Power market integration, focusing on the CHP switch to biomass and electric heating to replace fossil-fuelled heating

Capacity building for Renewable Energy Technologies and Policy in Ethiopia

Henrik Klinge Jacobsen
Systems Analysis Division
DTU Management Engineering

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DTU Management Engineering
Department of Management Engineering

Challenges for the transition and power market integration in Denmark

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- Market integration - high shares and volume of renewables = market impact
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Lessons Lea ns…

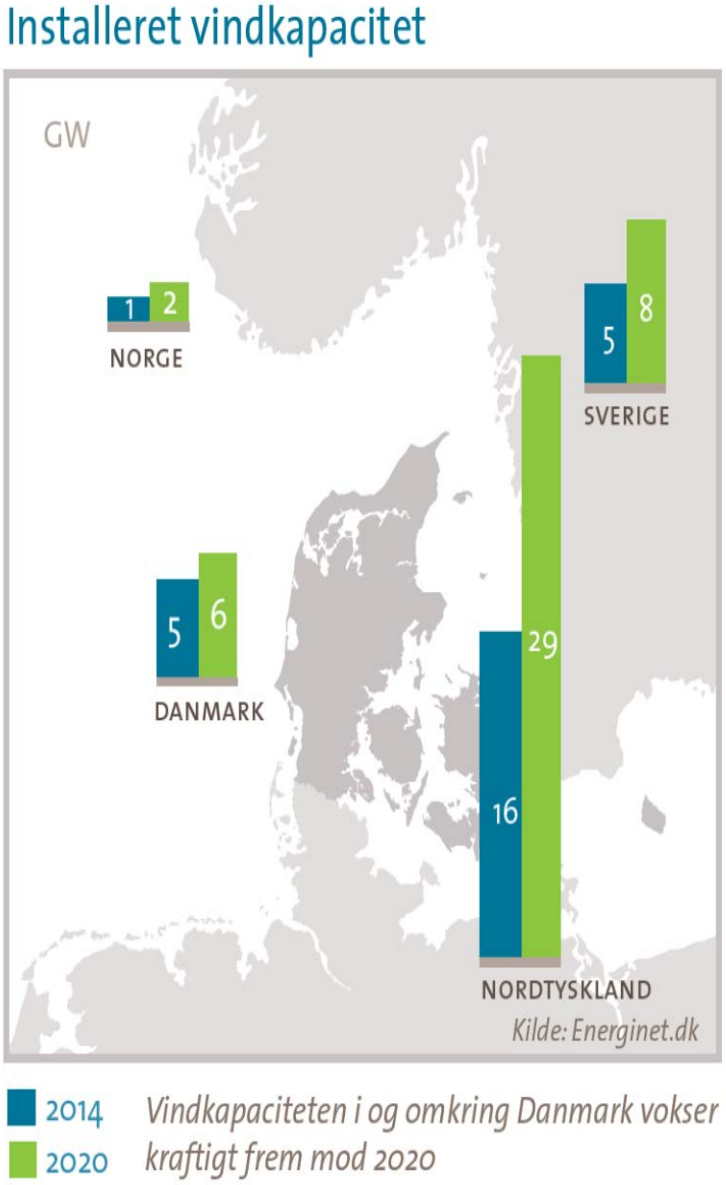
Denmark – *den*

→ **Objective**: 100
across *all* energ
(fossil fuel-free

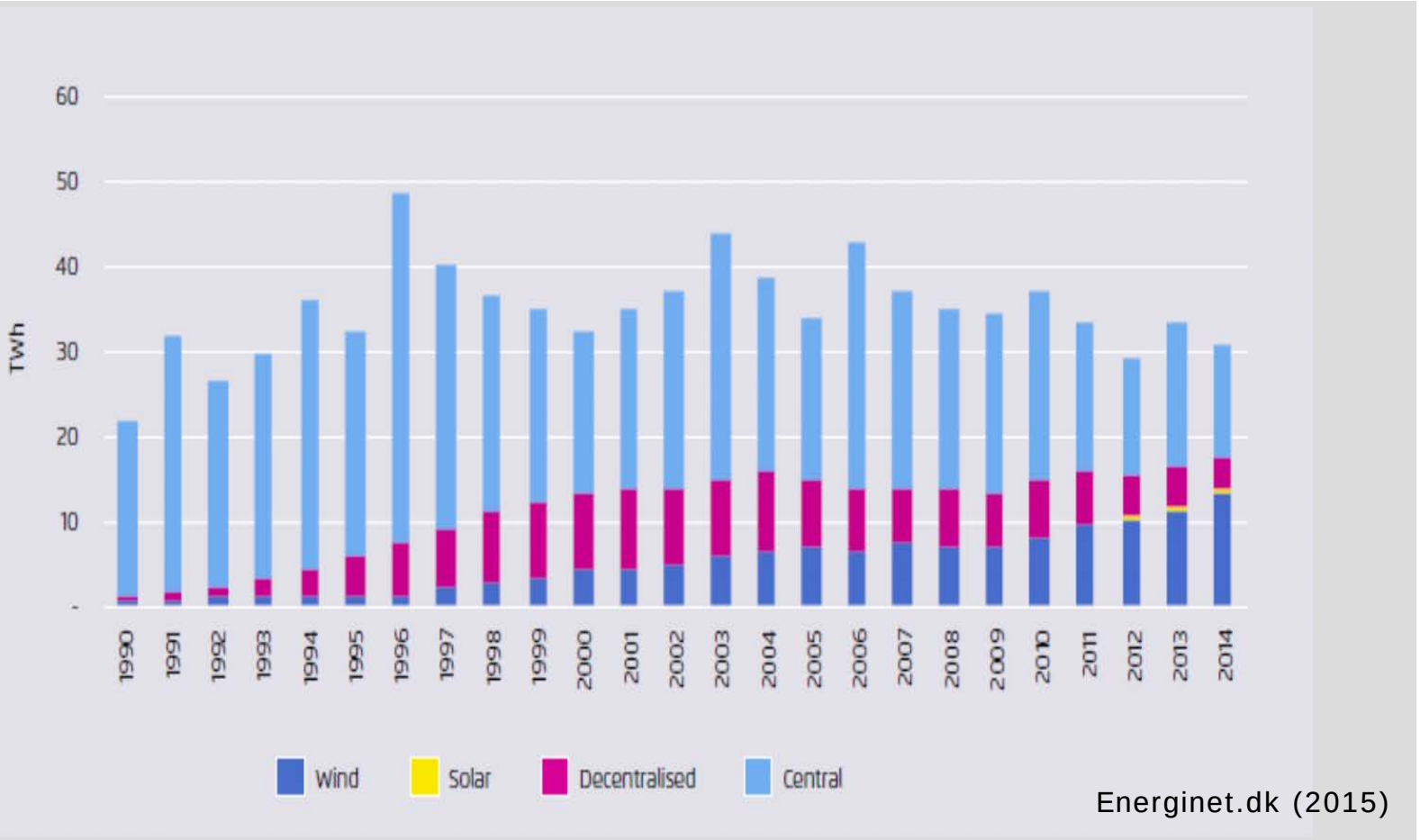
→ 50% wind shar
consumption by
2014: 39%).

→ Transition from
towards a renev
based system w
shares of variab
generation.

→ Strong integrat
heating sector
& biomass.



Electricity generation in Denmark from 1990 through 2014: Rising shares of wind energy – 39% in 2014 and *42% in 2015*

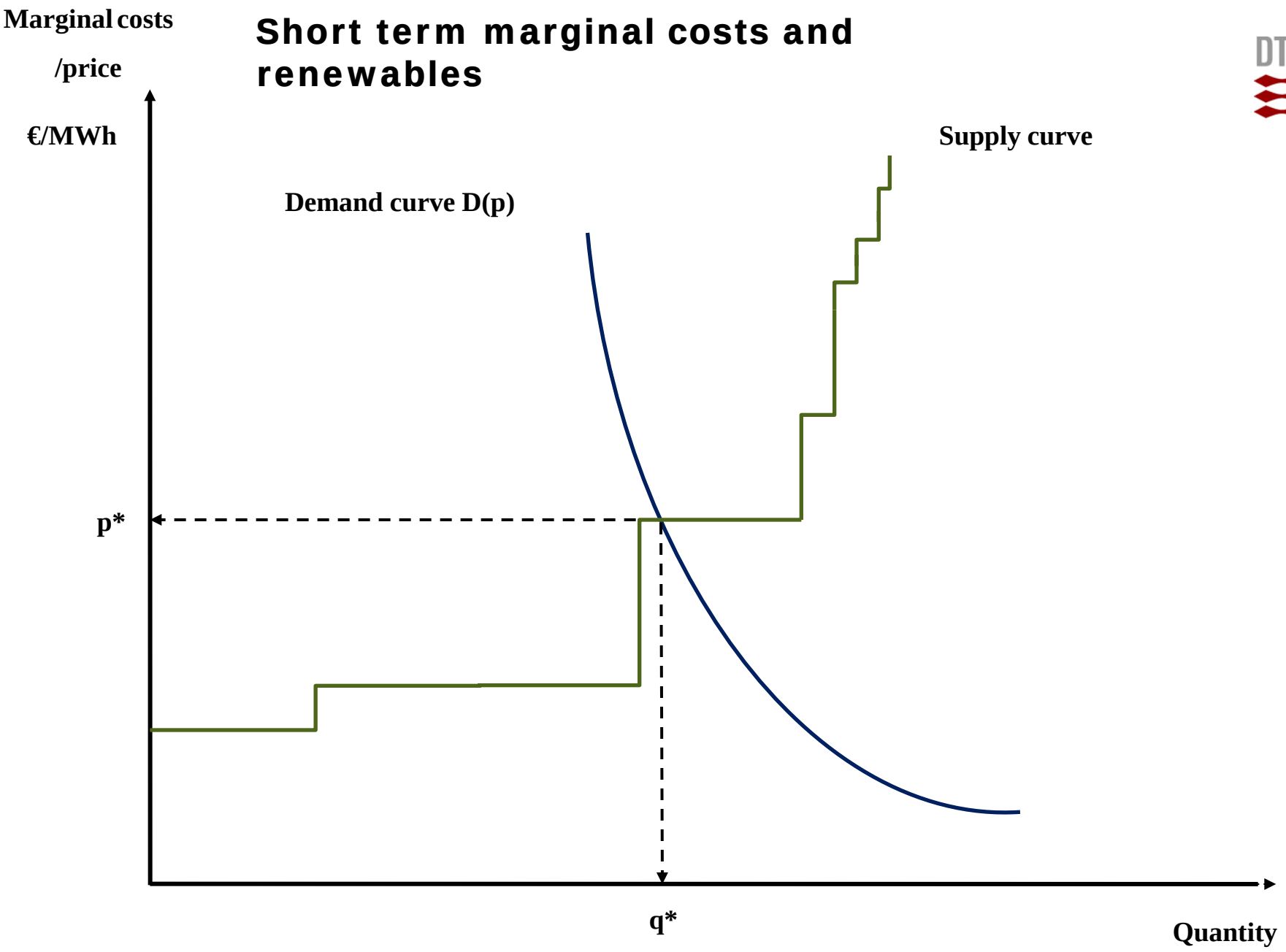


Energinet.dk (2015)

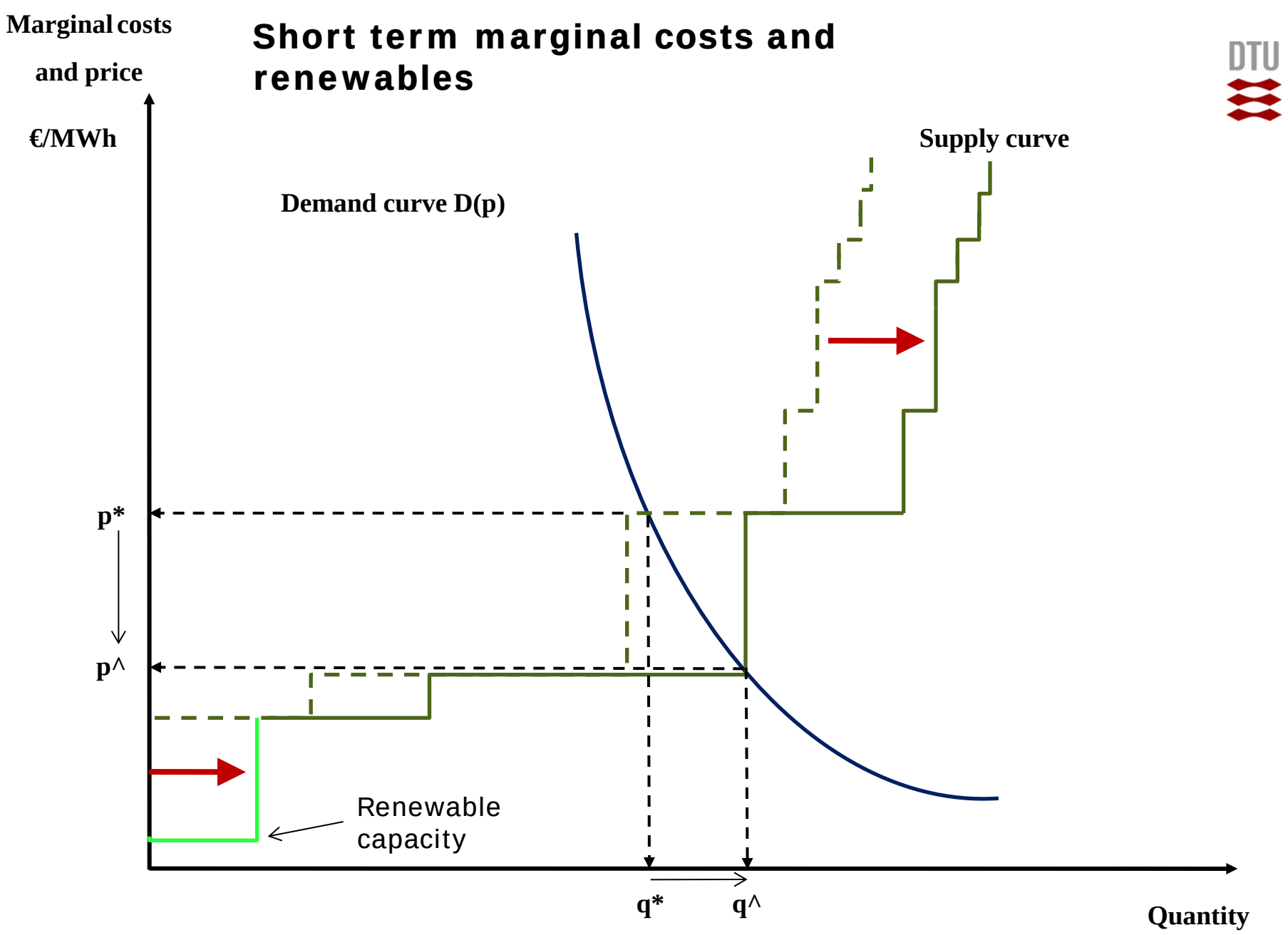
Short term marginal costs determine power price

- The supply curve in the day ahead market is reflecting the short term marginal costs – the additional fuel cost per additionally produced MWh
- Generation technologies differ with regard to the mix of variable and fixed costs
- Fluctuating renewable generation has *very low* short term marginal costs
- Fluctuating generation forms the *lower left part of the supply curve*
- Variation in generation from renewables will thus shift the entire supply curve

Short term marginal costs and renewables

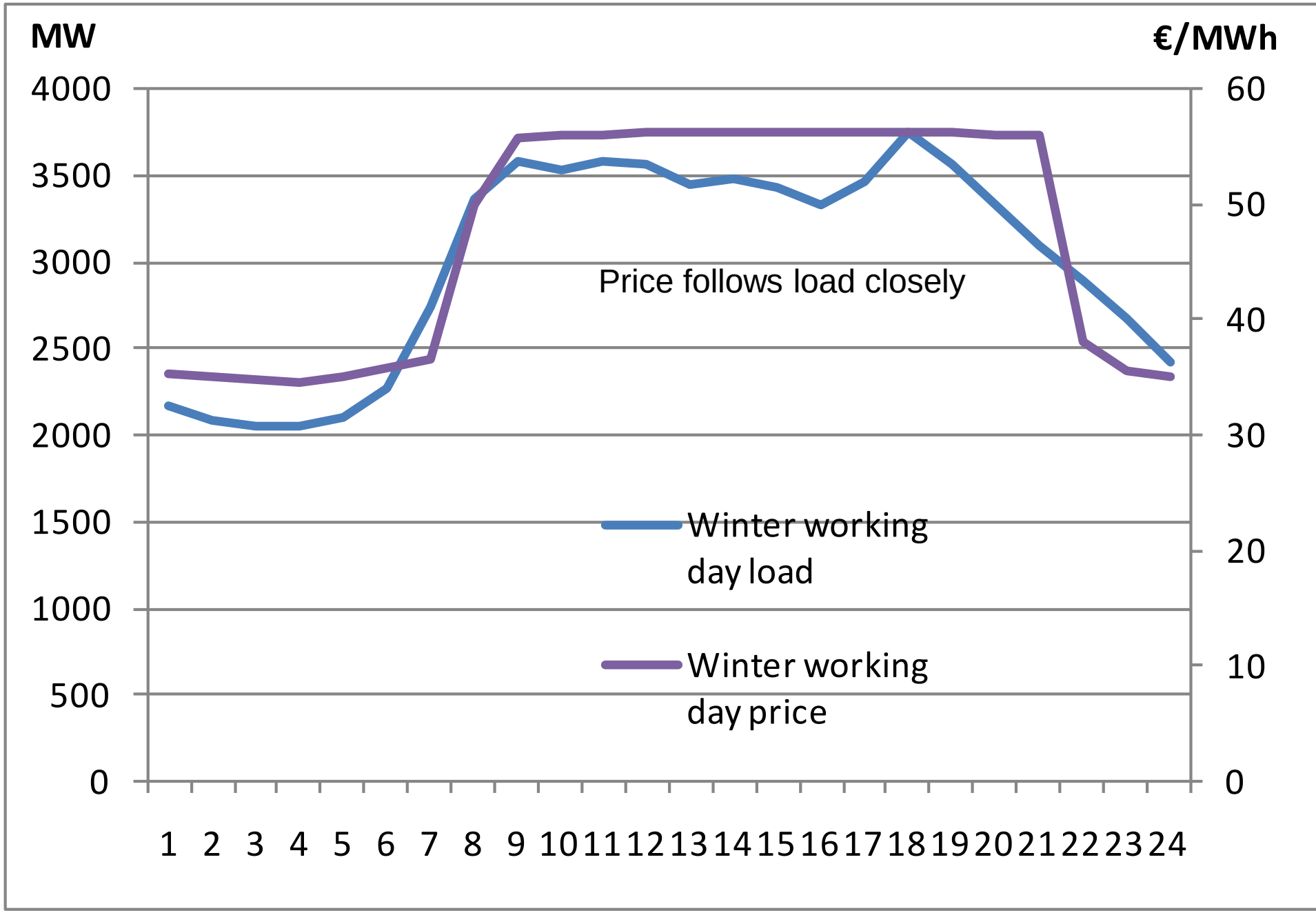


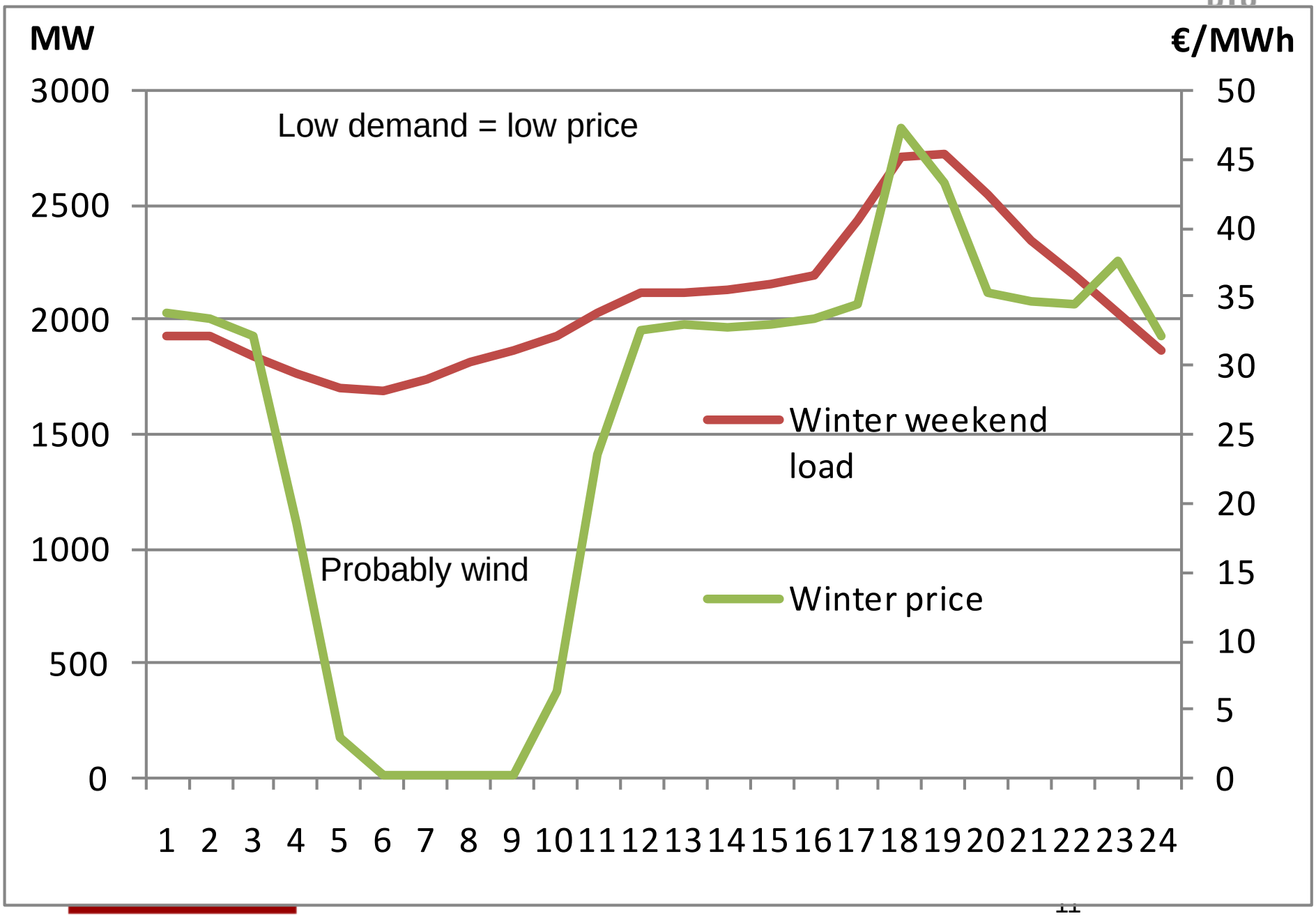
Short term marginal costs and renewables



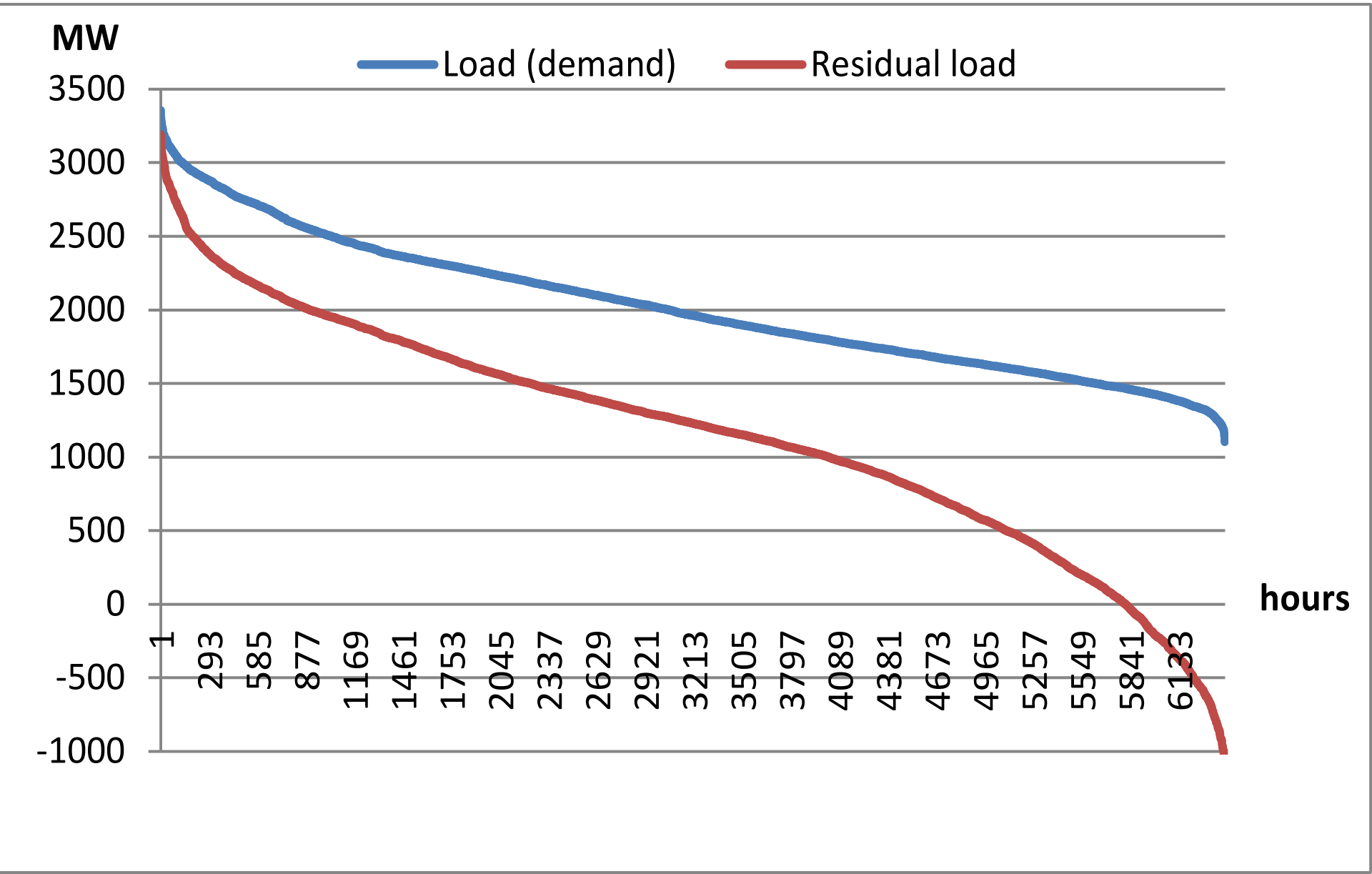
Adding renewable capacity and the short term price effect

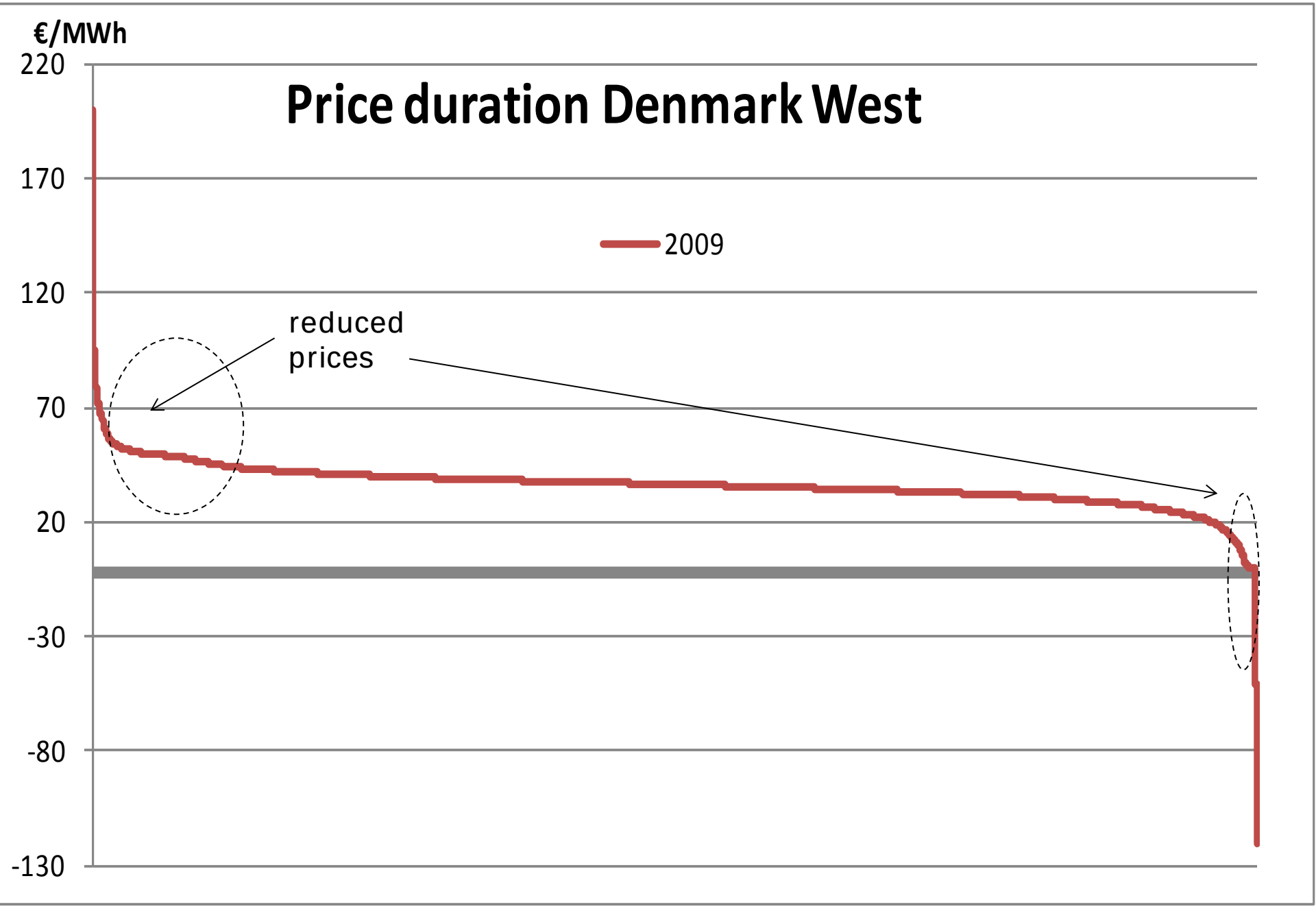
- Average wholesale power price is reduced
- Price is reduced the most when demand is high (peak load) and the least when demand is low
- The effect is the same as when adding other low variable cost generation. Base load technologies with low marginal cost would also shift the supply curve to the right.
- Lower average price means *reduced profitability for all generators*
- The relative effect for consumer price is not as great, since the network costs and all the taxes are added to the wholesale price (see later)


MW
€/MWh
4000
3500
3000
2500
2000
1500
1000
500
0
60
50
40
30
20
10
0
Price follows load closely
Winter working day load
Winter working day price
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24


MW
€/MWh
3000
2500
2000
1500
1000
500
0
50
45
40
35
30
25
20
15
10
5
0
Low demand = low price
Probably wind
Winter weekend load
Winter price
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

Subtracting the wind generation from load duration curve: Denmark West January-September 2013




€/MWh
220
170
120
70
20
-30
-80
-130
Price duration Denmark West
2009
reduced
prices

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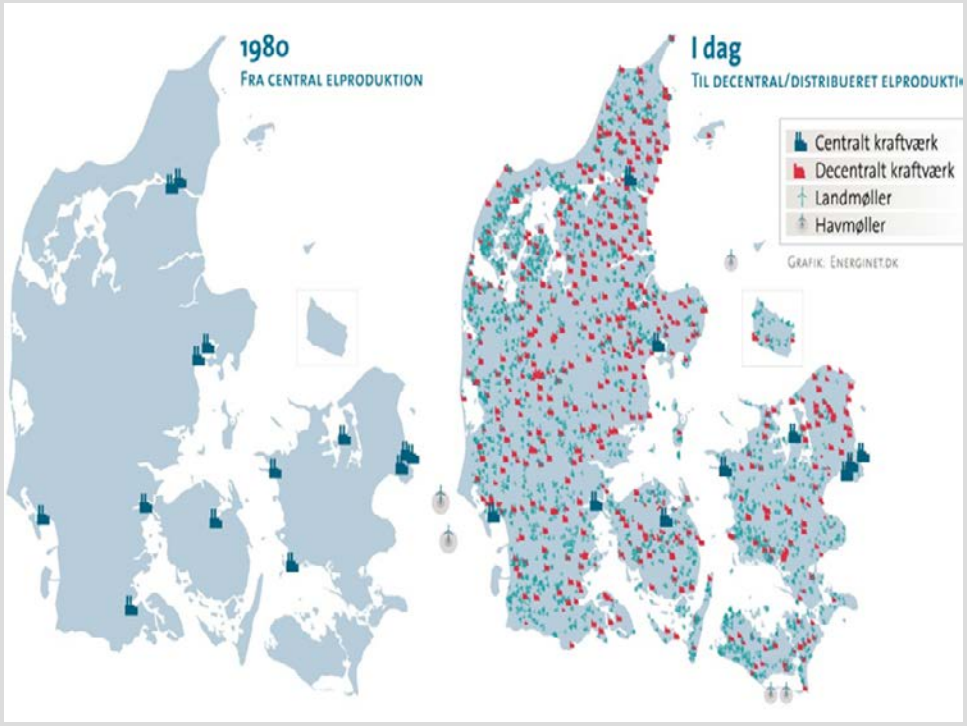
Structure of the Danish Electricity System: Yesterday (1980s) and today…

From central to distributed generation: 1980 and today



With friendly permission of Energinet.dk for *Agora & DTU (2015).*

Today Denmark has **central power stations** at **16 production sites** – based on coal, natural gas, oil and biomass (4.1 GW in 2014). Around **1,000 decentralised CHP**, industrial and local plants with generation based on natural gas, waste, biogas and biomass (2.5 GW in 2014). Capacity will be reduced until 2020.

More than 5,200 **wind turbines** are deployed (3.7 GW onshore and 1.3 GW offshore).

… and there are 92,000 solar PV installations. As of 10th Aug. 2015: around 630 MW installed.
(http://energinet.dk/DA/El/Engrosmarked/Udtraek-af-markedsdata/Sider/Statistik.aspx)

Danish Electricity System in 2014

Key figures 2014	Western DK	Eastern DK	Denmark
Electricity demand (TWh)	20.1	13.3	33.4
Peak demand (MW)	3,541	2,500	6,033
Wind power (TWh)	10.3	2.7	13.1
Wind share of demand (%)	51	21	39
Wind peak (MW)	3,527	947	4,444
Interconnectors to Norway/Sweden (MW)	2,372	1,700	4,072
Interconnectors to Germany (MW)	1,780	600	2,380

Wind energy supplied **42% of Danish electricity** consumption in 2015.

Wind energy and biomass are expected to play a major role in the future.

CHP plays a major role in electricity production (along with district heating that delivers more than 60% of Danish heat).

Danish electricity supply has evolved from a central to a dispersed structure.

Ea (2015), based on Energinet.dk and ENS data.

Flexibility in day ahead market and in short term deviations / disturbance situations

- Traditionally central power plants provided flexibility: firm capacity
- With small scale CHP, wind, PV and biogas providing a larger share of generation (and capacity) flexibility and controllability is reduced
- Therefore market incentives must adequately provide small scale CHP and even wind and PV with incentives to adjust (act flexible)
- Integration in DK was facilitated by very large interconnection capacity (Norway and Germany)
- Interconnection capacity is equal to peak demand and this capacity must be available for providing both flexibility in day ahead markets and in real time - it is not always like that!
- Small scale CHP was on a fixed tariff scheme until around 10 years ago and provided no flexibility - this has been corrected but it has also exposed those to falling electricity prices
- Today even wind act flexible with voluntary curtailment in case of negative market prices

Changes in electricity generation from 2013 to 2014…

Electricity production in Denmark [GWh]	2013	2014	Change
Net electricity production	32,956	30,615	-7 %
Net imports	1,081	2,855	-
Electricity consumption (incl. net losses)	34,037	33,471	-1.7 %
Electricity from central power plants	16,833	13,281	-21 %
Electricity from decentralised plants	4,468	3,643	-18 %
Onshore wind production	6,772	7,913	+17 %
Offshore wind production	4,351	5,165	+19 %
Solar PV production	518	597	+15 %
Hydropower generation	15	16	+6 %

Data: *Energinet.dk (2015)*

Increase in wind energy, decrease in CHP production.

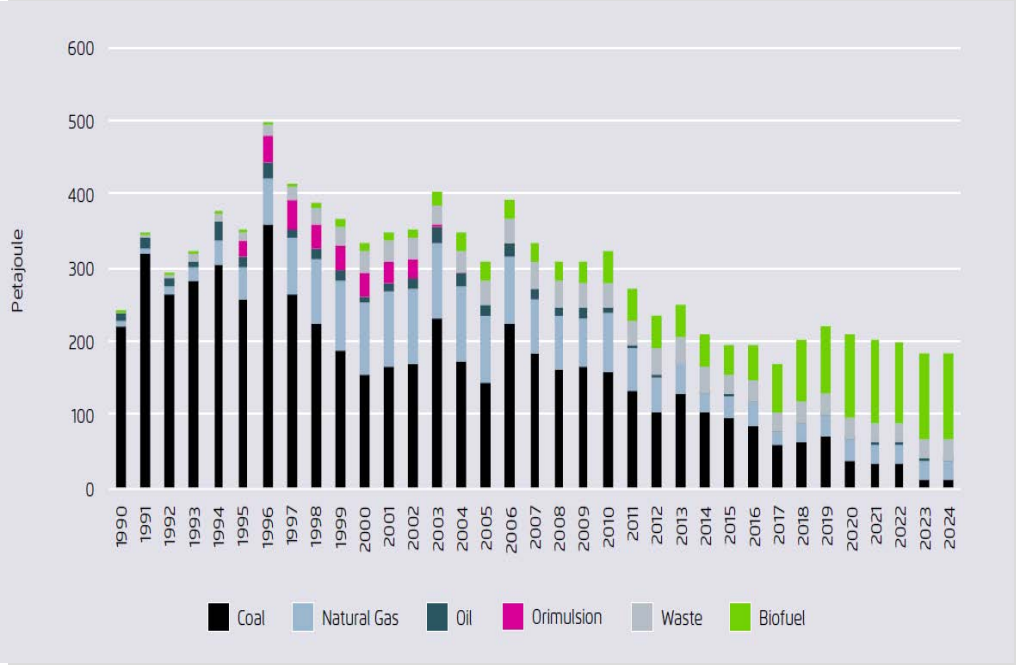
Flexibility needed but reduced remuneration from day ahead market

Major Trends Influencing Future Flexibility

- → Increasing shares of renewable energy create a need for **system flexibility**. This comprises both the demand and the supply side. Simultaneously, power plants with controllable generation face decreased profitability on the market. A **new market model** is required to cope with these challenges.
- → The **flexibility challenge** does not only encompass the electricity sector, but equally the **heating, transport and gas sectors**. The different energy sectors come to play new roles in their interplay for the energy transition.
- → The Danish energy system is influenced by **developments in its neighbouring countries**. This includes interconnectors, policy decisions and market design.
- → There is increasing integration of national electricity markets on the way to implementing a single **European electricity market**. European network codes lay down common connection, operational and market rules.

Heading toward the future…

Fuel consumption (*energy* sectors!) in Denmark: historical and forecast 2023



Energinet.dk (2015), in: *Agora & DTU (2015).*

The share of coal is decreasing: rising wind shares and conversion of power plants to biomass.

Still **coal phase-out** until 2030**?** **Implementation speed??** (discussed in recent election campaign)

How will the CHP and flexible plants be affected?

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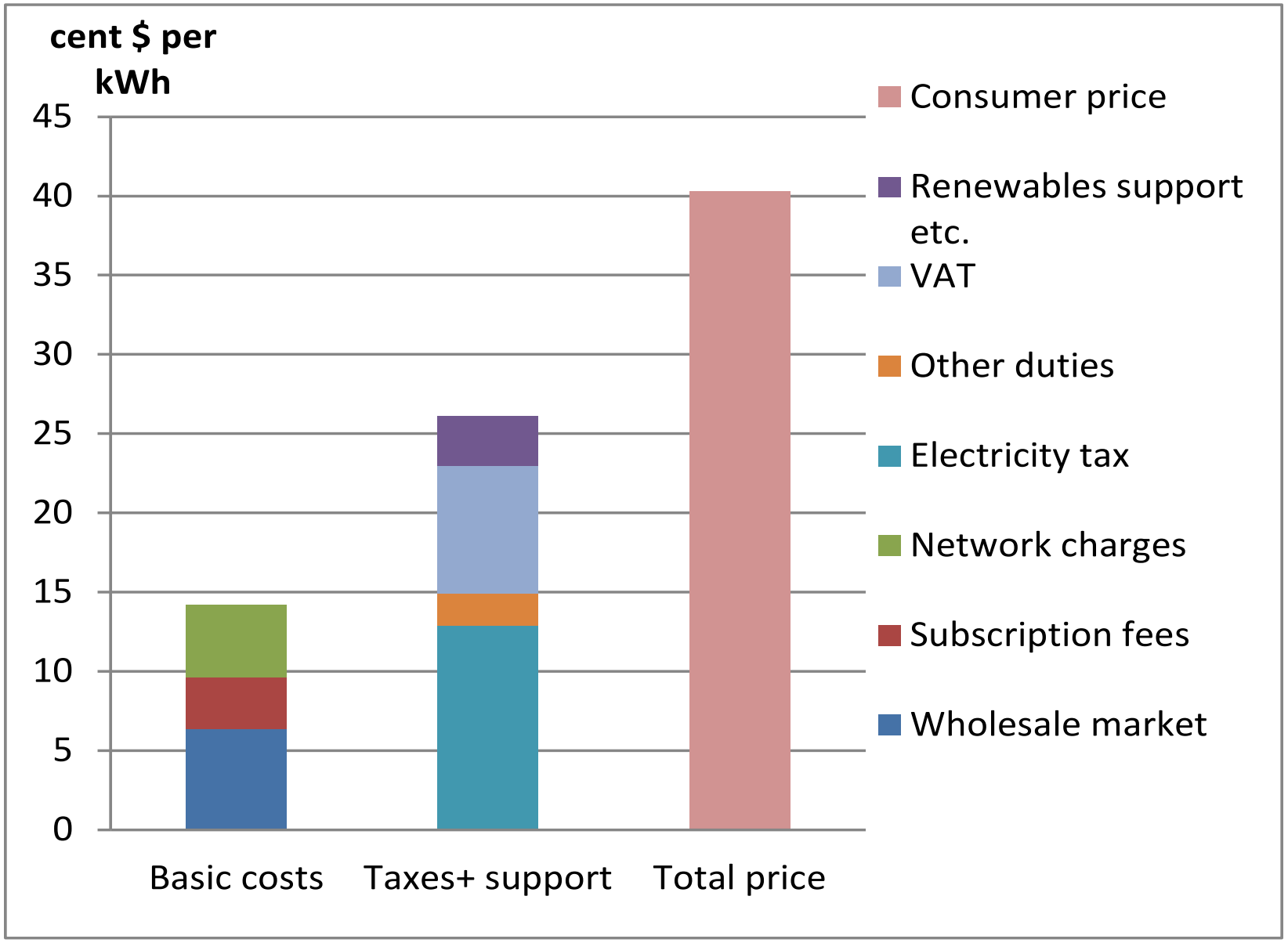
Long term marginal cost not reflected in day ahead market prices

- → Day ahead power markets reflect short term marginal cost for most hours
- → Financing of renewables are provided outside of wholesale day ahead markets
- → PSO end use tariff for all customers finance a major part of the investment in renewables
- → The investment incentive in day ahead markets is hereby distorted because the renewables have an impact on day ahead prices

- → We need the day ahead market price to increase for some hours (low wind and high demand) to balance the reduced price in other hours

- → This can only be achieved by reducing conventional capacity and depends on neighbouring market developments

Electricity price for residential consumer in 2013



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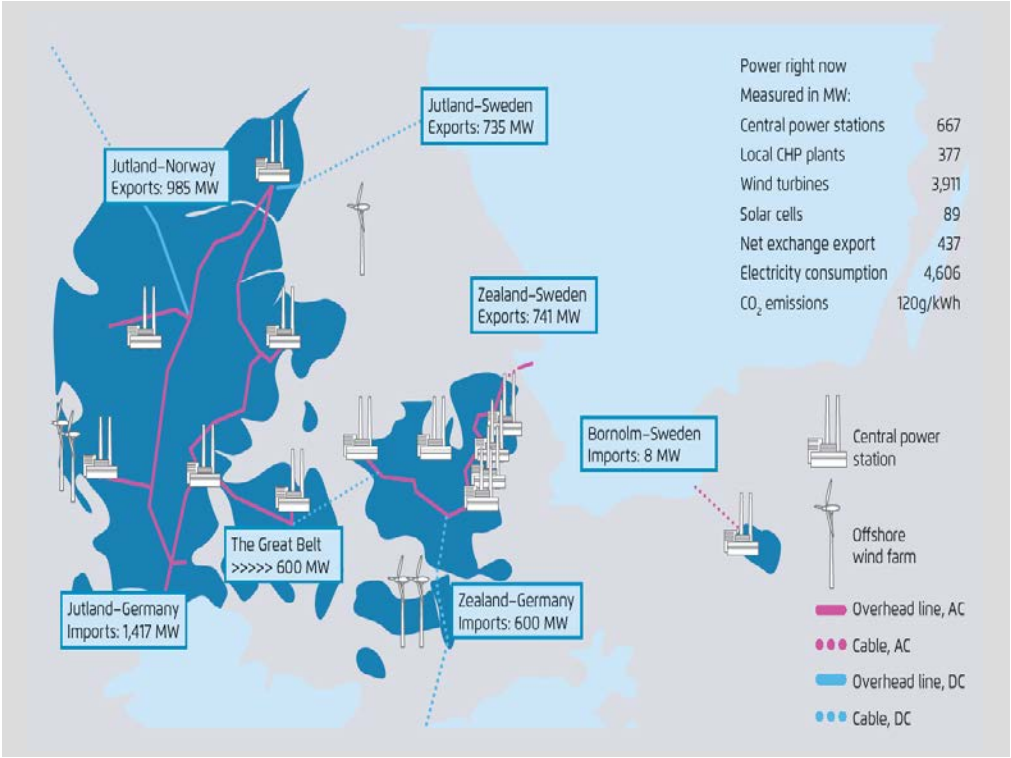
Interconnectors to neighboring countries have worked as a flexibility option

Example: Snapshot of Danish power system on 2 June 2015 at 13:17

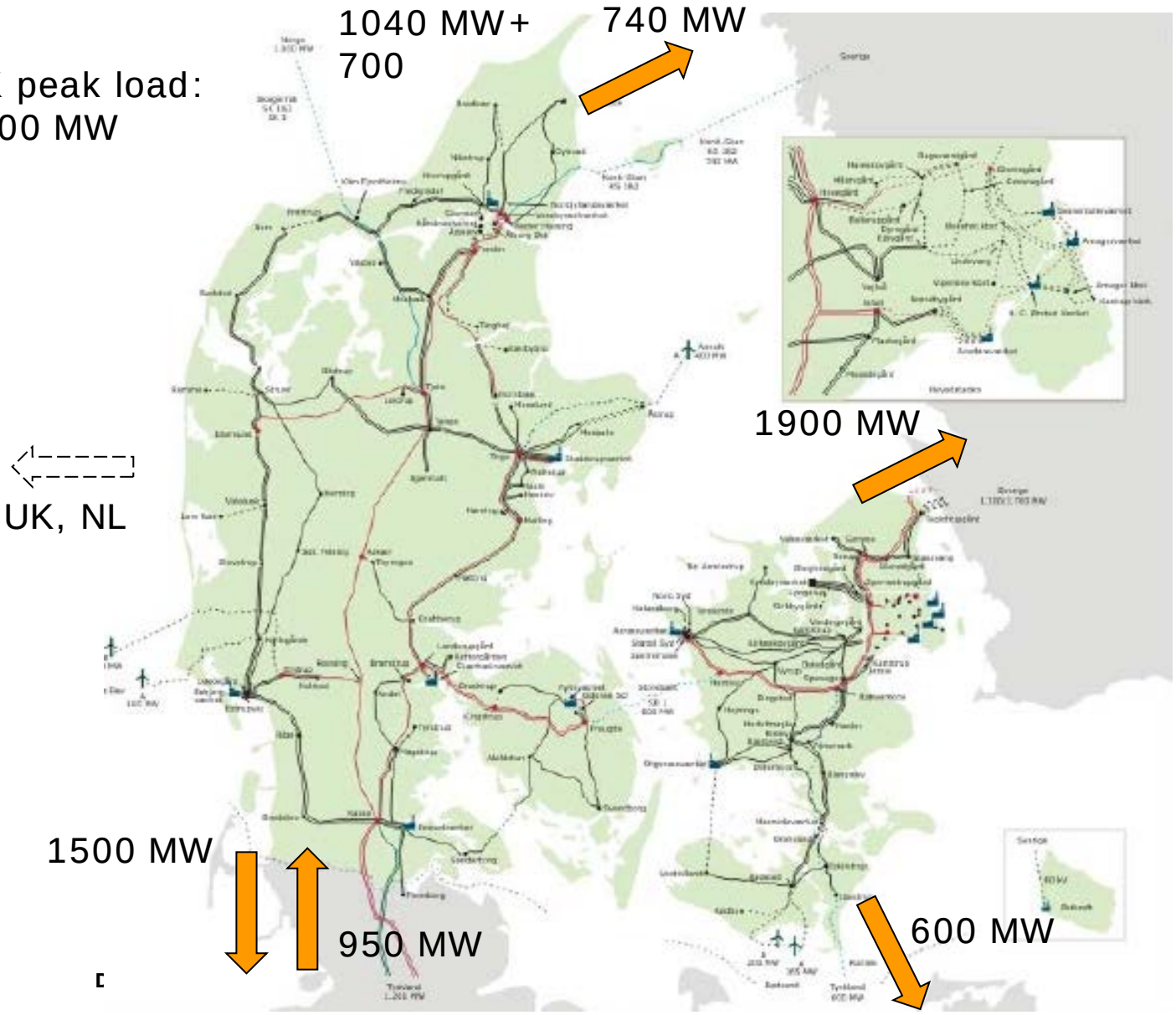


Energinet.dk

- → **Denmark has 6.4 GW of net transfer capacity to neighboring countries** (and peak load of 6 GW)**.** Capacity to Norway & Sweden: 4 GW and to Germany: 2.4 GW.
- → **Early Nordic market integration:** hydropower as "green battery" and export during hours with high wind energy feed-in.
- → Challenge of high wind energy feed-in in Denmark and Northern Germany.
- → **The future** also depends on energy mixes and transmission capacities available to neighboring countries (e.g. Skagerrak 4 and DK1-TenneT interconnector and internal German grid expansion).

Strong interconnections and additions facilitate use of pumped storage in reservoirs

DK peak load:
6500 MW



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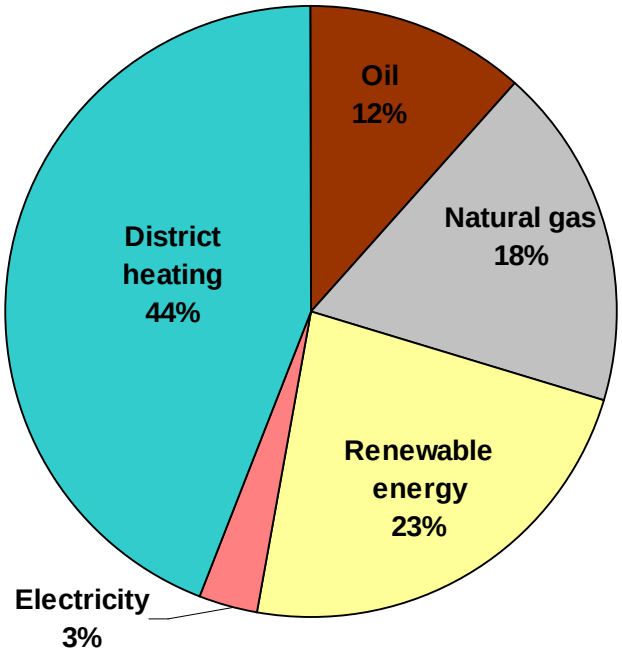
Heating sector in Denmark

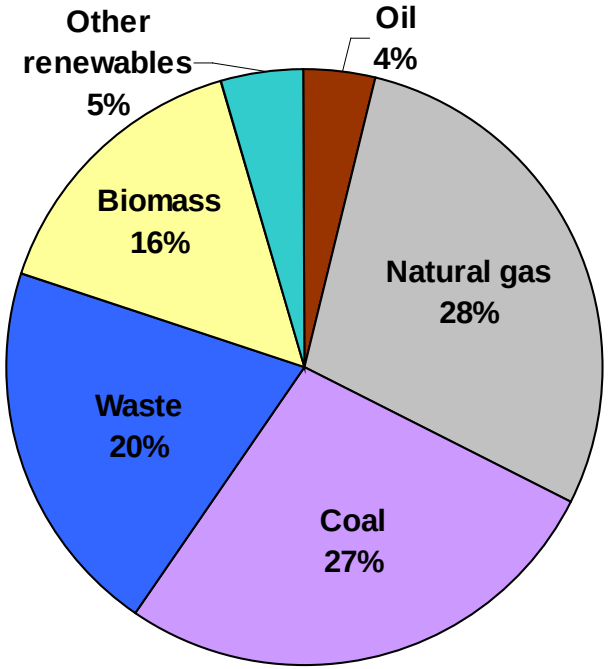
Supply of space heating



Heat demand for space heating 213 PJ –

24 % of primary energy consumption in DK

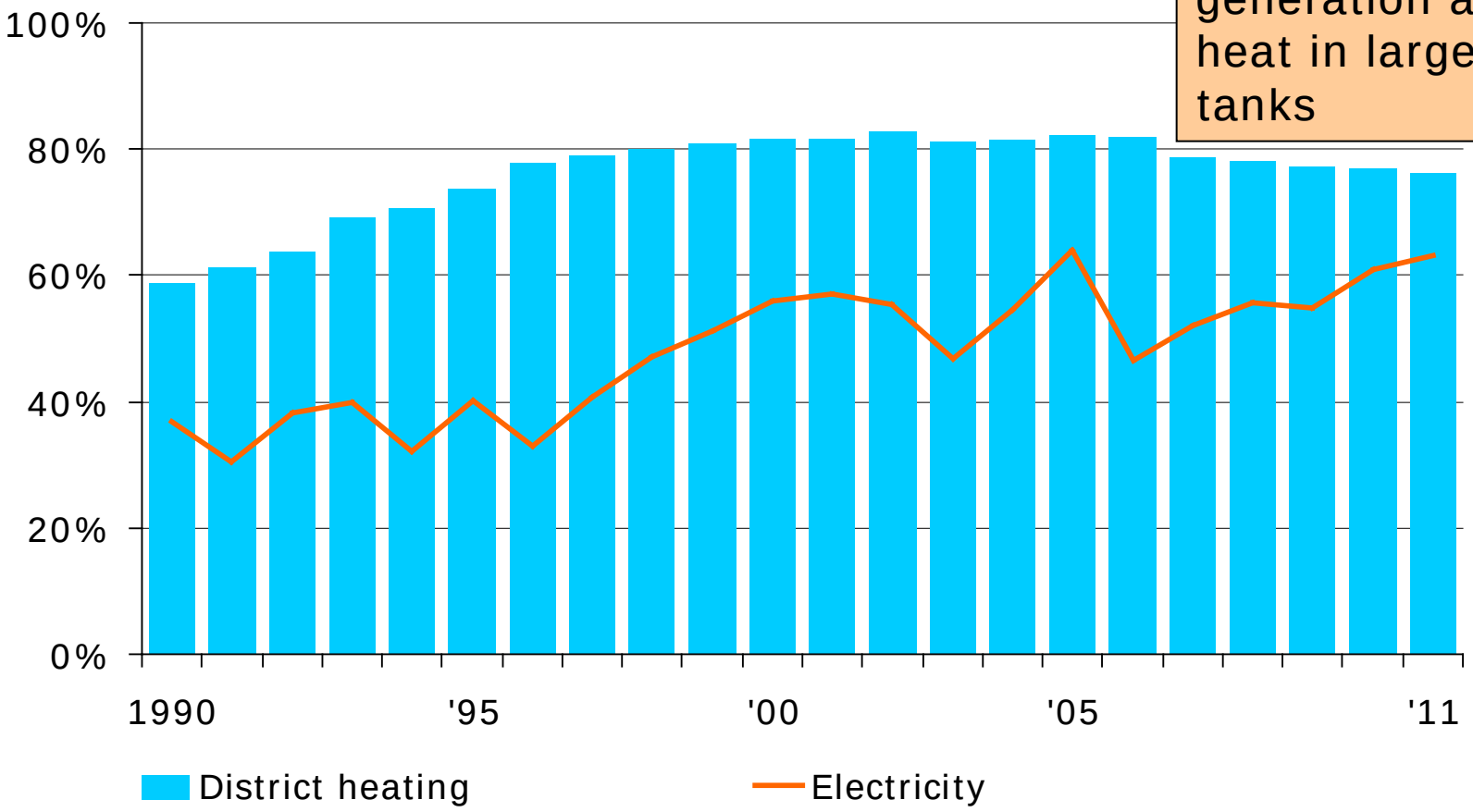
Fuel in District Heating Production



source: Danish Energy Agency, 2008

Combined Heat and Power (CHP) share of thermal power and district heating production

CHP provide flexibility in case of high wind generation and store heat in large storage tanks

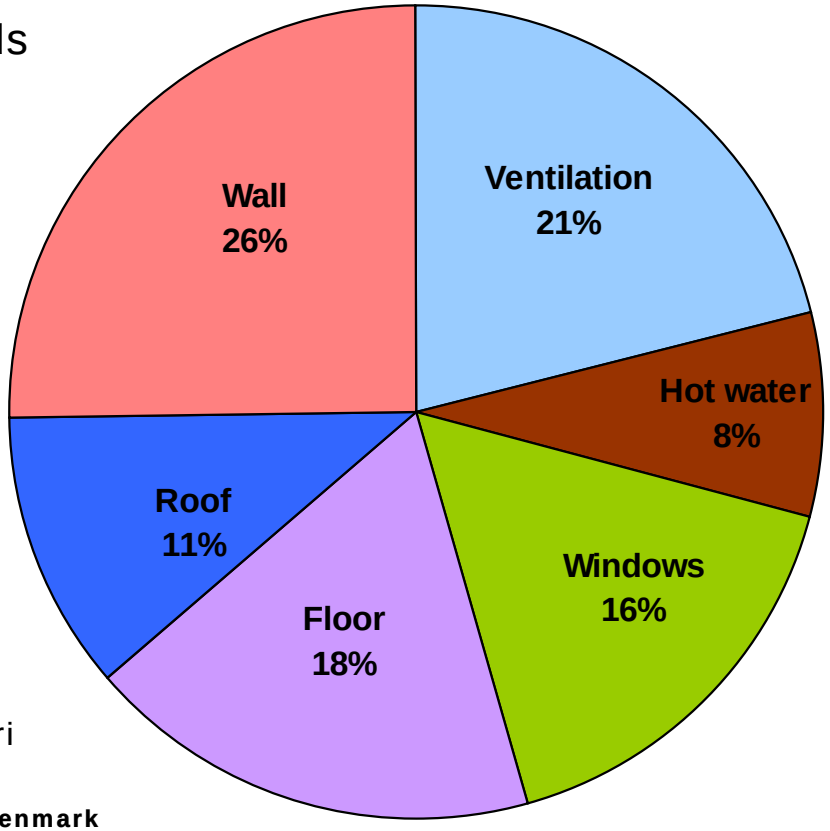


Heat saving potentials in buildings

- (Profitable) heat saving potential:
  - 80 % (over 45 years) in dwellings
  - 75 % in public buildings

- 75 % of residential and public buildings are built before 1979, when the first important tightening of building standards was introduced

Heat consumption in dwellings



source: Frandsen, F. B., Dansk Byggeri

Challenges for CHP and transition to biomass

- District heating consumption (demand) may decline through savings in buildings and better pipes (losses)
- CHP face lower electricity prices and less profitability from main product: electricity
- CHP heat production will be replaced by electricity in district heating grids when very low electricity prices (zero prices) (electric boilers and some heat pumps)
- An increasing number of hours with very low electricity prices reduce competitiveness of CHP and reduce annual full load hours (operational hours) away from base load characteristics
- The flexibility of the power system is reduced if less CHP is available in the future due to no new investment- leads to speculation that capacity payments are needed?
- Less CHP required will also reduce the options for switching the entire sector to more biomass

Possible trends in CHP and transition to biomass

- Reduced number of large CHP blocks
- Reduced capacity of large CHP plant - 400 MW to 200 MW?
- Reduced amount of small scale CHP plants
- Expansion of district heat coverage in Denmark has limited potential
- Change in tariffs for electricity based heating (reduced) compared to biomass based heating may affect the transition to biomass

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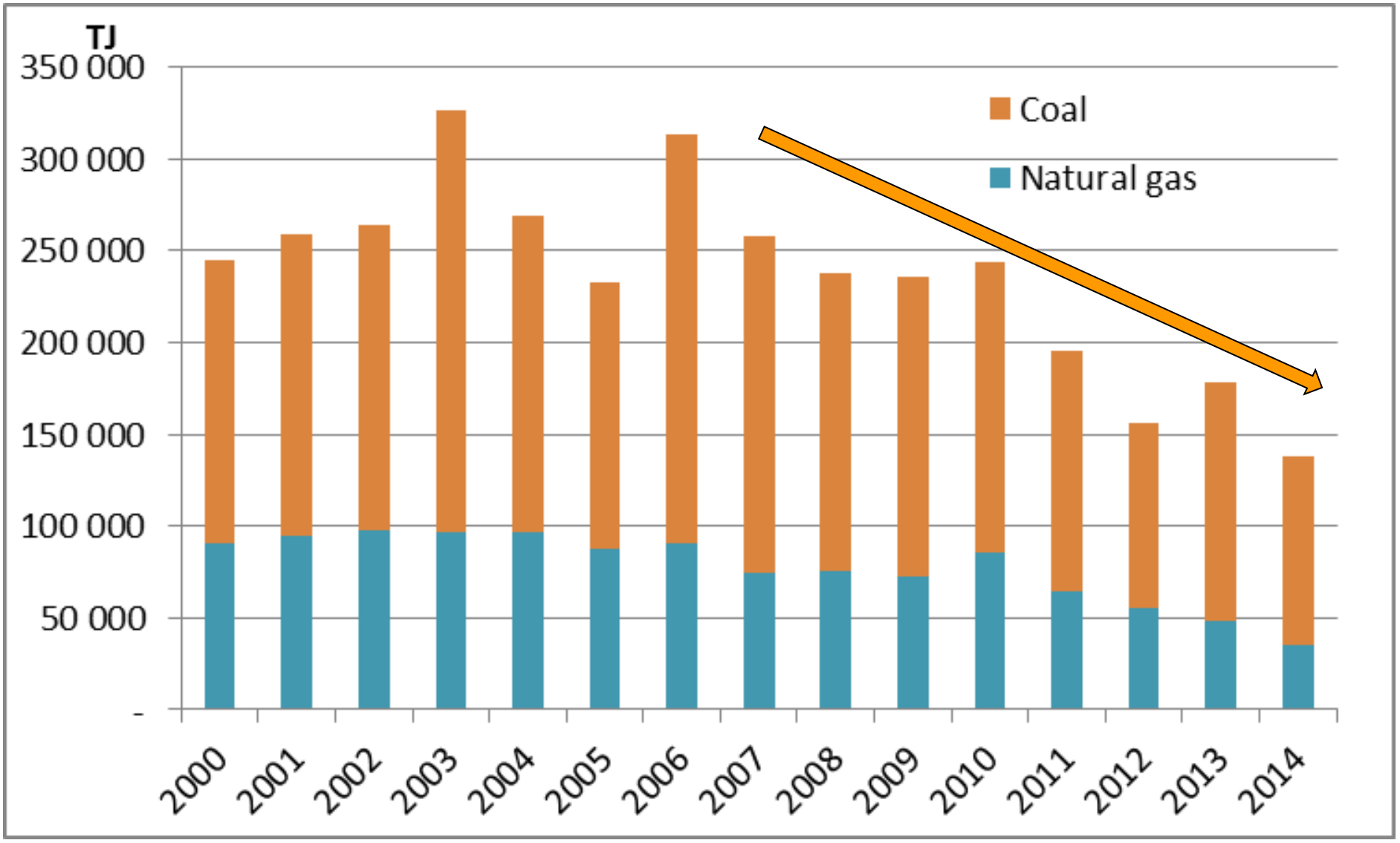
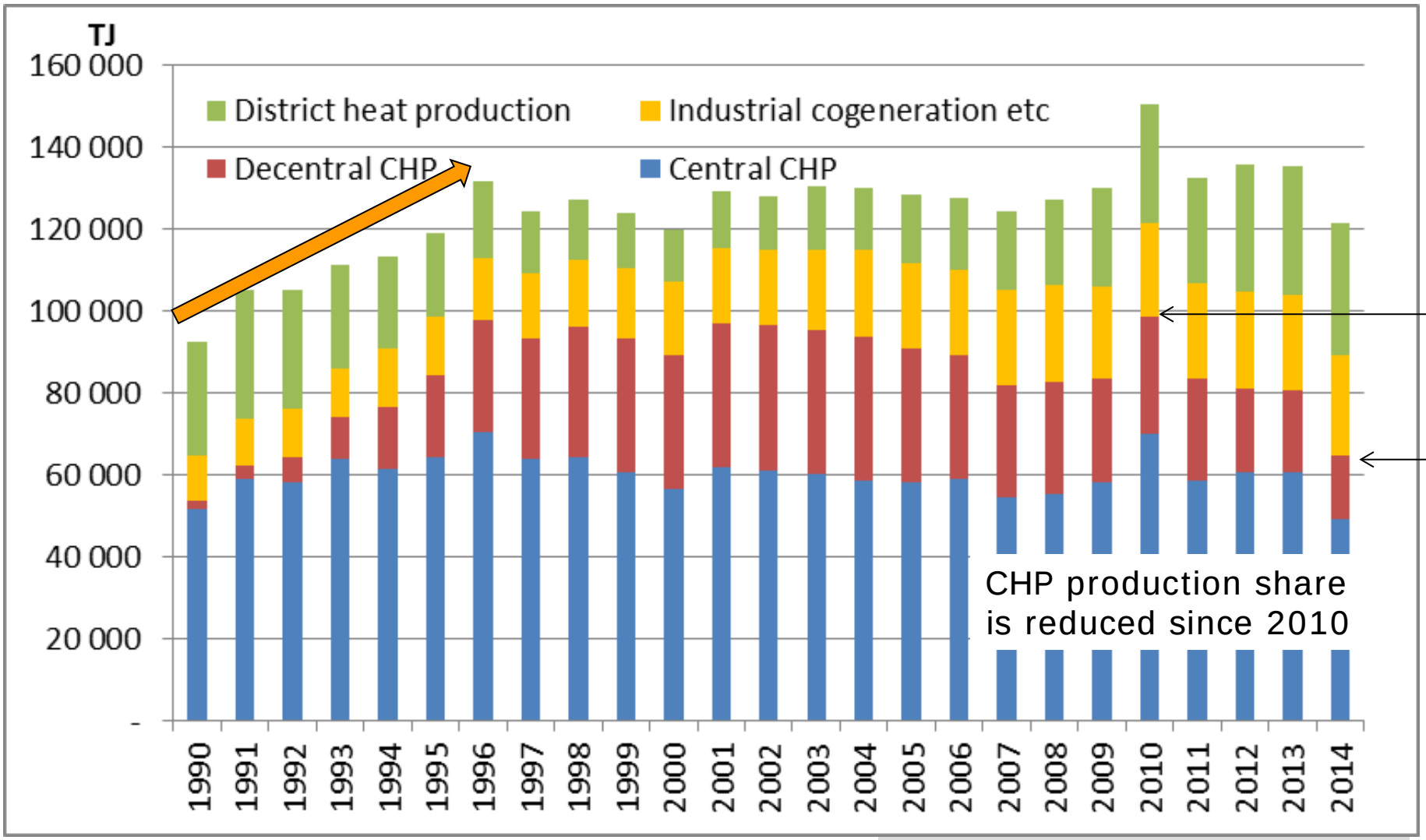
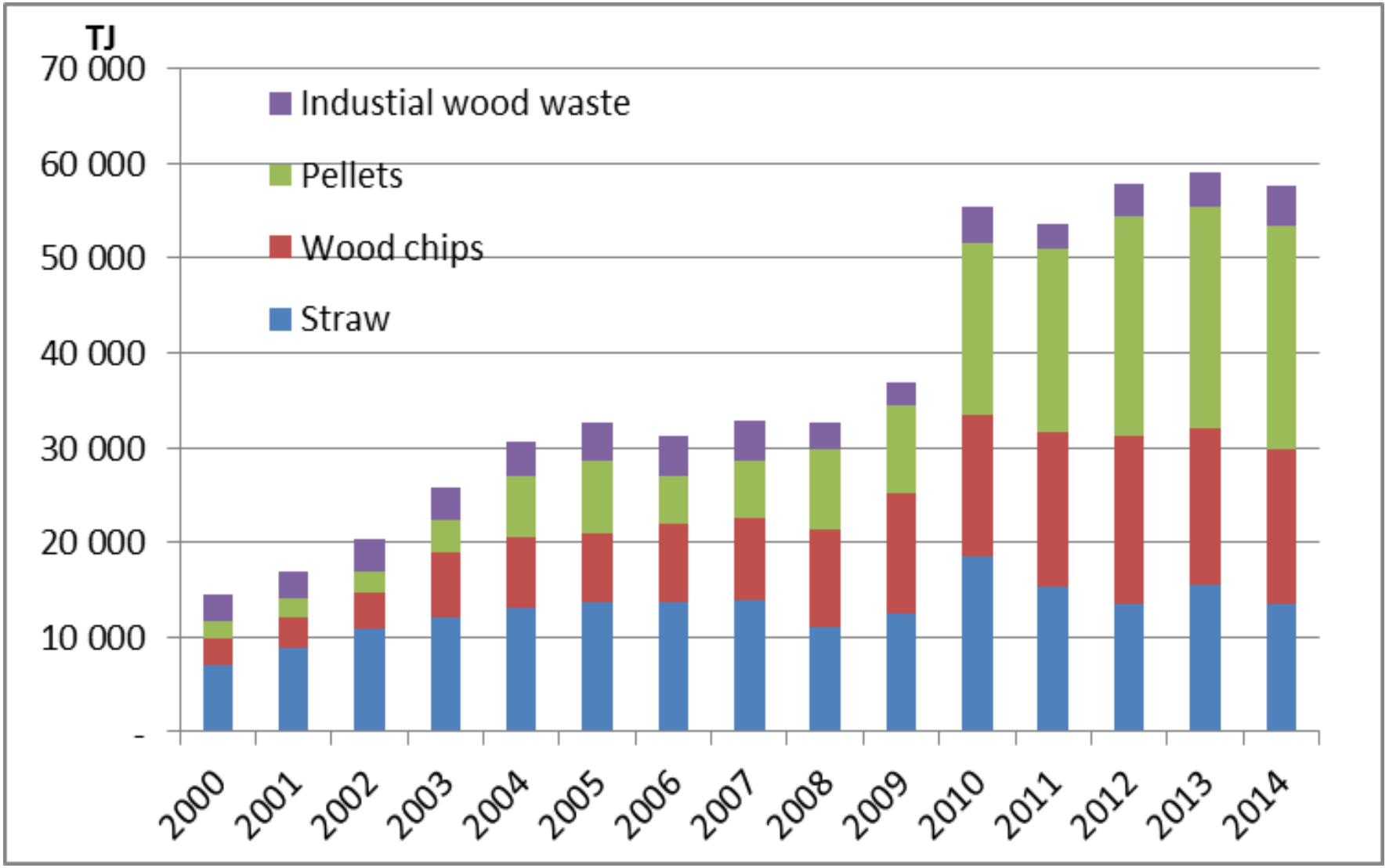
Coal and natural gas as fuels in electricity and district heat production in Denmark



Composition of district heating production



Biomass fuels in electricity and district heat production in Denmark - imports?



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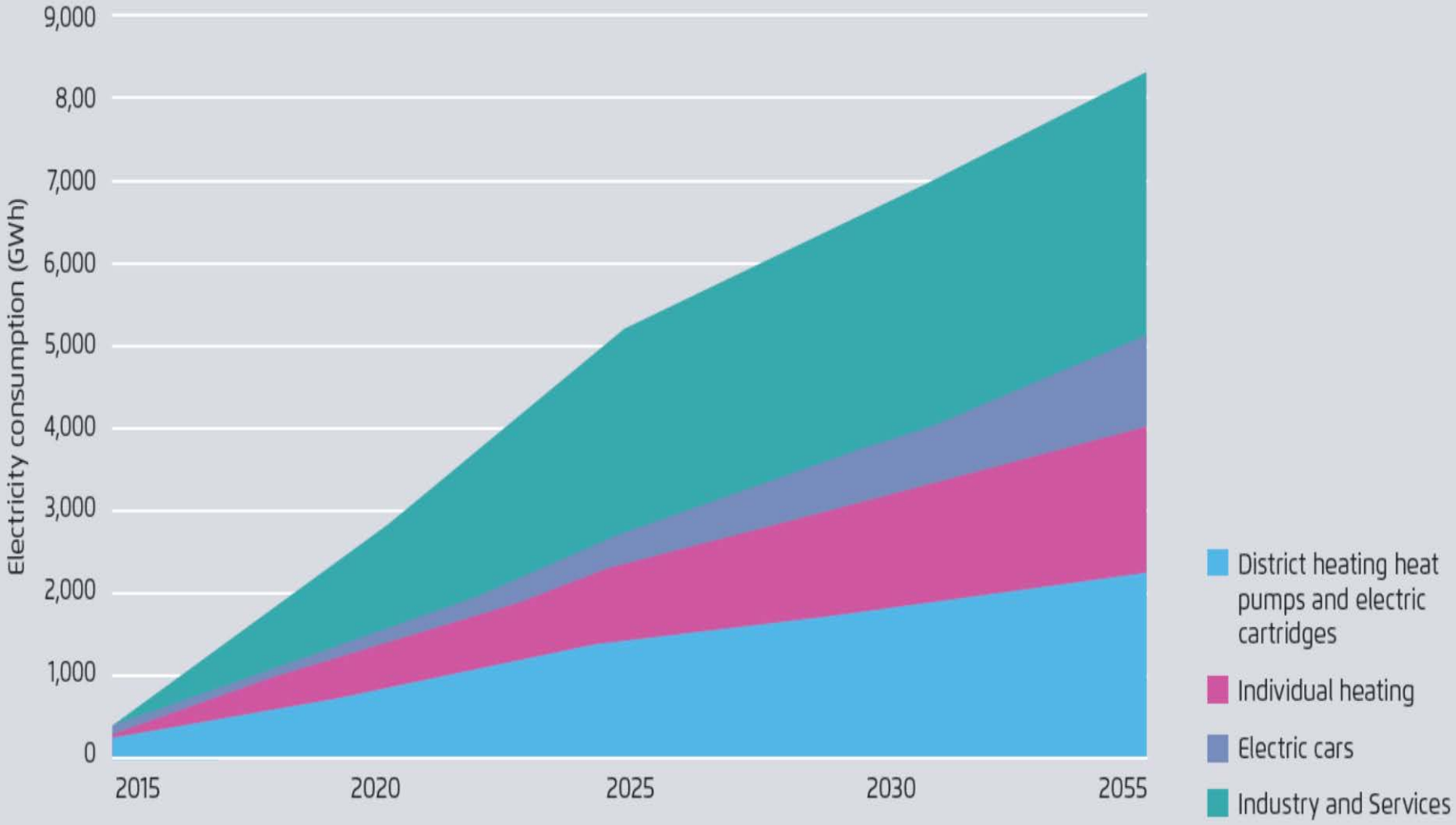
Danish Ministry of Climate, Energy and Building, Smart Grid Strategy The intelligent energy system of the future (KEBMIN, 2013), p. 11



Heat pumps adds flexibility by using electricity when cheap and shutting off when expensive

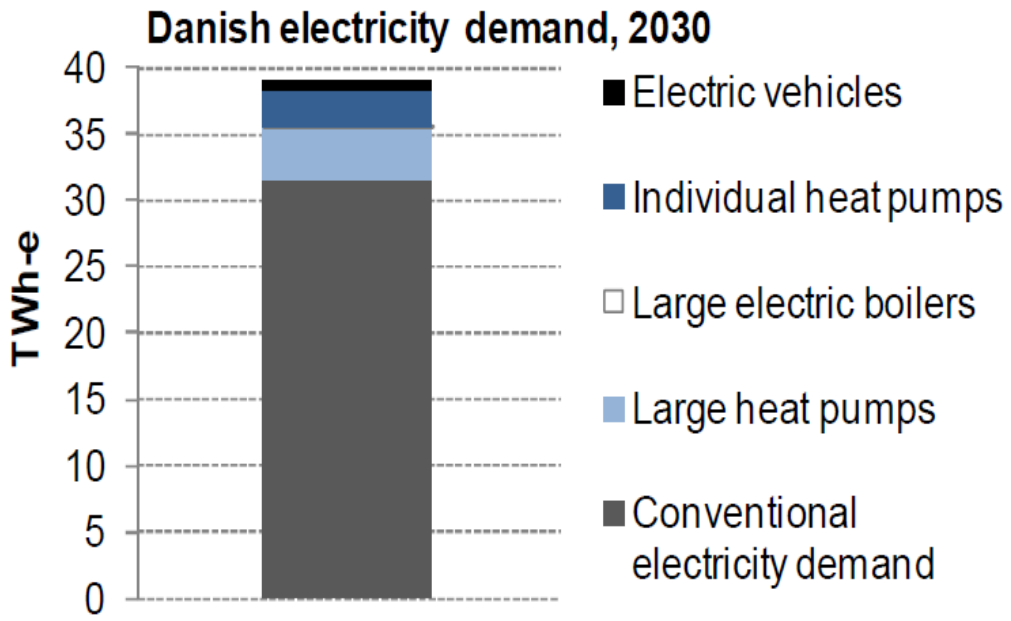


Figure 2. Danish electricity demand in 2030 as expected by Energinet.dk (incl. grid losses) [5].

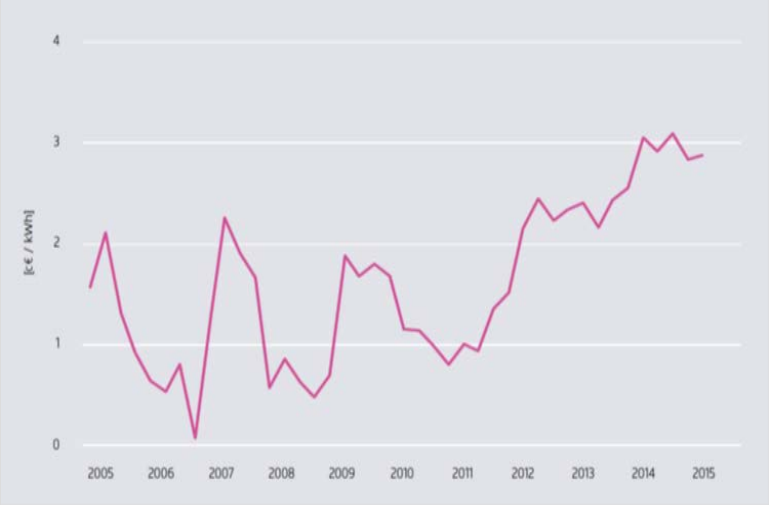
Conclusions

- Increasing shares of low marginal cost renewables have reduced average day ahead market prices and reduced normal daily price volatility
- Flexibility of all conventional generators large interconnection capacity, and heat storage facilitate integration now and in the future hopefully also demand response
- Market incentives for providing flexibility should include the biomass and gas based decentral generators and even renewables as wind and PV
- Renewables support (investment cost) is provided outside wholesale power market - reducing the market incentive to invest in capacity
- Combined Heat and Power is important in Denmark but will be challenged in the future
- Heating will be supplied by biomass (pellets, chips and waste) based CHP and increasingly by electric based heating (electric boilers, large heat pump, individual heat pumps)
- Additional electricity demand for heat and electric vehicles etc. should be partly flexible exploiting mainly the low price hours with abundant wind and/or PV conditions

Consumers – and the cost issue of financing the transition…

Quarterly PSO tariff for customers in West DK (2005-2015)

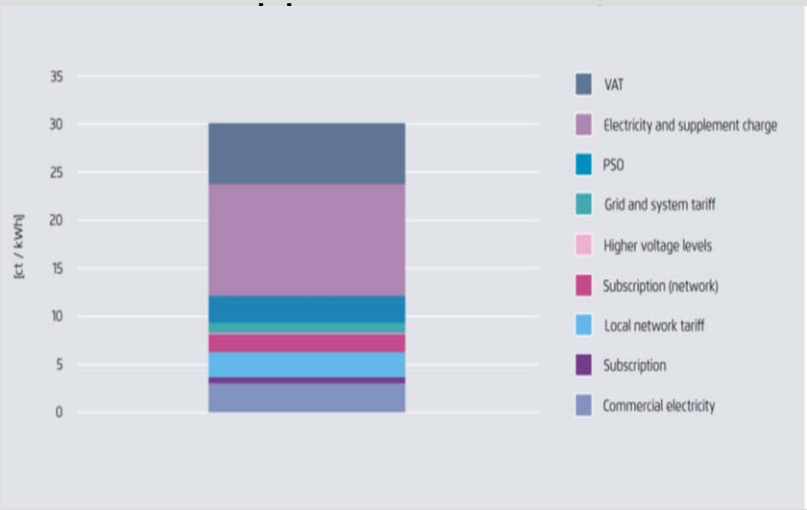
→ The **cost debate** on financing renewables (by means of the so-called PSO-tariff as part of the final electricity price) has gained increasingly attention in Denmark during the last years – especially



Final electricity retail price for households in August 2015

→ In 2014 **a reduction of the PSO component** was introduced by shifting some of the funding to the federal budget

→ A transfer to government budget



Own elaboration, based on Dansk Energi (2015) and PSO from Energinet.dk (2015), both in *Agora & DTU* (2015)