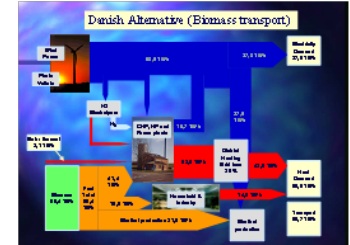


9<sup>th</sup> Annual ASPO Conference  
Albert Hall, Brussels  
27-29 April 2011



# Integration of Renewable Energy Sources in the European Electricity Grid

Henrik Lund  
Professor in Energy Planning  
Aalborg University



# Aalborg University, Denmark

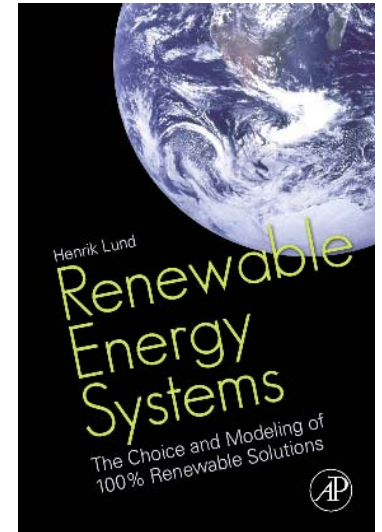


## Jutland/Denmark:

- 20% wind power (120,000 owners)
- High share of the world's offshore power
- 30% Distributed Generation
- 50% of electricity supplied by CHP

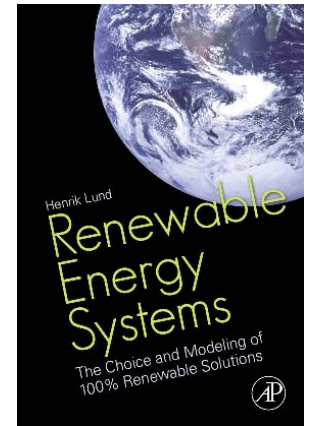
# Content

- Renewable electricity production and sustainable energy solutions
- Electricity Balancing:  
CHP and transport is part of the solution
- Smart Grid and CHP: The case of Skagen

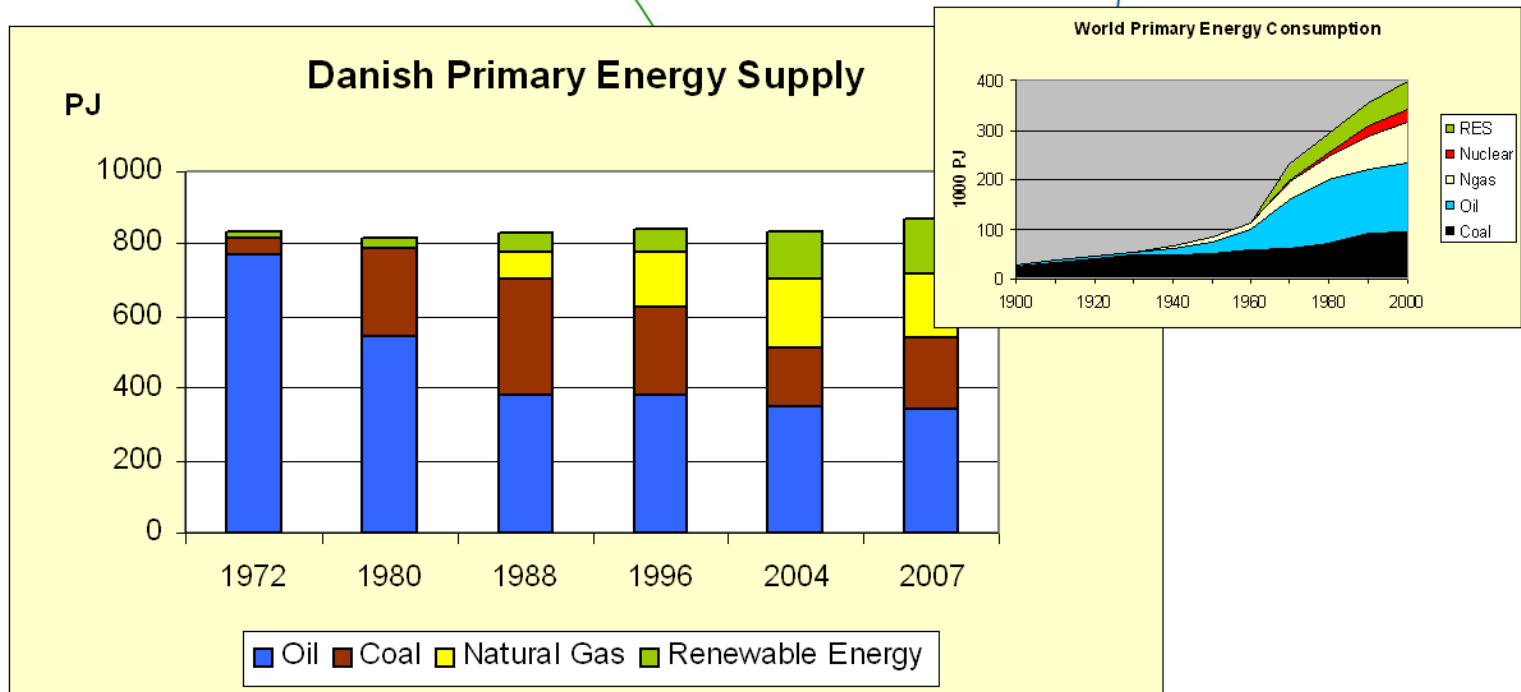


# Sustainable energy systems

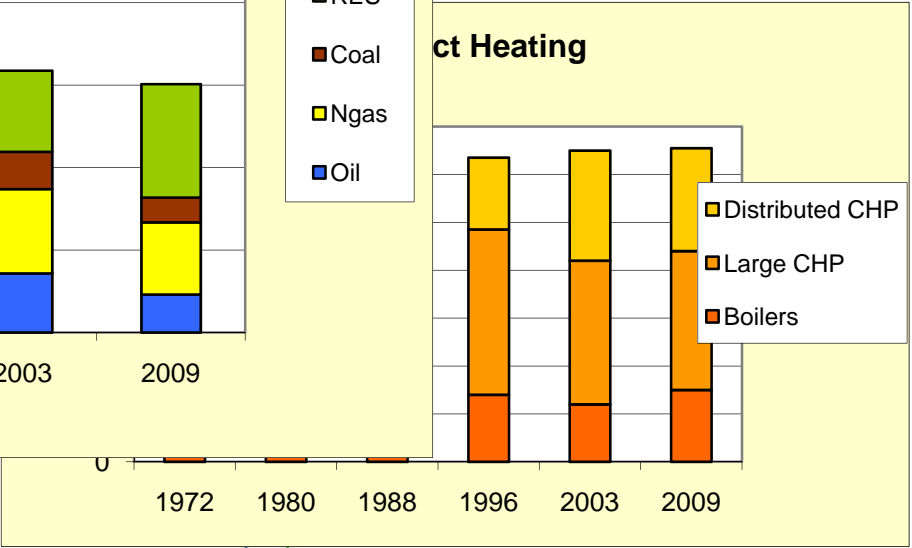
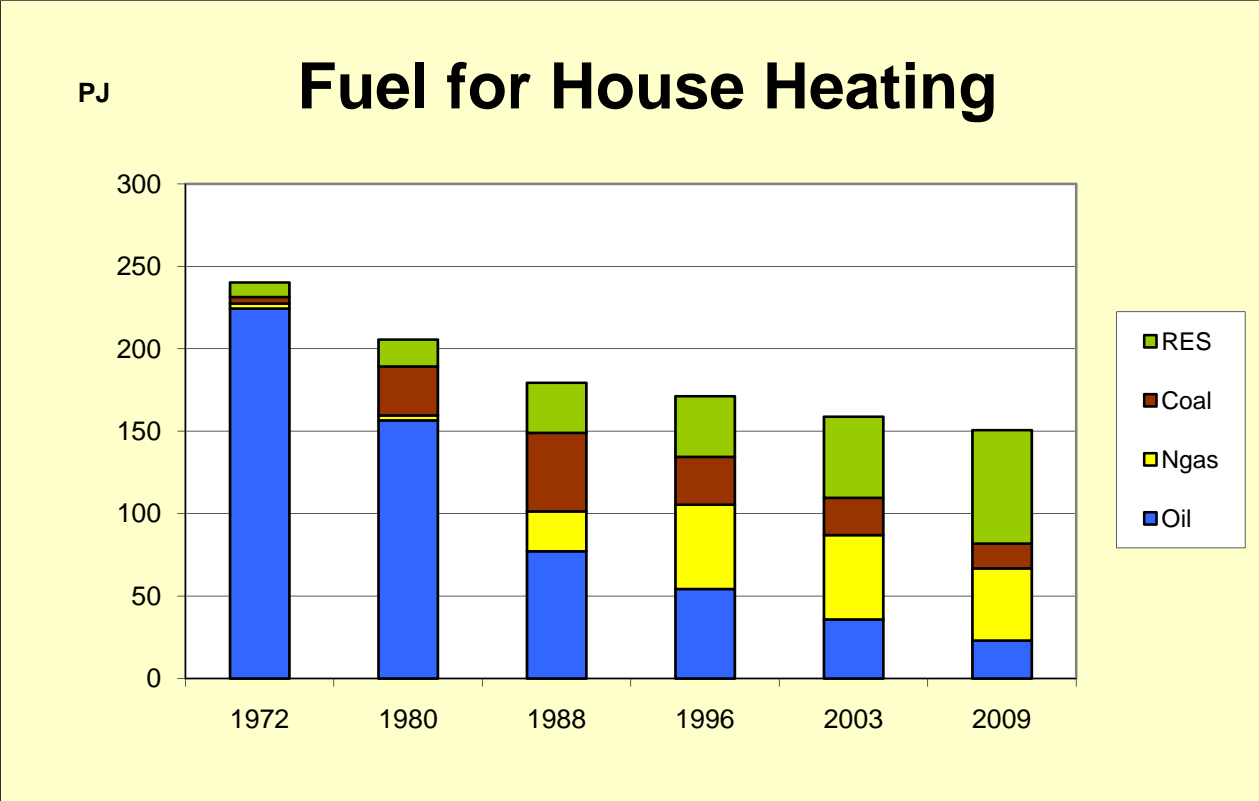
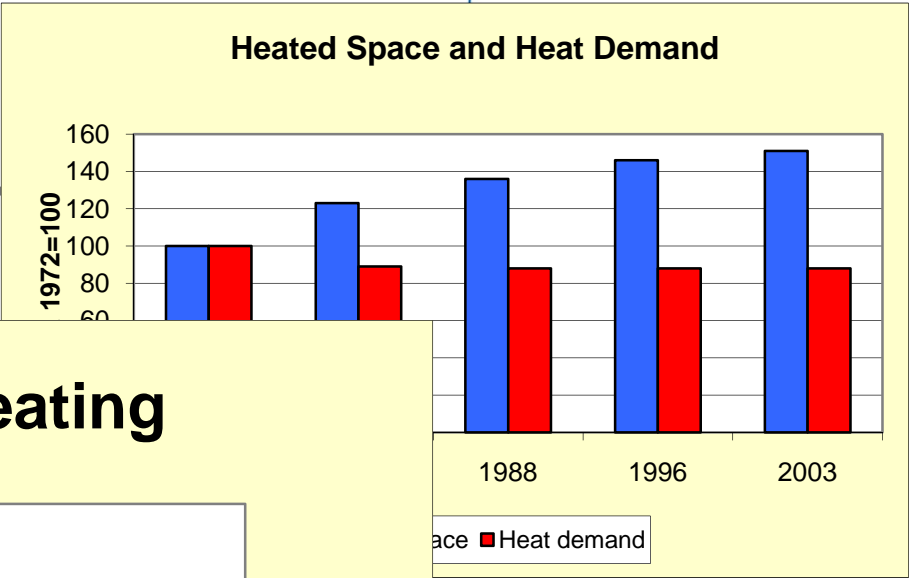
- A sole focus on renewable **electricity** production leads to storage solutions!
- Looking at renewable electricity as a part **energy systems** including heating, industry and transportation opens for cheaper and better solutions...



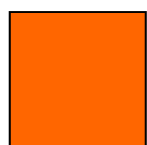
# 40 years with a stable energy consumption



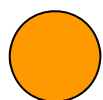
# Domestic heating



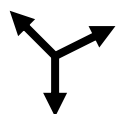
# Danish electricity production



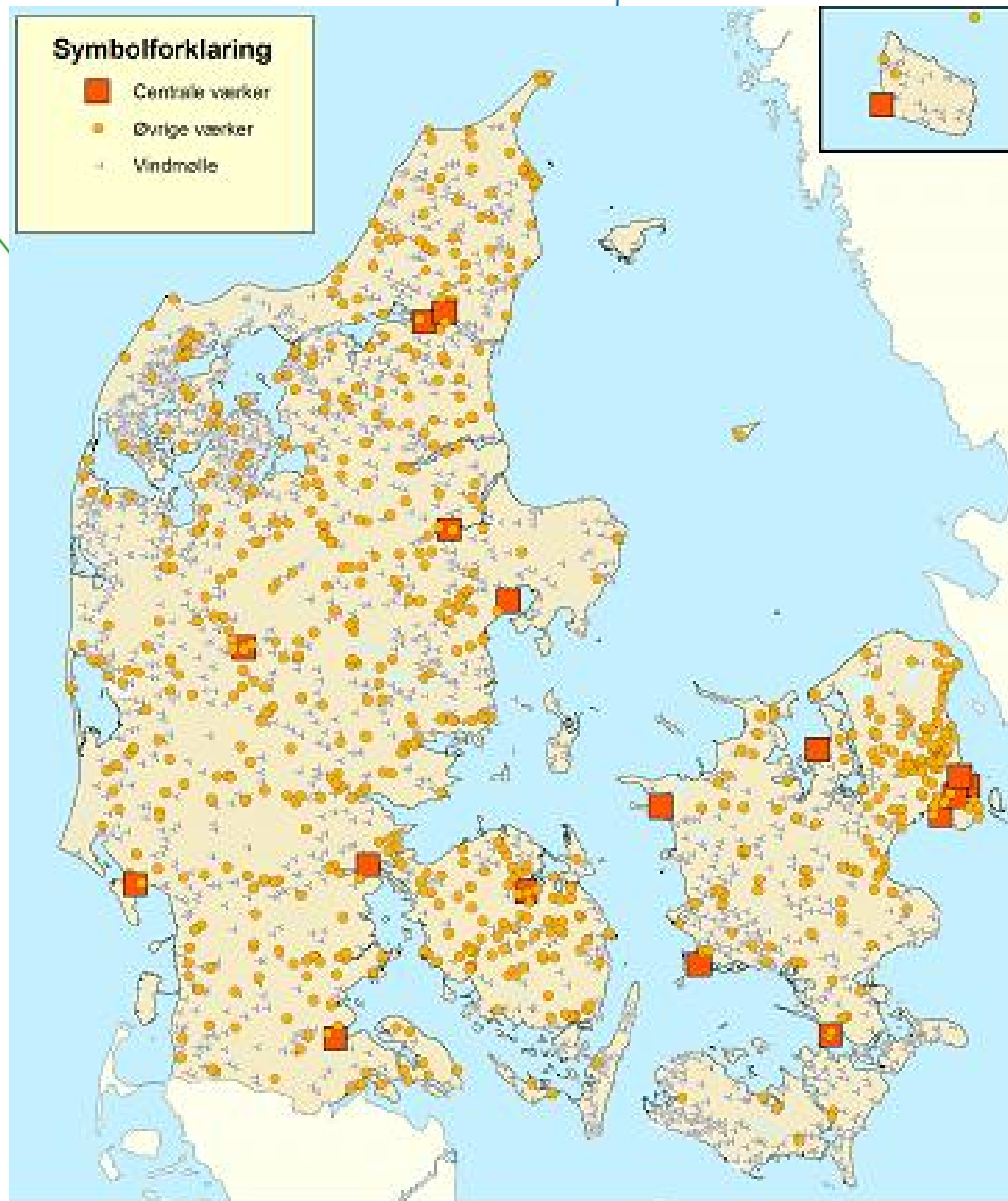
Big power stations



Small CHP plants



Wind turbines



# Energy System Analysis Model

The image displays the EnergyPLAN software interface, which is used for energy system analysis. It includes several windows and a central flow diagram.

**EnergyPLAN: DK2020Reference** (Top Left): Shows two line graphs for "Electricity Demand: 3 Days in January" and "Electricity Production: 3 Days in January". The y-axis represents power in MW, ranging from 0 to 10,000. The x-axis represents time in hours.

**EnergyPLAN: Startdata** (Top Right): A table for configuring system parameters.

Wind Power and PV Capacity:	Factor	Production	Distribution
On-shore	1000 MW	0	0,44 TWh/year
Off-shore	500 MW	0	1,04 TWh/year
Ph. Voltaic:	0 MW	0	0,00 TWh/year

Group II	TWh/year	Solar Thermal	Industrial CHP (CSHP):	DH prod	Electricity prod
CHP	DH Gr. 1:	0		0	0
Heat Pump	DH Gr. 2:	0		0	0
Boiler	DH Gr. 3:	0		0	0

**EnergyPLAN: Startdata** (Bottom Left): Shows regulation and market model settings.

Regulation Strategy:	1	Change Strategy	Market Model:	1
Minimum stabilisation prod. share	0,3	Change	Distribution	
Stabilisation share of CHP2	0	Addition factor	0	
Stabilisation share of wind	0	Multiplication factor	2	
Minimum CHP in gr. 3:	300	Dependency factor	0	
Heat Pump Maximum load:	0,5	Average price		
CEE regulation:	0	Marginal import price		
Maximum imp./exp. cap:	1600 MW	Marginal export price (P)		
		Marginal export price (C)		
		Marginal export price (H)		

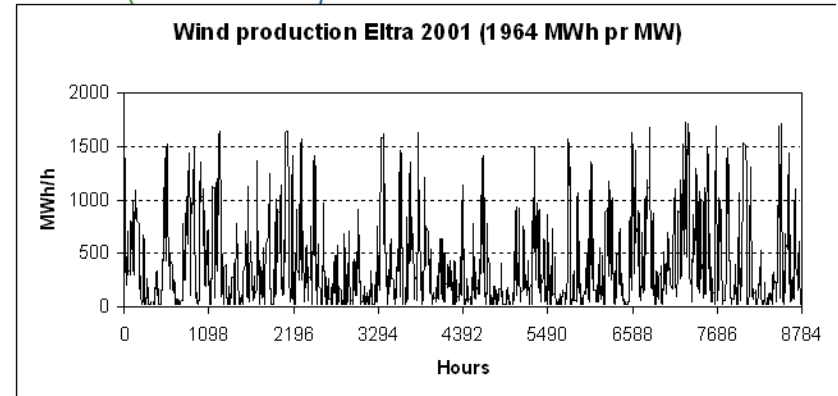
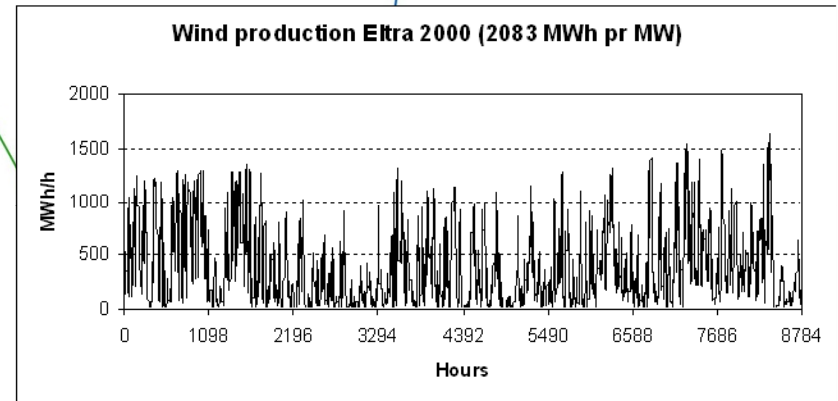
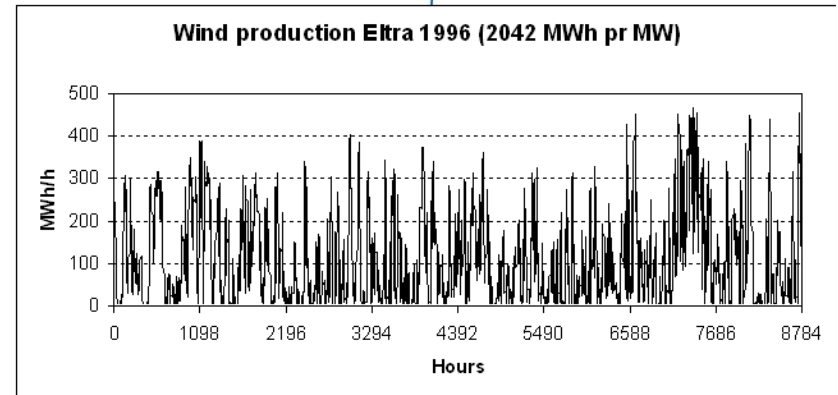
**www.EnergyPLAN.eu** (Center): The website address.

**System Flow Diagram** (Bottom Right): A schematic showing energy flows between various components. Inputs include "Fuel" and "RES heat". Key components include "PP" (Power Plant), "CHP" (Combined Heat and Power), "Boiler", "Heat pump and electric boiler", "Cooling device", "Heat storage", "H2 storage", "Electrolyser", "Cars", and "Industry". Outputs include "Electricity demand", "Cooling demand", "Heat demand", "Transport demand", and "Process heat demand".

# Wind energy

Input:

- Data from total productions of wind turbines in the TSO Eltra area (West Denmark).



# At present 99% of Danish Wind Power is used in Denmark to meet Domestic demands

By

**Henrik Lund, Frede Hvelplund, Poul A. Østergaard,  
Bernd Möller, Brian Vad Mathiesen**

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**Anders N. Andersen**

*EMD International, NOVI Research Park, Aalborg, Denmark*

**Poul Erik Morthorst, Kenneth Karlsson, Peter Meibom  
and Marie Münster**

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**Jesper Munksgaard**

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*Institute of Chemical Engineering, University of Southern Denmark, Odense,  
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**Hans Henrik Lindboe**

*Ea Energy Analyses, Copenhagen, Denmark*

CEESA (Coherent Energy and Environmental System Analysis) Research Project

## Danish Wind Power Export and Cost



By

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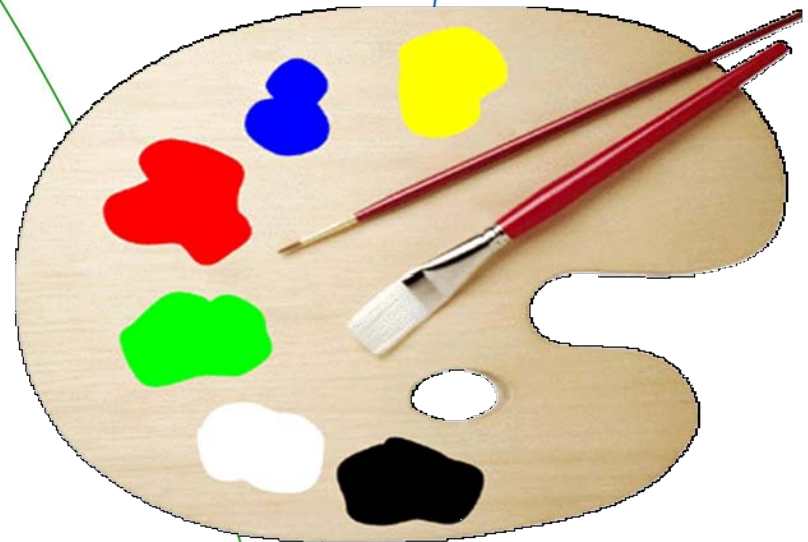
**Henrik Wenzel,**  
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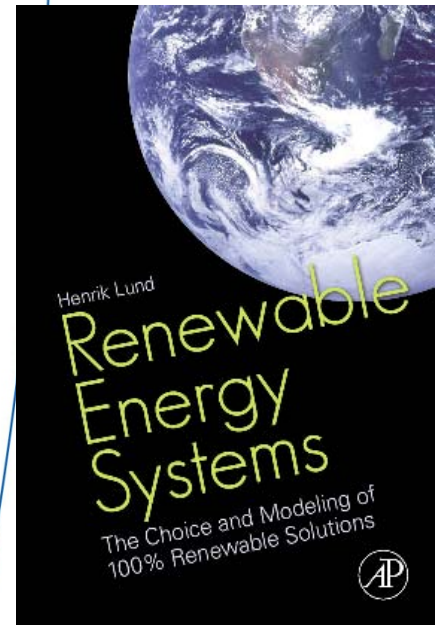
# A palette of solutions

- Flexible consumption
- Electricity storage
- CAES systems
- Regulation of CHP plants
- Electric heating
- Heat pumps
- Electric cars
- Stopping of wind turbines
- Production of hydrogen
- Transmission abroad
- V2G

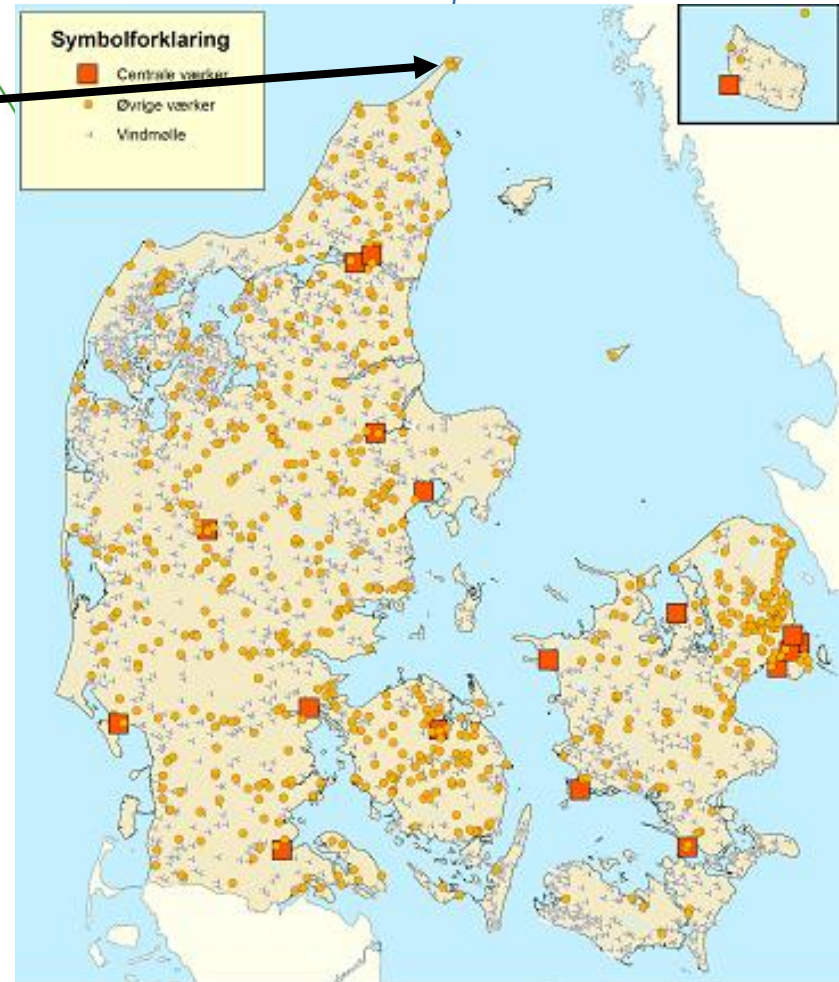


# Conclusions:

- Regulation of CHP and heat storage (implemented in DK in 2004): Makes possible to integrate 20% Wind Power (and 50% CHP)
- Adding large heat pumps and heat storage capacity to existing CHP plants: Makes possible to integrate 40% Wind Power (and 50% CHP)
- Electricity for transportation (integrate approx. 60% wind power)
- Important to involve the new flexible technologies in the grid stabilisation task



# Case: Skagen CHP plant



# Skagen CHP plant



- CHP capacity: 13 MWe and 16 MWth  
(Three 4.3 MWe Wärtsilä Natural Gas engines)
- 250 MWh heat storage
- 37 MW peak load boilers
- 10 MW electric boiler
- Heat Pumps Investment under consideration

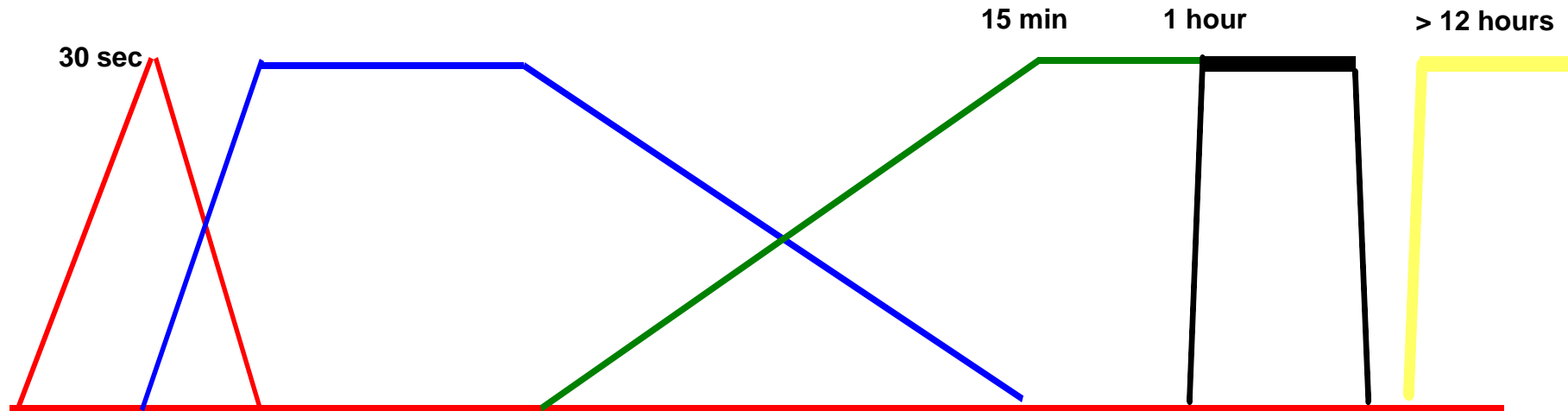
Operated together with a

Waste Incineration plant (heat only).



# The main electricity markets

- Primary reserves (frequency controlled production)**
- Secondary reserves (controlled by status of primary reserves)**
- Manuel regulating power (Tertiary reserves)**
- Intra day market**
- Day ahead spot market**



# Skagen

- Day ahead spot market in Jan. 2005
- Regulating power market in approx. 2006
- Automatic primary reserve market  
in Nov. 2009

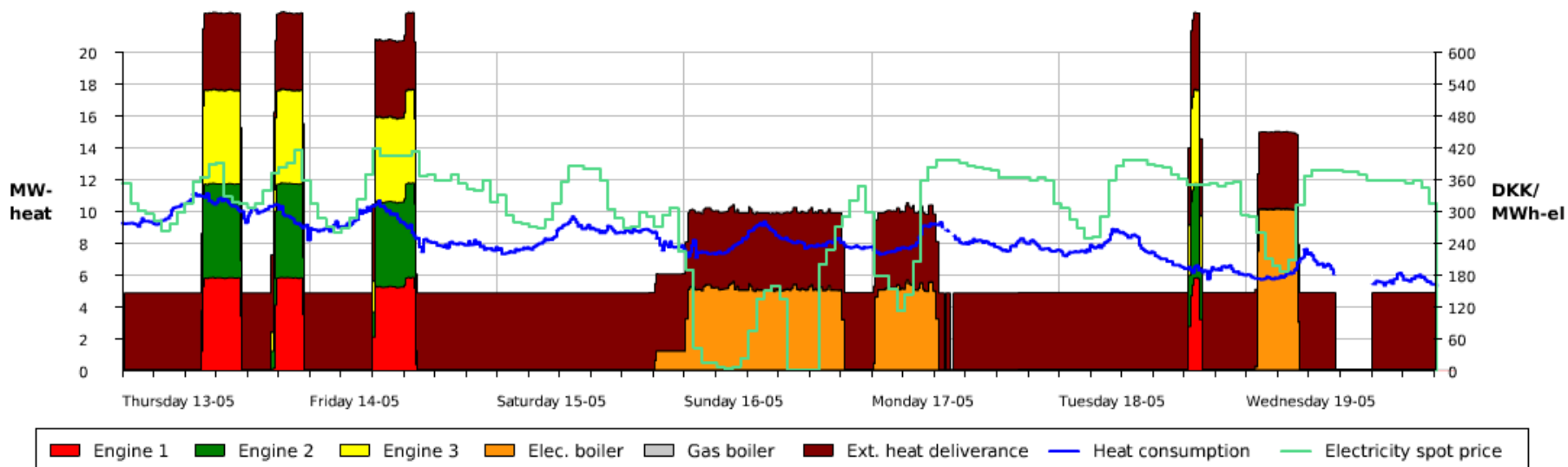
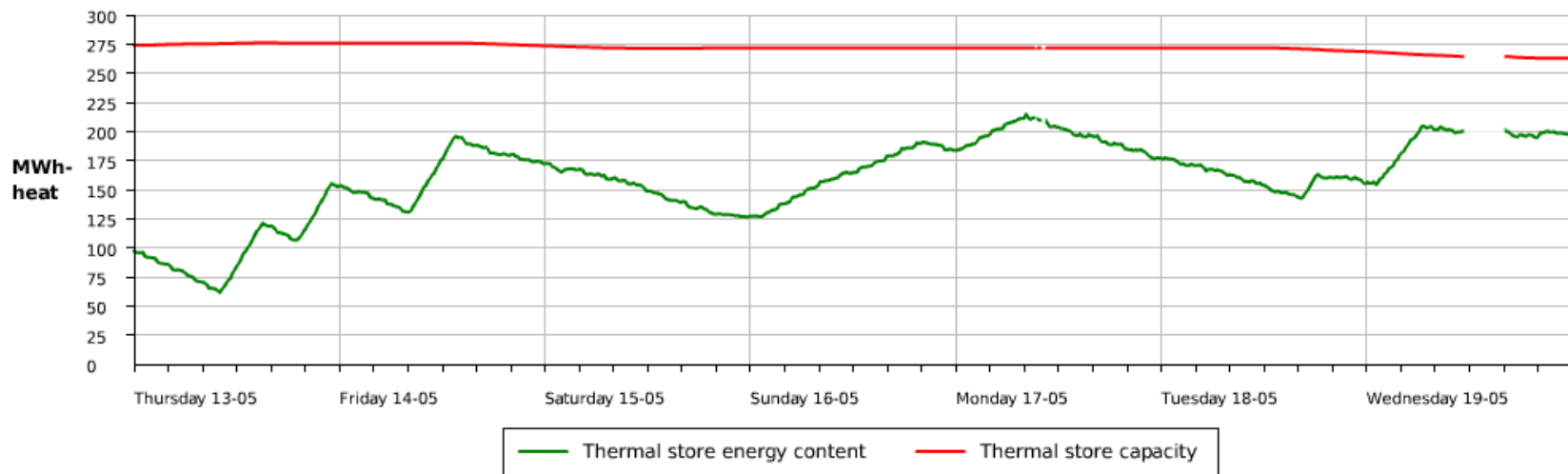


# Cost of entering primary automatic reserves market

- Cost of making +/- 1.4 MW available on the engines: Only approx. 27.000 EUR.
- Investing in 10 MW electric boiler:  
Approx 0.7 MEUR.



### Skagen CHP, history - Wednesday, 19-05-2010

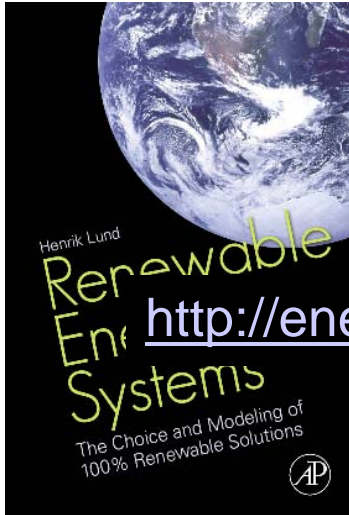


# Conclusions

- Denmark can operate a system with 20% Wind and 50% CHP
- By adding heat pumps to the CHP units the integration of wind power can be raised to approx. 40% with-out loosing efficiency (nor wind power)
- Including the CHP plants in the various electricity markets is essential.
- Once the markets are open for CHP plants the cost of entering them seams small.

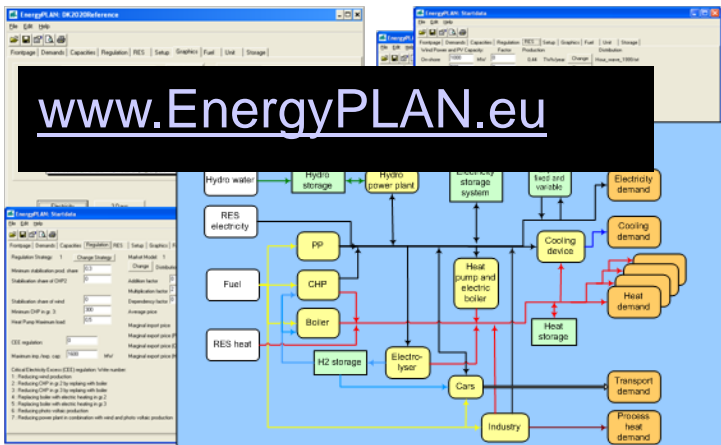


# More information



<http://energy.plan.aau.dk/book.php>

[www.energyplanning.aau.dk](http://www.energyplanning.aau.dk)

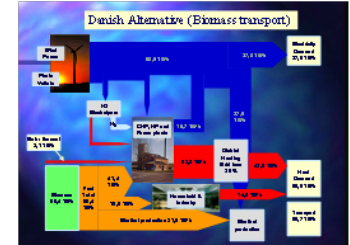


[www.EnergyPLAN.eu](http://www.EnergyPLAN.eu)



- <http://www.emd.dk/desire/skagen>
- <http://www.emd.dk/el>

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