INTEGRATION OF HEAT PUMPS IN INTENSIVE RENEWABLE ENERGY SCENARIOS

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Danish Energy policy

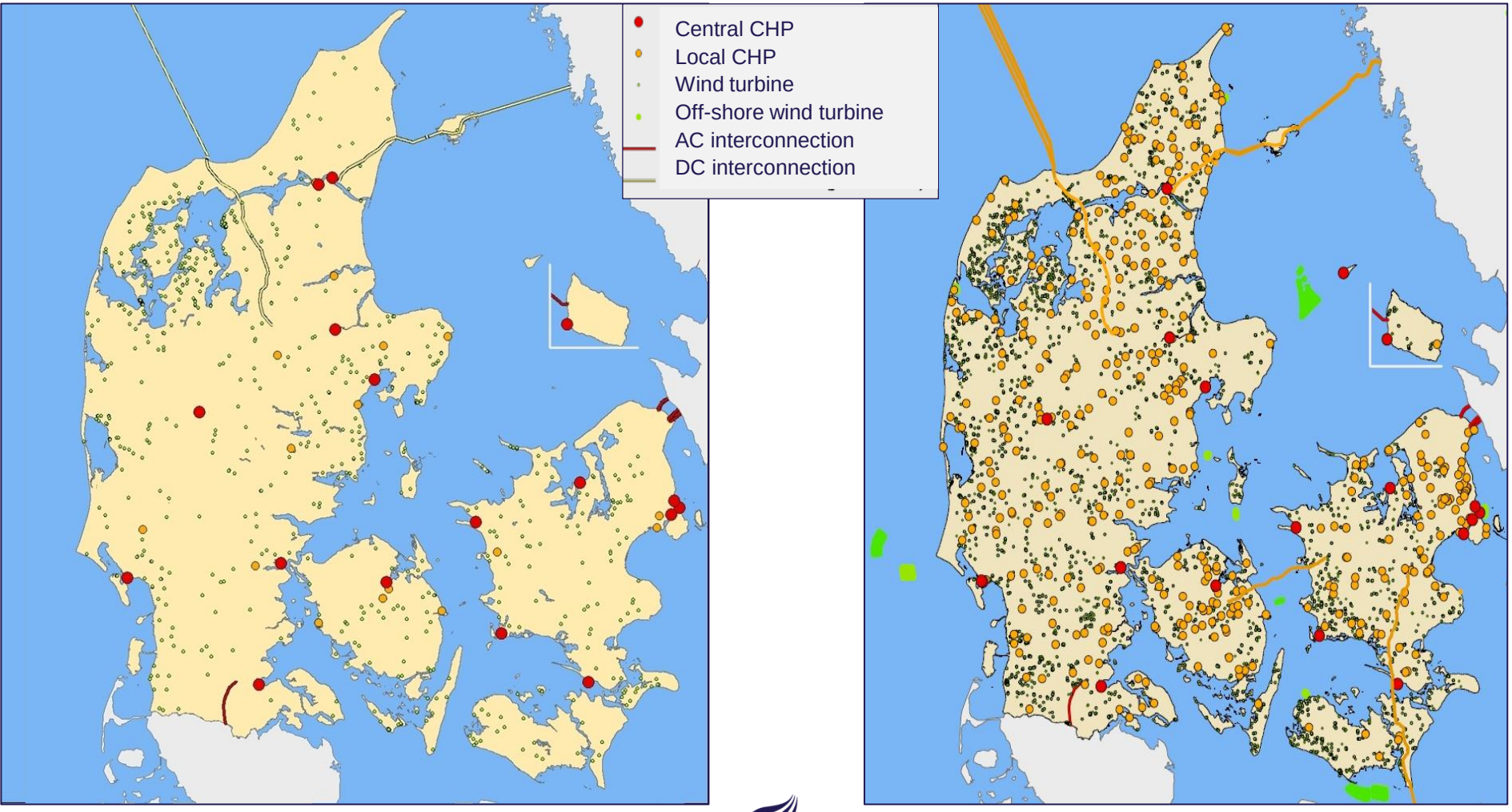
- In 2050
  - 100% RE in the energy and transport sectors

- In 2020
  - 30% of the final energy consumption must be based on RE
  - 10% of the energy use in transportation must come from RE
  - ~ 50% of the electricity demand should be covered by wind power

- June 1 2014 an amendment to the Danish building code will ban boilers for ”fossil gas or fossil oil” in new houses

- Incentives to convert from oil and natural gas boilers to RE

The Danish Energy System – from central to distributed



1985

2013

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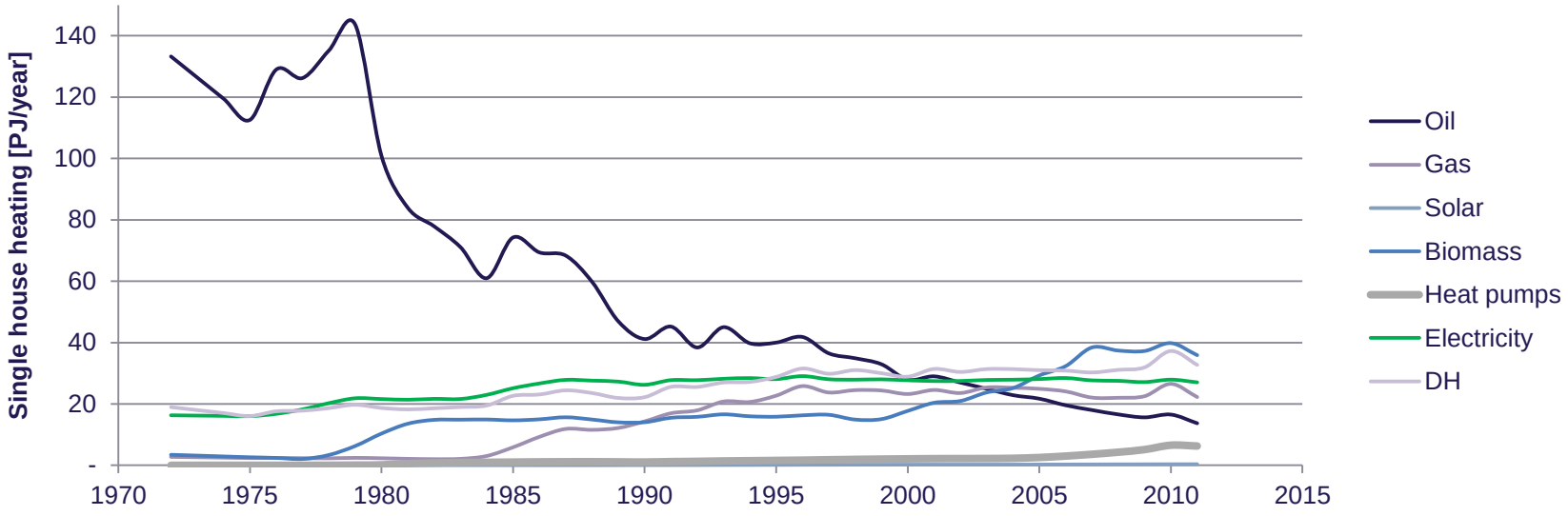
Source: Danish Energy Authority

Single family house heating in Denmark



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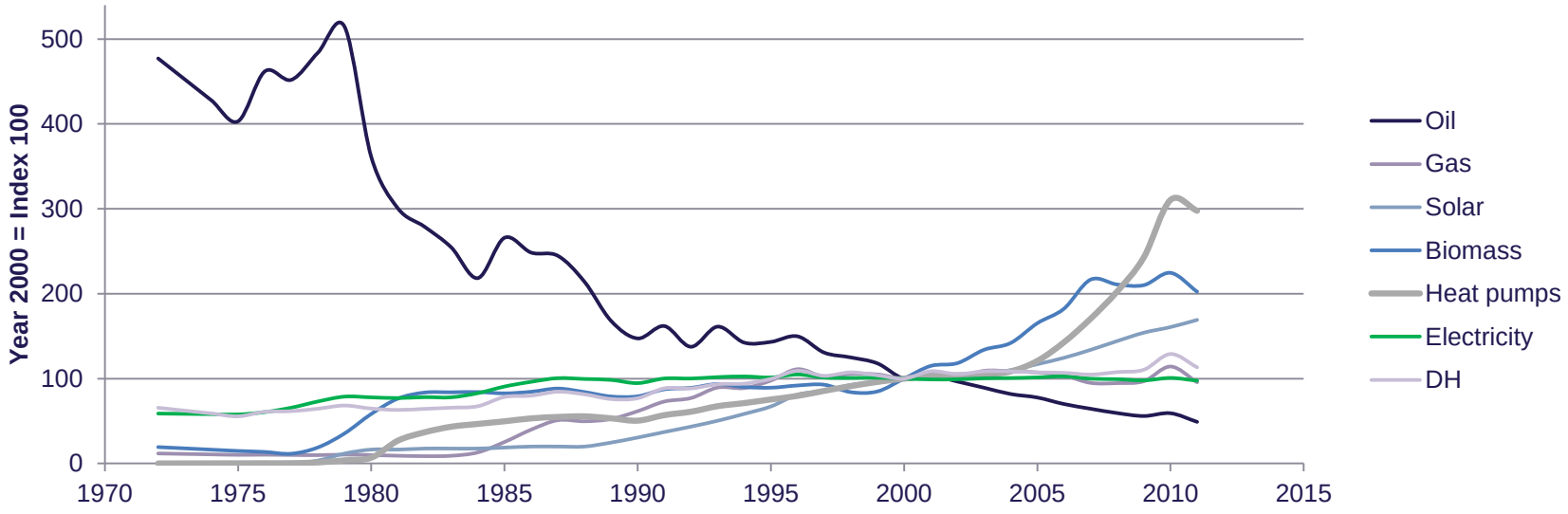
Single family house heating in Denmark



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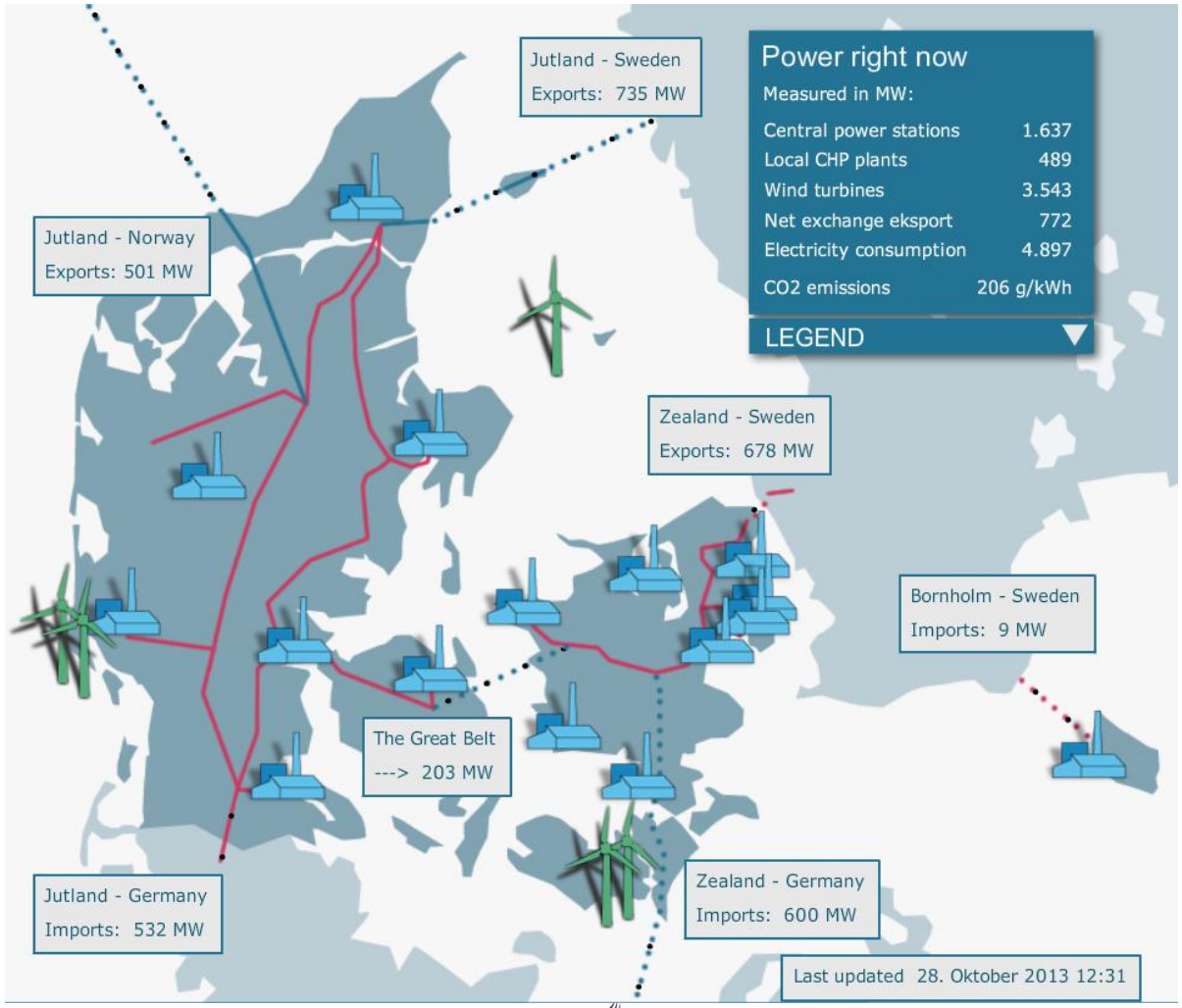
The Danish power system at time of preparing presentation



72% wind

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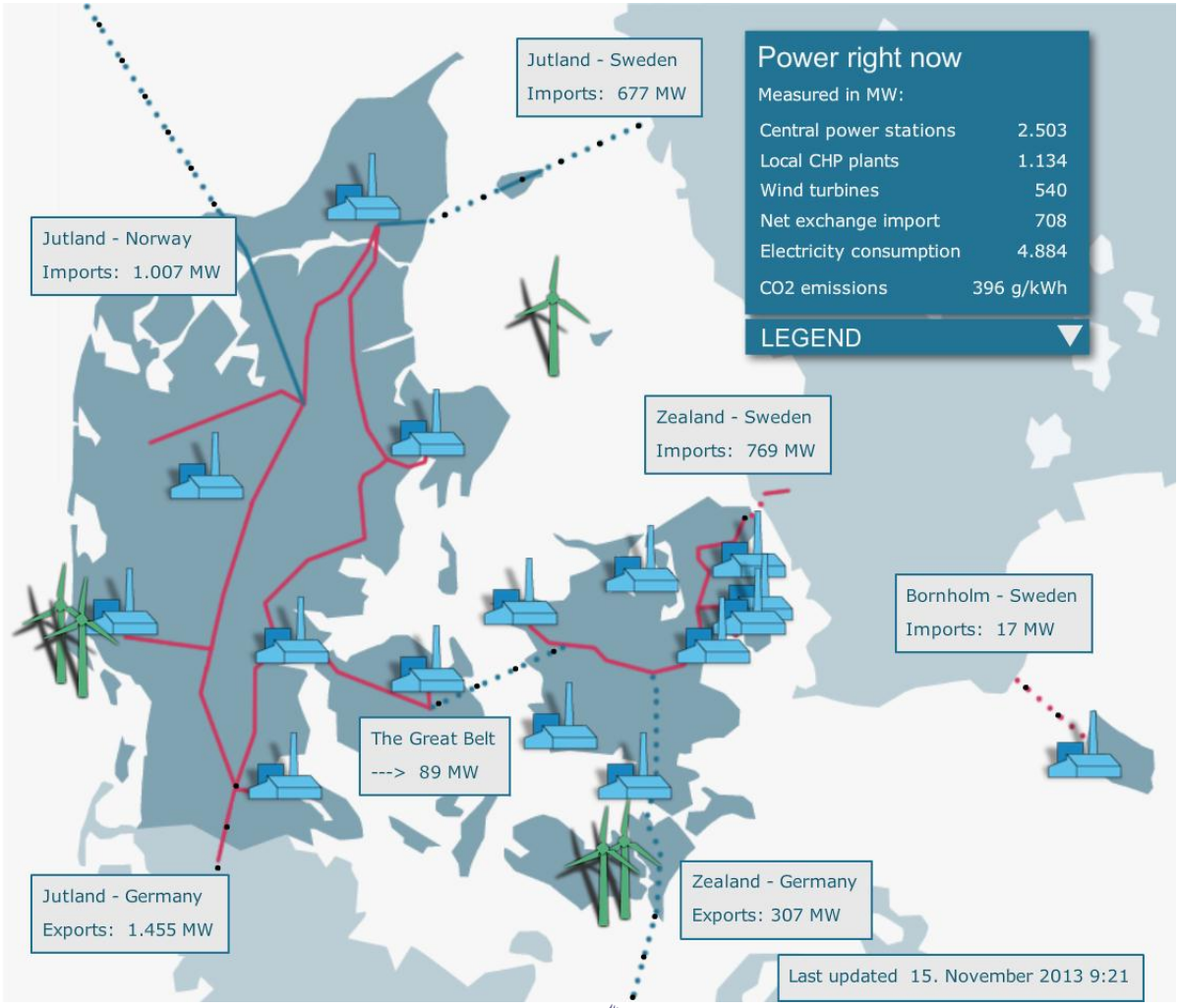
Source: energinet.dk

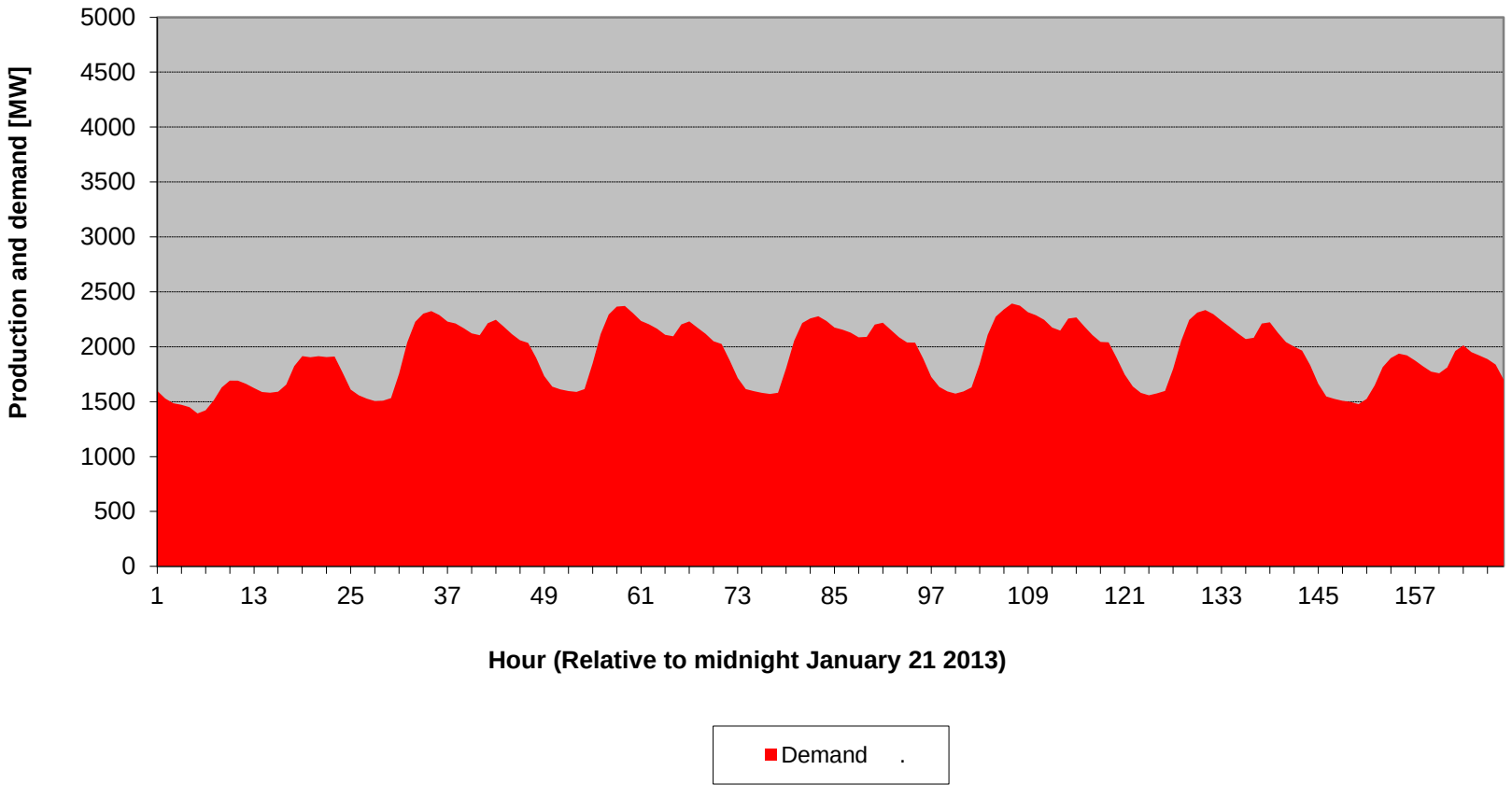
The Danish power system last Friday



11% wind

Source: energinet.dk

Load-curve building in Denmark – a summer week



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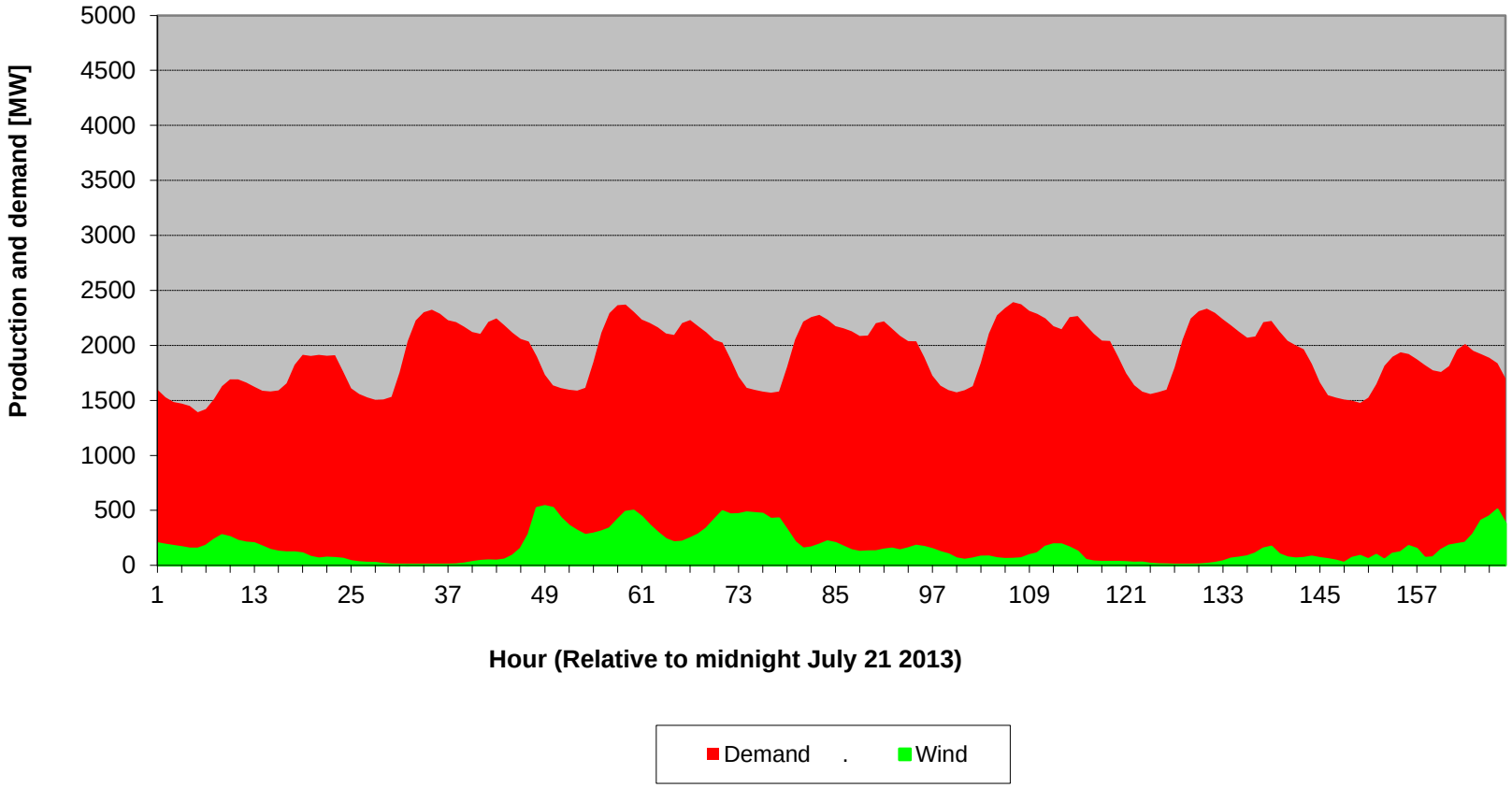

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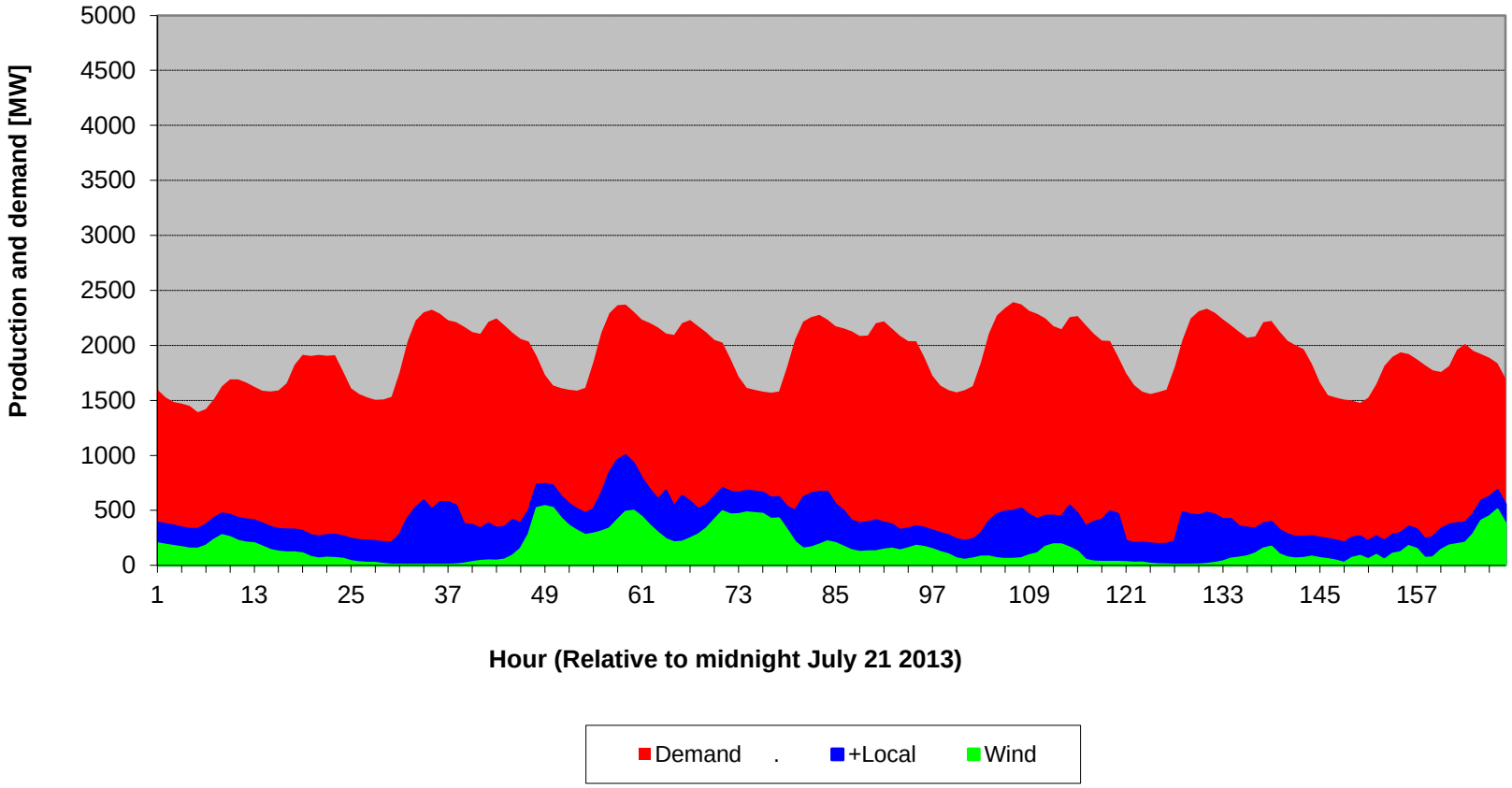

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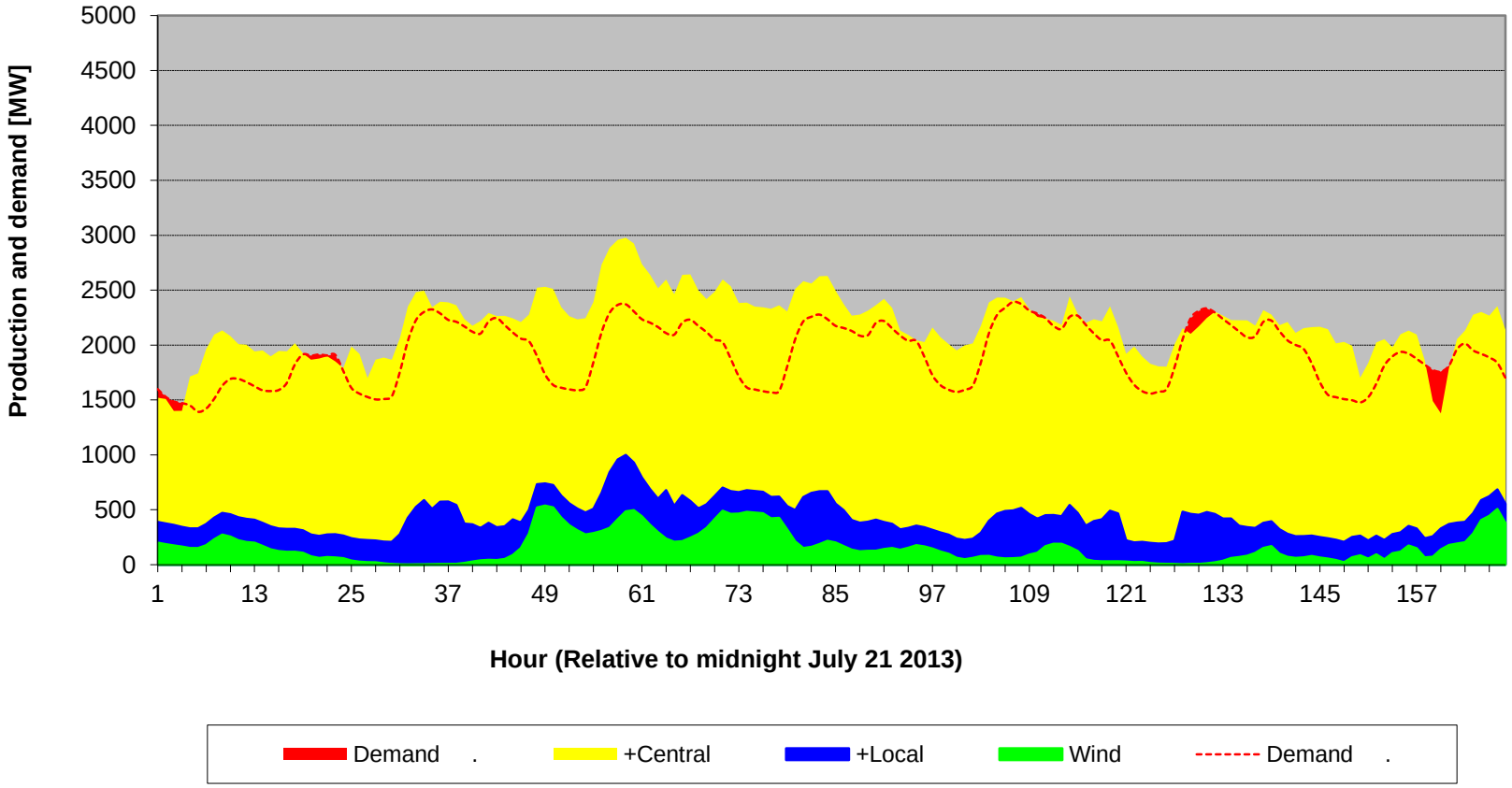

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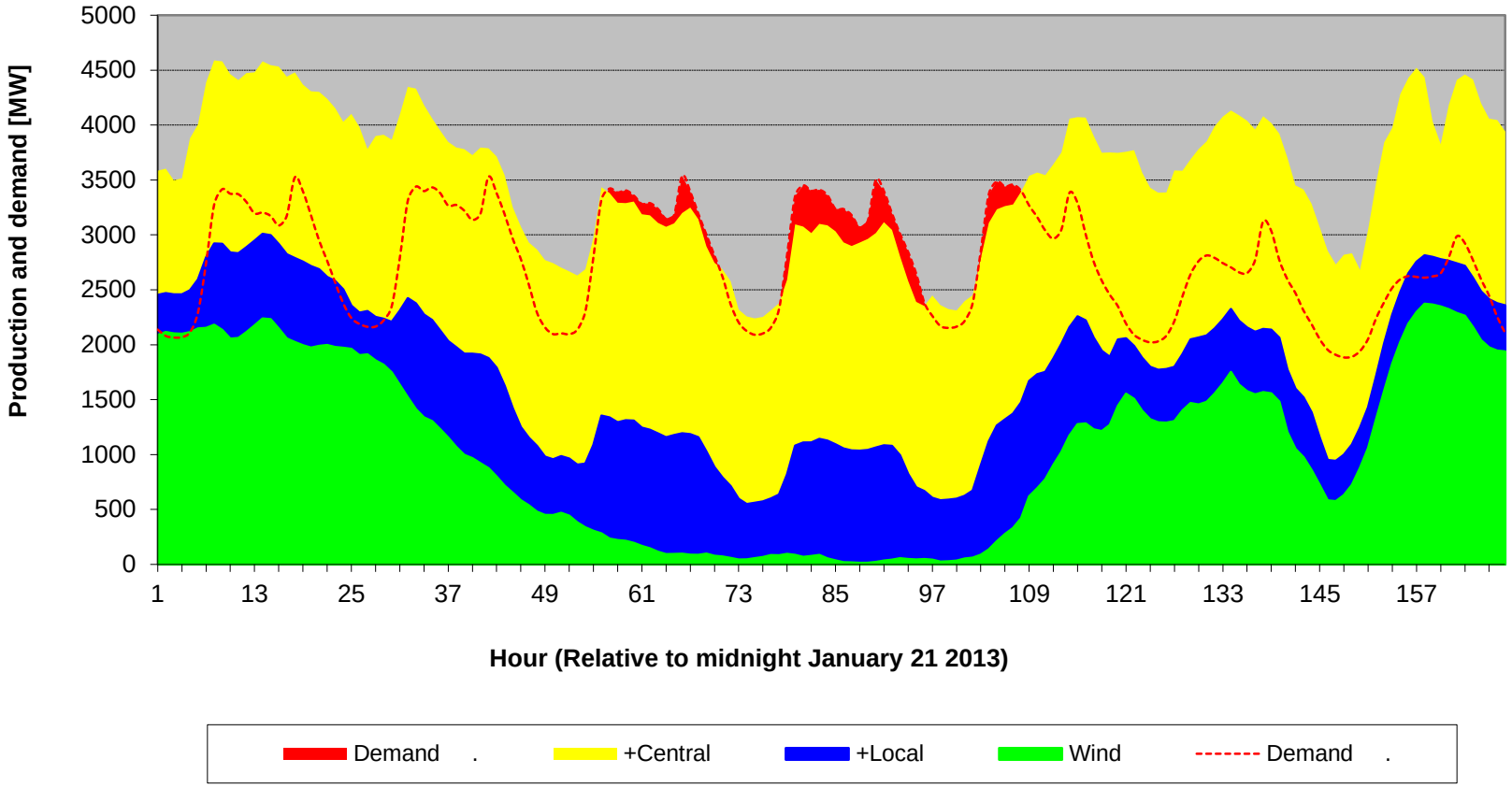
Load-curve building in Denmark – a winter week



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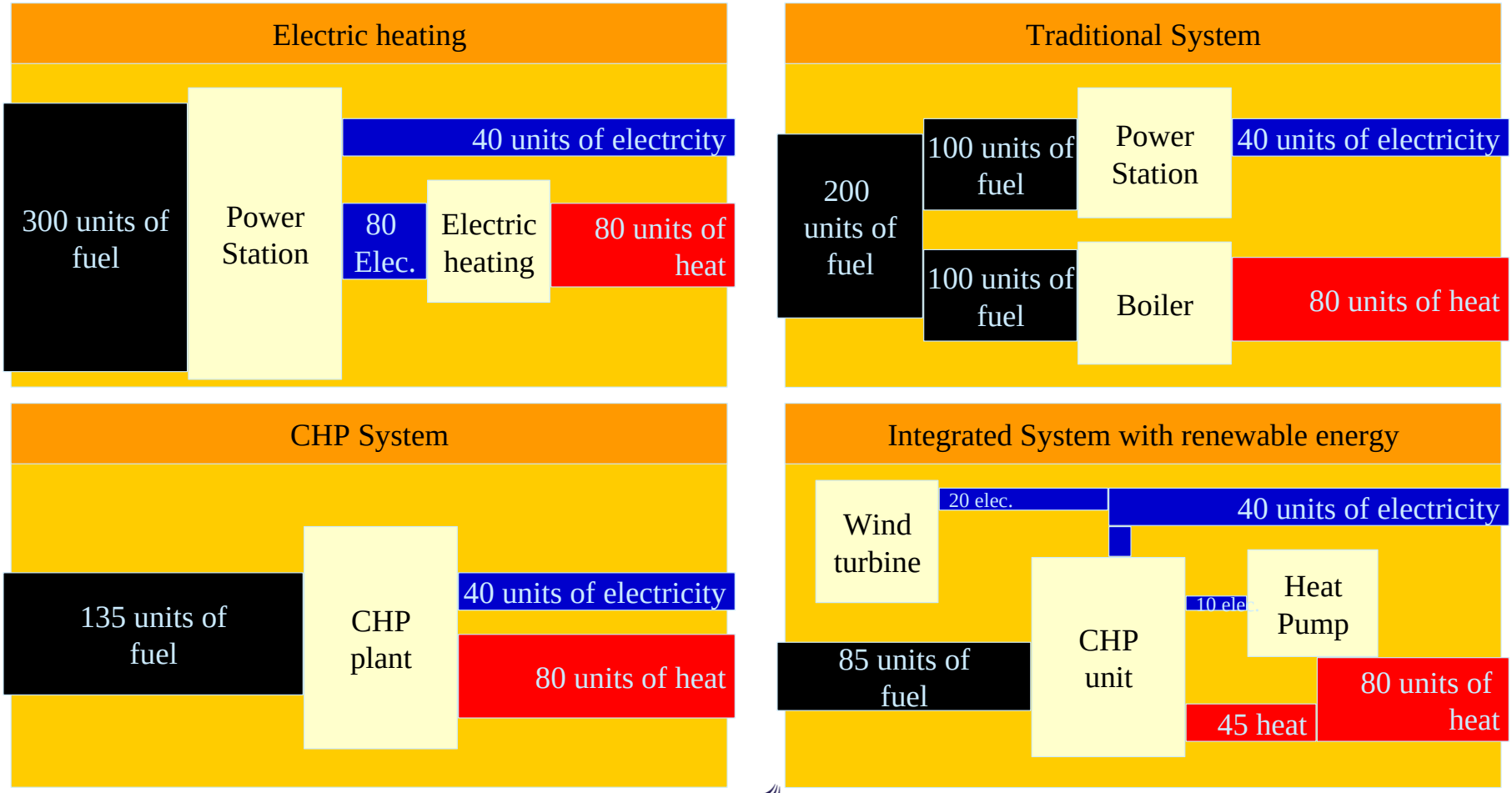
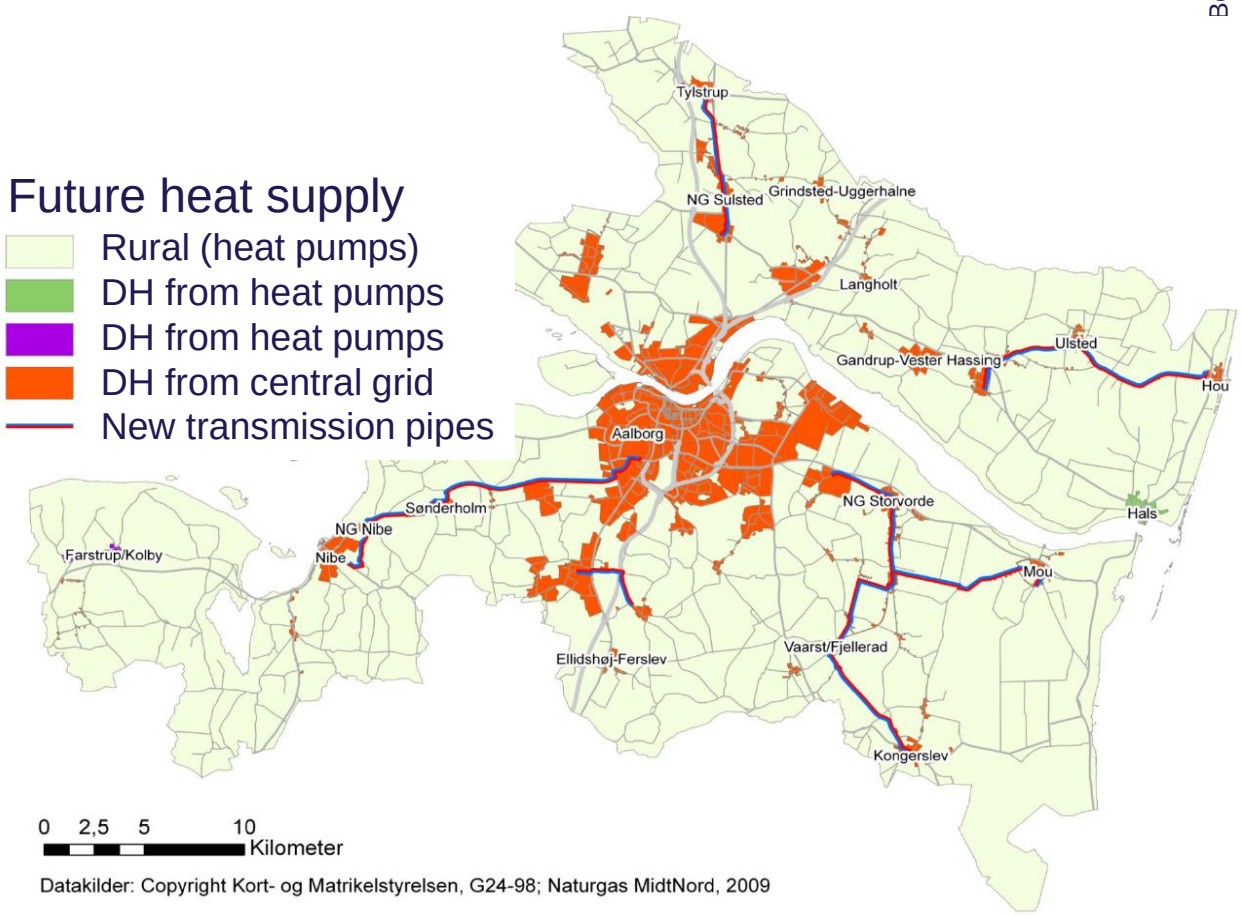
Four different systems



A RENEWABLE ENERGY SCENARIO FOR AALBORG

Aalborg in a glimpse

- City: 129,000 (4th)
- Municipality: 203,000 (6th)
- 1144 km^2 (3rd)
- 175 inhabitants/km^2 (>128)
- Largest Danish energy consumer Aalborg Portland 2.4% of TPES
- Extensive DH (CHP, Waste, industry, sewage, crematorium)



Bernd Möller

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Energy sources in the Vision

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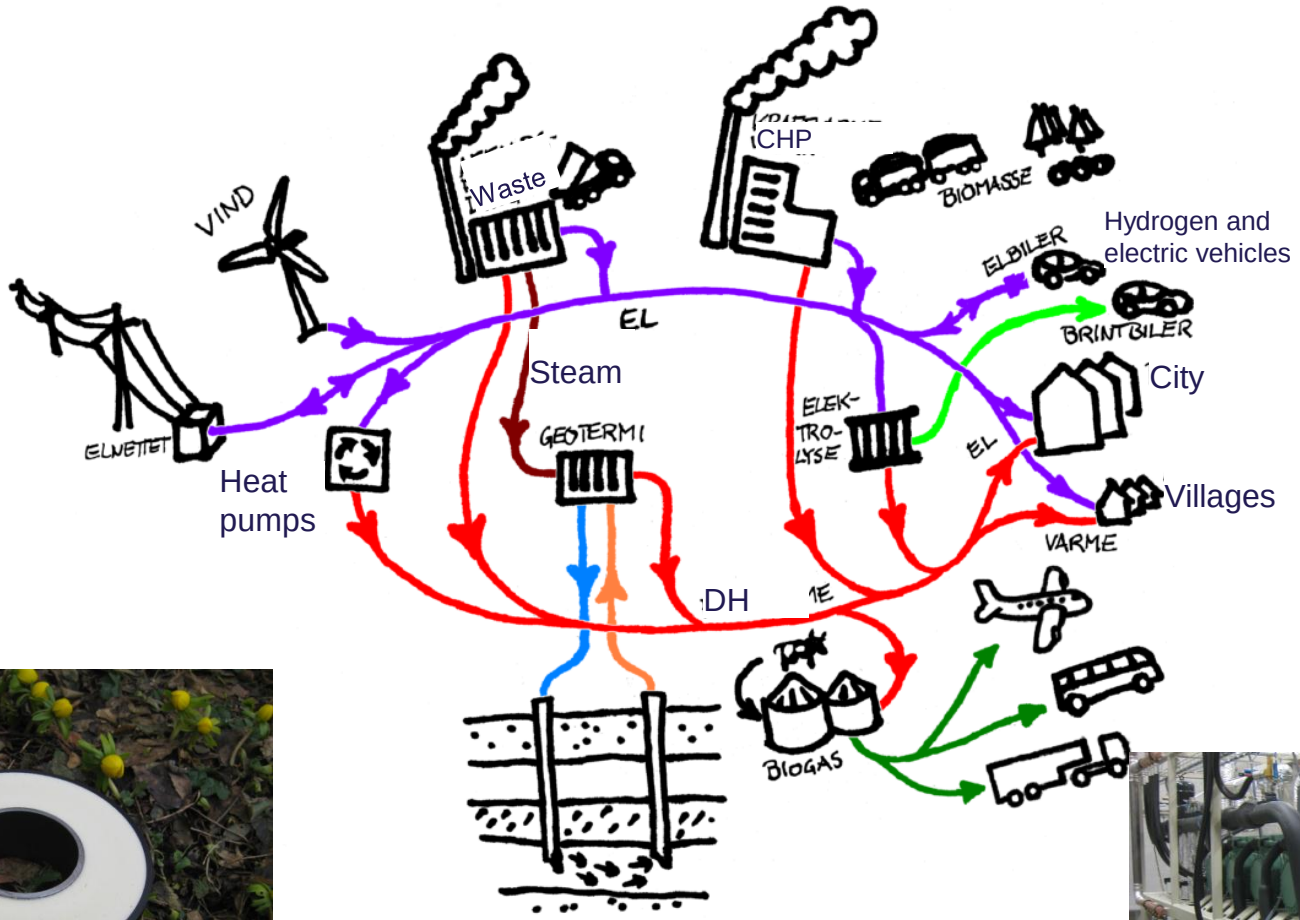
Centre image nicked from the Internet

The Energy Vision – Scenario design



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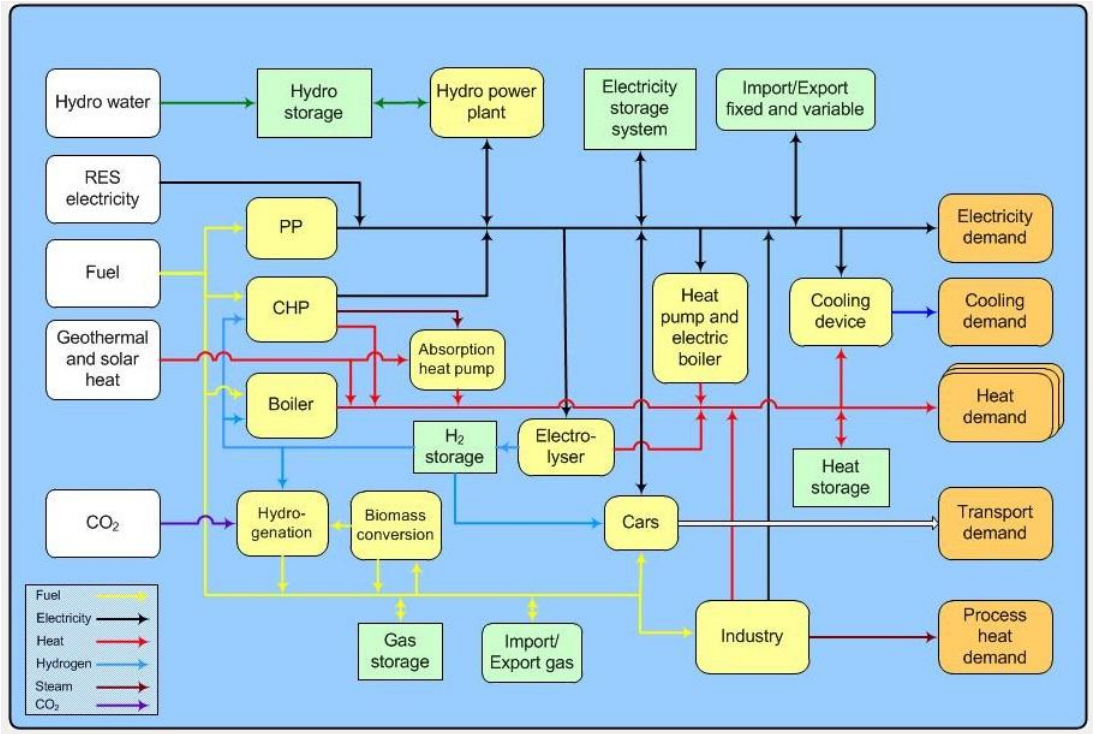
Energy systems simulation and analysis using EnergyPLAN

- Developed with a focus on the integration of RE in energy systems
- Entire energy system
- RES, CHP, DH, HP, Storages
- Deterministic
- One hour resolution
- One year
- Aggregated
- Endogenous priorities



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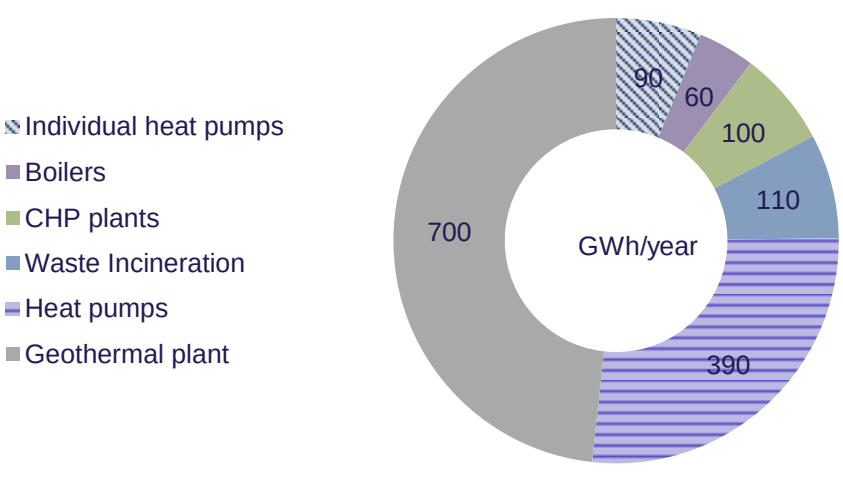
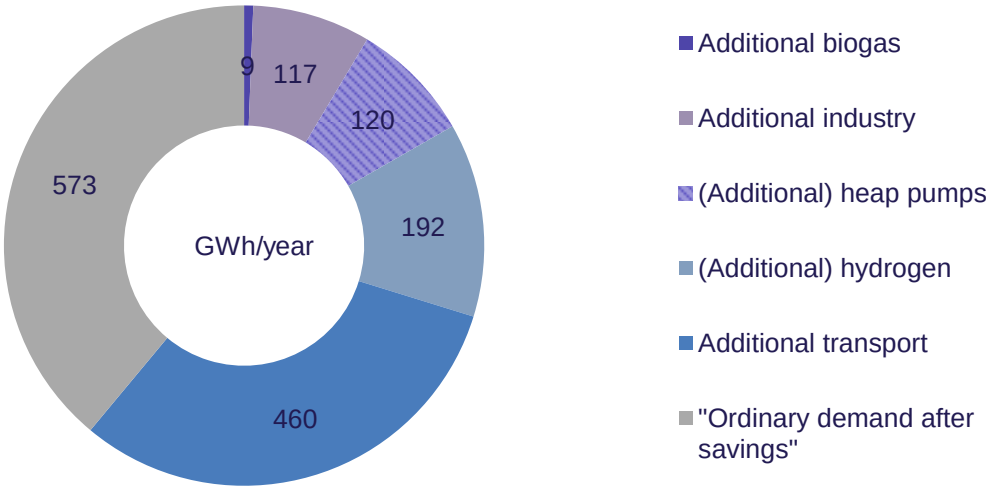
Heat supply in the Aalborg 2050 Vision

[GWh]	2007 Reference	100% RE Vision
Individual oil	104	0
Individual gas	52	0
Individual biomass	312	0
Individual HP	1	31
Individual electric	5	0
Individual solar	.5	.5
Boiler DH	38	0
Local CHP or HP DH	138	17
Central DH	1730	1344

Heat coverage and electricity demand



Heat supply in 2050



Electricity demand in 2050

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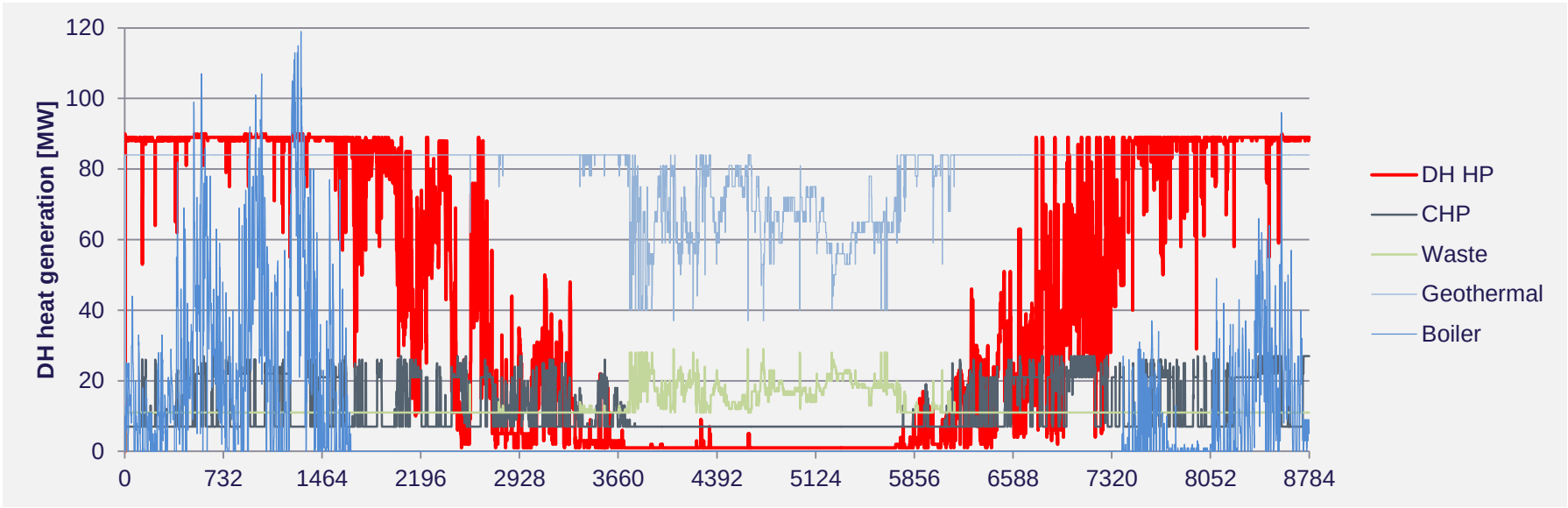
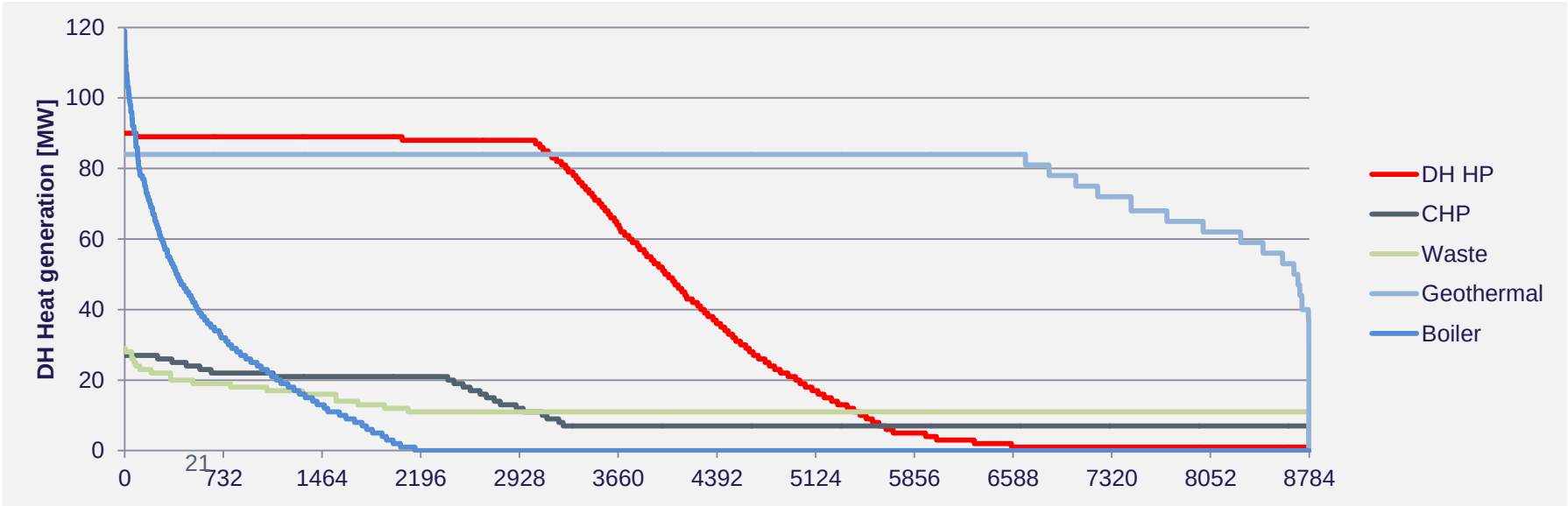
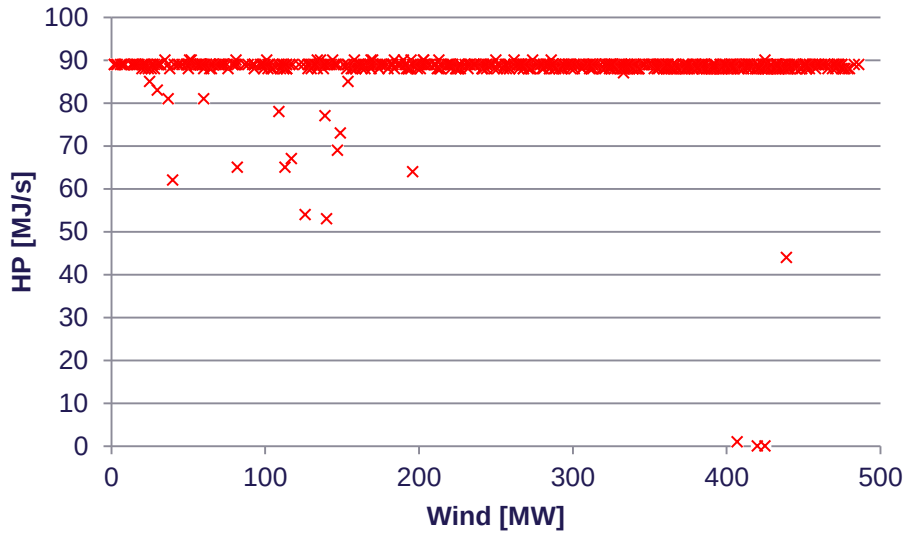
Heat generation over the year

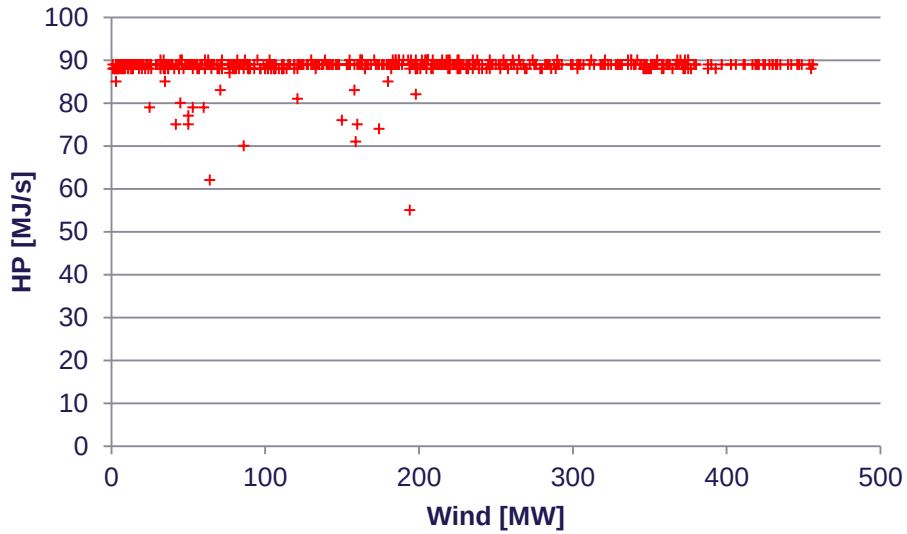




HP operation *vs* wind power: January



HP operation *vs* wind power: February



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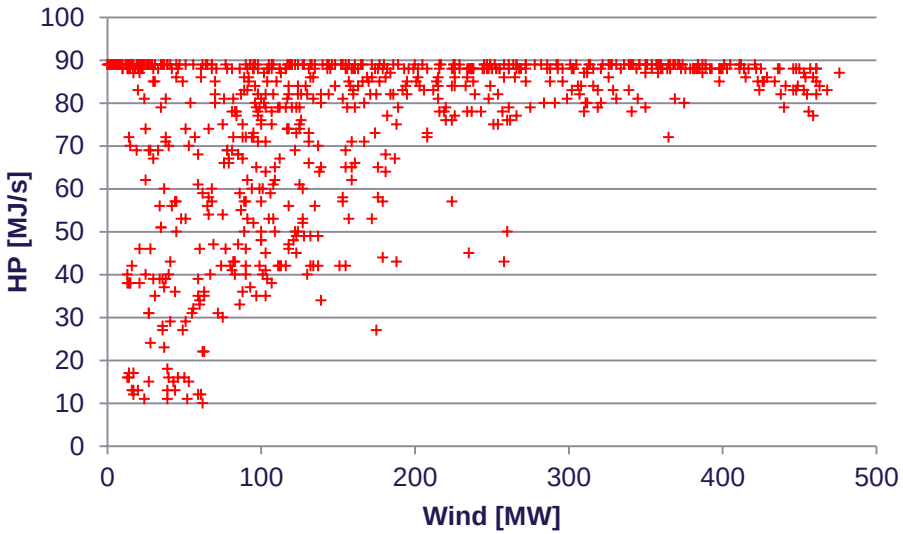
HP operation *vs* wind power: March



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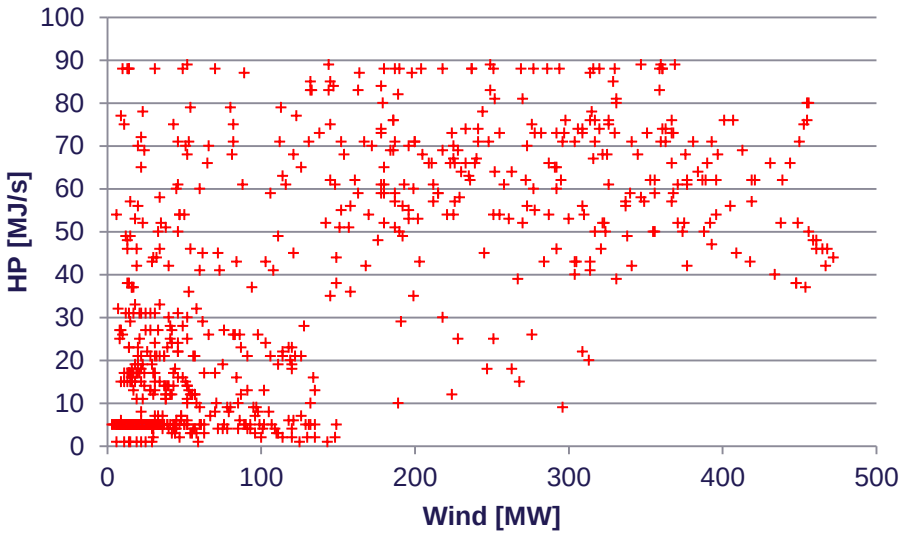
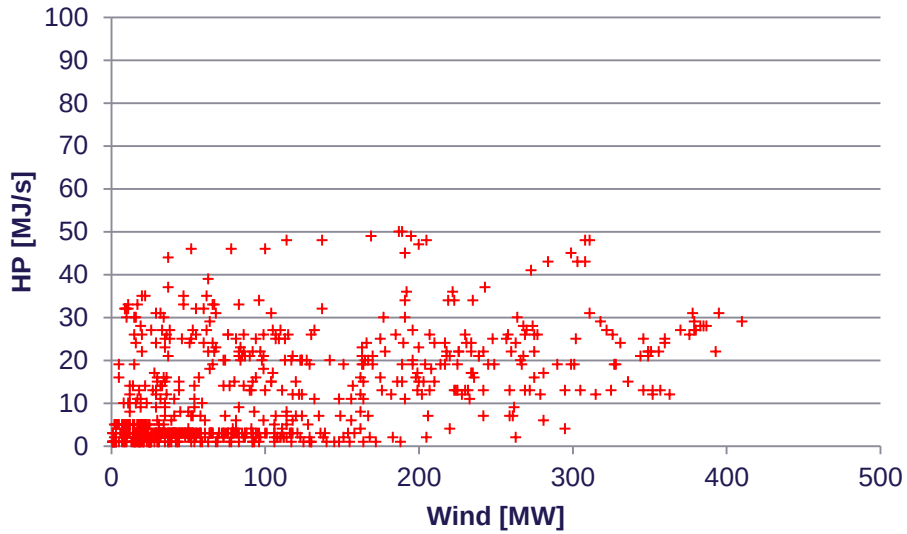
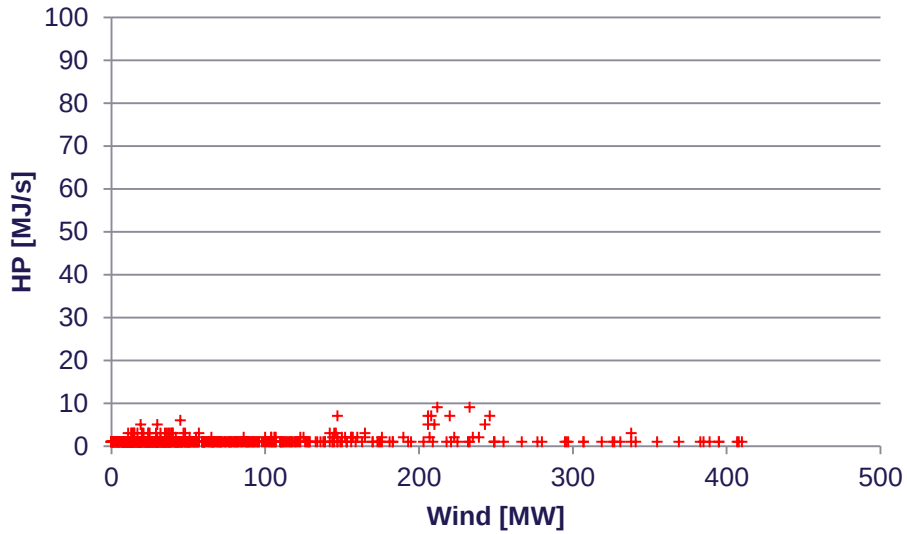
HP operation *vs* wind power: April



HP operation *vs* wind power: May



HP operation *vs* wind power: June



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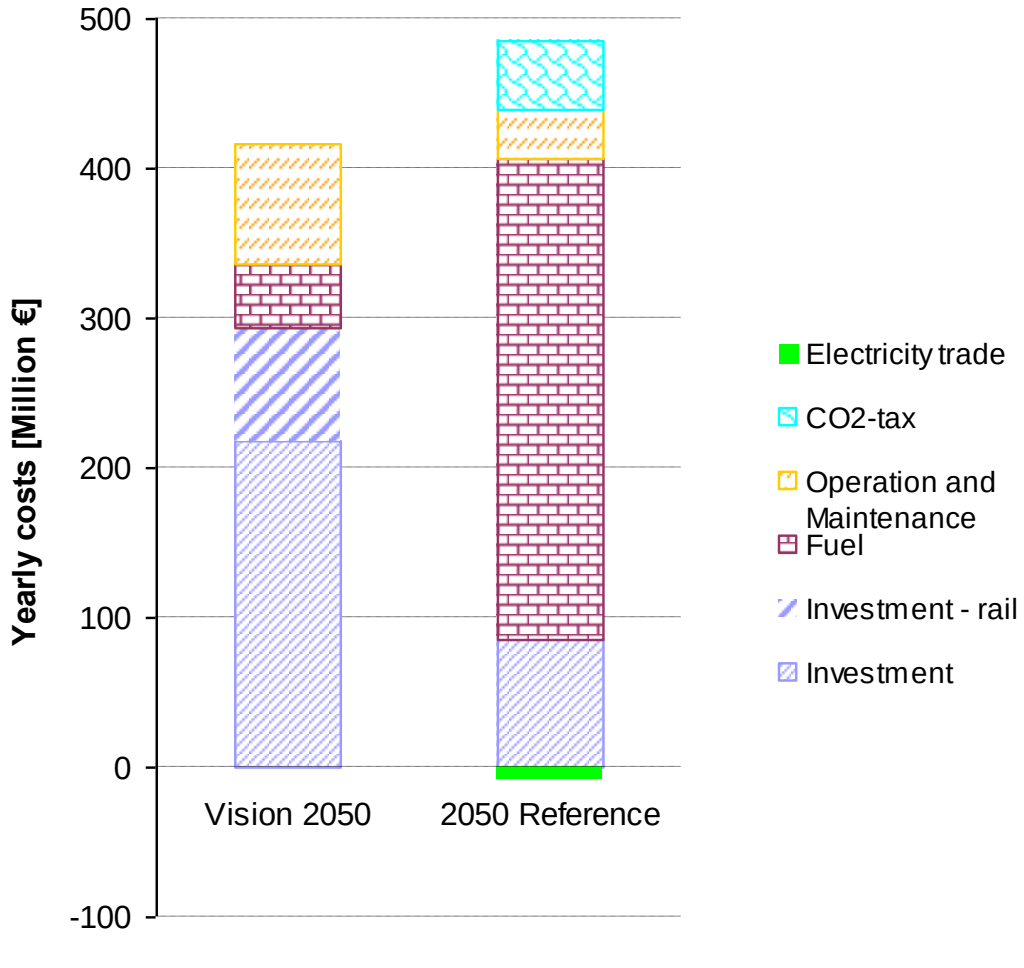
The economy of the Aalborg Vision

Item	Size	Investment [M€ / year]	Depreciation period [Years]	O&M [M € / year]
HP - Local DH grids	1.3 MWe	0.2	20	0.0
Heat storage DH grids	0.1 GWh	0.0	20	0.0
CHP - central DH grid	40 MWe	2.2	20	3.2
HP - central DH grid	24 MWe	0.9	20	0.2
DH boilers	310 MJ/s	2.8	20	1.2
Wind turbines	486 MW	34.8	20	12.4
Electrolytic converter	30 MWe	1.1	20	0.4
Hydrogen storage	1.0 GWh	0.5	30	0.0
Individual HP	9.0 MWe	5.5	15	0.5
Individual solar collectors	6.0 GWh/year	0.3	20	0.0
Heat savings	44% reduction	48.8	20	0.0
El. savings - resident.	50% reduction	6.6	10	0.0
El. savings - elsewhere	45% reduction	16.7	15	0.0
Industrial fuel savings	261 GWh/year	3.0	20	0.0
Geothermia and AHP	Four 200 m^3/h system	2.7	25	0.3
DH grid – expansion	One system	3.3	30	0.6
DH grid – existing	One system	36.3	40	12.6
Biogas plant	One system	4.9	20	7.3
Gasification plant	One system	5.4	20	13.6
Waste incineration. plant	14.0 MWe	9.4	20	4.6
Electric vehicles	One system	13.6	13	16.1
Hydrogen vehicles	One system	9.2	13	5.9
Charging stations	One system	9.9	10	0.0
Rail and light-rail	Aalborg's share	74.8	30	0.0
Total		292.9		79.1

The economy of the Aalborg Vision



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Additional readings

Energy 35 (2010) 4892–4901

Contents lists available at ScienceDirect

Energy

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

A renewable energy scenario for Aalborg Municipality based on low-temperature geothermal heat, wind power and biomass

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ABSTRACT

Aalborg Municipality, Denmark, wishes to investigate the possibilities of becoming independent of fossil fuels. This article describes a scenario for supplying Aalborg Municipality's energy needs through a combination of low-temperature geothermal heat, wind power and biomass. Of particular focus in the scenario is how low-temperature geothermal heat may be utilised in district heating (DH) systems. The analyses show that it is possible to cover Aalborg Municipality's energy needs through the use of locally available sources in combination with significant electricity savings, heat savings, reductions in industrial fuel use and savings and fuel-substitutions in the transport sector. With biomass resources being finite, the two marginal energy resources in Aalborg are geothermal heat and wind power. If geothermal heat is utilised more, wind power may be limited and vice versa. The system still relies on neighbouring areas as an electricity buffer though.

The costs of the scenario are at a comparable level with the reference situation, but with significantly higher needs for investments and lower fuel costs. Implementation of the scenario would therefore have a positive socio-economic impact as investments are more local labour-intensive than fuel supply.

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1. Introduction

Aalborg Municipality has decided to investigate the possibilities of becoming independent of fossil fuels before the year 2050 [1]. This is in line with the national Danish energy policy which has a short term objective of decreasing carbon dioxide emissions by 21% between 2008 and 2012 compared to 1990 and a long-term objective of reducing an anticipated future reliance on imported fossil fuels. The Danish Government thus has *"a vision of a society independent of fossil fuel supplies"* [2] (own translation).

Aalborg is investigating its possibilities of alignment with the national vision. While the national vision is not so concrete, a specific investigation for Aalborg takes into account that many of the investments in new infrastructures have technical lifetimes of several decades, and choices made today bear an impact on energy demands for a similar period.

Aalborg's ambitions are also in line with other areas in Denmark with similar ambitions such as Frederikshavn [3–6], Samsø, and Århus [7].

2. Scope of the article

This article outlines a scenario for the energy system of Aalborg Municipality based exclusively on renewable energy (RE) sources. The scenario is analysed with particular attention to the effects of implementing different penetrations of absorption heat pumps (AHPs) utilising low-temperature geothermal heat for DH production. The scenario is both analysed in terms of aggregate yearly energy balances and the hourly balance between electricity production and demand. Differences between economic cost structures are determined with a focus on whether costs are fuel costs or rather domestic labour-intensive investment costs.

3. Energy resources in Denmark

Denmark is currently the only European Union (EU) member country that is self-sufficient in terms of energy. This is largely due to oil and natural gas exploitation in the Danish license area of the North Sea.

Renewable energy resources in Denmark are sparse. Being a flat moraine landscape, Denmark does not posses a good potential for hydropower, and with a relatively high population density and with extensive use of the available land for agricultural purposes, biomass resources are limited though not insignificant. Municipa

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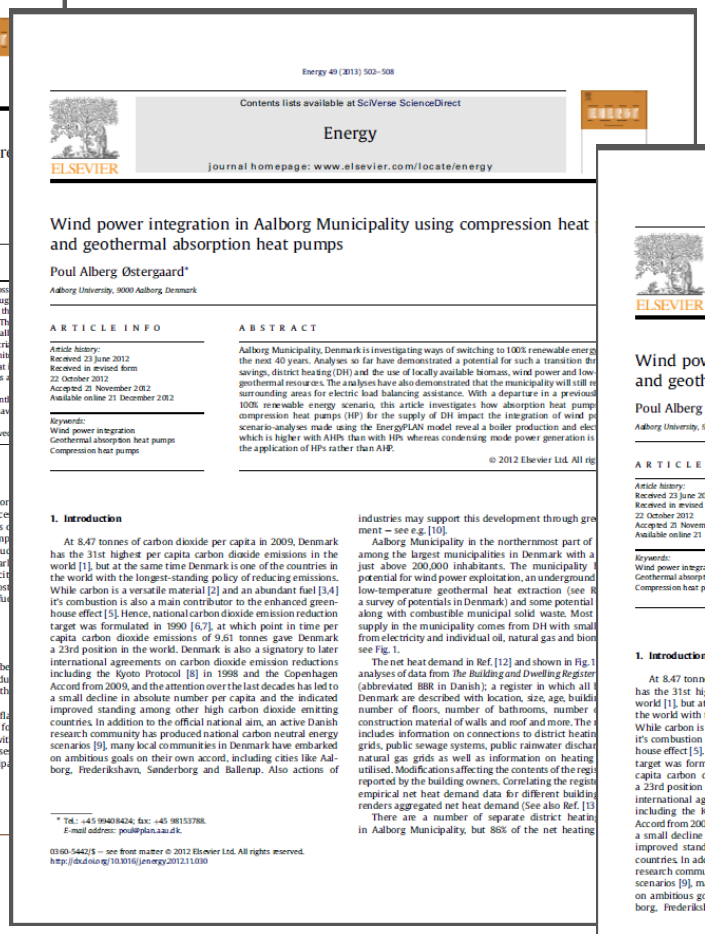

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Wind power integration in Aalborg Municipality using compression heat and geothermal absorption heat pumps

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ABSTRACT

Aalborg Municipality, Denmark is investigating ways of switching to 100% renewable energy supply over the next 40 years. Analyses so far have demonstrated a potential for such a transition through energy savings, district heating (DH) and the use of locally available biomass, wind power and low-temperature geothermal resources. The analyses have also demonstrated that the municipality will still rely heavily on surrounding areas for electric load balancing assistance. With a departure in a previously elaborated 100% renewable energy scenario, this article investigates how absorption heat pumps (AHP) and compression heat pumps (HP) for the supply of DH impact the integration of wind power. Hourly scenario-analyses made using the EnergyPLAN model reveal a boiler production and electricity excess which is higher with AHPs than with HPs whereas condensing mode power generation is increased by the application of HPs rather than AHP.

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1. Introduction

At 8.47 tonnes of carbon dioxide per capita in 2009, Denmark has the 31st highest per capita carbon dioxide emissions in the world [1], but at the same time Denmark is one of the countries in the world with the longest-standing policy of reducing emissions. While carbon is a versatile material [2] and an abundant fuel [3,4] it's combustion is also a main contributor to the enhanced greenhouse effect [5]. Hence, national carbon dioxide emission reduction target was formulated in 1990 [6,7], at which point in time per capita carbon dioxide emissions of 9.61 tonnes gave Denmark a 23rd position in the world. Denmark is also a signatory to later international agreements on carbon dioxide emission reductions including the Kyoto Protocol [8] in 1998 and the Copenhagen Accord from 2009, and the attention over the last decades has led to a small decline in absolute number per capita and the indicated improved standing among other high carbon dioxide emitting countries. In addition to the official national aim, an active Danish research community has produced national carbon neutral energy scenarios [9], many local communities in Denmark have embarked on ambitious goals on their own accord, including cities like Aalborg, Frederikshavn, Sønderborg and Ballerup. Also actions of industries may support this development through green procurement – see e.g. [10].

Aalborg Municipality in the northernmost part of Denmark is among the largest municipalities in Denmark with a population just above 200,000 inhabitants. The municipality has a good potential for wind power exploitation, an underground suitable for low-temperature geothermal heat extraction (see Ref. [11] for a survey of potentials in Denmark) and some potential for biomass along with combustible municipal solid waste. Most of the heat supply in the municipality comes from DH with smaller fractions from electricity and individual oil, natural gas and biomass boilers, see Fig. 1.

The net heat demand in Ref. [12] and shown in Fig. 1 is based on analyses of data from *The Building and Dwelling Register in Denmark* (abbreviated BBR in Danish); a register in which all buildings in Denmark are described with location, size, age, building material, number of floors, number of bathrooms, number of kitchens, construction material of walls and roof and more. The register also includes information on connections to district heating grids, gas grids, public sewage systems, public rainwater discharge systems, natural gas grids as well as information on heating technology utilised. Modifications affecting the contents of the register must be reported by the building owners. Correlating the register data with empirical net heat demand data for different building categories renders aggregated net heat demand (See also Ref. [13]).

There are a number of separate district heating networks in Aalborg Municipality, but 86% of the net heating demand is

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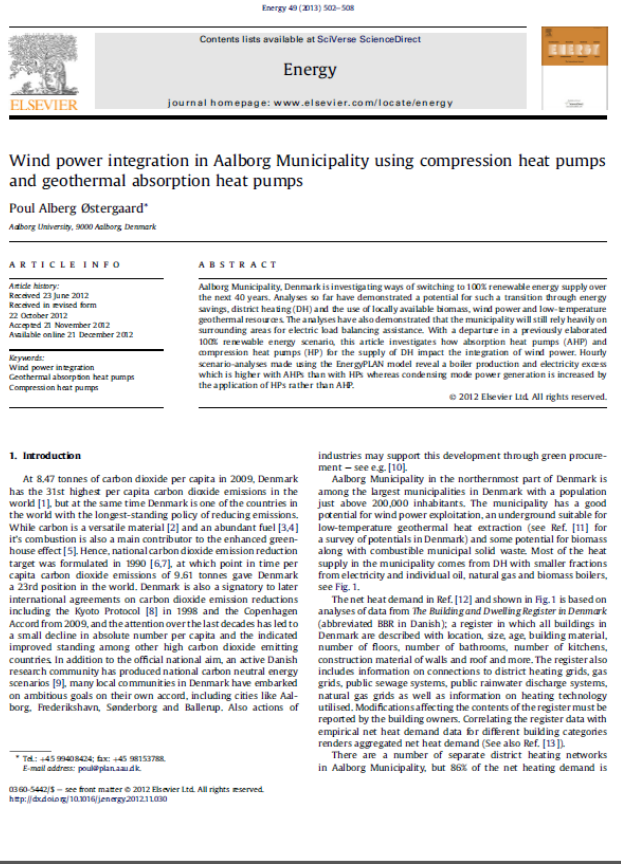

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INTEGRATION OF HEAT PUMPS IN INTENSIVE RENEWABLE ENERGY SCENARIOS

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