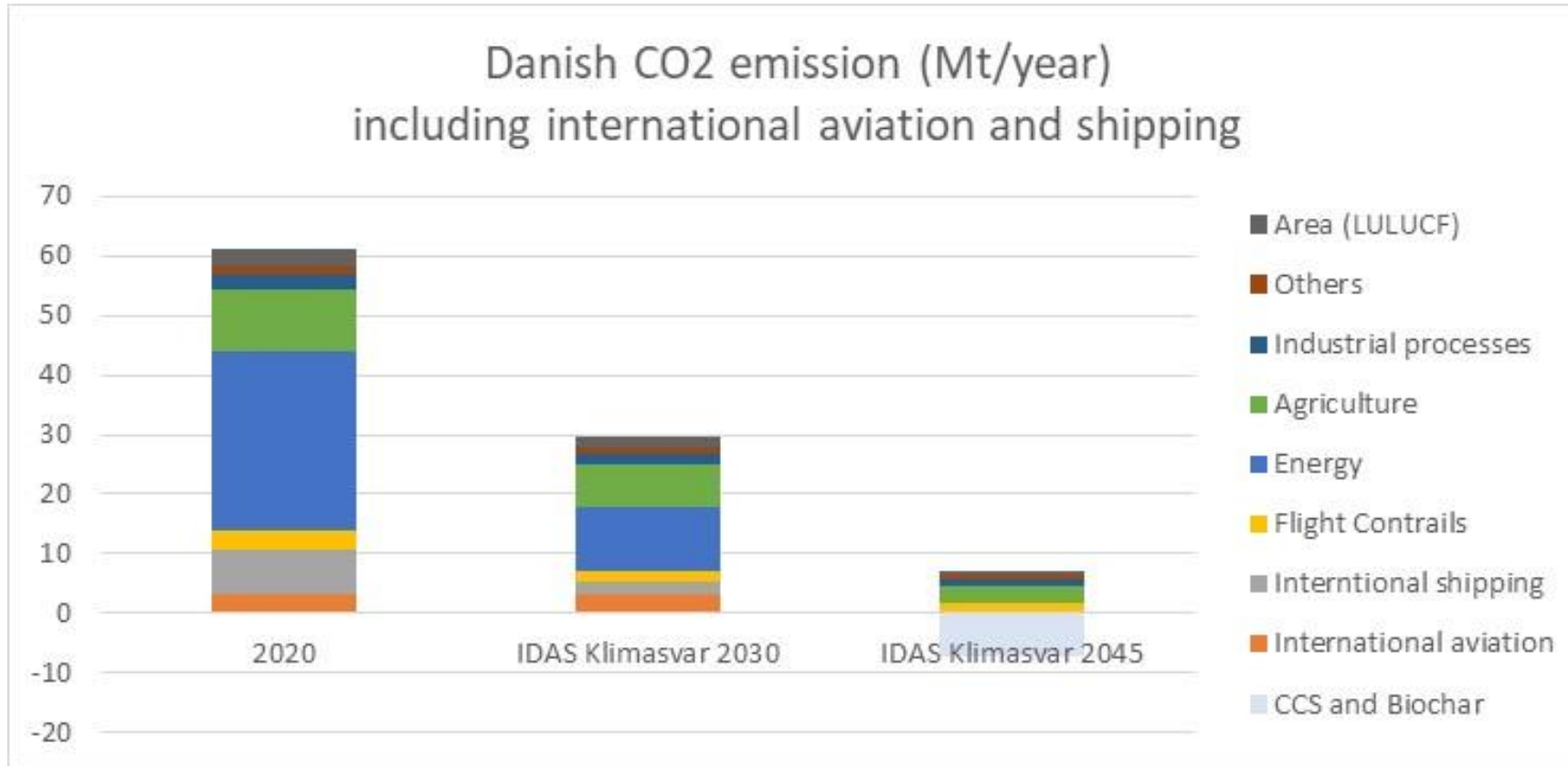
- Denmark should include the Danish share of **international aviation and shipping** even though it is not included yet in the UN way of calculating the Danish CO₂ emissions.
- Denmark should not exceed our share of **sustainable use of biomass** in the world.
- Denmark should make our contribution in terms of **flexibility and reserve capacity** to integrate wind and solar into the **European electricity supply**.



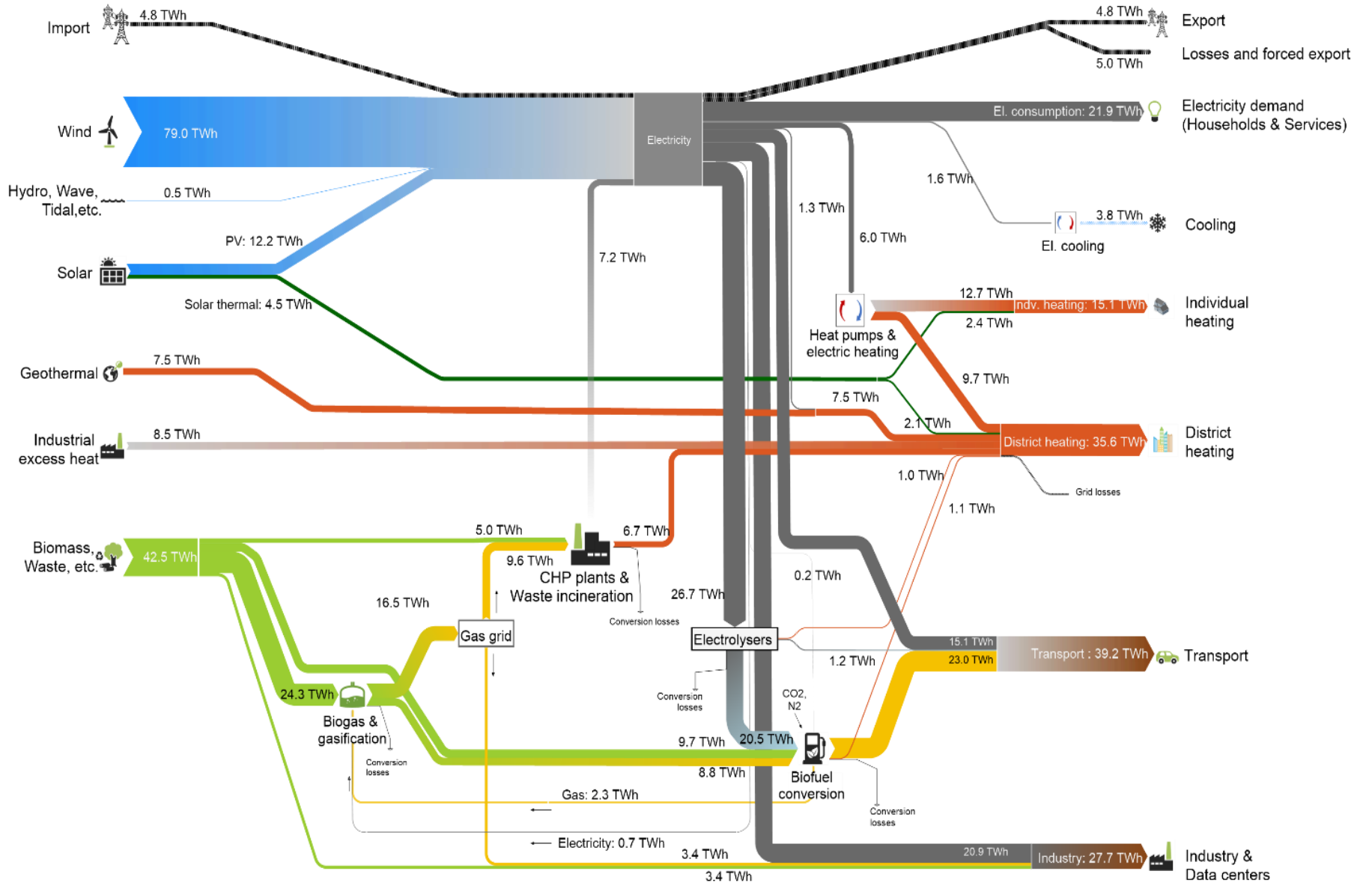
CO2 emissions in the UN accounting...



A fully decarbonized Denmark 2045



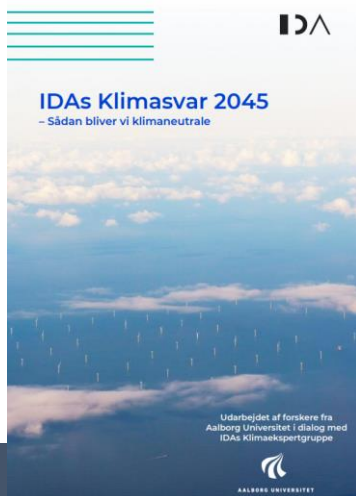
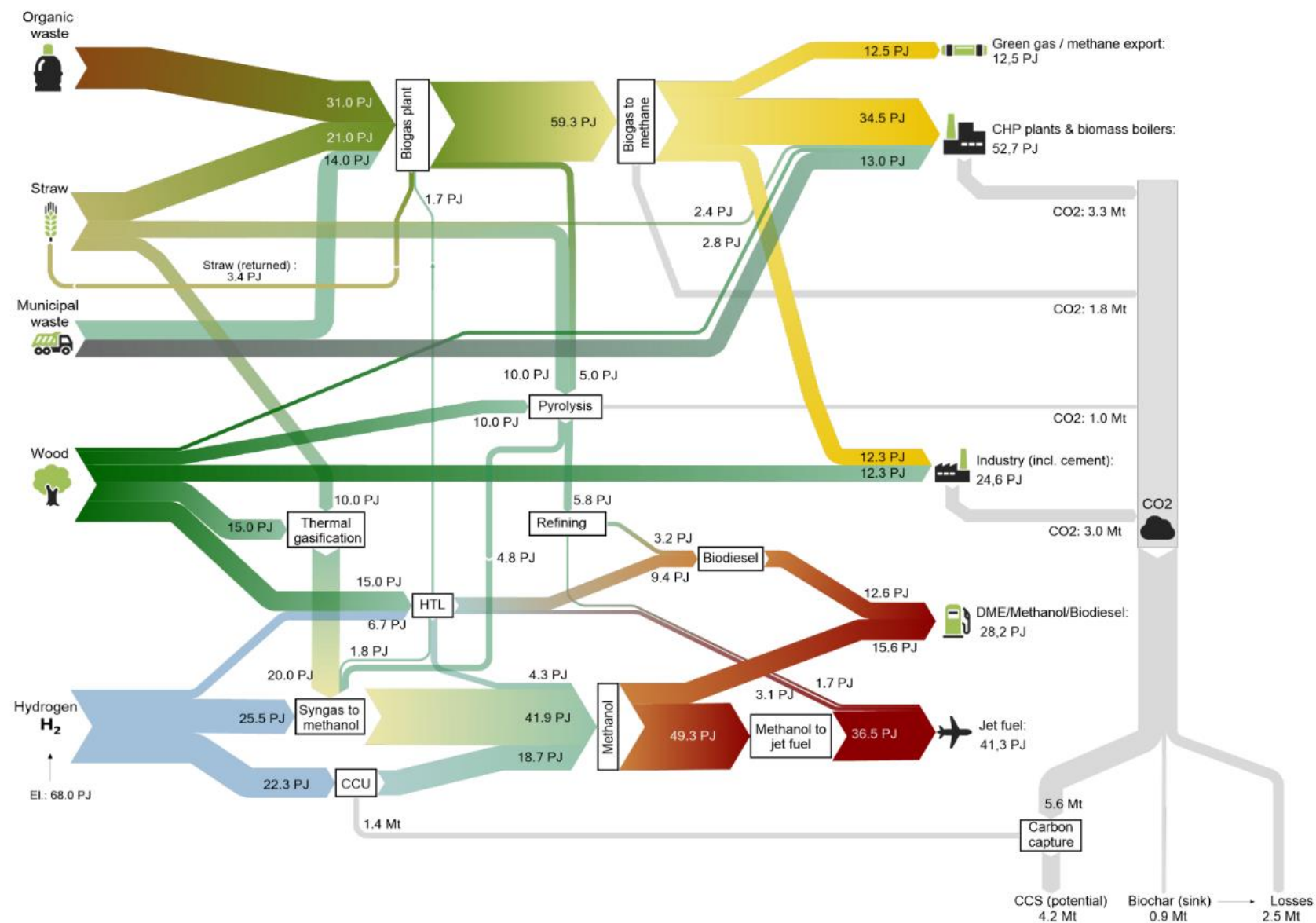
2045



Biomasse 2045

Overview:

**(153 PJ minus
eksport 13 PJ =
140 PJ svarende
til 23 GJ/capita)**



Biomass conversion incl. HTL and Pyrolysis

EnergyPLAN 16.0: Reference_oil.txt

Home Add-On Tools Help

Forum Training Documentation FIDE Guide Warnings Error Messages About

Warnings Appear Here:

Overview

- Demand
 - Electricity
 - Heating
 - Cooling
 - Industry and Fuel
 - Transport
 - Desalination
- Supply
 - Heat and Electricity
 - Central Power Production
 - Variable Renewable Ele
 - Heat Only
 - Fuel Distribution
 - Waste
 - Liquid and Gas Fuels
 - Biofuels
 - Biogases
 - Hydrogen
 - Electrofuels
 - HTL and Pyrolysis**
 - CO2
 - Balancing and Storage
 - Cost
 - Simulation
 - Output

HTL: Hydrothermal Liquifaction

Fuel input	TWh/year	Efficiency (TWh/TWh)	Outputs TWh/year
Hydrogen	0,00	0,446	H2/bio input
Biomass:	<input type="text" value="0"/>	0,205	JP/bio input
Waste:	<input type="text" value="0"/>	0,678	BioDiesel/bio input
Total:	0,00	0,288	Methanol/bio input
		0,081	Bio Petrol/bio input
		0,119	Gas/bio inpi
		0,162	DH Gr 3/bio
		0,112	Biogas/bio i

Pyrolysis

Fuel Input	TWh/year	Efficiency (TWh/TWh)	Outputs
Biomass:	<input type="text" value="0"/>	0,19	Syngas/bio
Waste:	<input type="text" value="0"/>	0,08	JP/bio input
From Biogas:	0,00	0,15	Bio Diesel/b
Total:	0,00	0,4	Bio char/bio

Biomass conversion plants

Biogas Plant Biogas Biogas production is used as Primary Energy Consumption

Input TWh/year								Output TWh/year				
Dry Biomass	Wet Biomass	Electricity	Input from HTL	DH gr.1	DH gr. 2	DH gr.3	Output to Pyrolysis	Biogas	Output to Methanation Pyrolysis	Upgrade to grid Efficiency	Input to Gas Grid TWh/year	
<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0,00"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0,00"/>	<input type="text" value="0,00"/>	<input type="text" value="0,00"/>	
<input type="button" value="Change distribution"/> const.txt								<input type="button" value="Change distribution"/> const.txt				

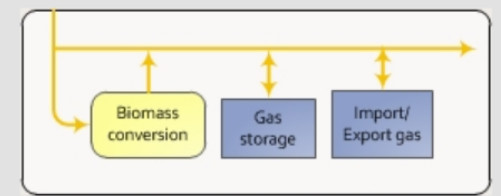
Gasification Plant

Biomass TWh/year	Electricity Share %)	Steam Share %)	Steam Efficiency **)	Coldgas Efficiency	Gas Output Capacity Average MW-Gas	Max Cap MW-Gas	DH gr.3 Share %)	Output TWh/year DH gr.3	Hydrogen Syngas	HTL and Pyrolysis Syngas demand	Upgrade to grid Efficiency	Input to Gas Grid TWh/year
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*) Share in relation to biomass input

**) Defined as steam output divided by biomass input (subtracted in biomass input)

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Literature:

- Smart Energy Denmark. A consistent and detailed strategy for a fully decarbonized society. [Renewable and Sustainable Energy Reviews](#)
- Smart Energy Europe: [The technical and economic impact of one potential 100% renewable energy scenario for the European Union](#). [Renewable and Sustainable Energy Reviews, Vol 60](#), pp. 1634–1653, July 2016.
- The role of sustainable bioenergy in a fully decarbonised society. [Renewable Energy](#), August 2022, <https://doi.org/10.1016/j.renene.2022.06.026>
- [Energy efficient decarbonisation strategy for the Danish transport sector by 2045](#), Smart Energy, February 2022. <https://doi.org/10.1016/j.segy.2022.100063>



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

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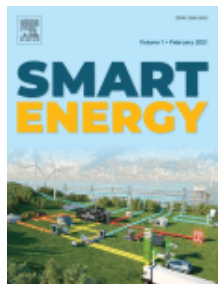
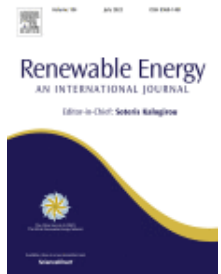
ABSTRACT

This study presents one scenario for a 100% renewable energy system in Europe by the year 2050. The transition from a business-as-usual situation in 2005 to a 100% renewable energy Europe is analysed in a series of steps. Each step reflects one major technological change. For each step, the impact is presented in terms of energy (primary energy supply), environment (carbon dioxide emissions), and economy (total annual socio-economic cost). The steps are ordered in terms of their scientific and political certainty as follows: decommissioning nuclear power, implementing a large amount of heat savings, converting the private car fleet to electric, providing heat in rural areas with heat pumps, providing heat in urban areas with district heating, converting fuel in heavy-duty vehicles to a renewable electrofuel, and replacing natural gas with methane. The results indicate that by using the Smart Energy System approach, a 100% renewable energy system in Europe is technically possible without consuming an unreasonable amount of bioenergy. This is due to the additional flexibility that is created by connecting the electricity, heating, cooling, and transport sectors together, which enables an interannual renewable penetration of over 80% in the electricity sector. The cost of the Smart Energy Europe scenario is approximately 10–15% higher than a business-as-usual scenario, but since the final scenario is based on local investments instead of imported fuels, it will create approximately 30 million additional direct jobs within the EU. © 2016 Elsevier Ltd. All rights reserved.

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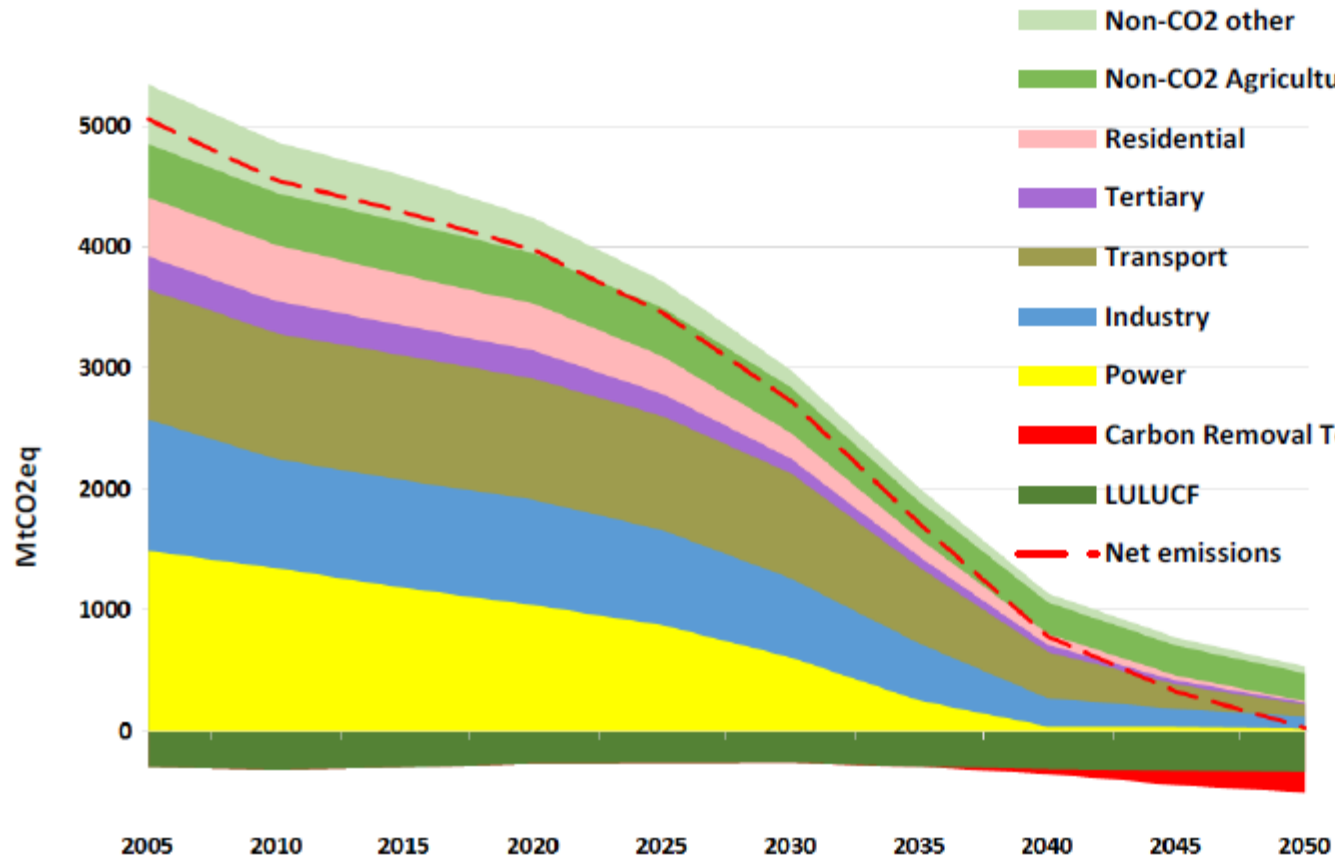
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E-mail address: denny@jan.aau.dk (D. Connolly).
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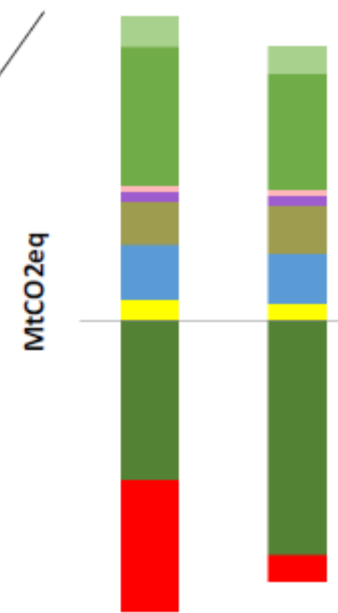
A Clean Planet for all

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

Climate Neutral



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



Long Term Strategy Options

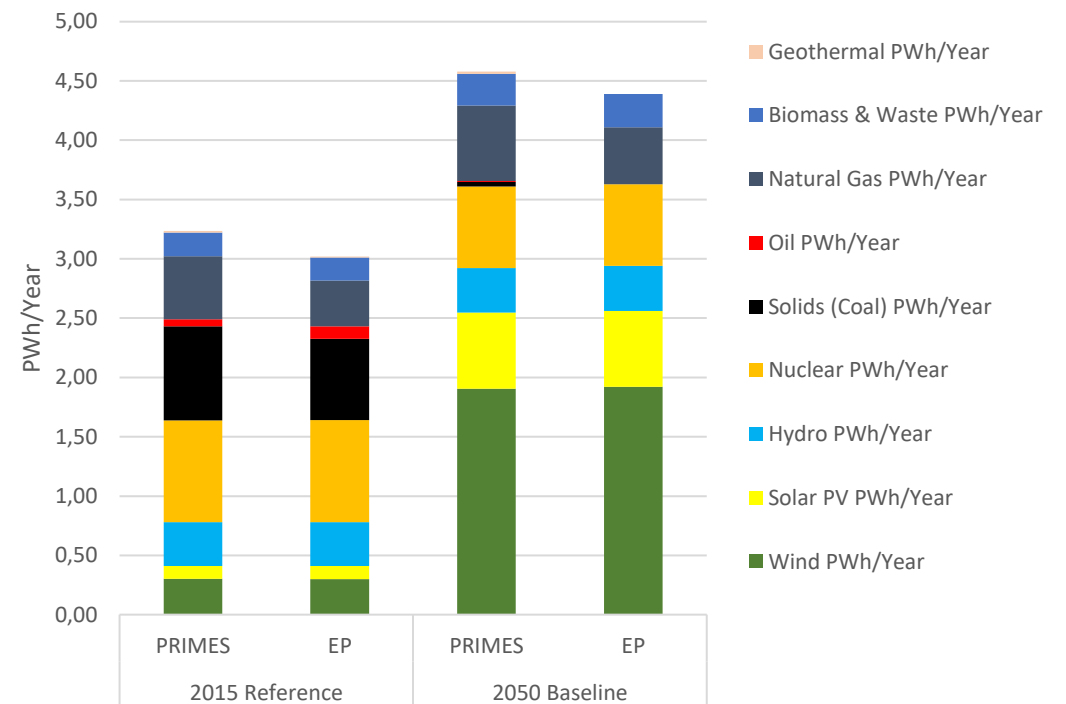
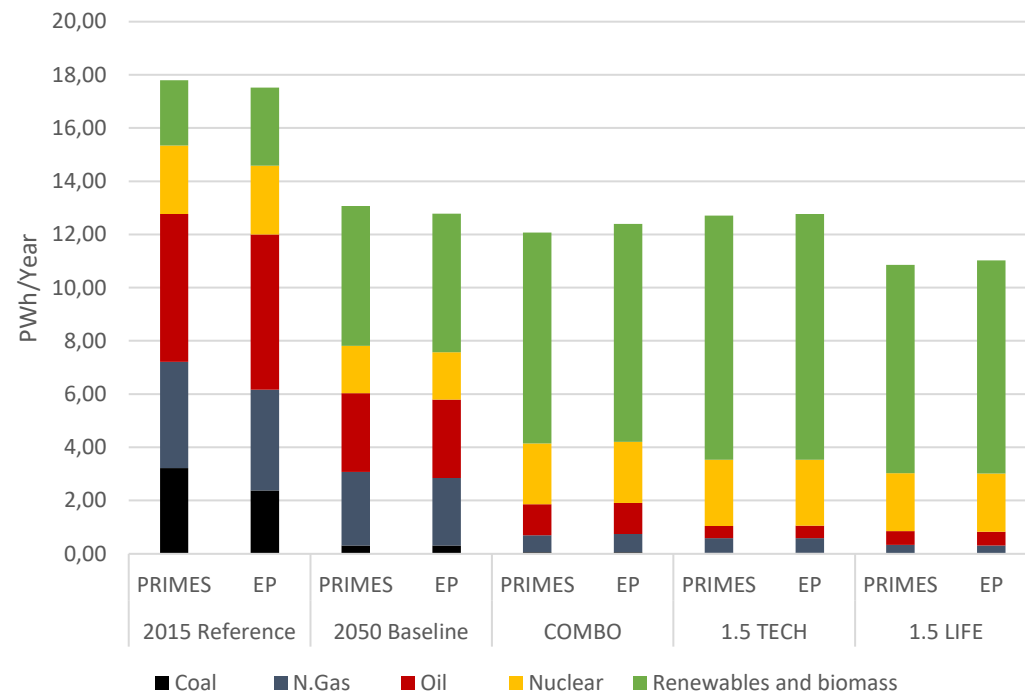
	Electrification (ELEC)	Hydrogen (H2)	Power-to-X (P2X)	Energy Efficiency (EE)	Circular Economy (CIRC)	Combination (COMBO)	1.5°C Technical (1.5TECH)	1.5°C Sustainable Lifestyles (1.5LIFE)
Main Drivers	Electrification in all sectors	Hydrogen in industry, transport and buildings	E-fuels in industry, transport 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	<ul style="list-style-type: none"> Higher energy efficiency post 2030 Deployment of sustainable, advanced biofuels Moderate circular economy measures Digitilisation 				<ul style="list-style-type: none"> 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			<ul style="list-style-type: none"> 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



Our replication



Long Term Strategy Options								
	Electrification (ELEC)	Hydrogen (H2)	Power-to-X (P2X)	Energy Efficiency (EE)	Circular Economy (CE)	Combination (COMBO)	1.5°C Technical (1.5TECH)	1.5°C Sustainable (1.5SUST)
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 CE with lifestyle changes
GHG target in 2050	-80% GHG (excluding sinks) (Trend below 2°C emission)					-90% GHG (incl. sinks)		-100% GHG (incl. sinks) (Trend below 2°C emission)
Major Common Assumptions	<ul style="list-style-type: none"> Higher energy efficiency post 2030 Deployment of sustainable, advanced biofuels Moderate circular economy measures Digitalisation 					<ul style="list-style-type: none"> 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	(demand-side response)		Power is nearly decarbonised by 2050. Strong penetration of RES facilitated by system optimization (storage, interconnections, risk of procurement). 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 (including CE)	COMBO but stronger	CE+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		COMBO but stronger	CE+COMBO but stronger
Transport sector	Factor 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		COMBO but stronger	CE+COMBO but stronger
Other Drivers		H2 in gas distribution grid	E-gas in gas distribution grid				Limited enhancement natural sink	Dietary changes * Enhancement natural sink



Stepwise implementation of smart energy systems

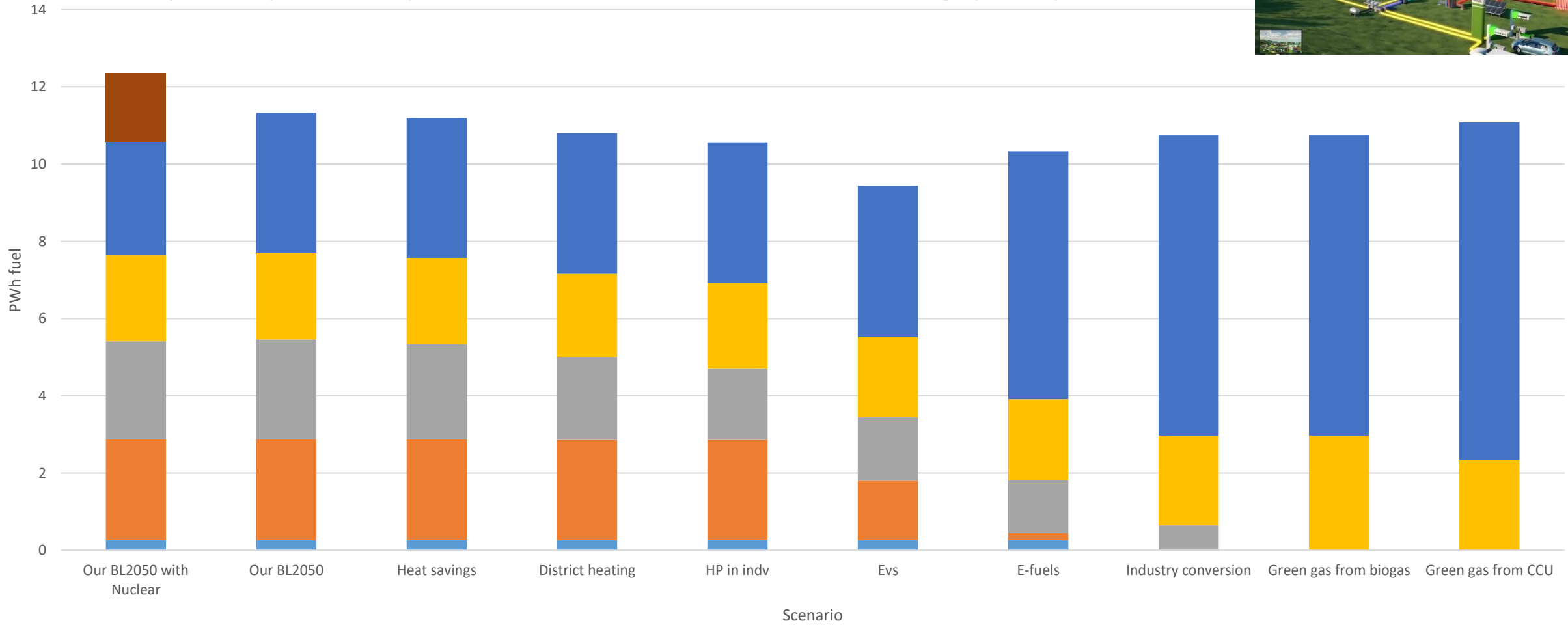
1. Specify reference scenario. PRIMES 2050 Business as Usual is used as a reference. Here a starting point with and without nuclear is discussed.
2. Energy savings in the different demand sectors
3. Implementation of district heating
4. Transition individual heating
5. Electrification of transport
6. E-fuels in transport
7. Replacing remaining fossil fuel with biofuels, biogas, e-gas and e-fuels



Increase renewable energy production



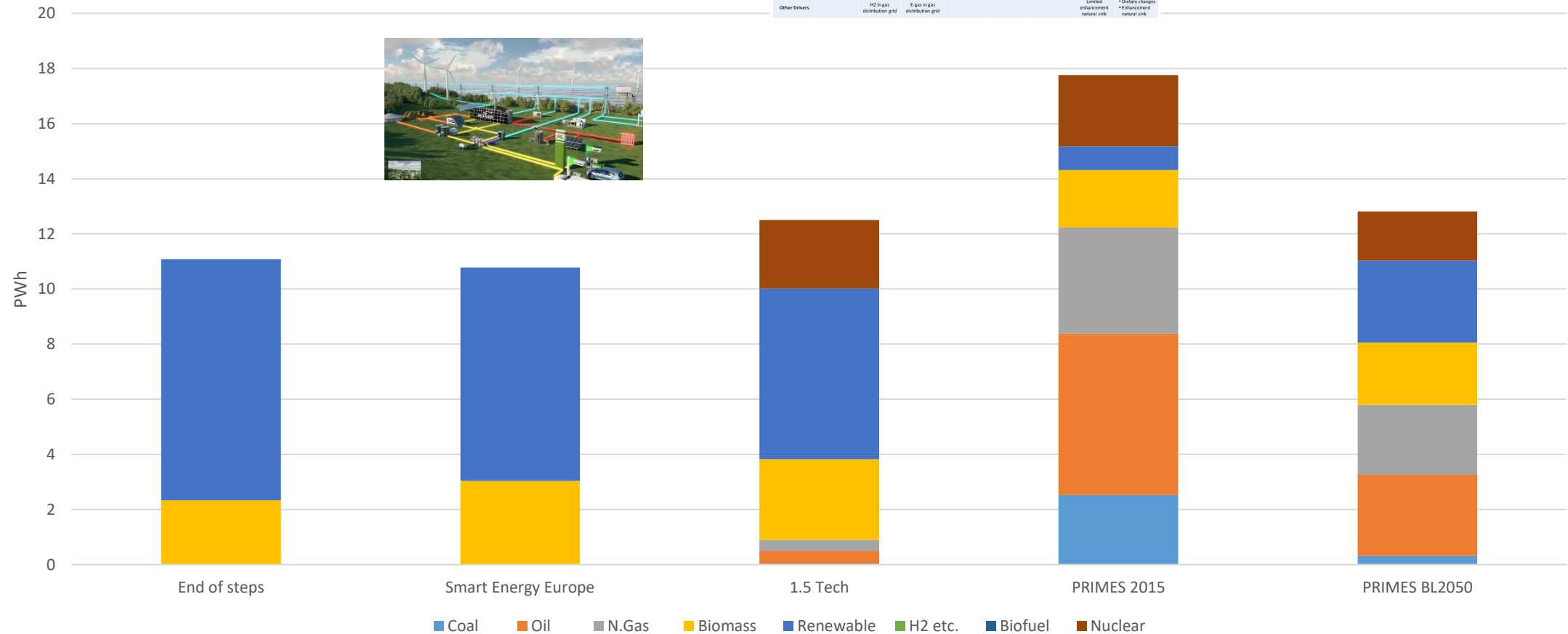
Step by step to a smart energy system



Energy balance

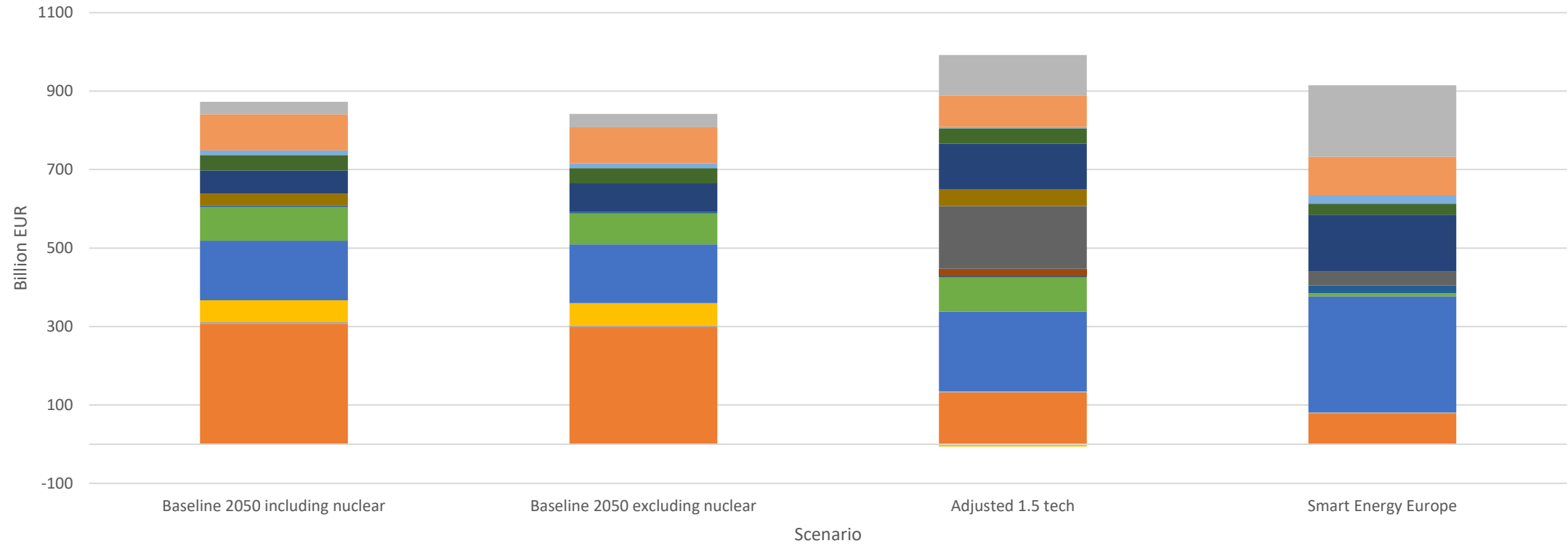
Long Term Strategy Options								
	Electrification (E1CC)	Hydrogen (H2)	Power-to-X (P2X)	Energy Efficiency (E2)	Circular Economy (CE)	Combination (COMBO)	1.5°C Technical (1.5TCH)	1.5°C Sustainable (1.5TSC)
Main Drivers	Electrification in all sectors	Hydrogen in industry, transport and buildings	E-fuels 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 CE with lifestyle changes
GHG target in 2050	80% GHG (excluding sinks) (well below 2°C emissions)			90% GHG (incl. sinks)		100% GHG (incl. sinks) (2.5°C emissions)		
Major Common Assumptions	<ul style="list-style-type: none"> Higher energy efficiency post 2030 Deployment of sustainable, advanced biofuels Moderate circular economy measures Digitisation 			<ul style="list-style-type: none"> Market coordination for infrastructure deployment BECCS present only post 2050 in 2°C scenario 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 producers). 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 (including 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		COMBO but stronger	CIRC+COMBO but stronger
Transport sector	Factor 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			<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> Dietary changes Enhancement natural sink

BAU Baseline



Costs

Long Term Strategy Options										
Classification	Hydrogen	Power-to-gas	Renewable energy	Climate	Construction	Energy	Energy	Energy	Energy	Energy
Main Objectives	Hydrogen in transport and buildings	Power-to-gas in transport and buildings	Renewable energy in transport and buildings	Climate	Construction	Energy	Energy	Energy	Energy	Energy
Key Messages	Hydrogen in transport and buildings	Power-to-gas in transport and buildings	Renewable energy in transport and buildings	Climate	Construction	Energy	Energy	Energy	Energy	Energy
Major Considerations	Hydrogen in transport and buildings	Power-to-gas in transport and buildings	Renewable energy in transport and buildings	Climate	Construction	Energy	Energy	Energy	Energy	Energy
Policy Sector	Hydrogen in transport and buildings	Power-to-gas in transport and buildings	Renewable energy in transport and buildings	Climate	Construction	Energy	Energy	Energy	Energy	Energy
Industry	Hydrogen in transport and buildings	Power-to-gas in transport and buildings	Renewable energy in transport and buildings	Climate	Construction	Energy	Energy	Energy	Energy	Energy
Buildings	Hydrogen in transport and buildings	Power-to-gas in transport and buildings	Renewable energy in transport and buildings	Climate	Construction	Energy	Energy	Energy	Energy	Energy
Transport sector	Hydrogen in transport and buildings	Power-to-gas in transport and buildings	Renewable energy in transport and buildings	Climate	Construction	Energy	Energy	Energy	Energy	Energy
Other Drivers	Hydrogen in transport and buildings	Power-to-gas in transport and buildings	Renewable energy in transport and buildings	Climate	Construction	Energy	Energy	Energy	Energy	Energy



- Electricity import
- Fuel
- V O&M
- CO2
- Fixed O&M
- Electricity grid
- District heating grid
- Additional transport costs
- Energy savings
- Nuclear
- Renewables
- Power plants
- District heating supply
- Individual heating
- Remaining investment

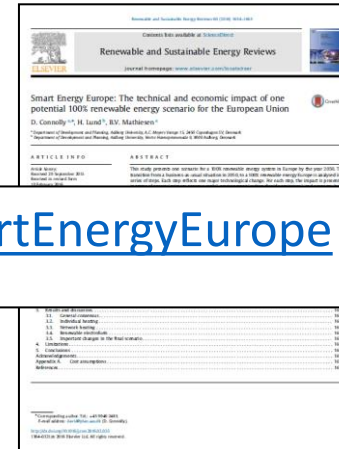
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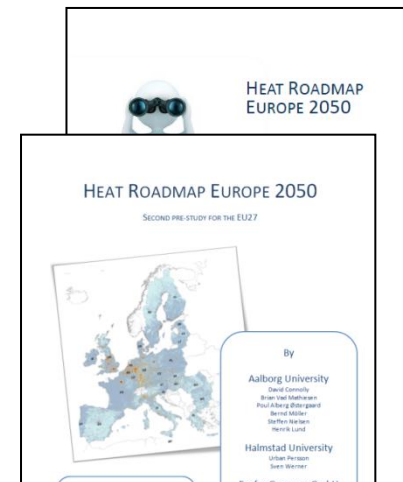


More information:

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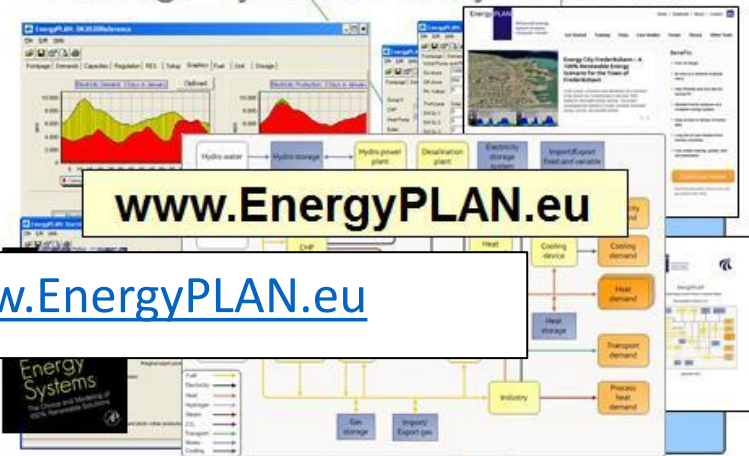
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www.heatroadmap.eu



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