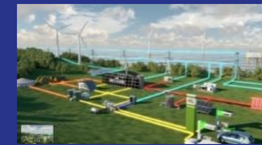
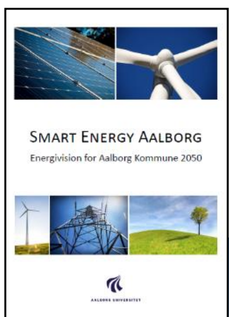
sdewes | 14th CONFERENCE ON SUSTAINABLE DEVELOPMENT OF ENERGY, WATER AND ENVIRONMENT SYSTEMS

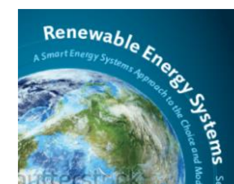


4DH
4th Generation District Heating Technologies and Systems

100% Renewable Smart Energy Systems



Henrik Lund
Professor in Energy Planning
Aalborg Universitet



Heat Roadmap Europe

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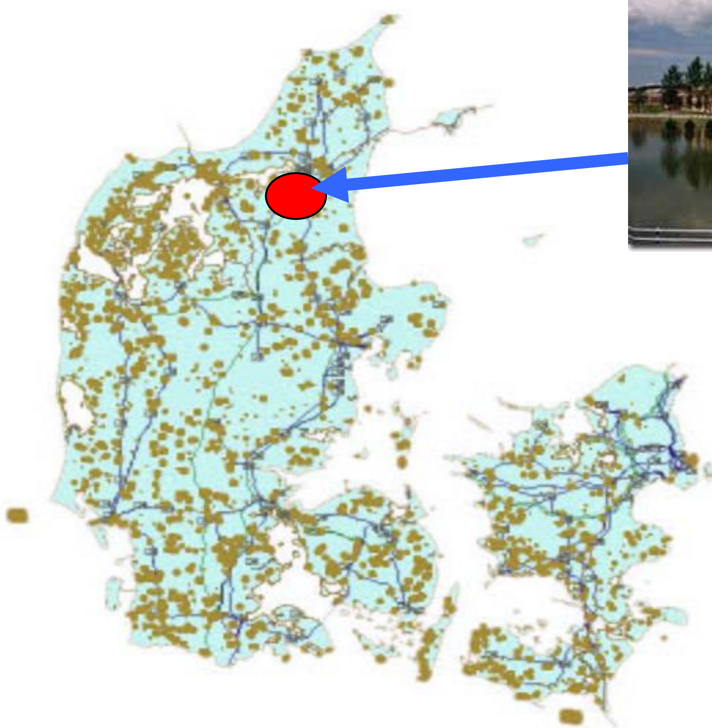
reINVEST

CITIES
Centre for IT Intelligent Energy Systems

Aalborg University, Denmark



Jutland/Denmark:

- > 40% wind power (local owners)
- High share of the world's offshore power
- 30% Distributed Generation
- 50% of electricity supplied by CHP
- >50% District Heating
- 10% of Natural Gas produced from Biogas

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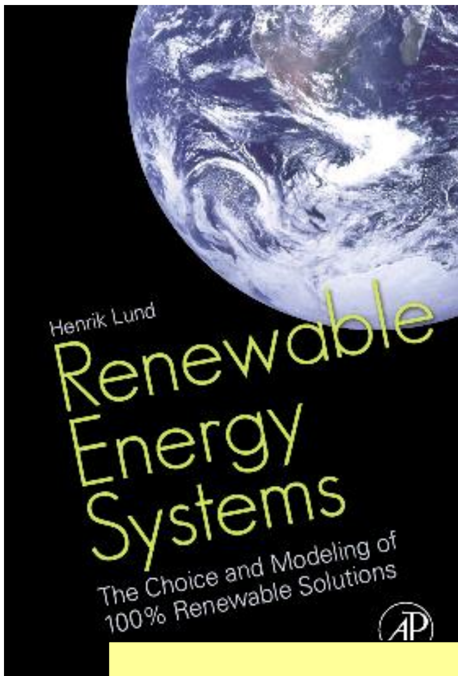
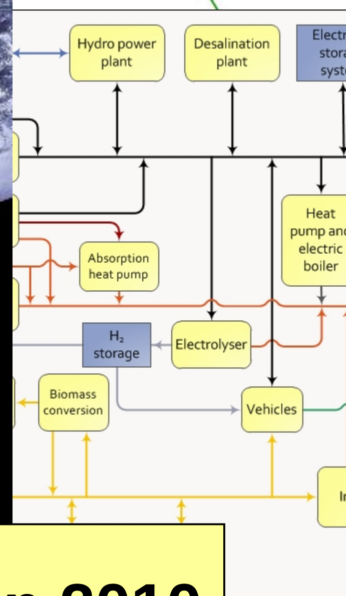
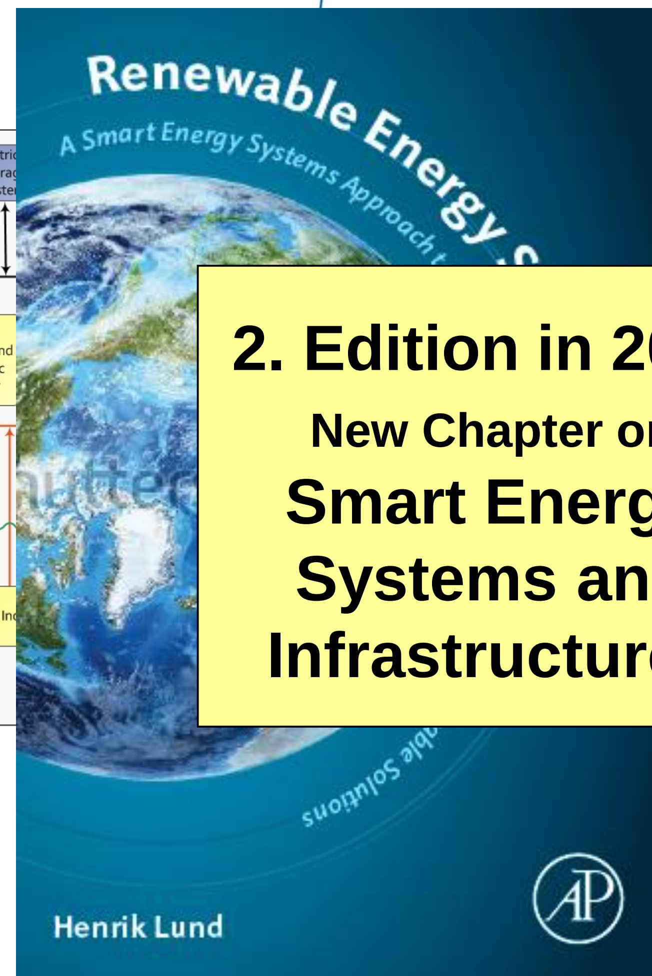
Renewable Energy Systems

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

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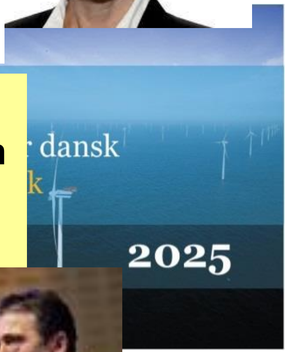
The long-term Objective of Danish Energy Policy

Expressed by former Prime Minister Anders Fogh Rasmussen in his opening speech to the Parliament in 2006 and in several political agreements since then:

To convert to 100% Renewable Energy



Prime minister 16 November 2008:
”We will free Denmark totally from fossil fuels like oil, coal and gas”

Prime minister 16 November 2008:
”… position Denmark in the heart of green growth”

Prime minister June 2019:
”… 70% reductions in Green House gases by 2030..”

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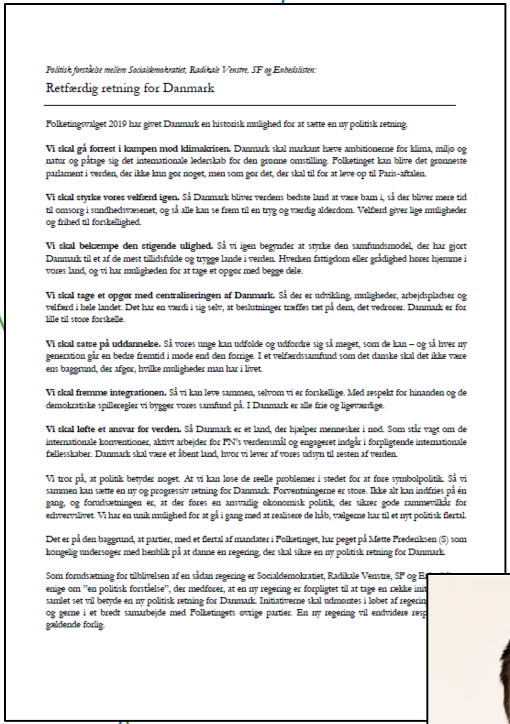
2019 New Government and agreement:

70% reductions in Greenhouse gases by 2030

Climate Law and Action plan:

1. Energy savings in among others public buildings
2. National Strategy for Sustainable buildings
3. Strategy for electrification of transport, industry and society in general
4. More funds for green research and demonstration projects
5. Assessment of Danish and North Sea countries mutual expansion of offshore wind
6. Investigation of energy island of 10 GW wind before 2030
7. Support afforestation (new forest)
8. Climate adoption via coordination of coastal protection



Politisk forståelse mellem Socialdemokratiet, Radikale Venstre, SF og Enhedslisten:

Retfærdig retning for Danmark

Folketingsvalget 2019 har givet Danmark en historisk mulighed for at sætte en ny politisk retning.

Vi skal gå forrest i kampen mod klimakrisen. Danmark skal markant hæve ambitionerne for klima, miljø og natur og påtage sig det internationale lederskab for den grønne omstilling. Folketinget kan blive det grønneste parlament i verden, der ikke kun gør noget, men som gør det, der skal til for at leve op til Paris-aftalen.

Vi skal styrke vores velfærd igen. Så Danmark bliver verdens bedste land at være barn i, så der bliver mere tid til omsorg i sundhedsvæsenet, og så alle kan se frem til en tryg og værdig alderdom. Velfærd giver lige muligheder og frihed til forskellighed.

Vi skal bekæmpe den stigende ulighed. Så vi igen begynder at styrke den samfundsmodel, der har gjort Danmark til et af de mest tillidsfulde og trygge lande i verden. Hverken fattigdom eller grådighed hører hjemme i vores land, og vi har muligheden for at tage et opgør med begge dele.

Vi skal tage et opgør med centraliseringen af Danmark. Så der er udvikling, muligheder, arbejdspladser og velfærd i hele landet. Det har en værdi i sig selv, at beslutninger træffes tæt på dem, det vedrører. Danmark er for lille til store forskelle.

Vi skal satse på uddannelse. Så vores unge kan udfolde og udfordre sig så meget, som de kan – og så hver ny generation går en bedre fremtid i møde end den forrige. I et velfærdssamfund som det danske skal det ikke være ens baggrund, der afgør, hvilke muligheder man har i livet.

Vi skal fremme integrationen. Så vi kan leve sammen, selvom vi er forskellige. Med respekt for hinanden og de demokratiske spilleregler vi bygger vores samfund på. I Danmark er alle frie og ligeværdige.

Vi skal løfte et ansvar for verden. Så Danmark er et land, der hjælper mennesker i nød. Som står vagt om de internationale konventioner, aktivt arbejder for FN's verdensmål og engageret indgår i forpligtende internationale fællesskaber. Danmark skal være et åbent land, hvor vi lever af vores udsyn til resten af verden.

Vi tror på, at politik betyder noget. At vi kan løse de reelle problemer i stedet for at føre symbolpolitik. Så vi sammen kan sætte en ny og progressiv retning for Danmark. Forventningerne er store. Ikke alt kan indfries på én gang, og forudsætningen er, at der føres en ansvarlig økonomisk politik, der sikrer gode rammevilkår for erhvervslivet. Vi har en unik mulighed for at gå i gang med at realisere de håb, vælgerne har til et nyt politisk flertal.

Det er på den baggrund, at partier, med et flertal af mandater i Folketinget, har peget på Mette Frederiksen (S) som kongelig undersøger med henblik på at danne en regering, der skal sikre en ny politisk retning for Danmark.

Som forudsætning for tilblivelsen af en sådan regering er Socialdemokratiet, Radikale Venstre, SF og [illegible] enige om "en politisk forståelse", der medfører, at en ny regering er forpligtet til at tage en række [illegible] samlet set vil betyde en ny politisk retning for Danmark. Initiativerne skal udmøntes i løbet af [illegible] og gerne i et bredt samarbejde med Folketingets øvrige partier. En ny regering vil endvidere [illegible] gældende forlig.

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100% Renewable Energy 2050
...... but how…???!!

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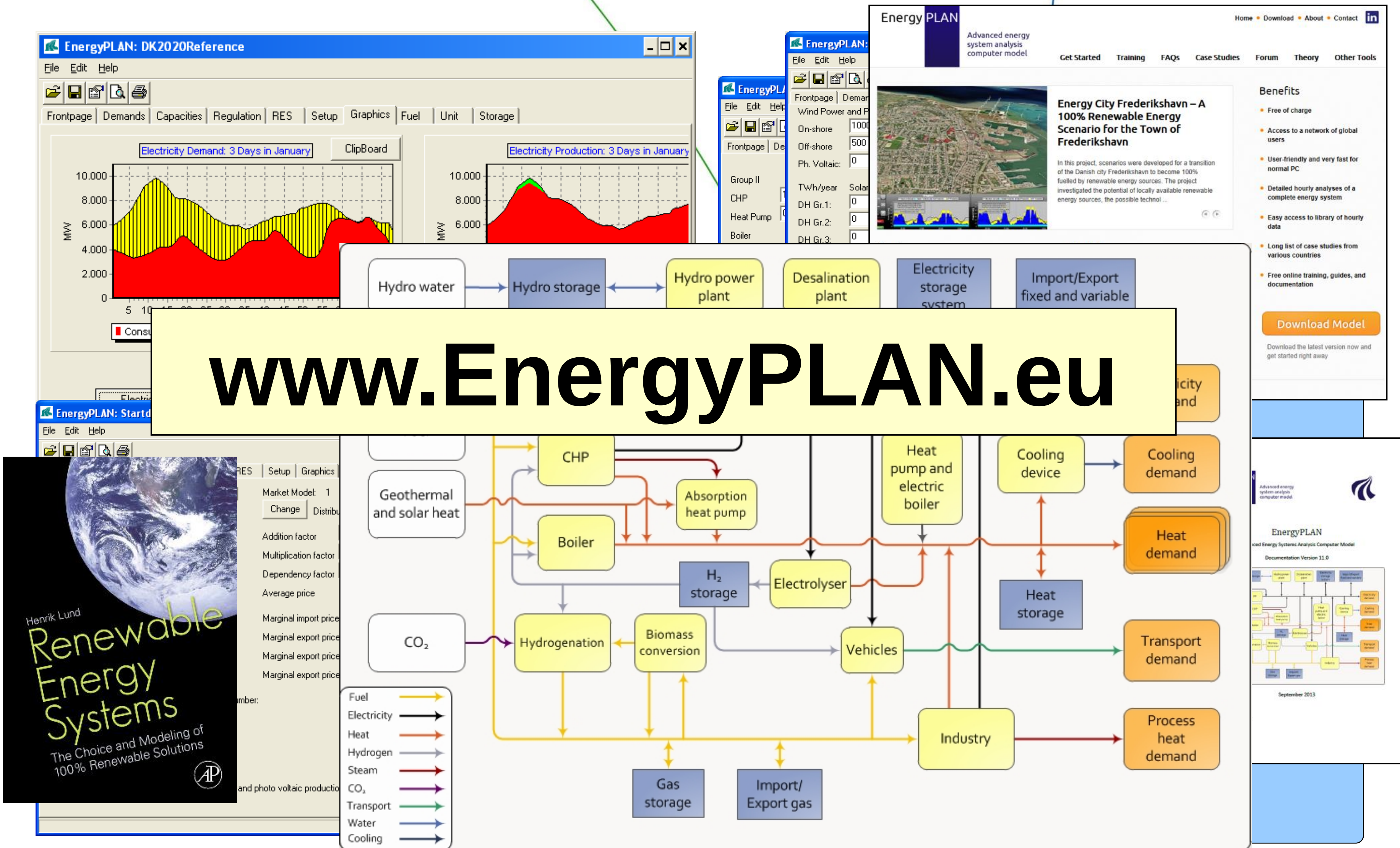
Energi System Analyse Model



www.EnergyPLAN.eu

Members Map

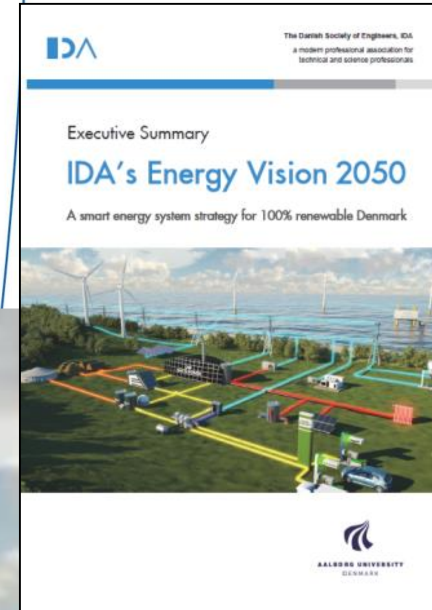
This is a map of the people who have registered with the EnergyPLAN website. Select a country to identify all users from that country, and then select their name on the right hand side if you would like to contact them. We hope that this map will connect users that have a common interest with one another.

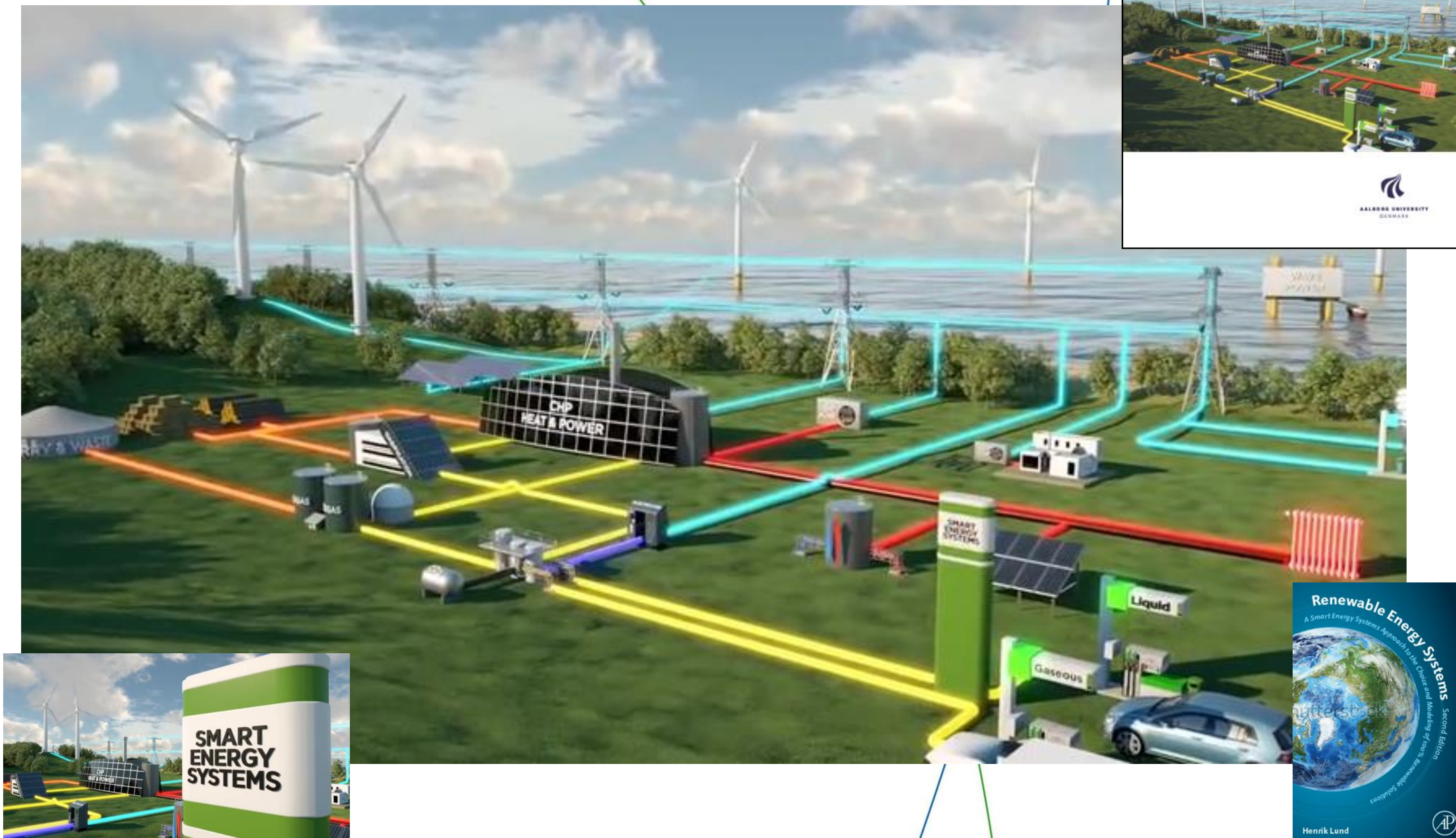
1-25 >25 >50 >100 >200

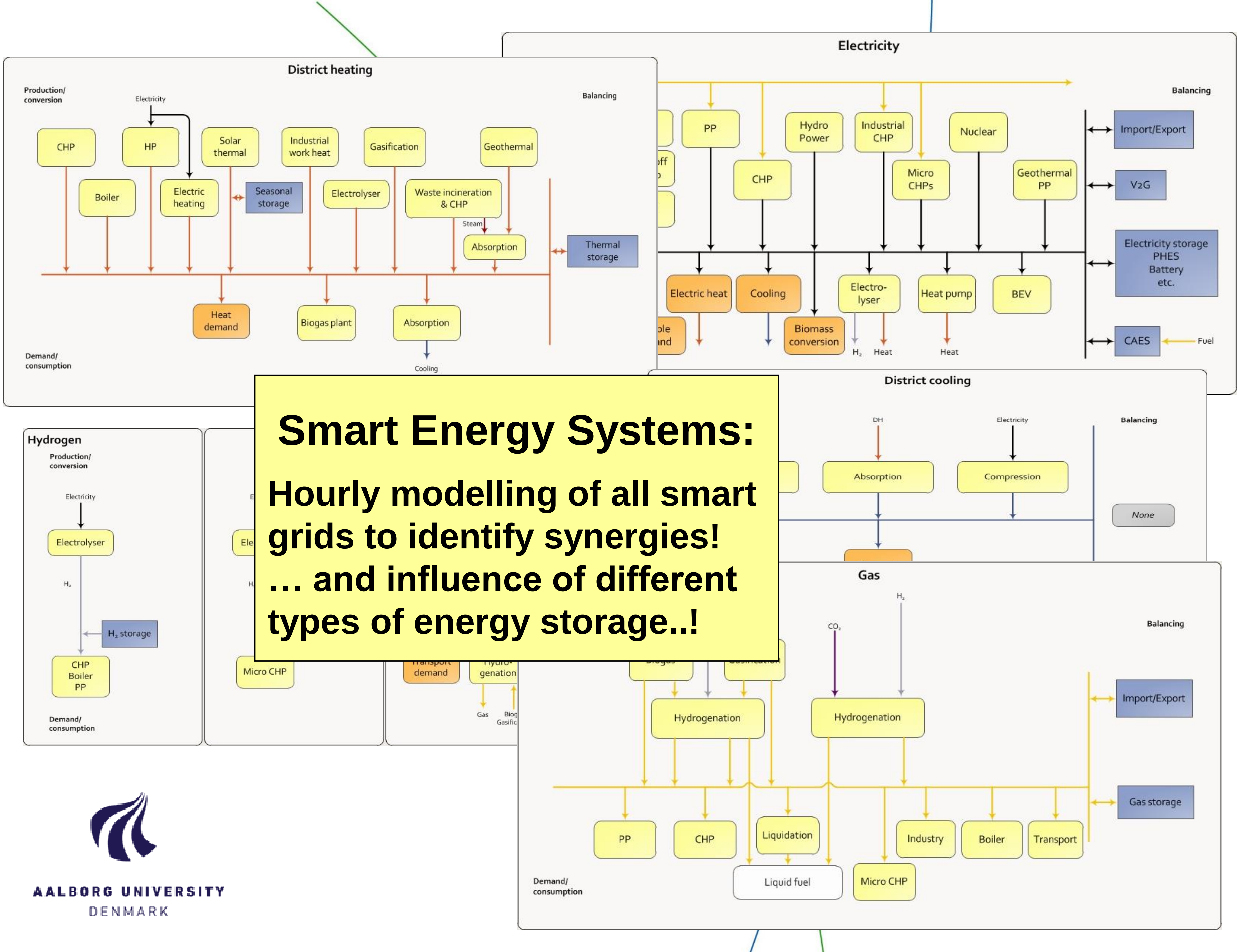
Members L

- Roger Bess
- Abi Babajic
- ali adabi
- Andrew Ba
- Les Clark
- Andrew Fa
- Alexsandra
- Aziz Khiyar
- Alessandra
- Alfredo For
- Andrew Ma
- aaa aaaa
- Ambarish N
- Silvia Melcl
- Anu Ramas
- Aaron Smit
- Arturo Sos
- Anthony Te
- Raphael Ap
- Ayman Kha
- Baqer Ame

Smart Energy Systems







Smart Energy Systems:

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

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Smart Energy Systems

www.energyplan.eu/smartenergysystems/

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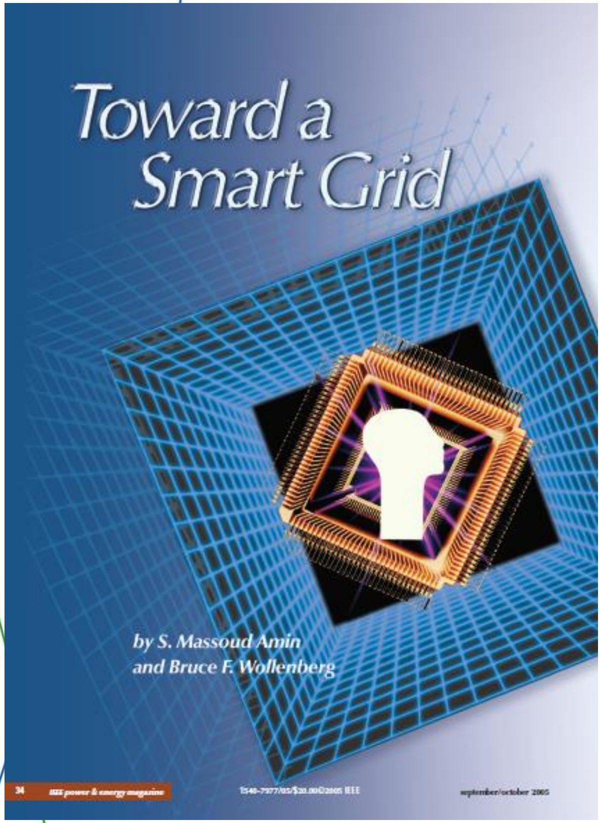
Smart Grid (2005)

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)

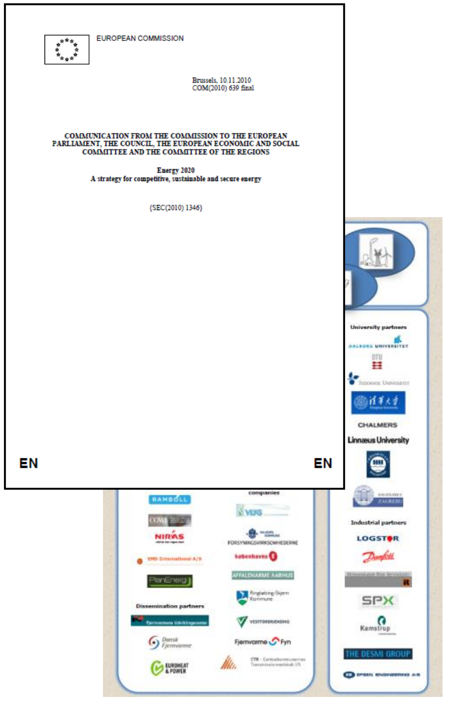
“*Smart Grids* … concerns an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both - in order to efficiently deliver sustainable, economic and secure electricity supplies.” (SmartGrids European Technology Platform,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

Smart heating and cooling grids - 2010

- 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}

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4DH
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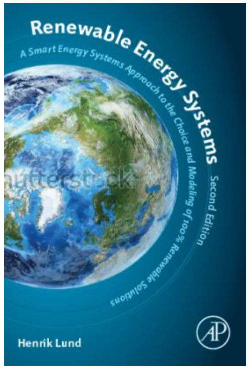
Smart Energy Systems



- **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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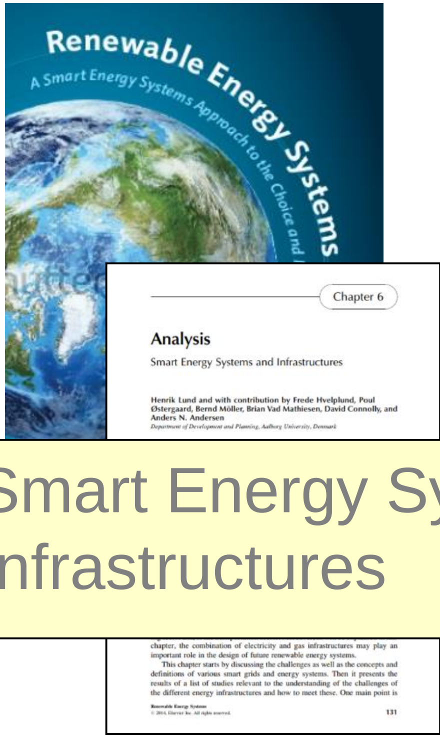
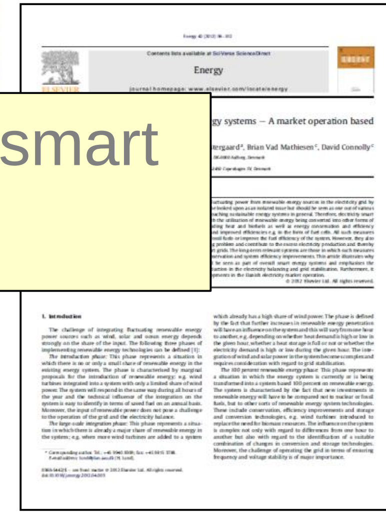
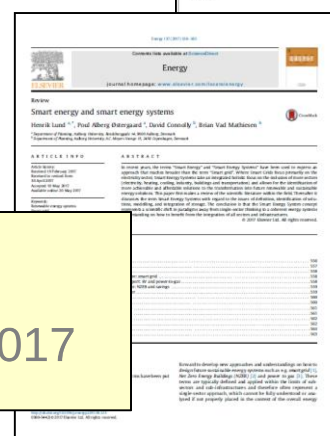


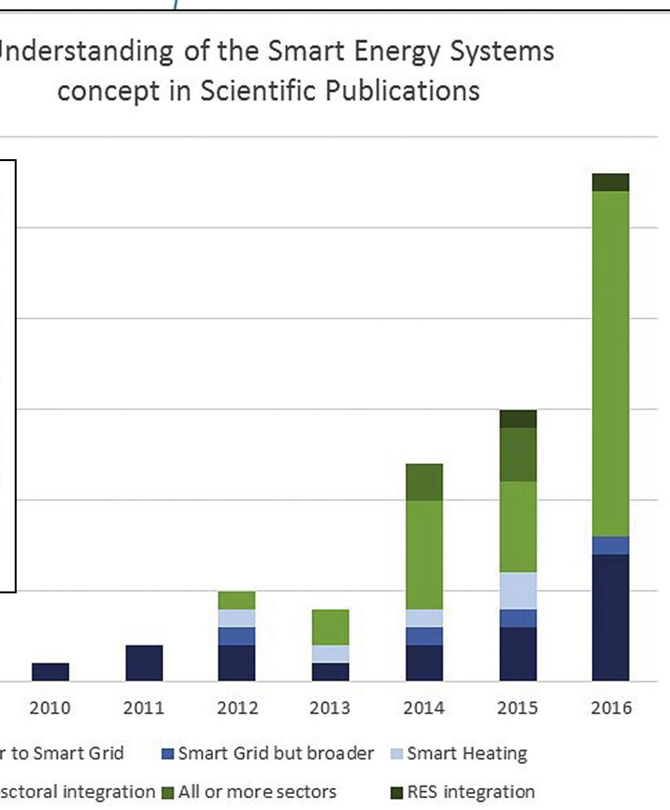


From electricity smart grids to smart energy systems published 2012

Smart Energy Systems and Infrastructures published 2014



Smart Energy and Smart Energy Systems published 2017



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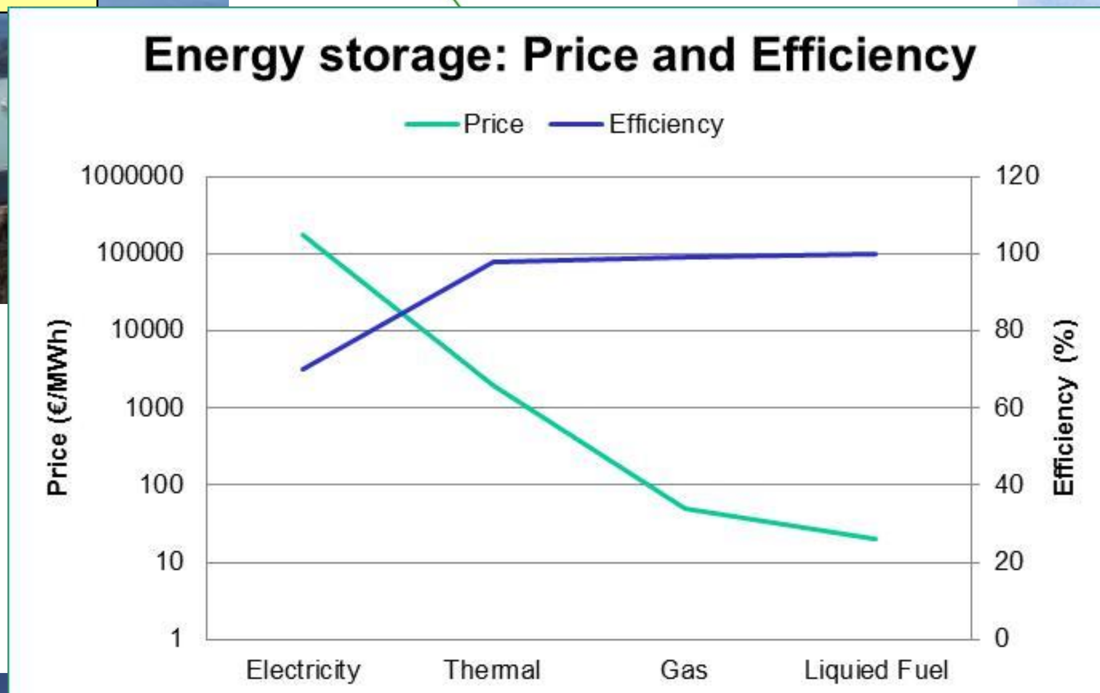
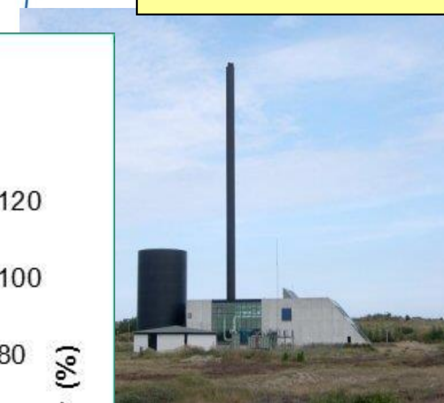
Energy Storage

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)

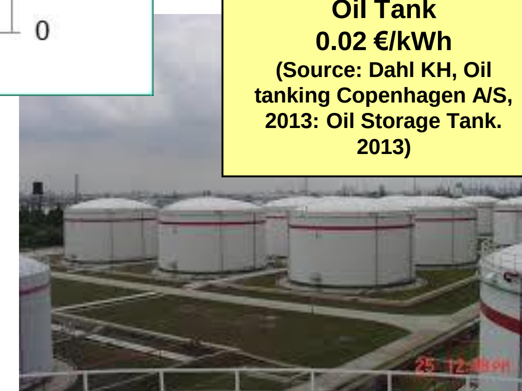


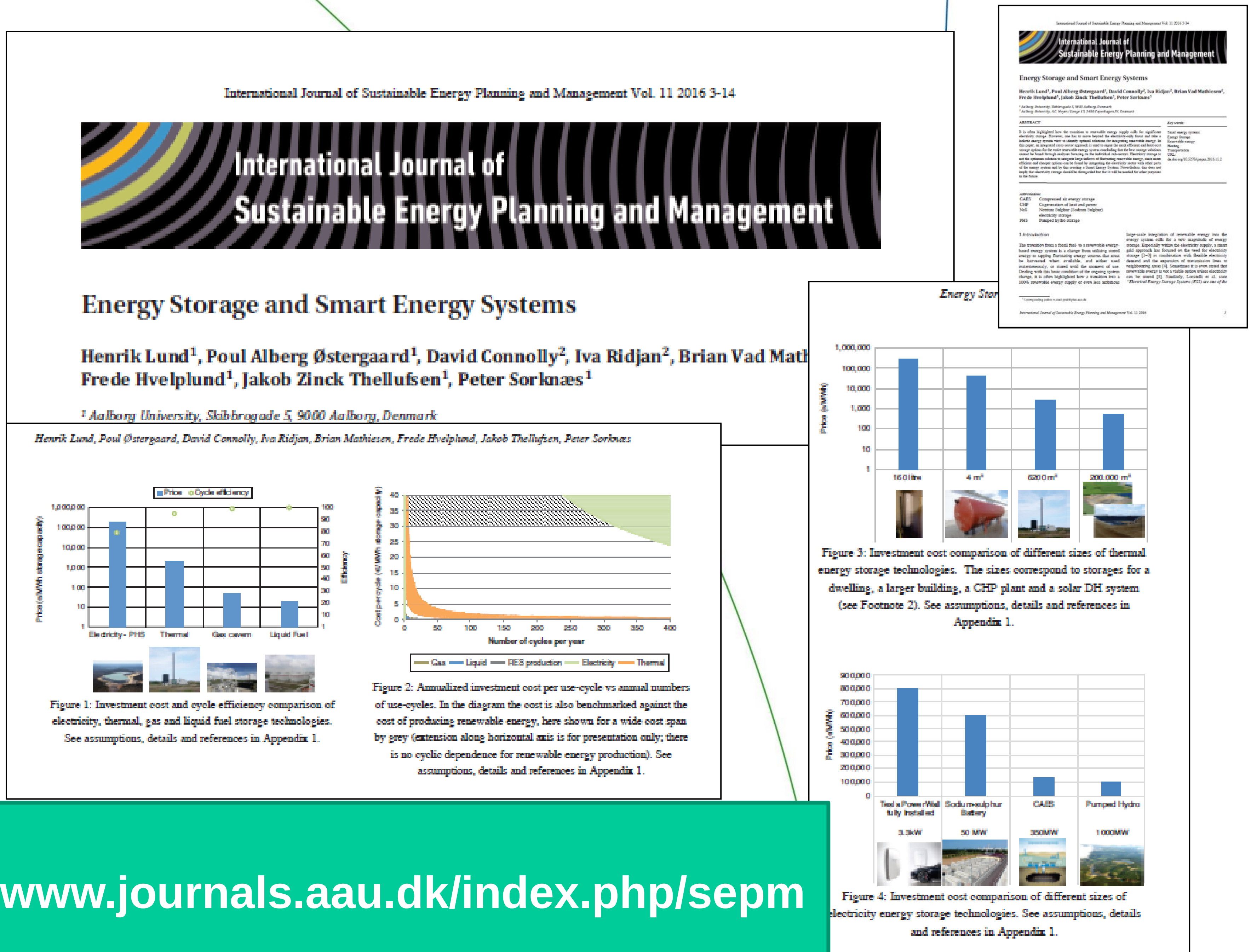
Thermal Storage
1-4 €/kWh
(Source: Danish Technology Catalogue, 2012)



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 Vol. 11 2016 3-14

International Journal of Sustainable Energy Planning and Management

Energy Storage and Smart Energy Systems

Henrik Lund[1], Poul Alberg Østergaard[1], David Connolly[2], Iva Ridjan[2], Brian Vad Math...
Frede Hvelplund[1], Jakob Zinck Thellufsen[1], Peter Sorknæs[1]

[1] Aalborg University, Skibbrogade 5, 9000 Aalborg, Denmark

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.

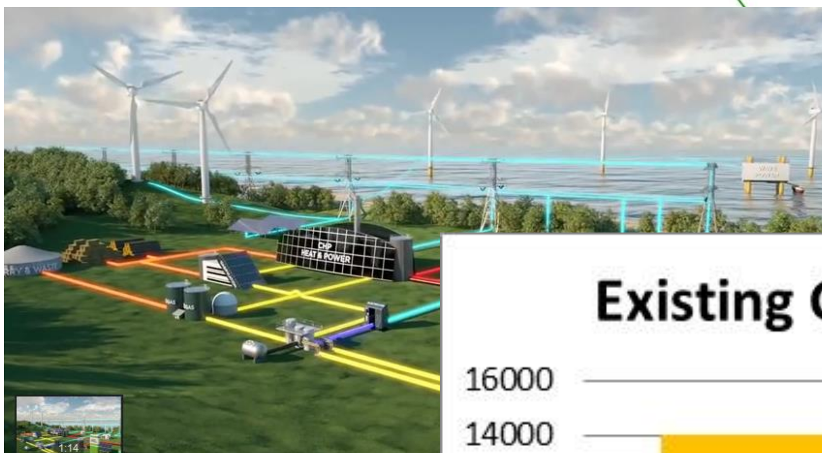
Figure 2: Annualized investment cost per use-cycle vs annual numbers of use-cycles. In the diagram the cost is also benchmarked against the cost of producing renewable energy, here shown for a wide cost span by grey (extension along horizontal axis is for presentation only; there is no cyclic dependence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

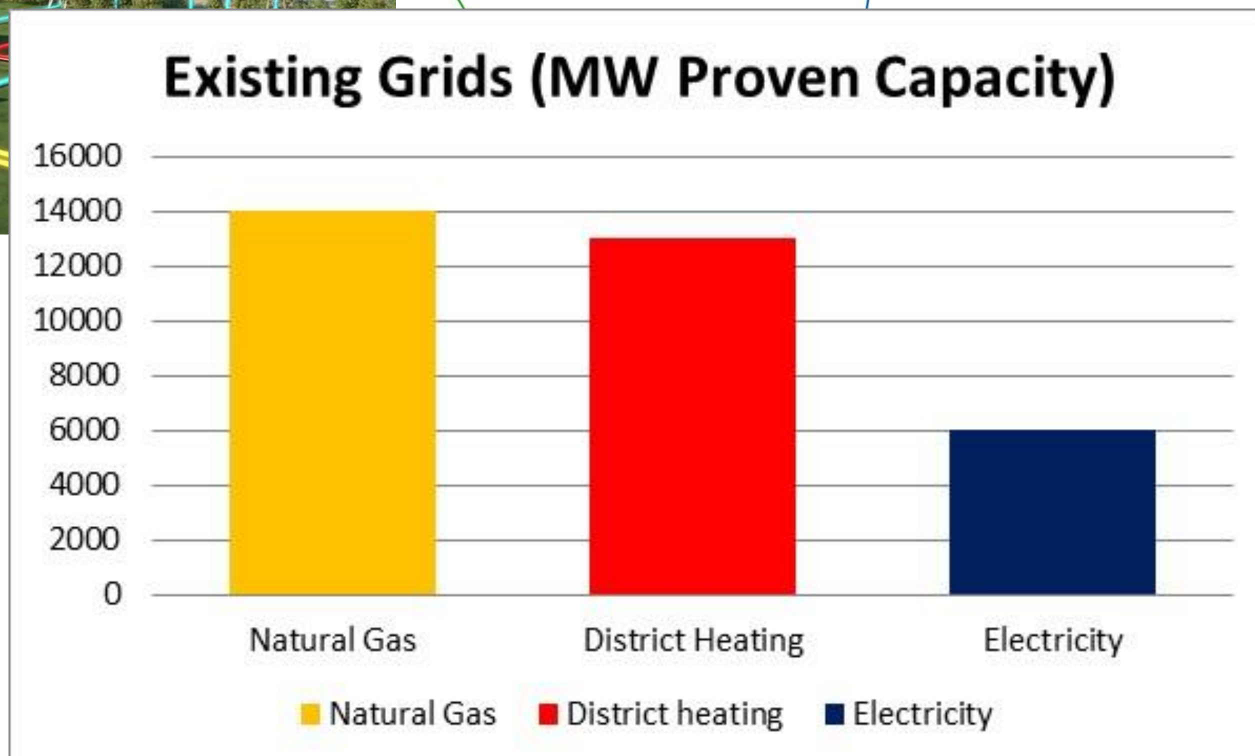
Figure 3: Investment cost comparison of different sizes of thermal energy storage technologies. The sizes correspond to storages for a dwelling, a larger building, a CHP plant and a solar DH system (see Footnote 2). See assumptions, details and references in Appendix 1.

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

Existing distribution grids in DK





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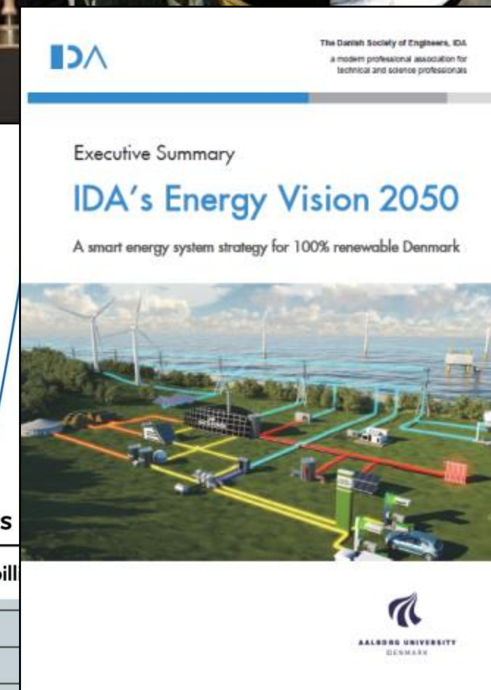

The Danish Society of Engineers, IDA
a modern professional association for technical and science professionals

Executive Summary

IDA's Energy Vision 2050

A smart energy system strategy for 100% renewable Denmark

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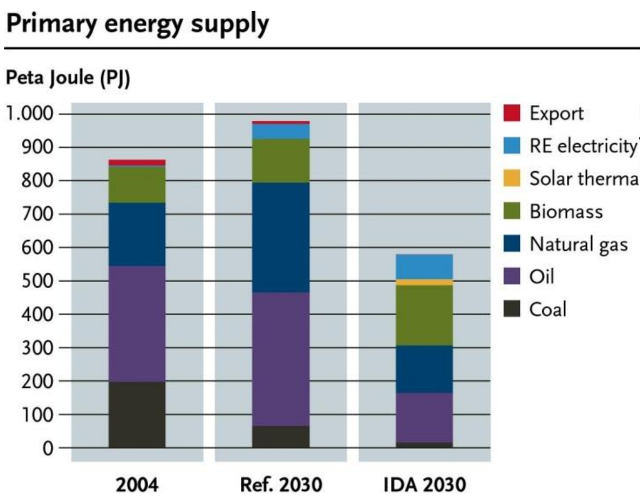
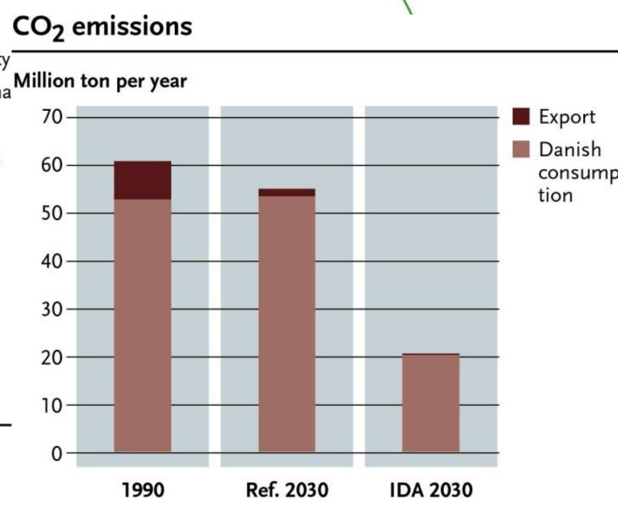
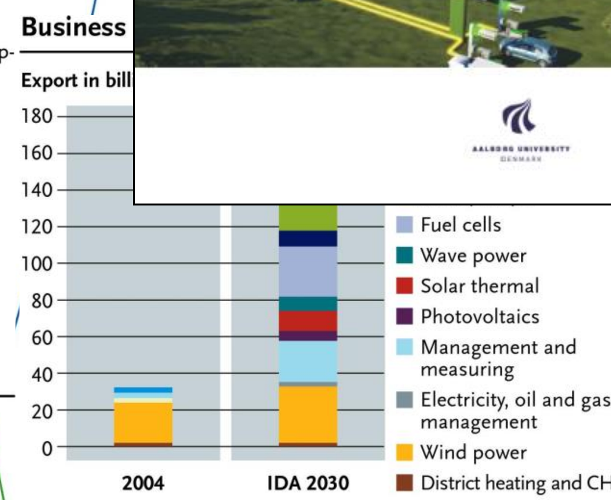
IDA Energiplan 2030







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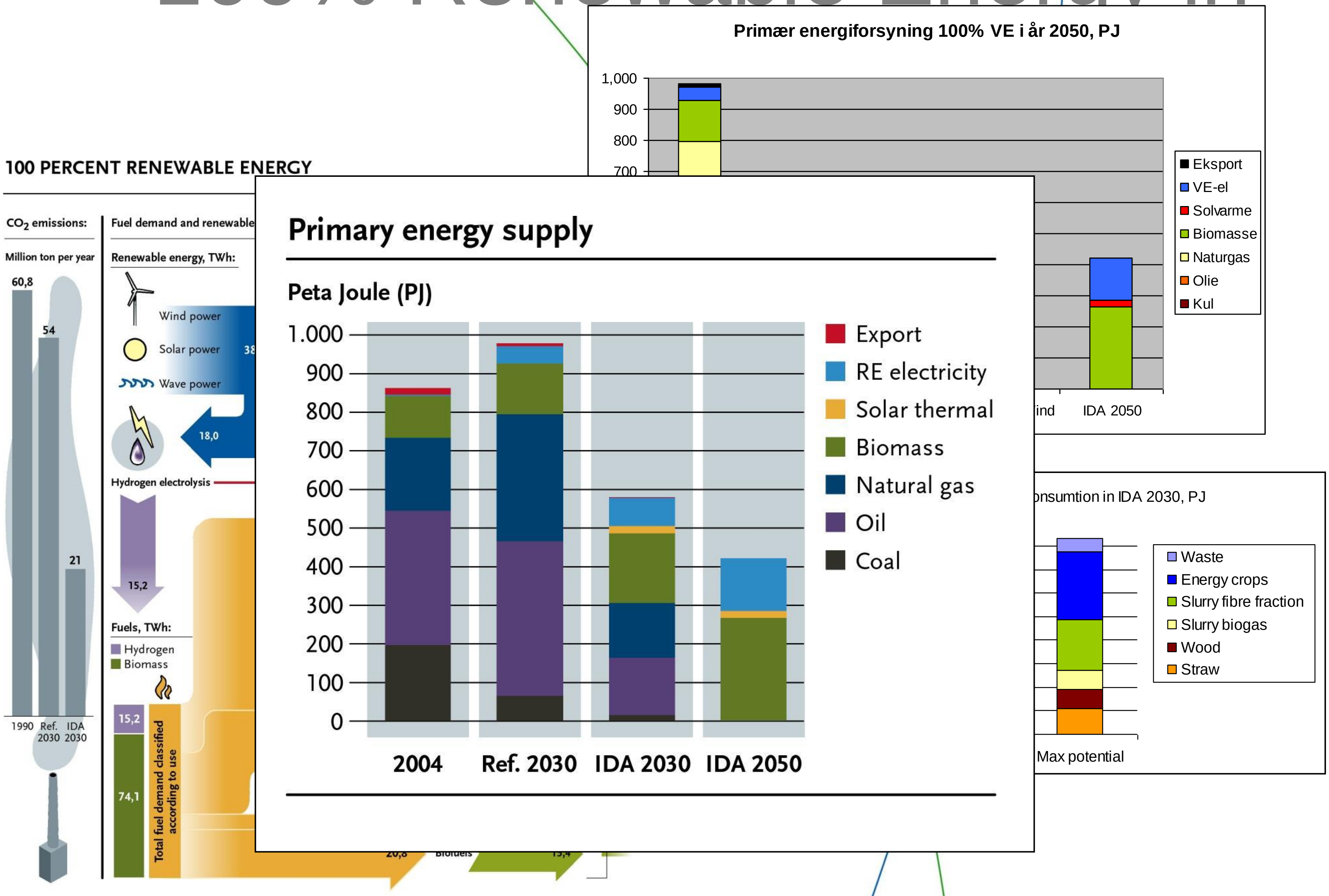
100% Renewable Energy in



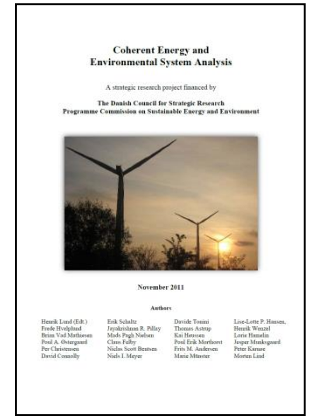
DTU Danmarks Tekniske Universitet

CBS COPENHAGEN BUSINESS SCHOOL HANDELSHØJSKOLEN

AALBORG UNIVERSITY DENMARK

KØBENHAVNS UNIVERSITET

SYDDANSK UNIVERSITET


Coherent Energy and Environmental System Analysis

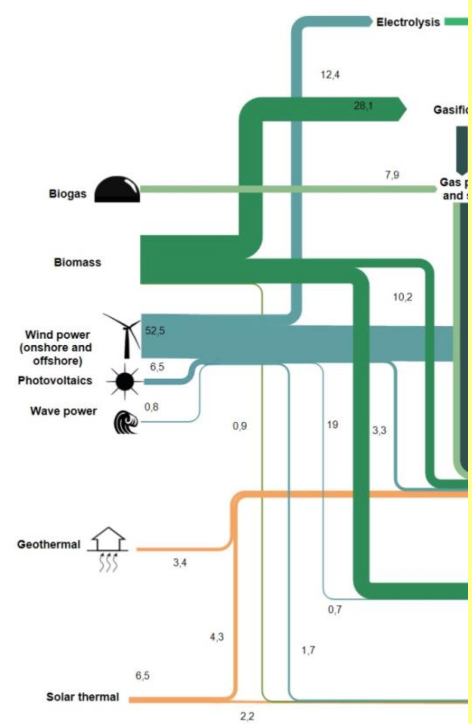
A strategic research project financed by

The Danish Council for Strategic Research Programme Commission on Sustainable Energy and Environment

November 2011

Authors

CEESA Project 2011/2012



Transport:

Electric vehicles is best from an energy efficient point of view. But gas and/or liquid fuels is needed to transform to 100%.

Biomass:

.. is a limited resource and can not satisfy all the transportation needs.

Consequence

… Electricity from Wind (and similar resources) needs to be converted to gas and liquied fuels in the long-term perspective…

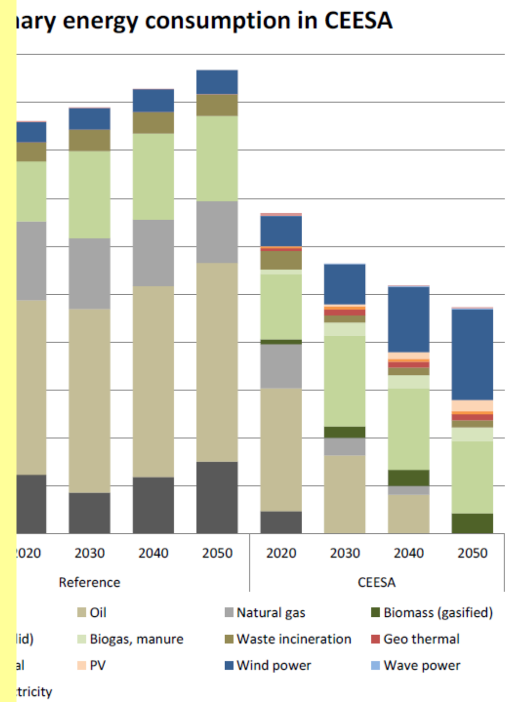


Figure 2: Primary Energy Supply in CEESA.

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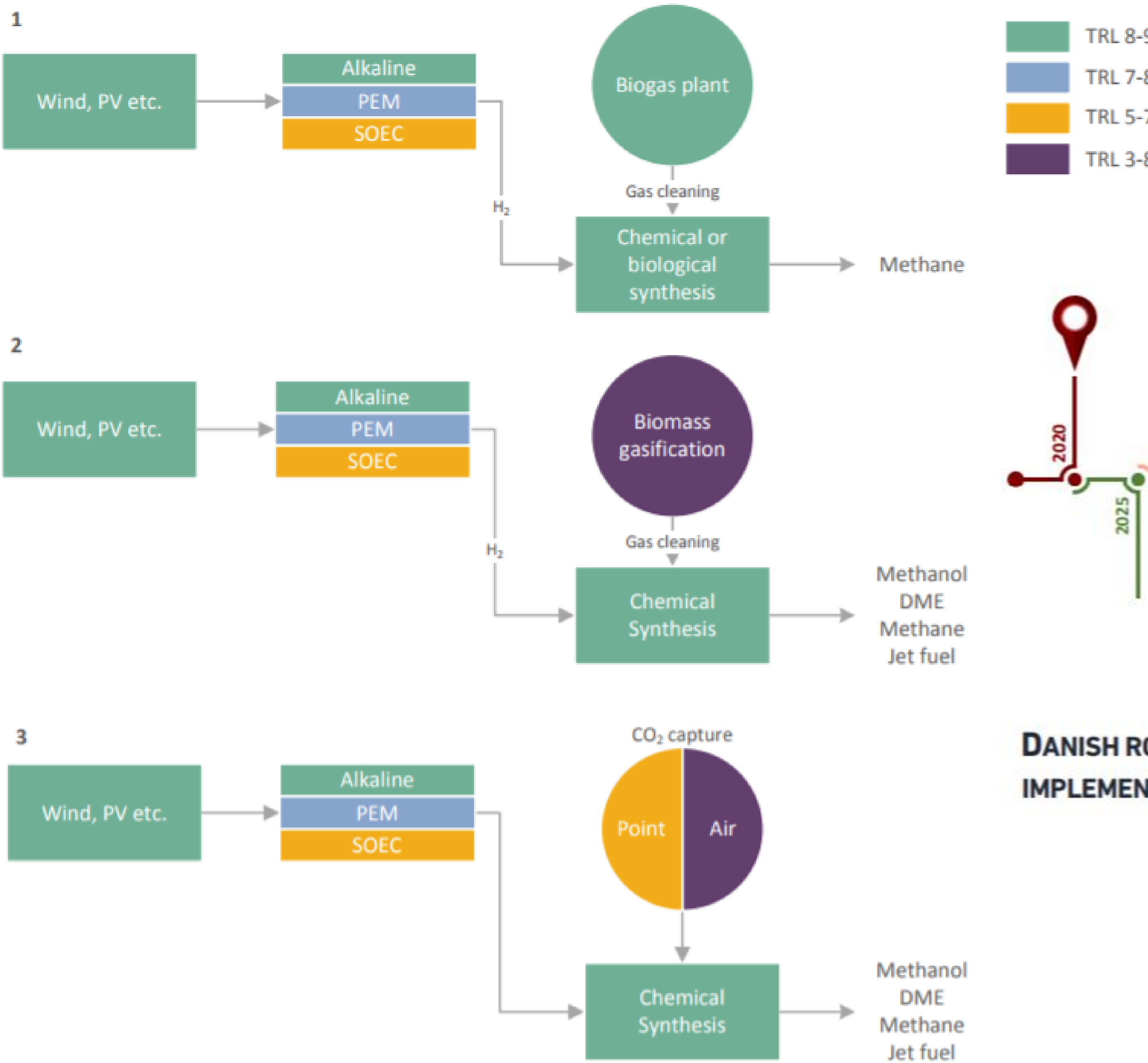
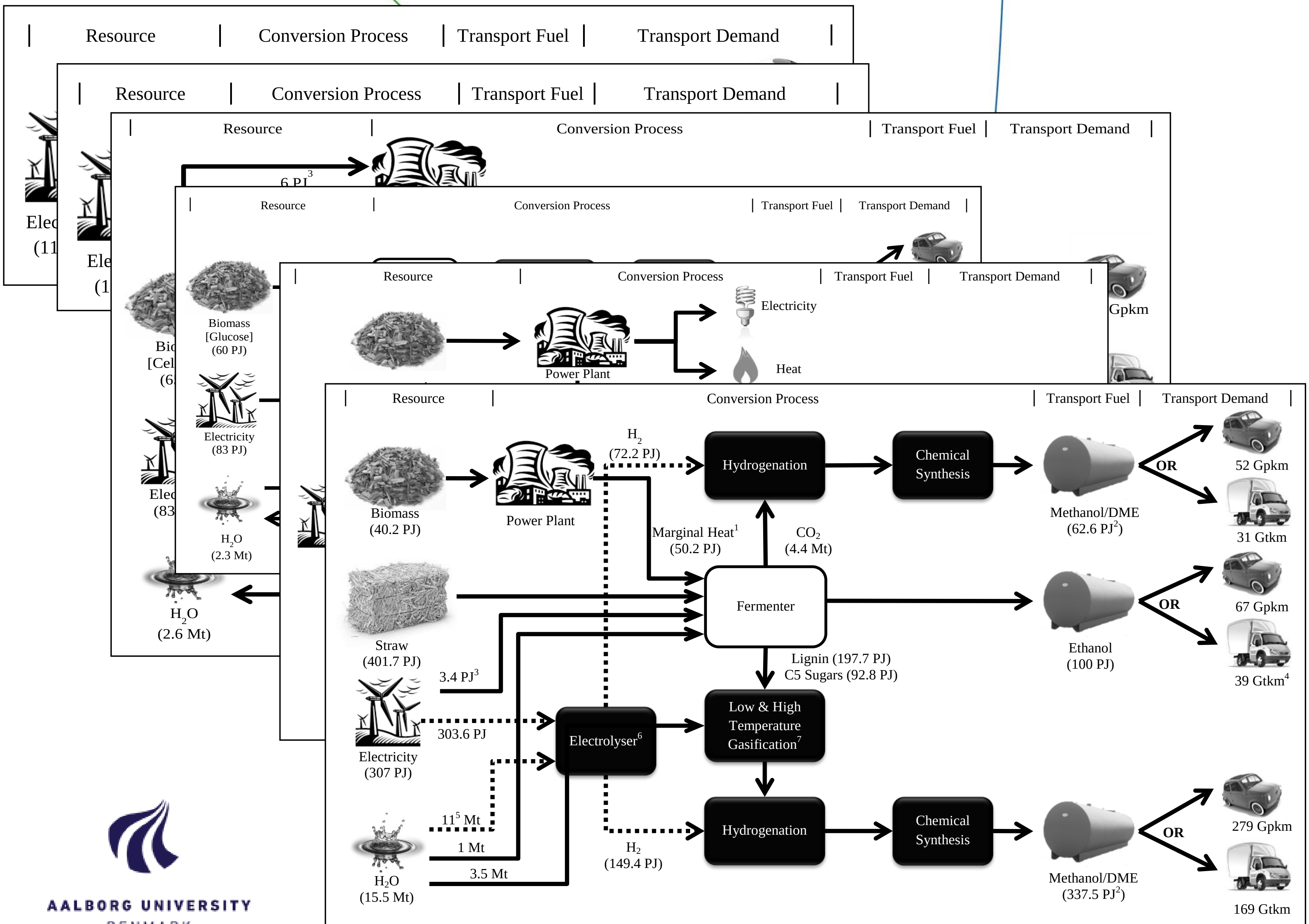


DANISH ROADMAP FOR LARGE-SCALE IMPLEMENTATION OF ELECTROLYSERS

DENMARK



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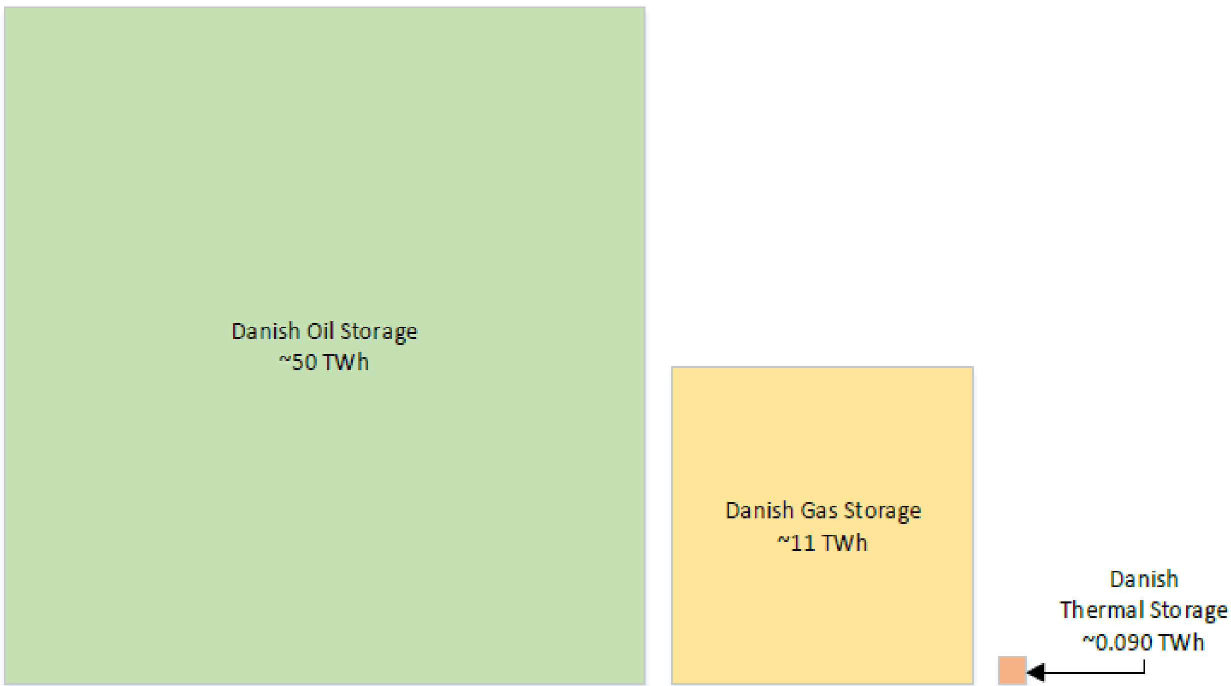
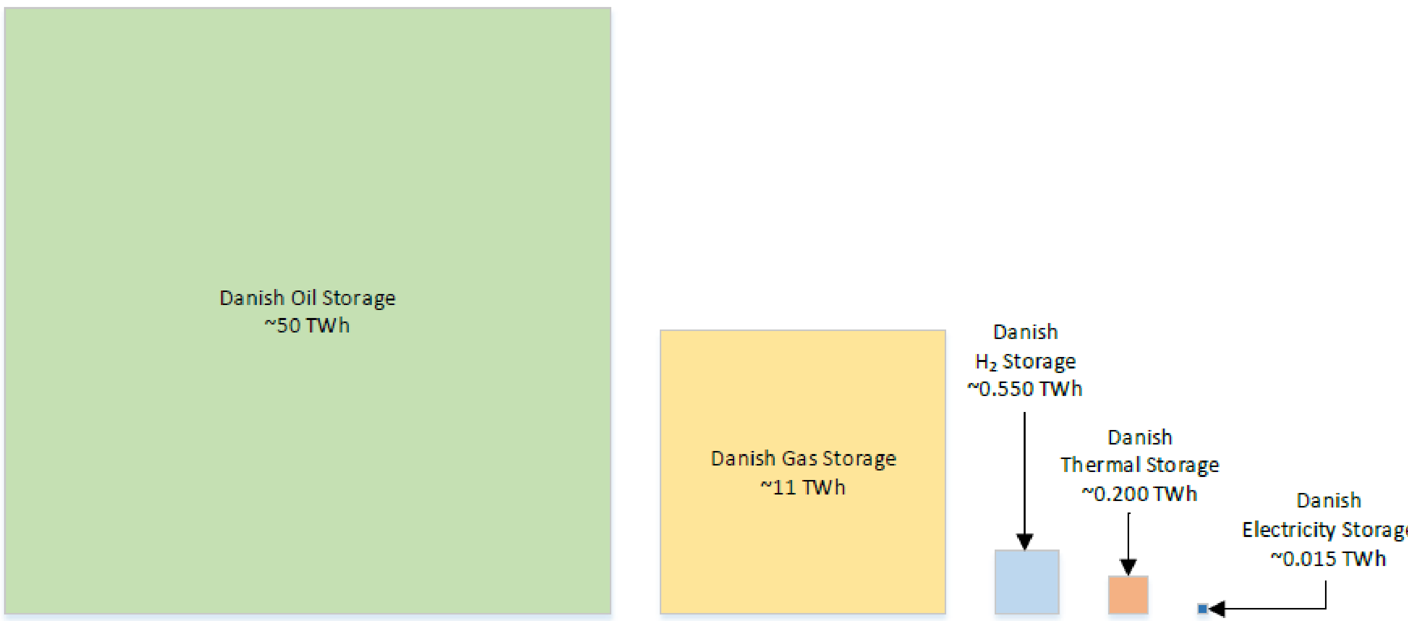
Energy Storage Capacities in Denmark






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



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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

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

CrossMark

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 p
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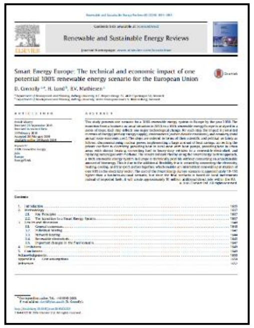

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A Clean Planet for all

A European long-terr strategic vision for a prosperous, modern, competitive and climate neutral nomy

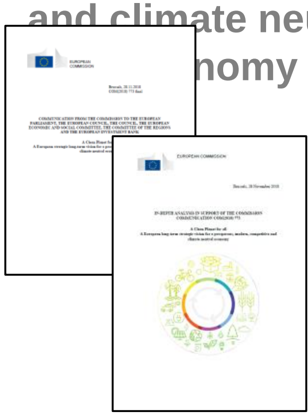

Table 1: Overview of main scenario building blocks

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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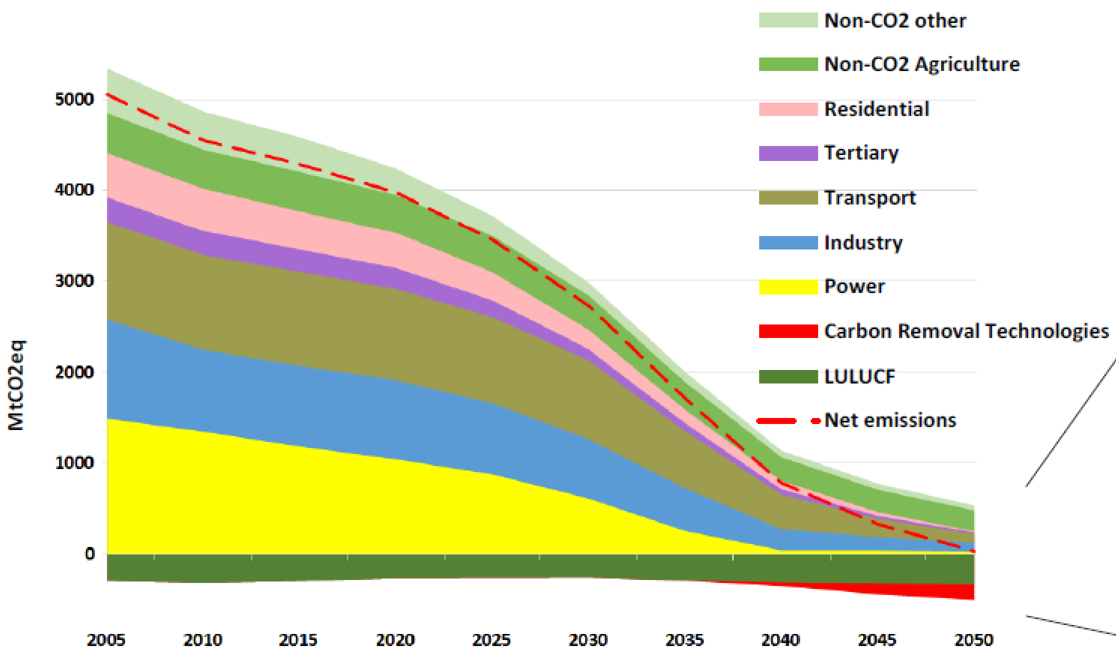
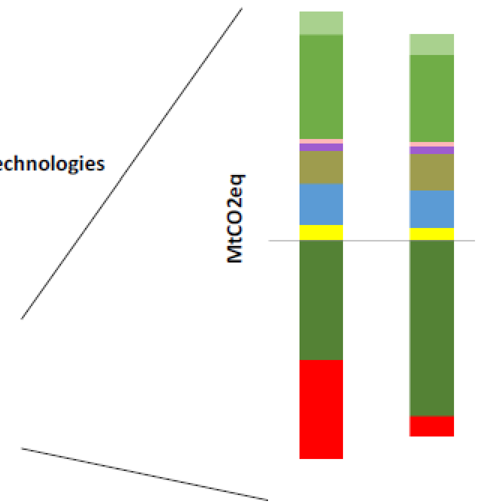


Different zero GHG pathways lead to different levels of remaining emissions and absorption of GHG emissions



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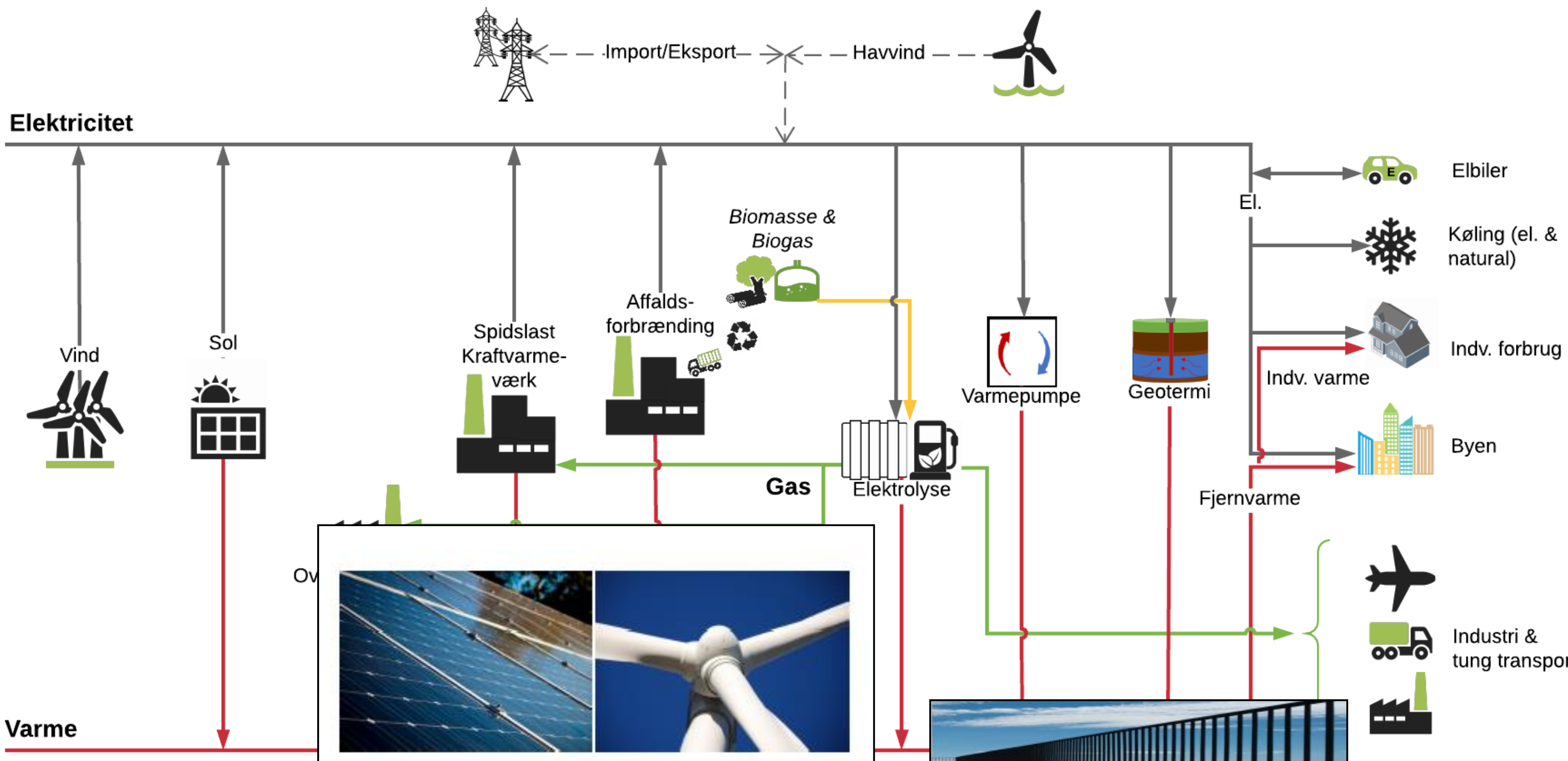

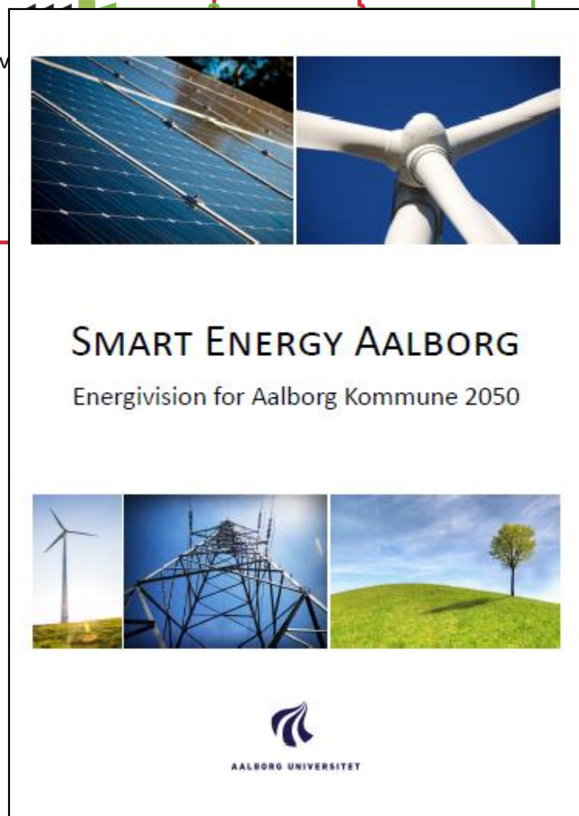

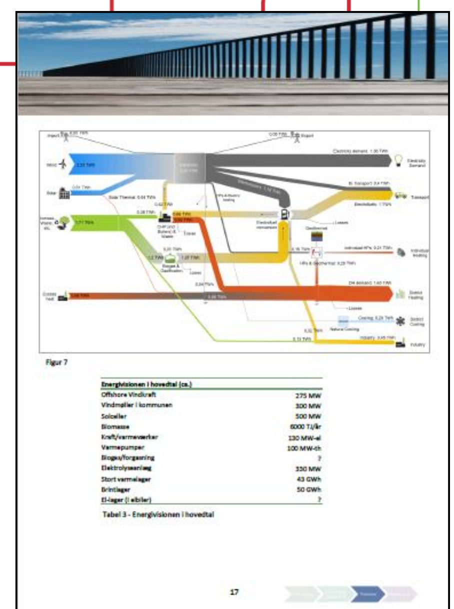

Figur 7

Energivisionen i hovedtal (ca.)	
Offshore Vindkraft	275 MW
Vindmøller i kommunen	300 MW
Solceller	500 MW
Biomasse	6000 TJ/år
Kraft/varmeværker	130 MW-el
Varmepumper	100 MW-th
Biogas/forgasning	?
Elektrolyseanlæg	330 MW
Stort varmelager	43 GWh
Brintlager	50 GWh
El-lager (i elbiler)	?

Tabel 3 - Energivisionen i hovedtal

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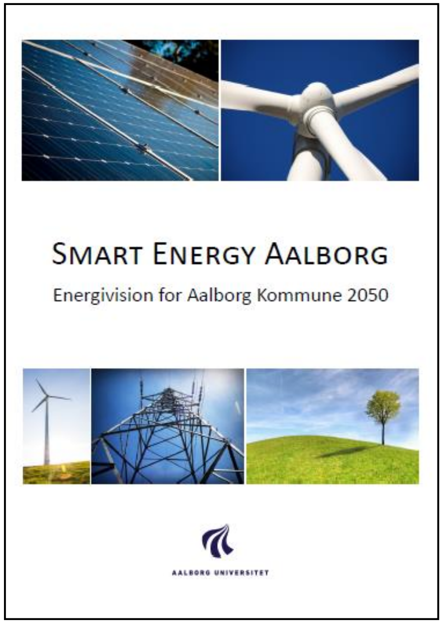
Guiding principle:
transitioning the current energy system in Aalborg to 100% Renewable Energy in a way so it fits into 100% RES in DK, then Europe and finally the World

- Sustainable use of Biomass
- Definition of transport demands
- How to handle Industry
- How to balance electricity demand and supply as well as other fuels



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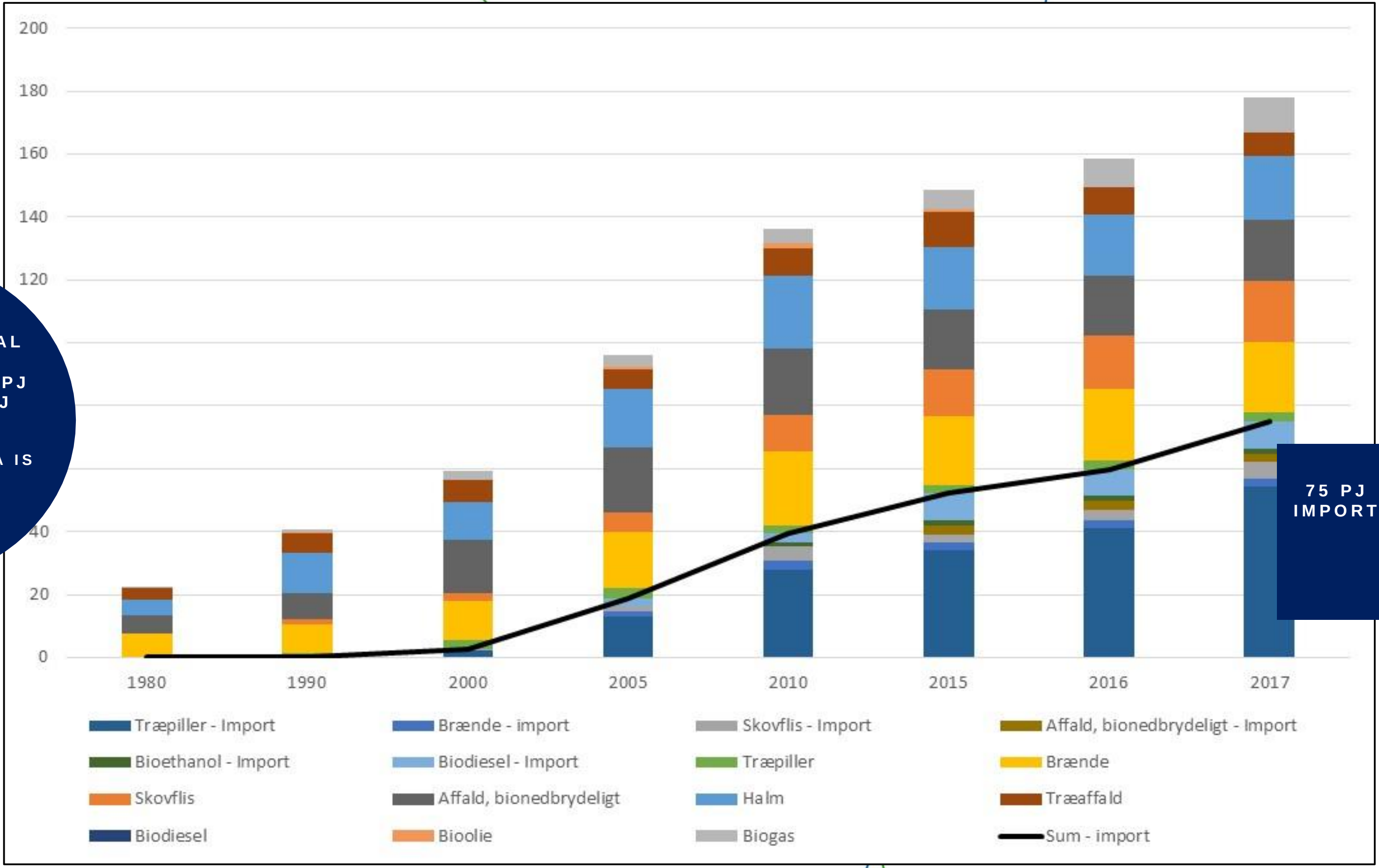
Biomass in Denmark – Power and Heat



BIOMASS POTENTIAL

OPTIMIST: CA. 300 PJ
PESSIMIST: 165 PJ
REALIST: 200 PJ

30 GJ BIO PR. CAPITA IS HIGH GLOBALLY

75 PJ IMPORT

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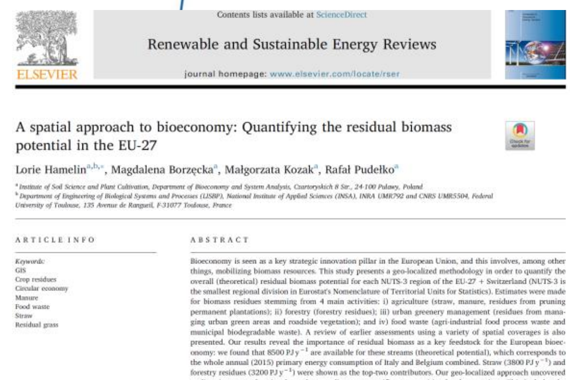
The Danish and the Global Biomass Challenge

	Biomass per. person
Today in DK (175 PJ)	30 GJ/capita
Recent research for EU (8500 PJ)	17 GJ/capita
EU 2050 scenario (A Clean Planet for all)	15-21 GJ/capita
IDA 100% RES in DK in 2050 (200 PJ)	30 GJ/capita
Danish Energy Agency scenario 2014	35-45 GJ/capita



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A spatial approach to bioeconomy: Quantifying the residual biomass potential in the EU-27

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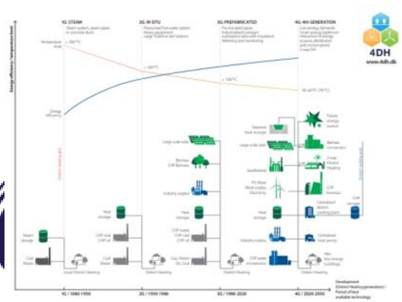
Food waste
Straw
Residual grass

ABSTRACT
Bioeconomy is seen as a key strategic innovation pillar in the European Union, and this involves, among other things, mobilizing biomass resources. This study presents a geo-localized methodology in order to quantify the overall (theoretical) residual biomass potential for each NUTS-3 region of the EU-27 + Switzerland (NUTS-3 is the smallest regional division in Eurostat's Nomenclature of Territorial Units for Statistics). Estimates were made for biomass residues stemming from 4 main activities: i) agriculture (straw, manure, residues from pruning permanent plantations); ii) forestry (forestry residues); iii) urban greenery management (residues from managing urban green areas and roadside vegetation); and iv) food waste (agri-industrial food process waste and municipal biodegradable waste). A review of earlier assessments using a variety of spatial coverages is also presented. Our results reveal the importance of residual biomass as a key feedstock for the European bioeconomy: we found that 8500 PJ y^{-1} are available for these streams (theoretical potential), which corresponds to the whole annual (2015) primary energy consumption of Italy and Belgium combined. Straw (3800 PJ y^{-1}) and forestry residues (3200 PJ y^{-1}) were shown as the top-two contributors. Our geo-localized approach uncovered



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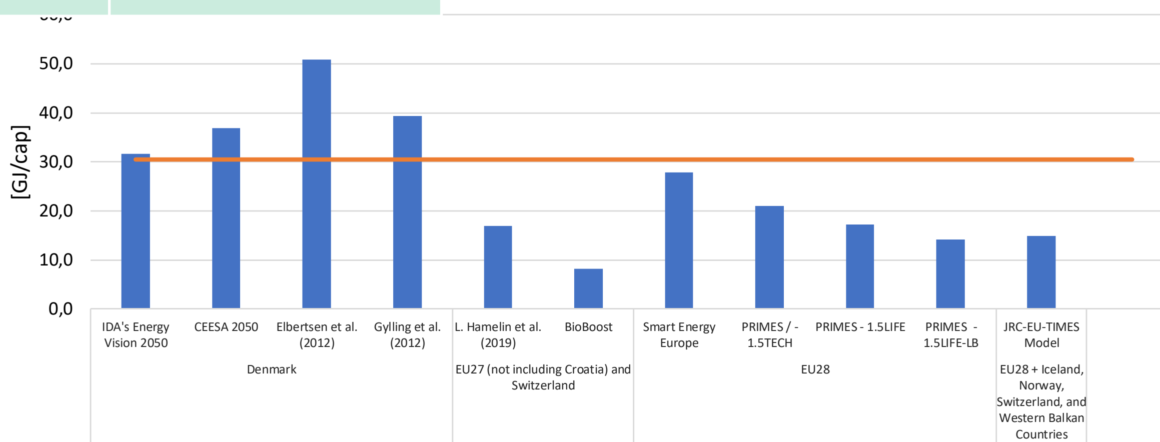
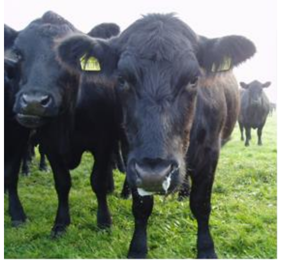


Biomass

- Local Biomass resources in Aalborg (incl. waste) 6100 TJ/year.

- Aalborg´s share of Danish sustainable biomass resources (incl. bio-share of waste, straw/wood and biogas) approx. 6200 TJ/year.



[TJ/år]	Andel af DKs forventede ressourcer efter befolkning	Biomasseressourcer i Aalborg Kommune
Halm	1800	980
Træ	1600	670
Biogas	1400	520
Fiberfraktion	-	60
Bioafgrøder	-	1360
- heraf græs	-	200
Affald	1400	2300
I alt	6200	6090

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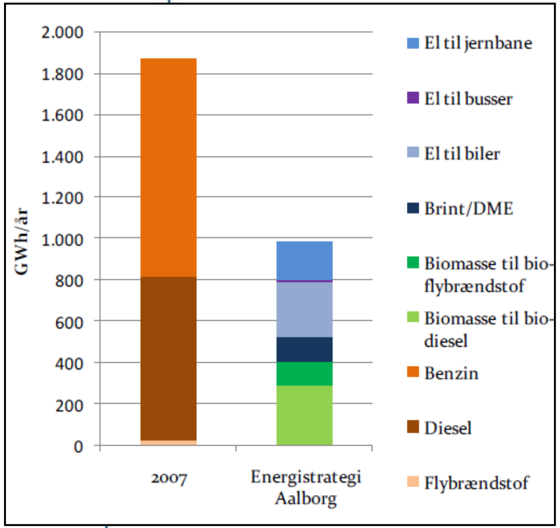
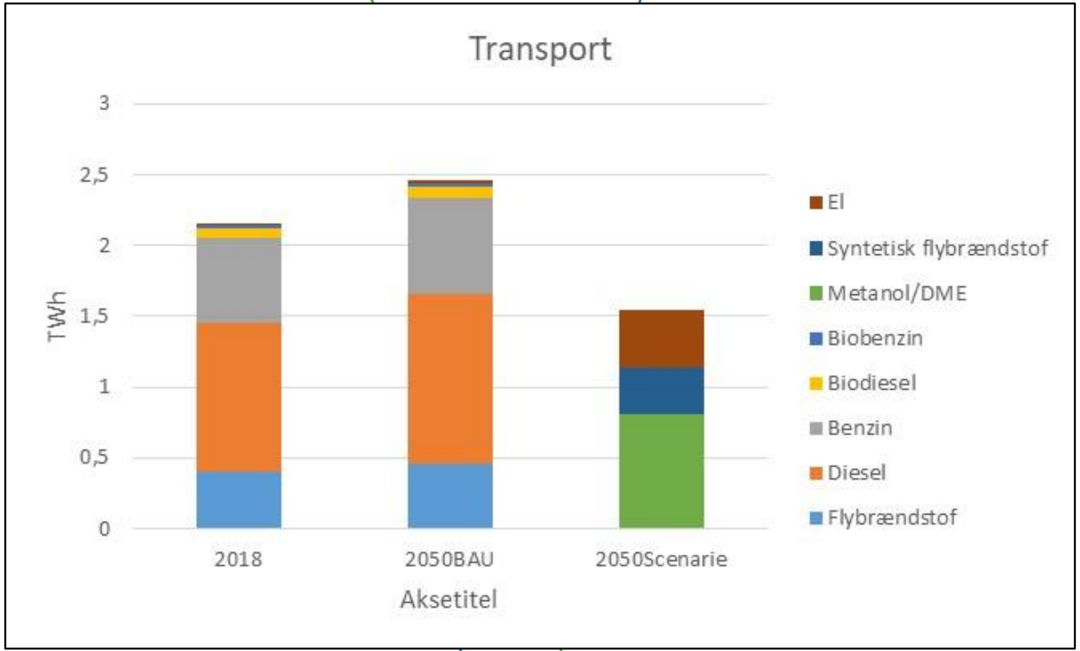
Transport

- Transport part/share of 100% RES in DK as a whole:
- IDA Energy Vision 2050: As much electric vehicles as possible. Supplemented by bio-fuels for aviation, trucks etc.





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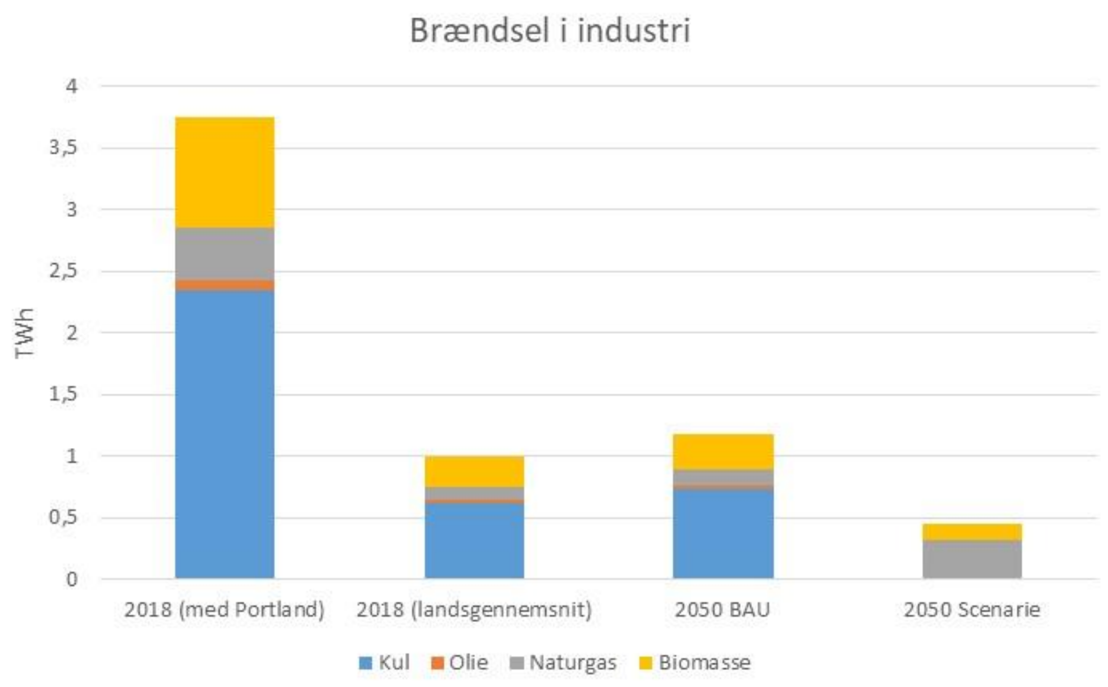
Industry

- Coal, oil and natural as in Industry in Aalborg constitutes 3.750 GWh/year (incl. Portland)
- Aalborg’s share (population) of Danish consumptions are 990 GWh/year.
- IDA-plan: Savings, efficiencies, district heating and cooling, electricity and green gas.



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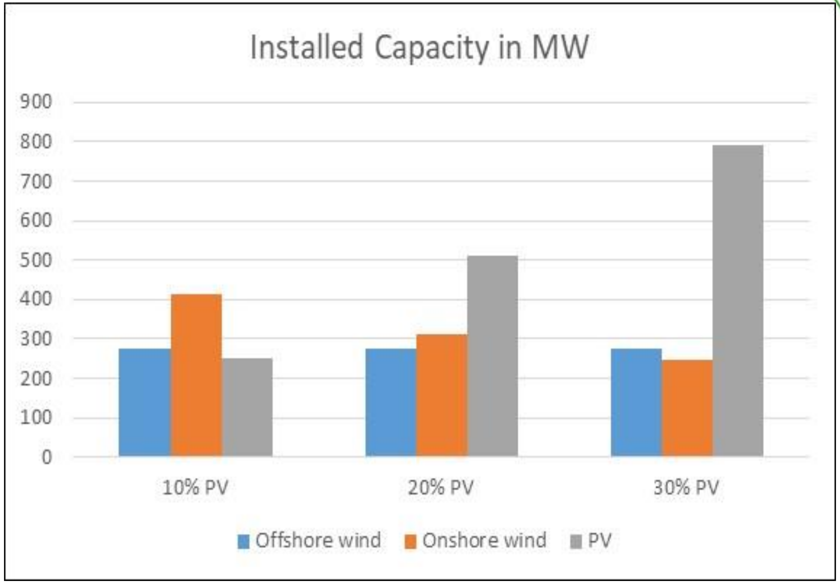
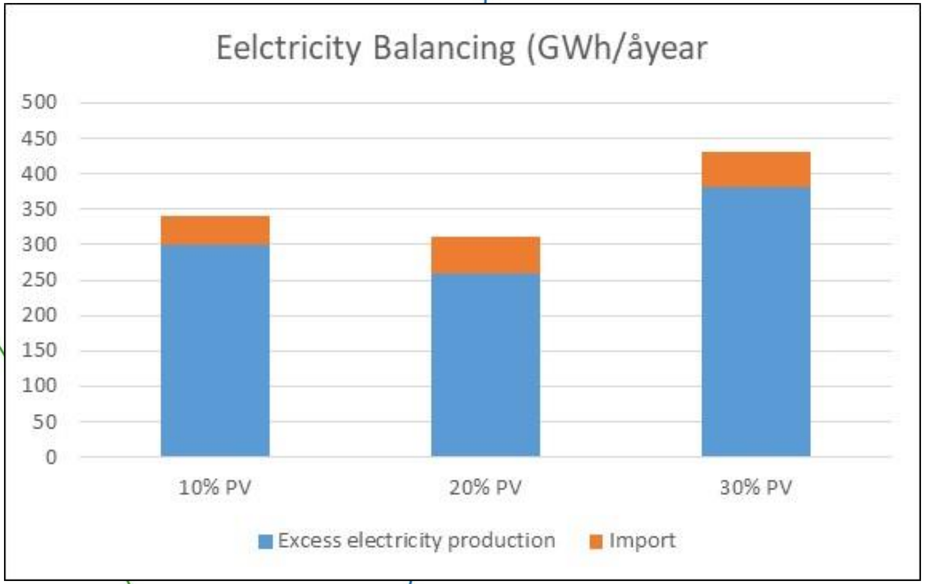
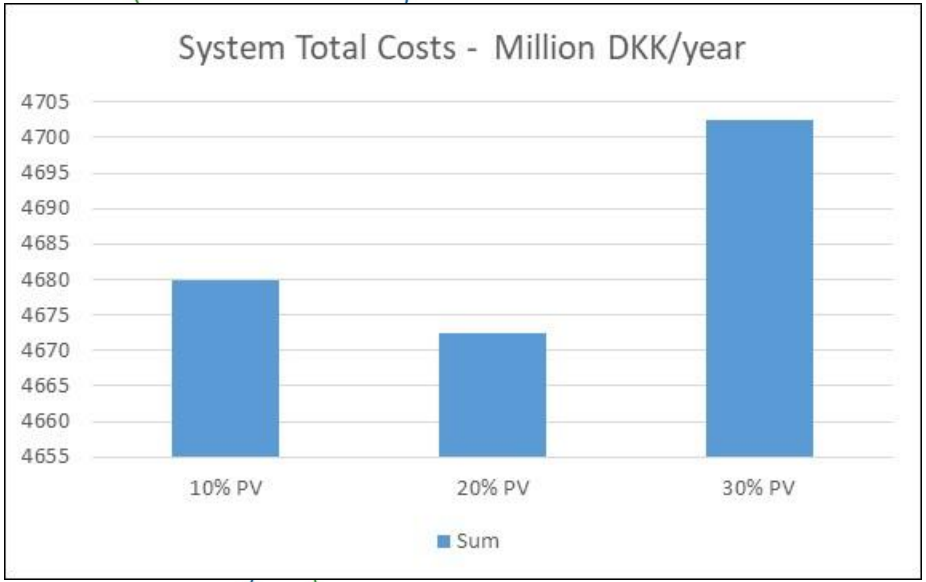
PV versus Wind







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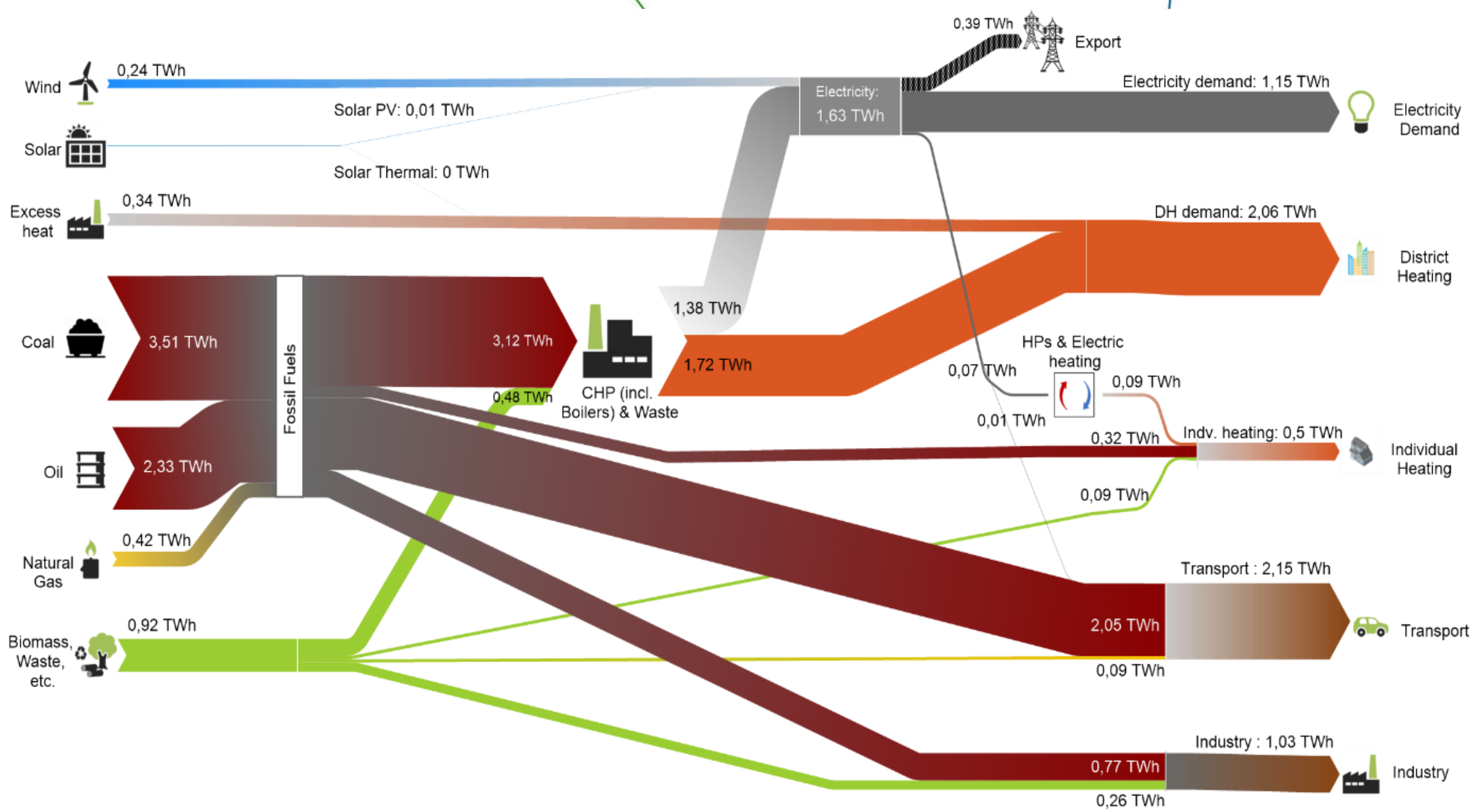
Sankey diagram of the current system



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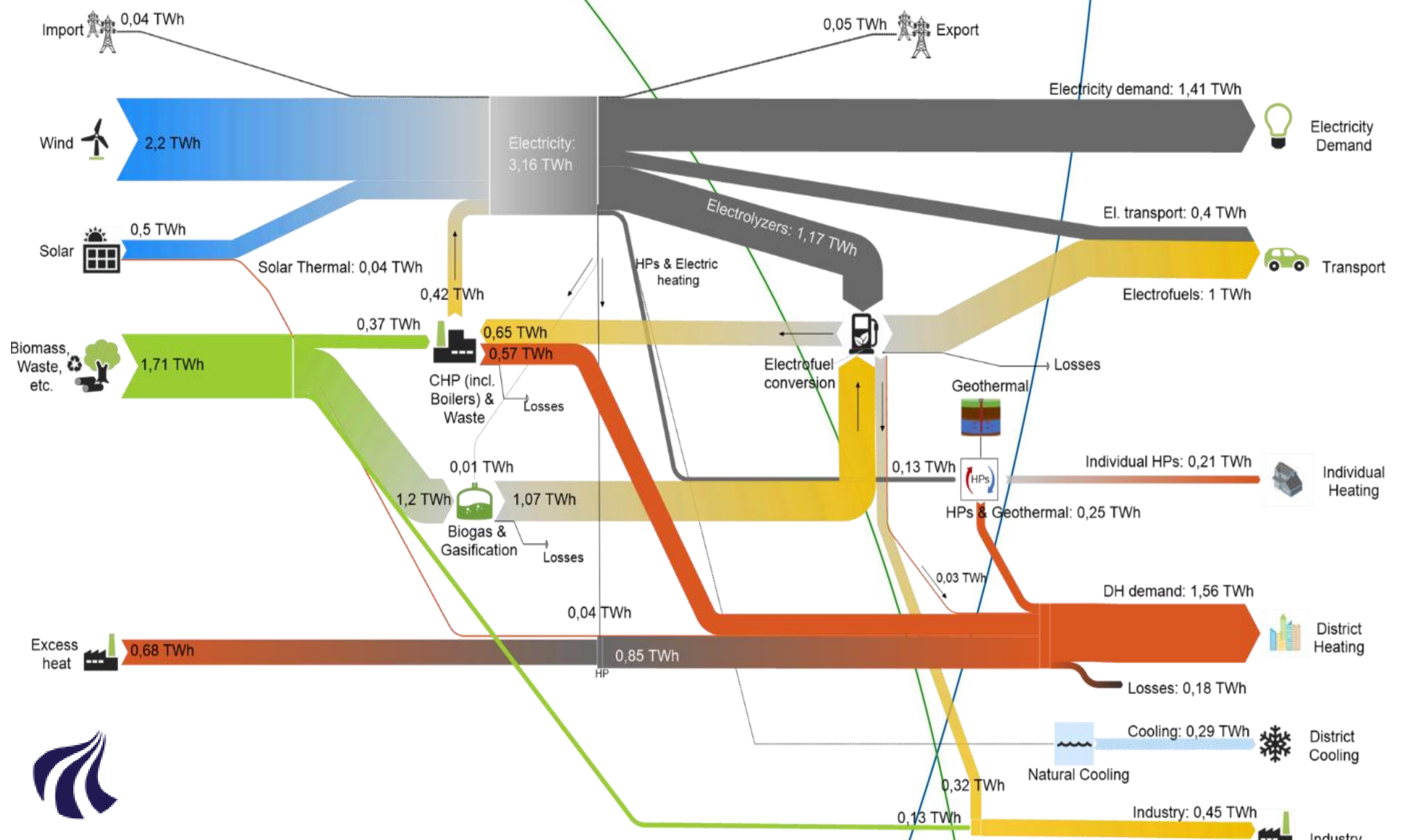
Sankey diagram of the 2050 system



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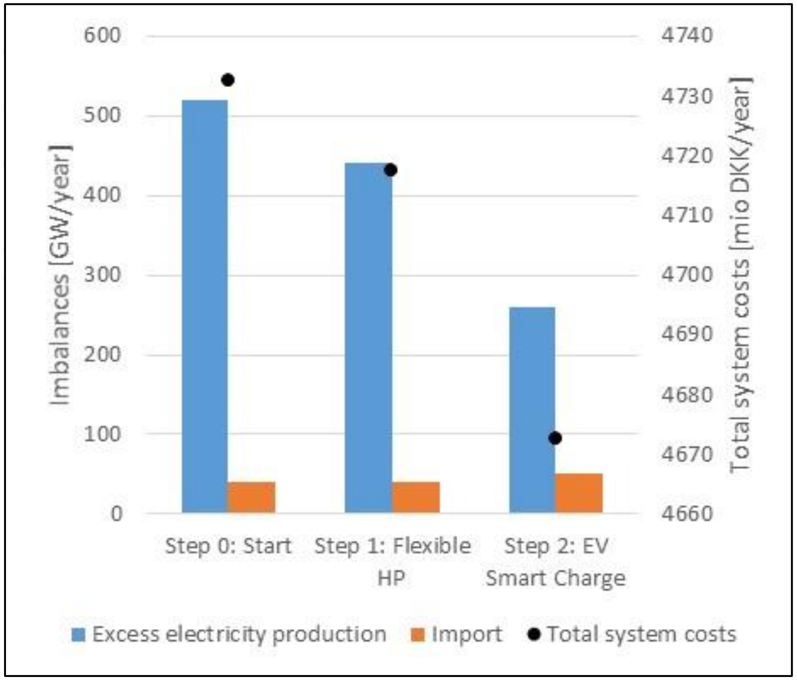
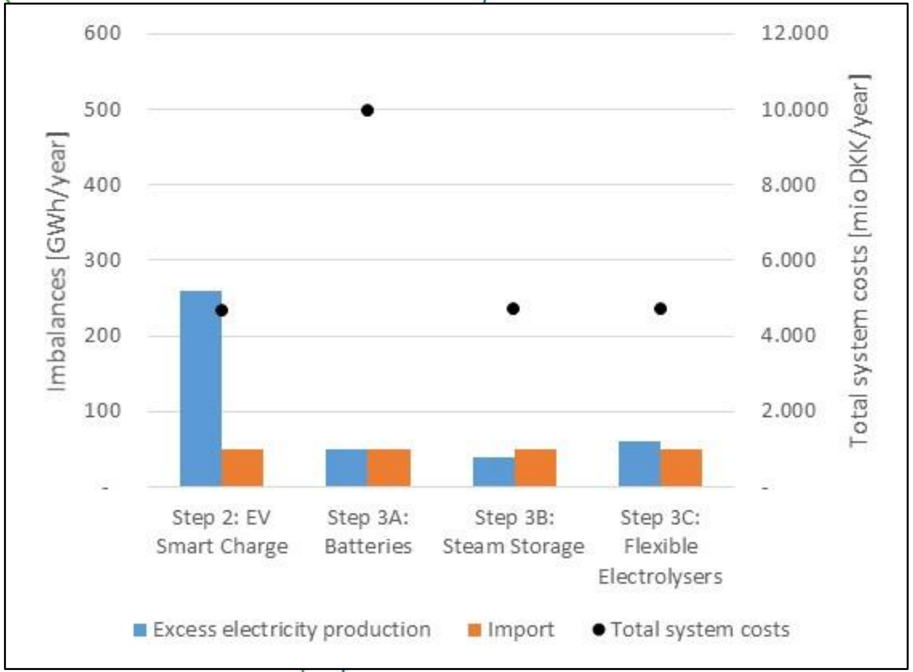
Hourly balancing of electricity demand and supply





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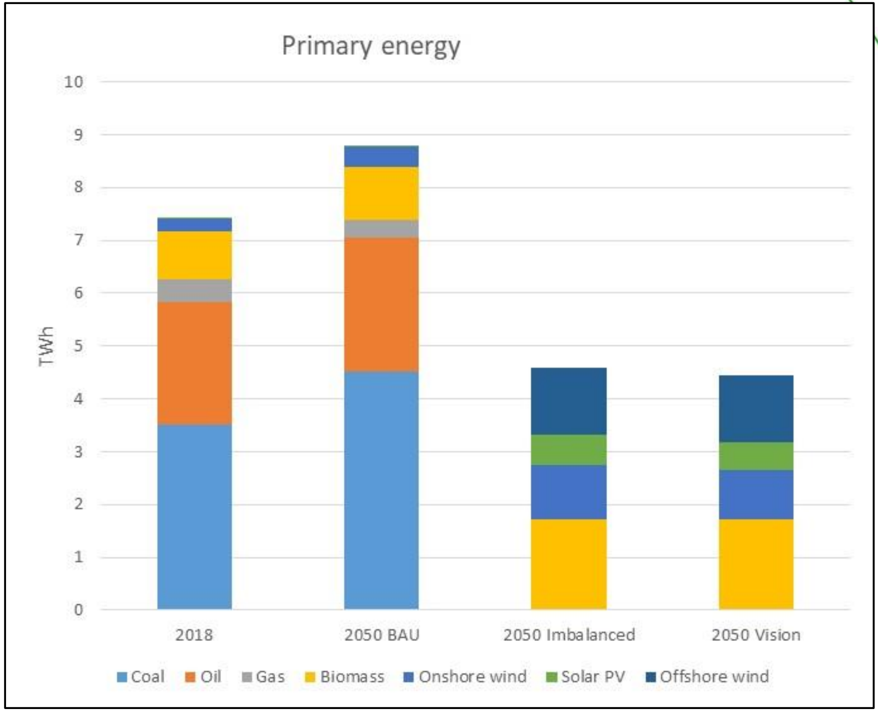
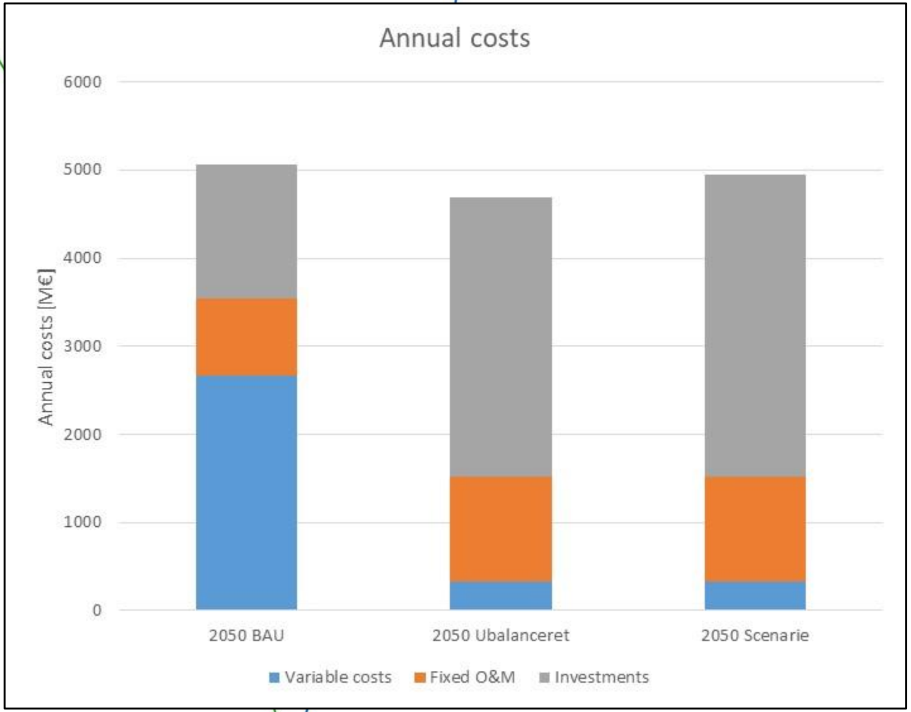
Vision results





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PV (570 GWh/y from 500 MW)

- Equal to 20% of electricity production
- Could in principle by on existing roofs:
  - 950 hektar out of 2200
  - 950 hektar could fully exploited produce 1060 GWh/year
- Or around 800 hektar fields (including roads etc. - based on "Vust Holme")
- In the Energy Vision prices have been based on a mix between the two…

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Wind:1050 GWh/y from 300 MW

- Aalborg already has 158 MW
- New wind farm (Nørkær Enge) will increase to 220 MW
- Replacement by bigger wind turbines is expected before 2050
- Additional expected 280 MW off shore will produce 1270 GWh/year.

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6TH INTERNATIONAL CONFERENCE ON

Smart Energy Systems

6-7 OCTOBER 2020 • AALBORG

sEEnergies

4DH
4th Generation District Heating Technologies and Systems

reINVEST

Location:

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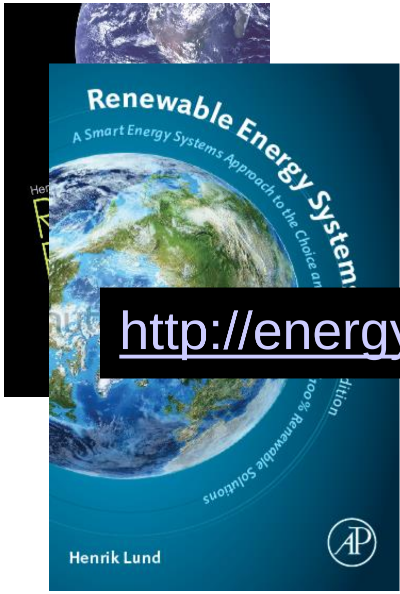

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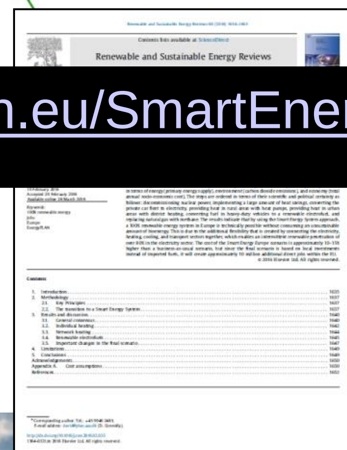

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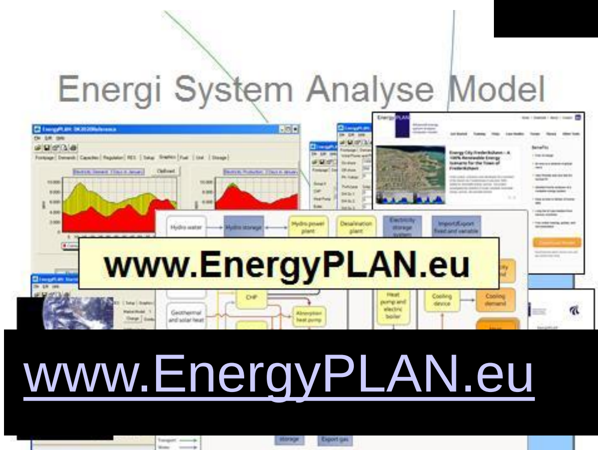

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