



## Why Wind Works: Denmark's Model for Sustainability

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# Why Wind Works: Denmark's Model for Sustainability

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Innovation: The Danish Way, A Danish American Heritage Society  
Conference  
Des Moines, October 10-12, 2013

**DTU Management Engineering**  
Department of Management Engineering

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# Why Wind Works: Denmark's Model for Sustainability

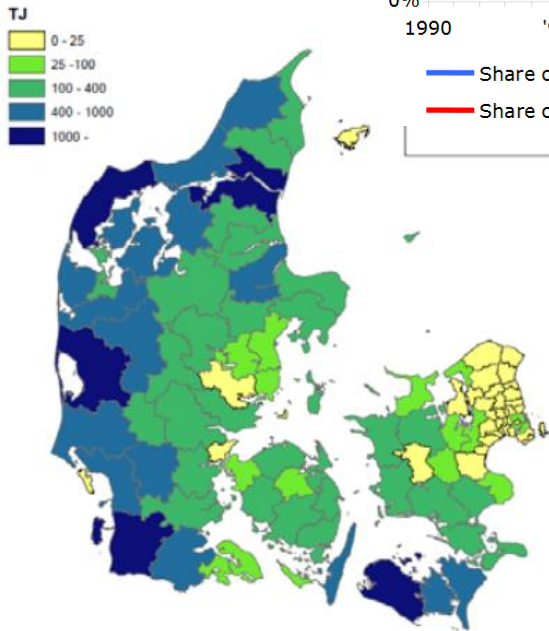
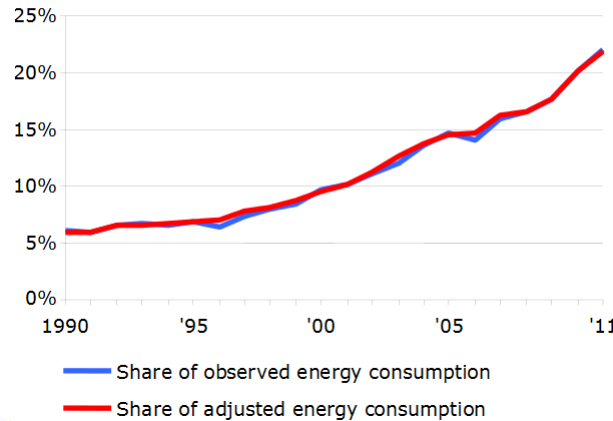


## AGENDA

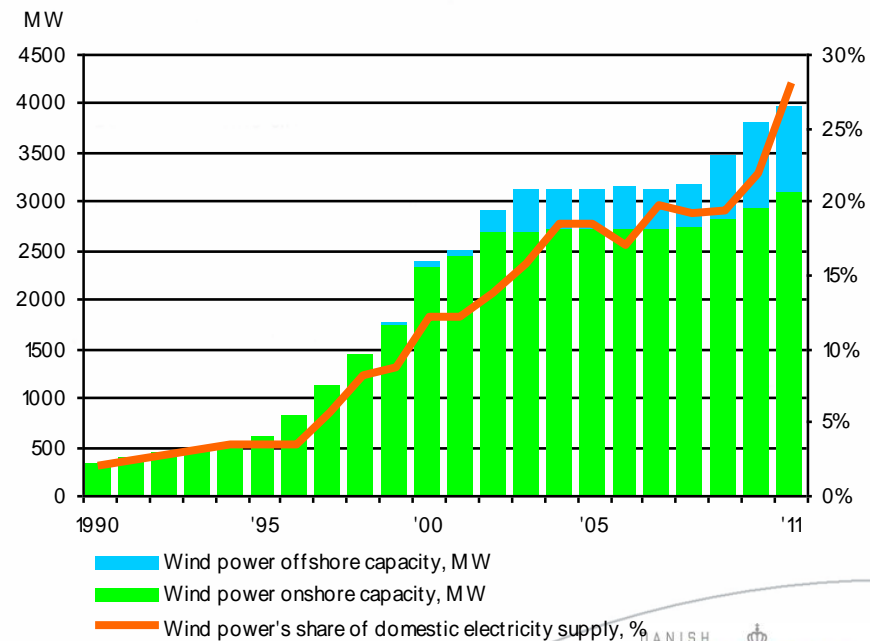
- Favourable position – power highway continent - Scandinavia
- Excess generation capacity
- Flexible hydro storage in Norway
- Moving wind expansion off-shore
- Relatively shallow off-shore locations with medium costs
- Nice off-shore planning environment
- Price effects but they can be accommodated
- High consumer prices for power and willingness to pay among residential customers

# What has been achieved: Renewable energy

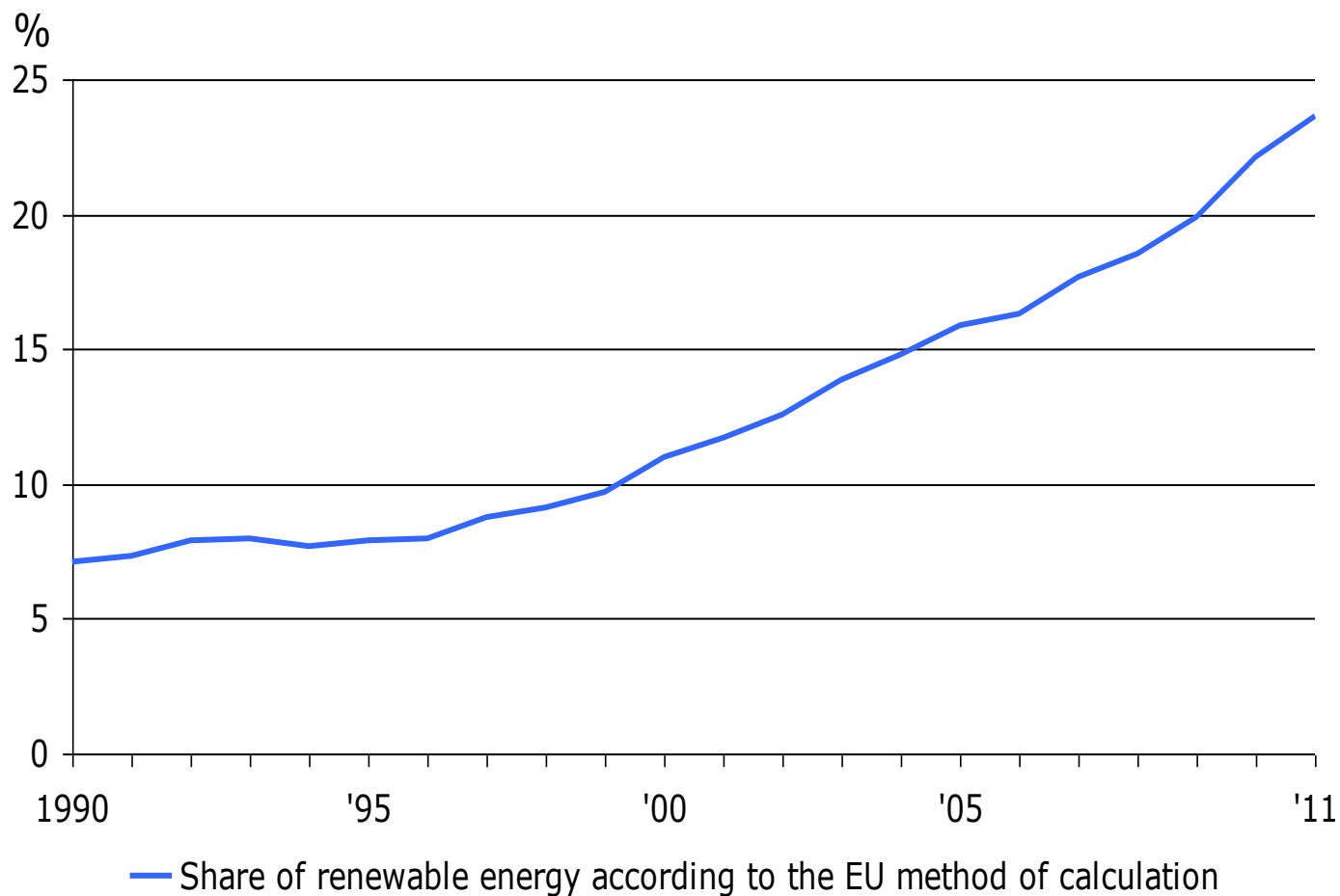
Renewable energy – share of total energy consumption



## Wind power capacity and wind power's share of domestic electricity supply



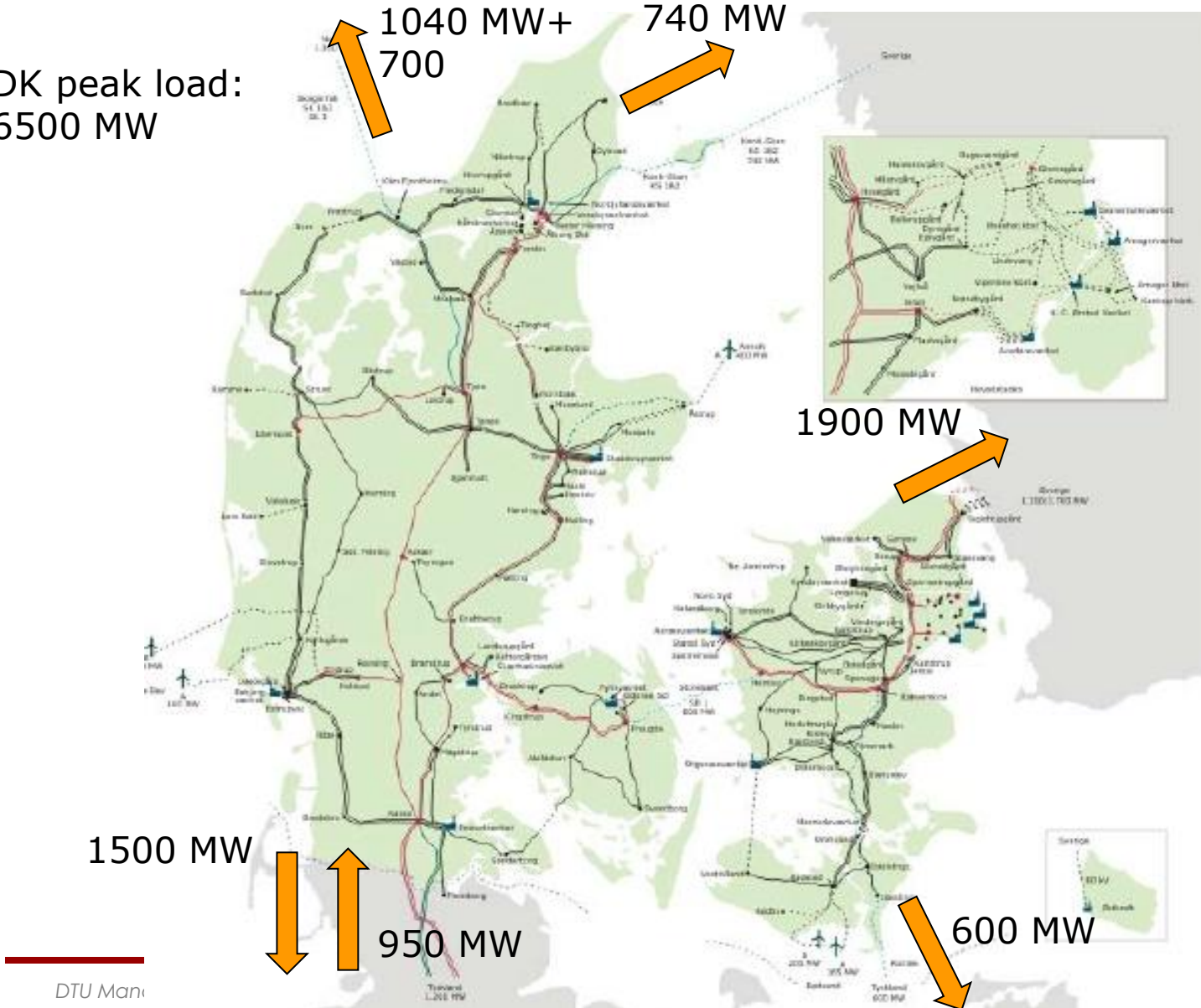
# Share of renewable energy and EU target for Denmark (EU method)

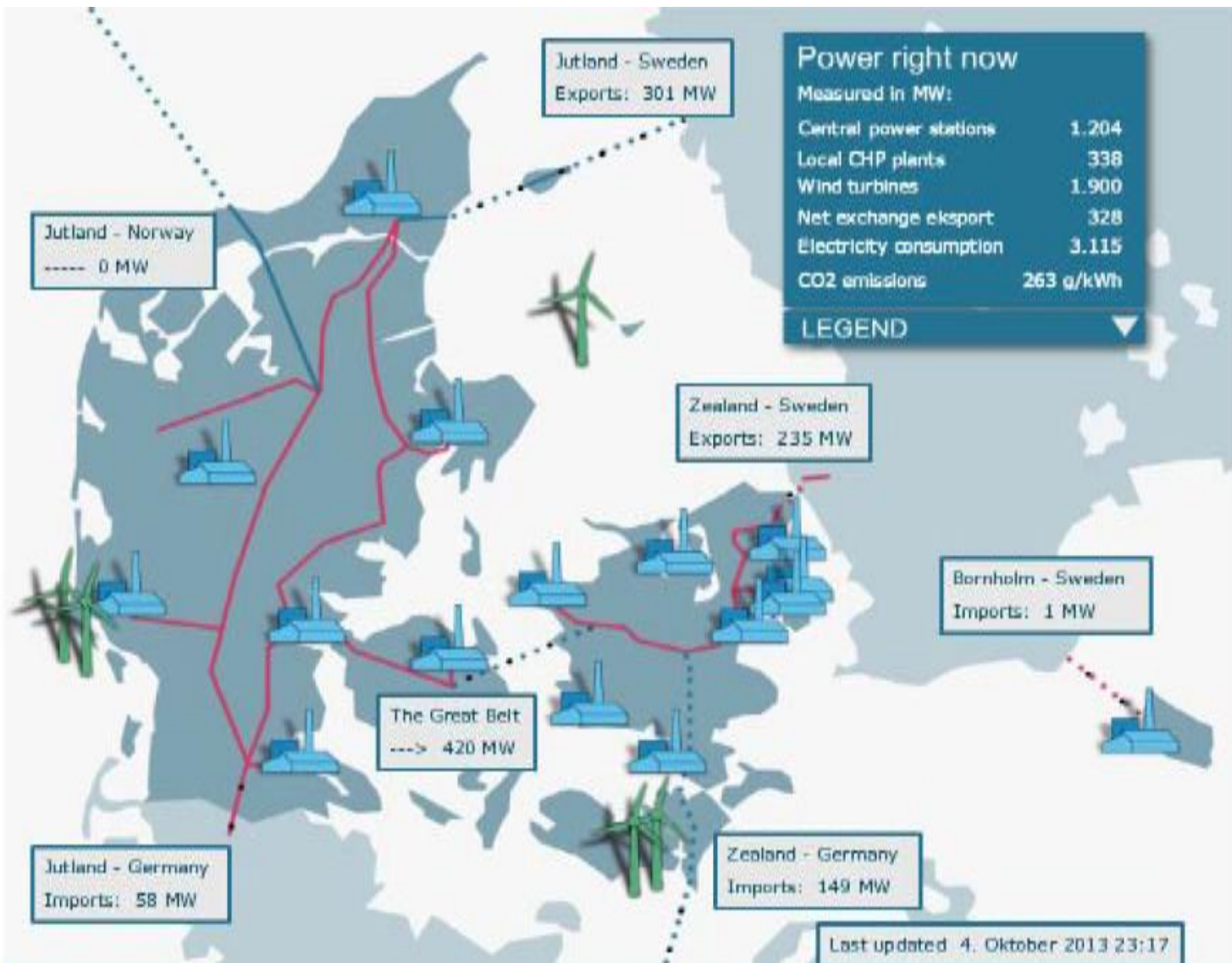


EU target for Denmark in 2020: **30%**

# Strong interconnections

DK peak load:  
6500 MW





Jutland - Sweden  
Exports: 301 MW

Jutland - Norway  
----- 0 MW

Power right now	
Measured in MW:	
Central power stations	1.204
Local CHP plants	338
Wind turbines	1.900
Net exchange eksport	328
Electricity consumption	3.115
CO2 emissions	263 g/kWh

LEGEND

Zeoland - Sweden  
Exports: 235 MW

Bornholm - Sweden  
Imports: 1 MW

The Great Belt  
---> 420 MW

Jutland - Germany  
Imports: 58 MW

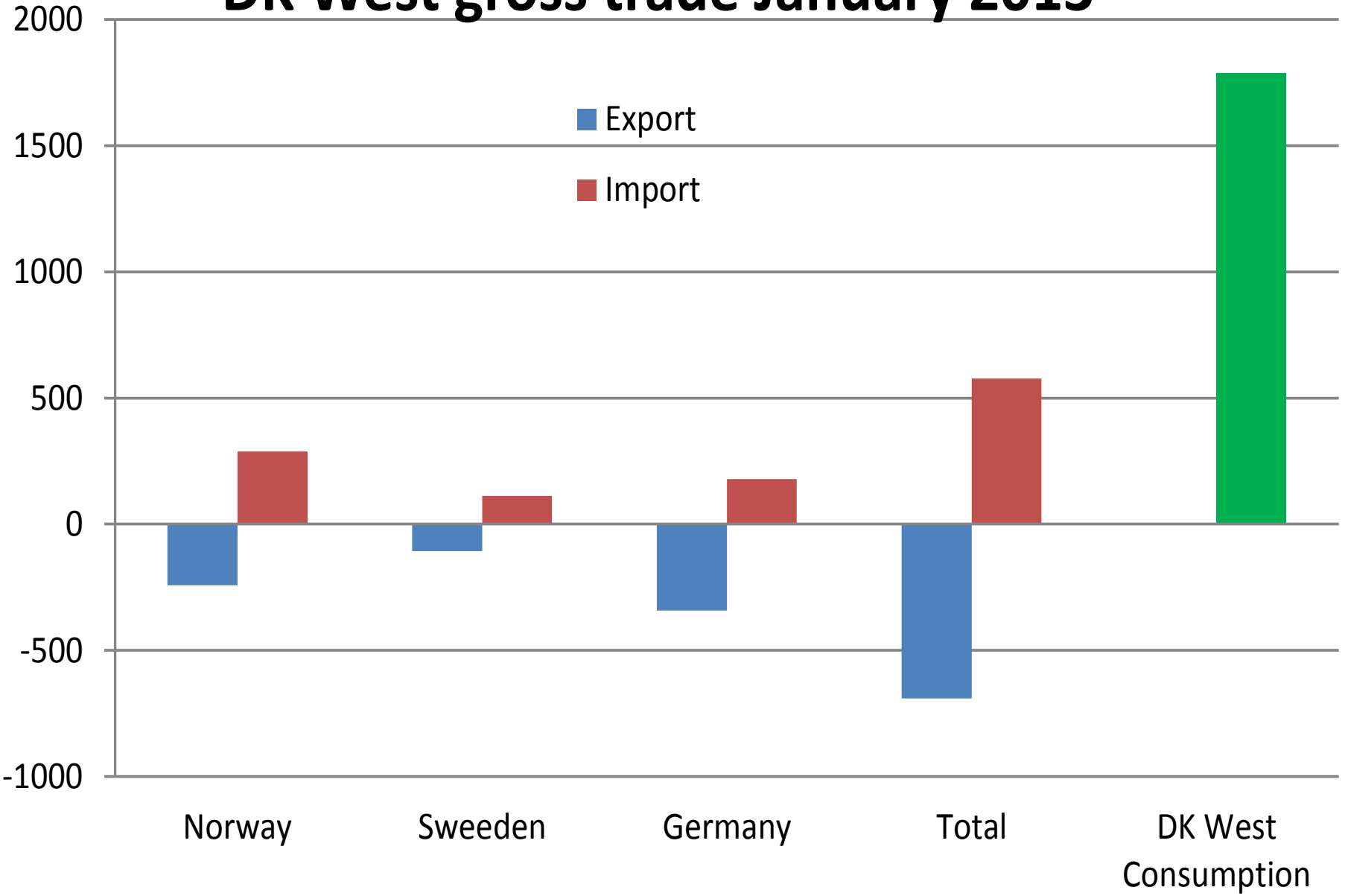
Zeoland - Germany  
Imports: 149 MW

Last updated 4. Oktober 2013 23:17



# DK West gross trade January 2013

GWh



# Excess power capacity – still?

# Nordic system power balance

## POWER BALANCE 2012-2013

With estimated power exchange [MW]  
Cold winter day in 1 of 10 winters

NORDIC MARKET	TOTAL
P = Available capacity TSO reserves excluded	72 930
C = Peak demand	*) 71 640
B = Balance without power exchange	1 290
R = Reserves available for the TSOs	4 750

SWEDEN	
P	27 700
C	27 500
B	200
R	1 400

FINLAND	
P	13 300
C	15 000
B	-1 700
R	1 100

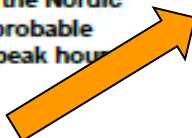
NORWAY	
P	26 200
C	24 000
B	2 200
R	1 200

DENMARK	
P	5 730
C	6 600
B	-870
R	1 050

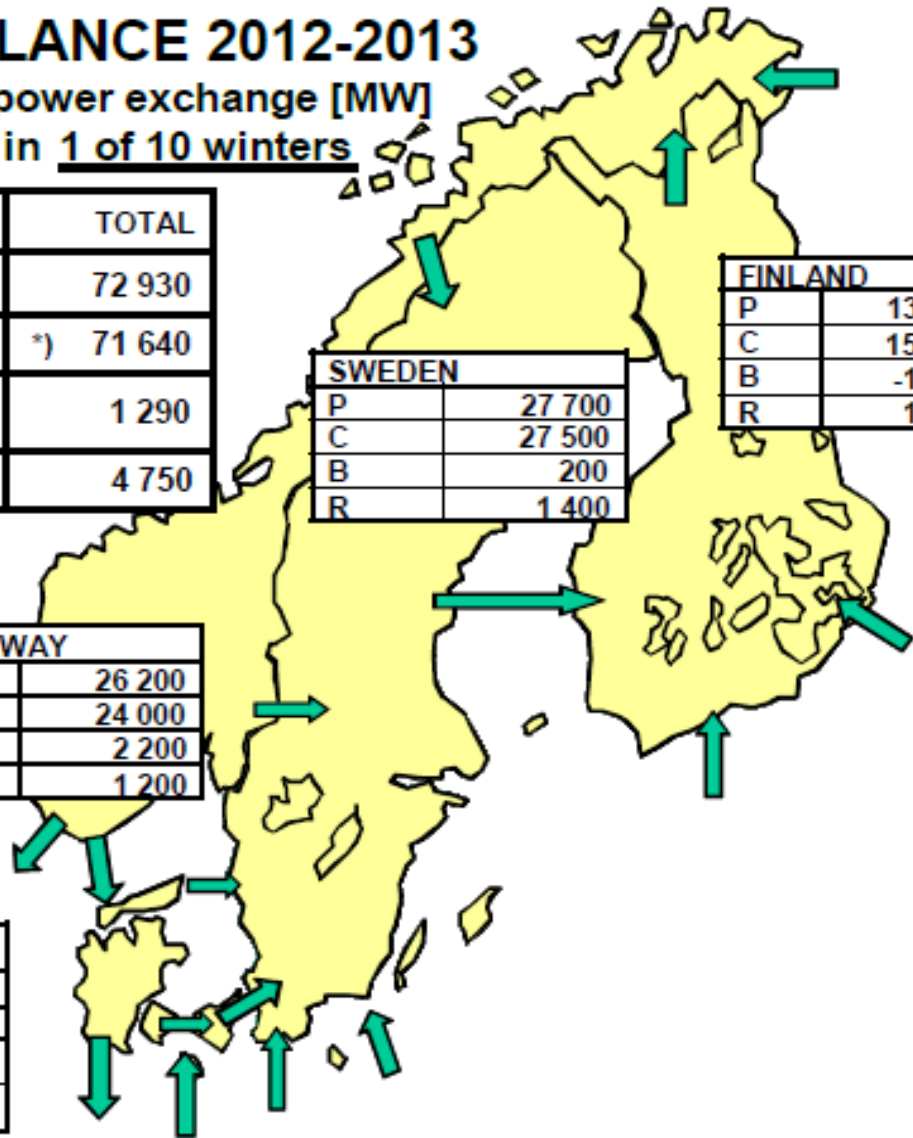
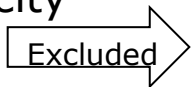
\*) 2 % lower than sum of national peaks.

Arrows between and to/from the Nordic countries indicate the most probable power flow direction during peak hours

Hydro

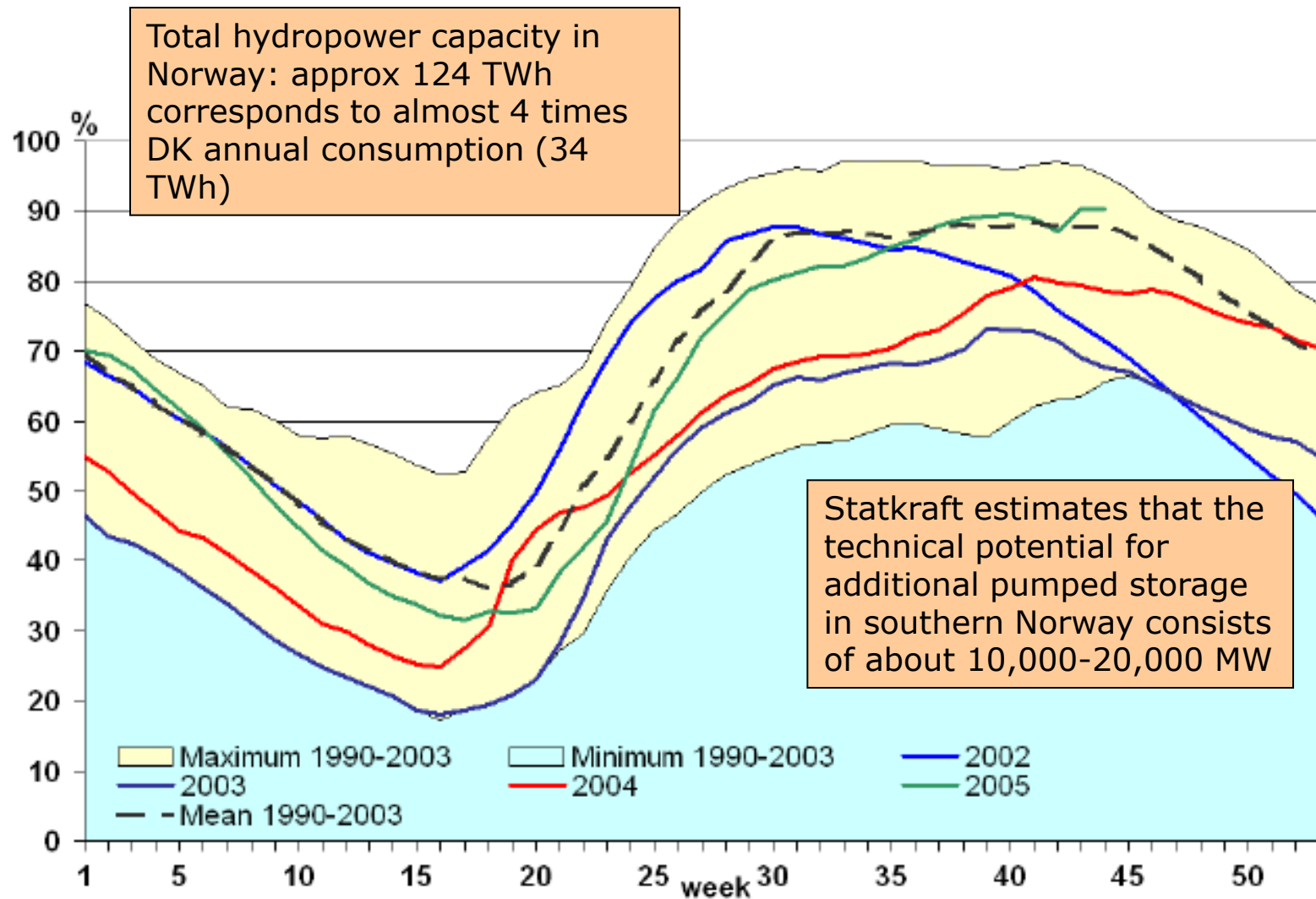


Wind capacity value of 4000 MW

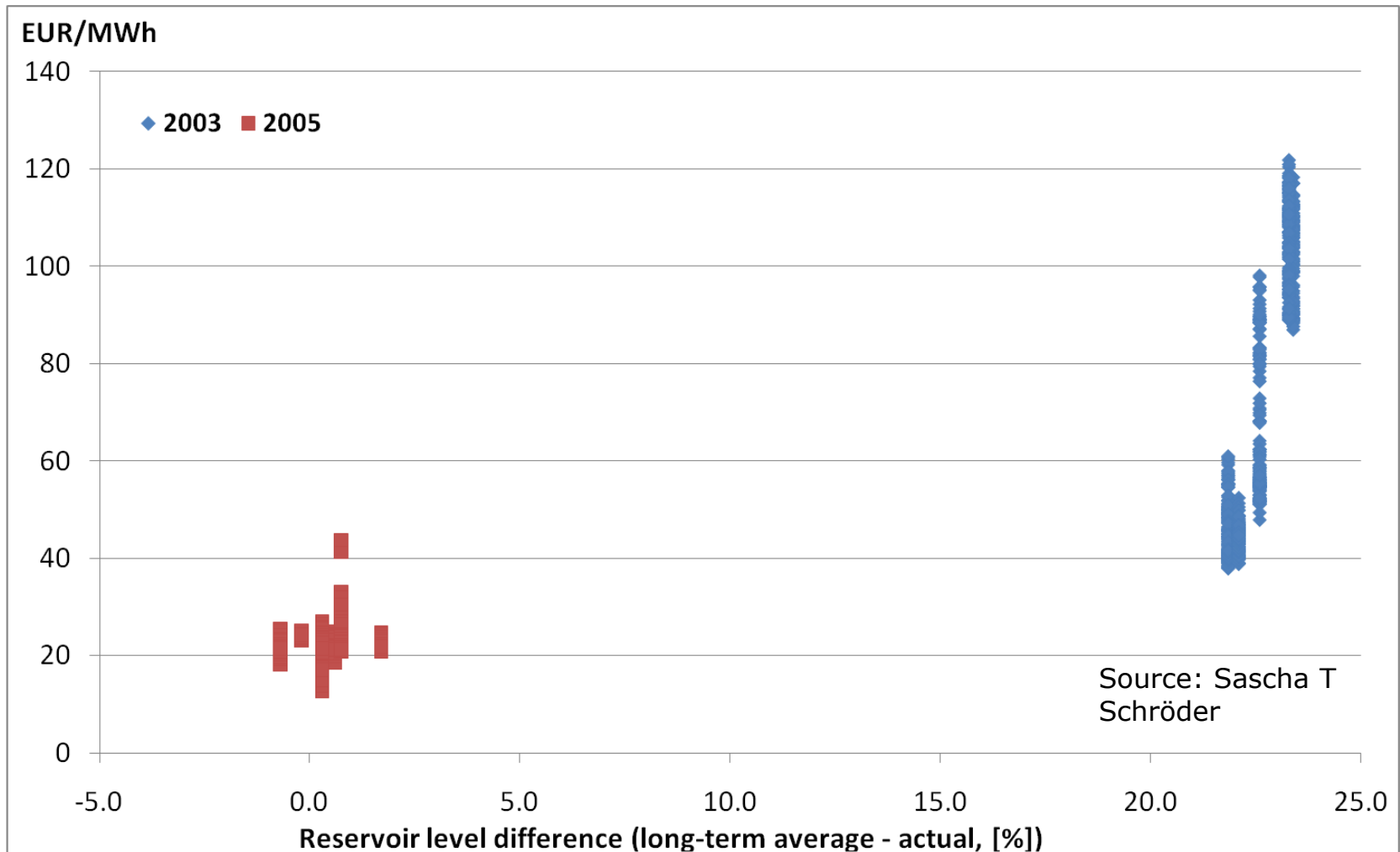


# Norwegian hydropower – flexible storage

# Norwegian reservoir levels vary but capacity and prospects for pumped hydro large



# Norway: Reservoir levels and prices



# Moving off-shore



The Anholt wind power plant's total installed electrical generating capacity of 400 megawatts is enough to supply around 400,000 Danish households with clean power, thereby meeting about four percent of Denmark's total power demand.

Anholt consists of 111 wind turbines with a capacity of 3.6 megawatt each and a rotor diameter of 120 meters



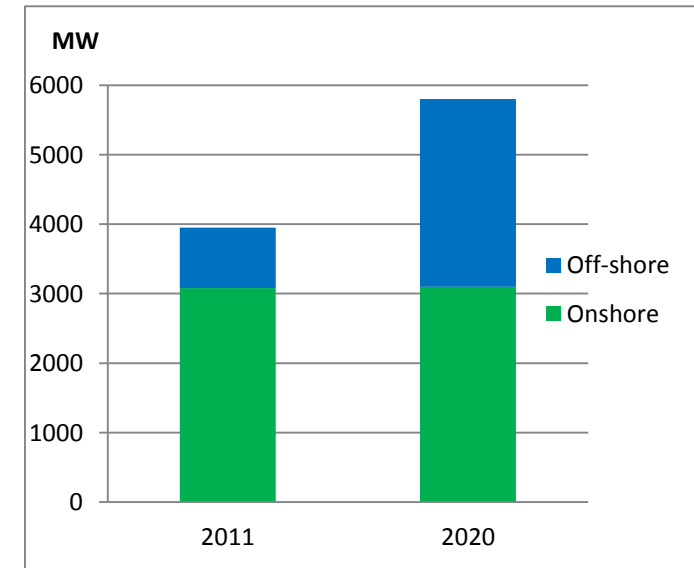
2013-Sep-04

Official opening of the Anholt Offshore Wind Farm on Wednesday, September 04, 2013 (from left) Danish Prime Minister Helle Thorning-Schmidt, Her Majesty Queen Margrethe II of Denmark, His Royal Highness Prince Henrik, Prince Consort of Denmark, and Fritz Schur, Chairman of the Board of Directors for DONG Energy.



# Danish offshore wind turbine development and projects in planning

Location	Size
1. Vindeby (1991)	11 turbines, 5 MW
2. Tunø Knob (1995)	10 turbines, 5 MW
3. Middelgrunden (2000)	20 turbines, 40 MW
4. Horns Rev I (2002)	80 turbines, 160 MW
5. Rønland (2003)	8 turbines, 17 MW
6. Nysted (2003)	72 turbines, 165 MW
7. Samsø (2003)	10 turbines, 23 MW
8. Frederikshavn (2003)	3 turbines, 7 MW
9. Horns Rev II (2009)	91 turbines, 209 MW
10. Avedøre Holme (2009/10)	3 turbines, 10-13 MW
11. Sprogø (2009)	7 turbines, 21 MW
12. Rødsand II (2010)	90 turbines, 207 MW
13. Anholt (2012/13)	400 MW
14. Horns Rev III (2017/18)	400 MW
15. Kriegers Flak (2017/19)	600 MW
Coastal areas off-shore (2016/20)	500 MW
Additional planned sites?	3200 MW

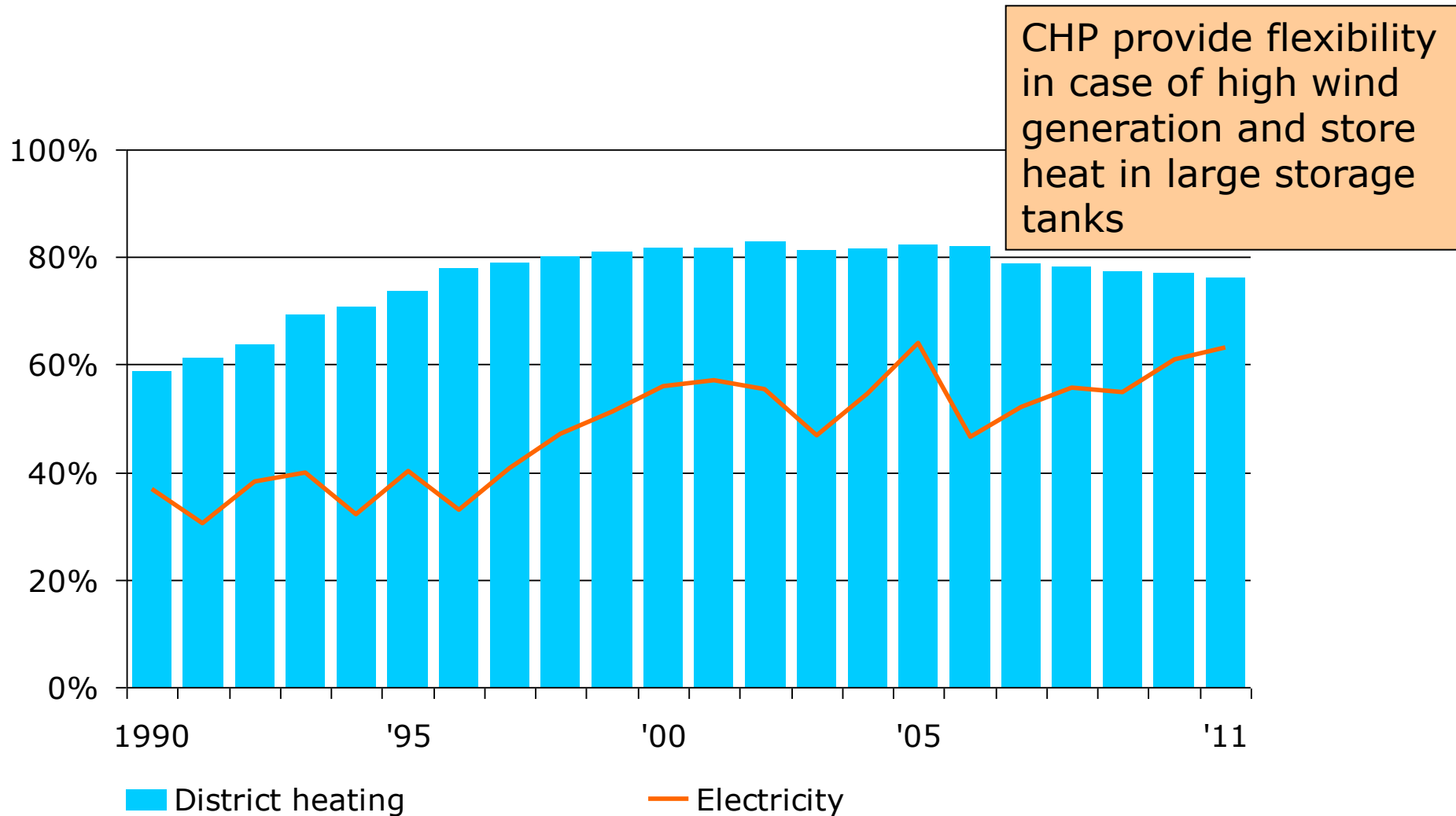




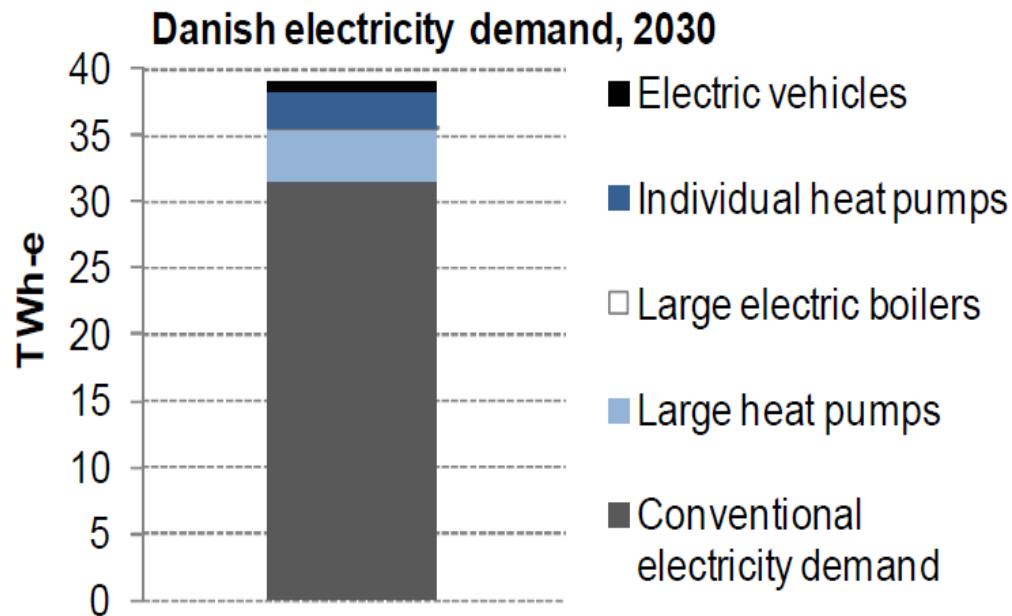
Size has changed dramatically also for the installation infrastructure  
Offshore installation vessels for WT are a critical planning resource

# Danish district heating and heat pumps supply flexibility

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



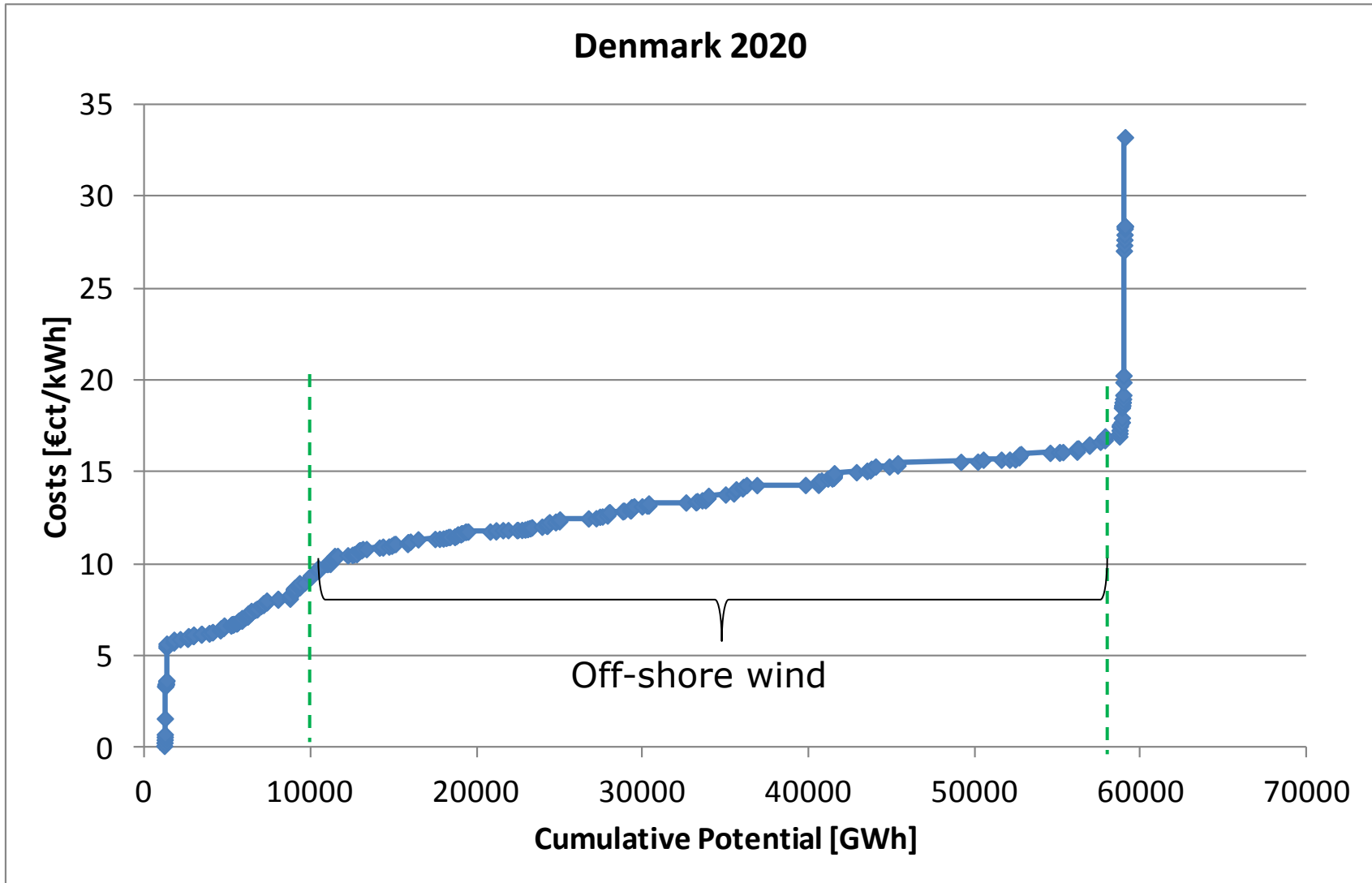
# Heat pumps adds flexibility



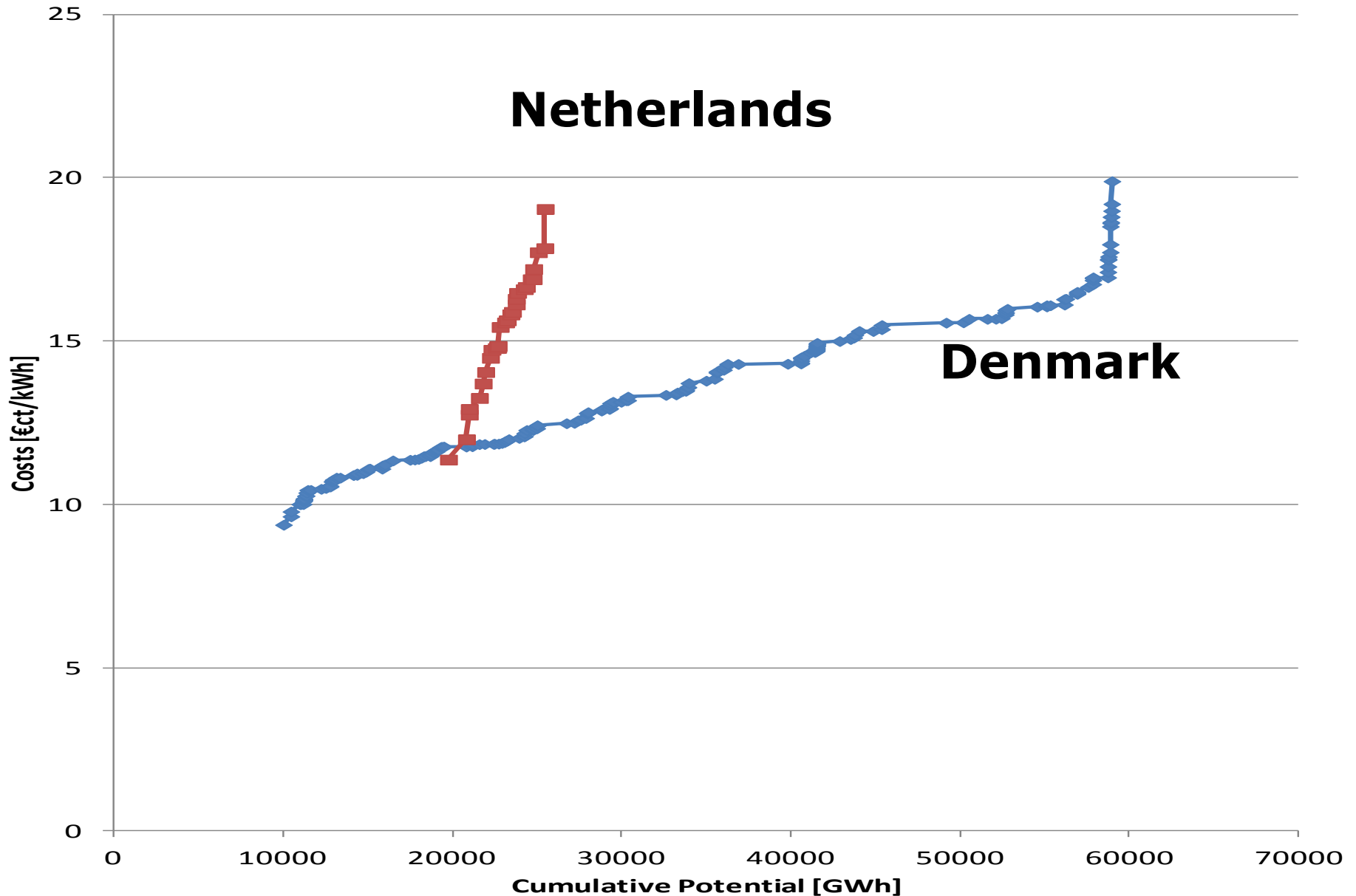
**Figure 2.** Danish electricity demand in 2030 as expected by Energinet.dk (incl. grid losses) [5].

# Favourable costs and planning conditions for adding more off-shore wind

# RES-E potential in Denmark from RES4LESS project



# Offshore wind generation costs projected to 2020





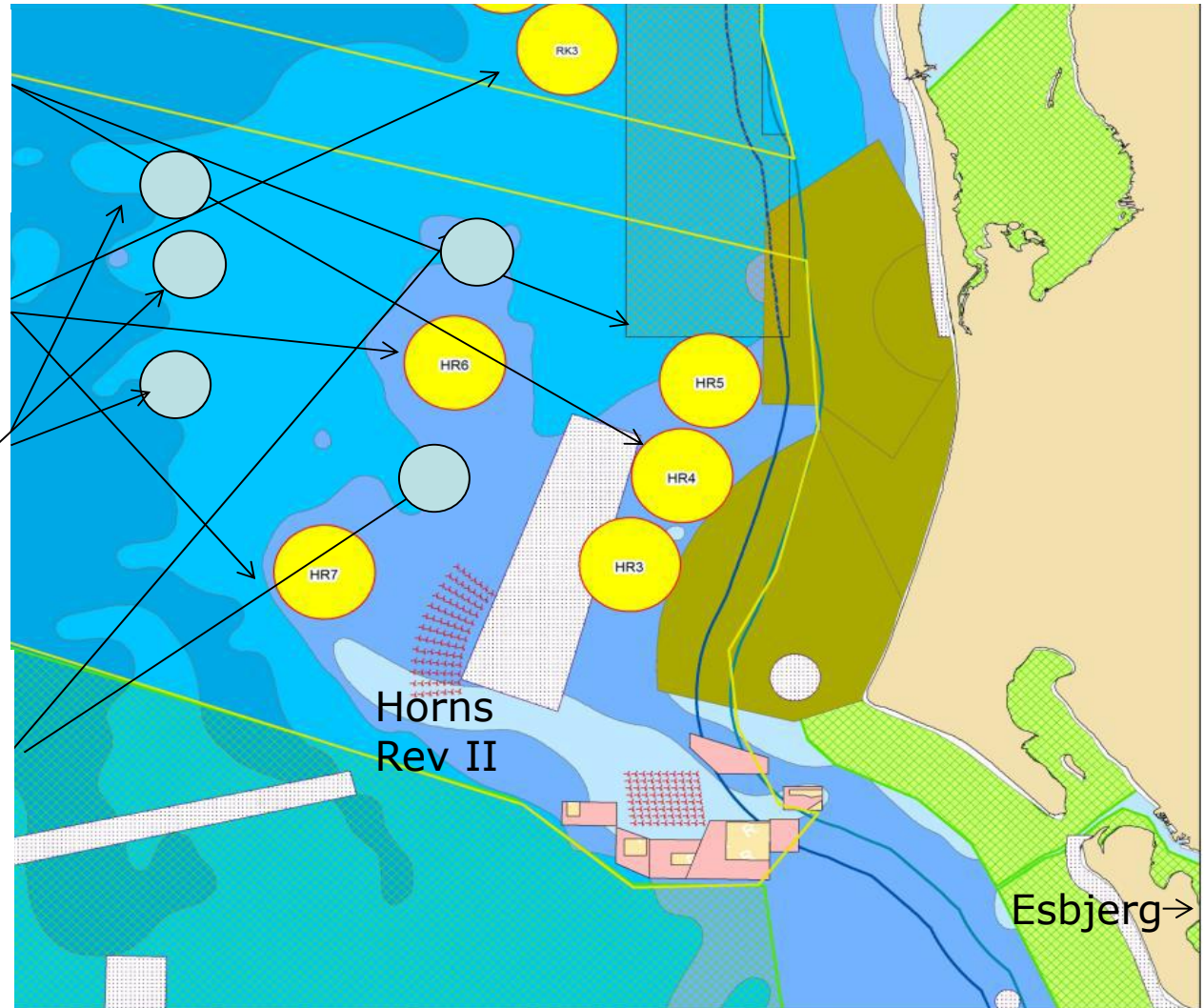
# Horns Rev planned (yellow) wind farms and additional options

Shallow with low cost

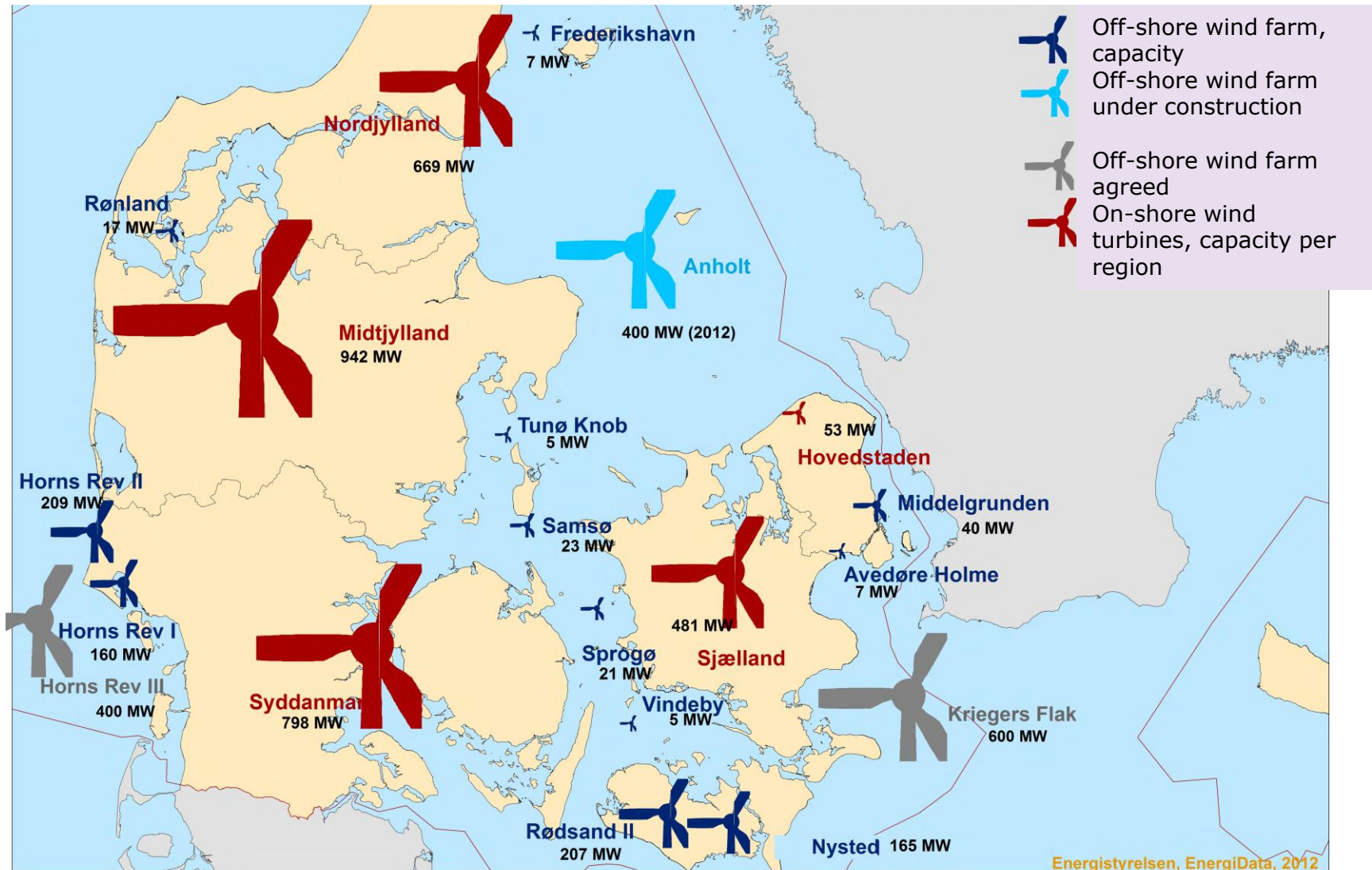
Medium cost location

Additional deeper locations with higher costs

Locations with minor negative costs on neighbour wind farms



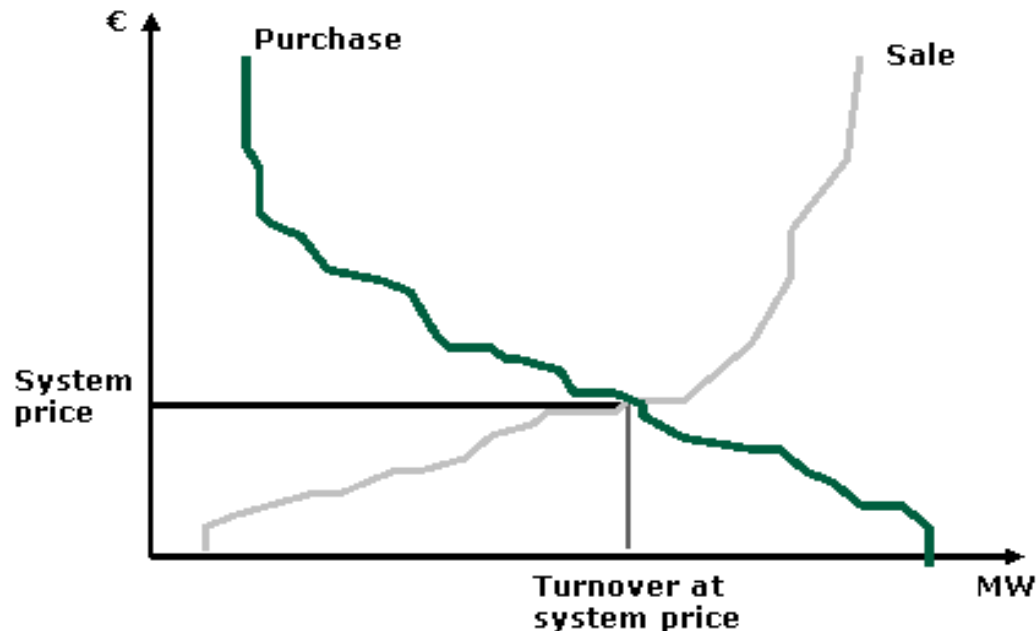
# Off-shore and on-shore wind capacity



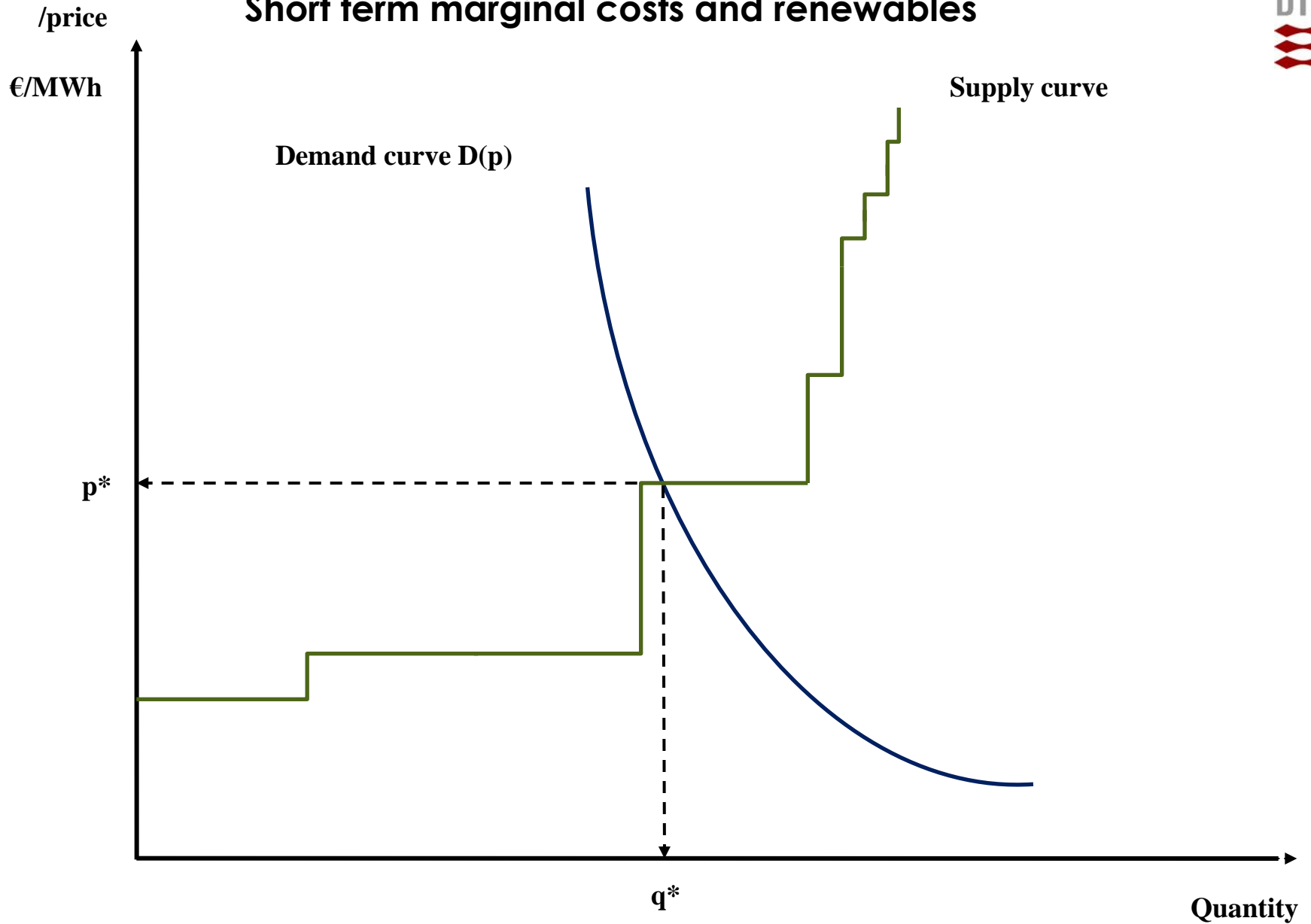
**Additional wind generation reduce  
wholesale prices but it can be  
accommodated**

# Electricity markets: standard supply and demand

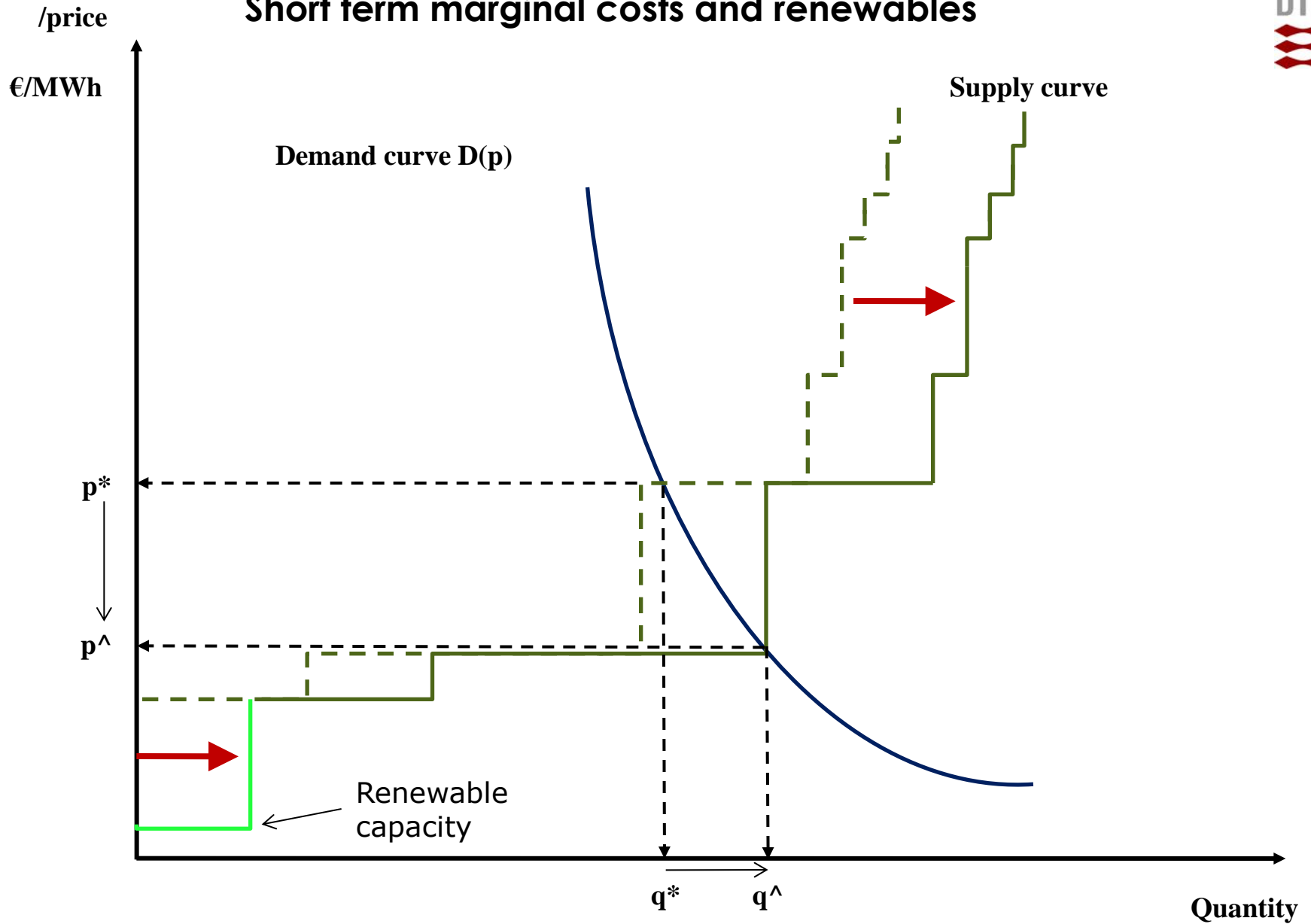
- Spot (day ahead) markets
- European spot markets (day ahead), hourly resolution
- Buyers and sellers bid *stepped curves*



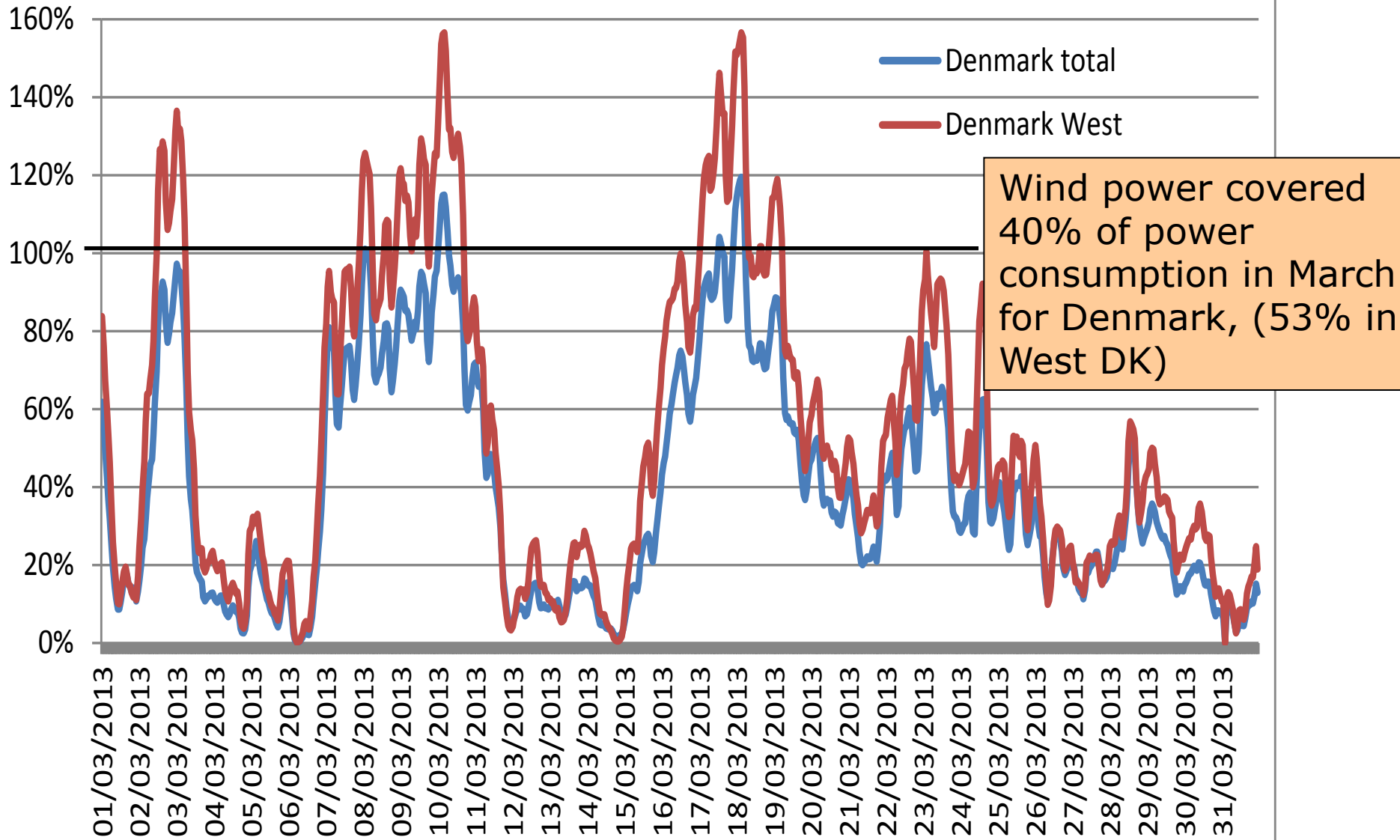
# Short term marginal costs and renewables



# Short term marginal costs and renewables



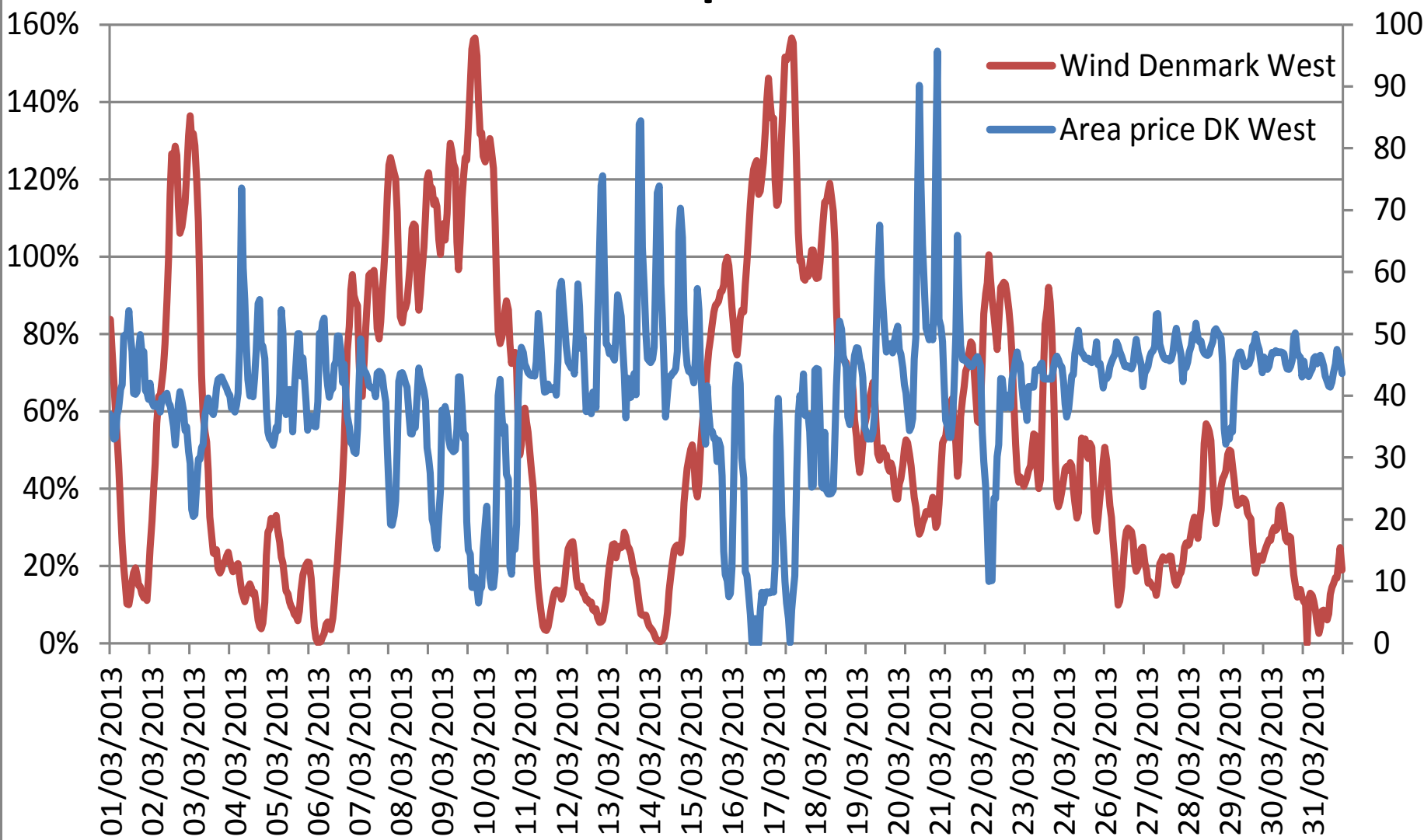
# Wind share of consumption March 2013



Hourly power price is negatively correlated with wind generation

# Wind share and price March 2013

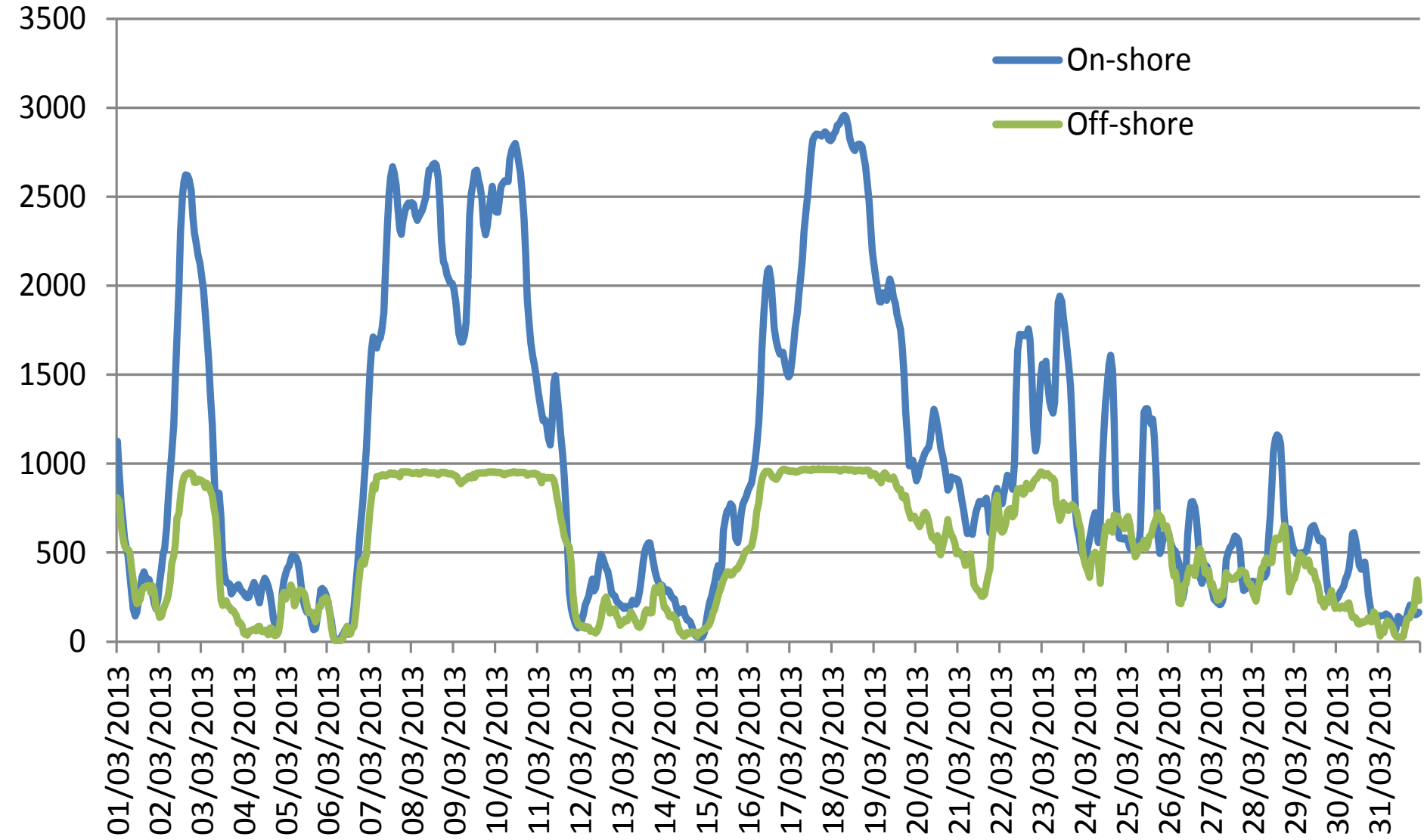
Euro/MWh





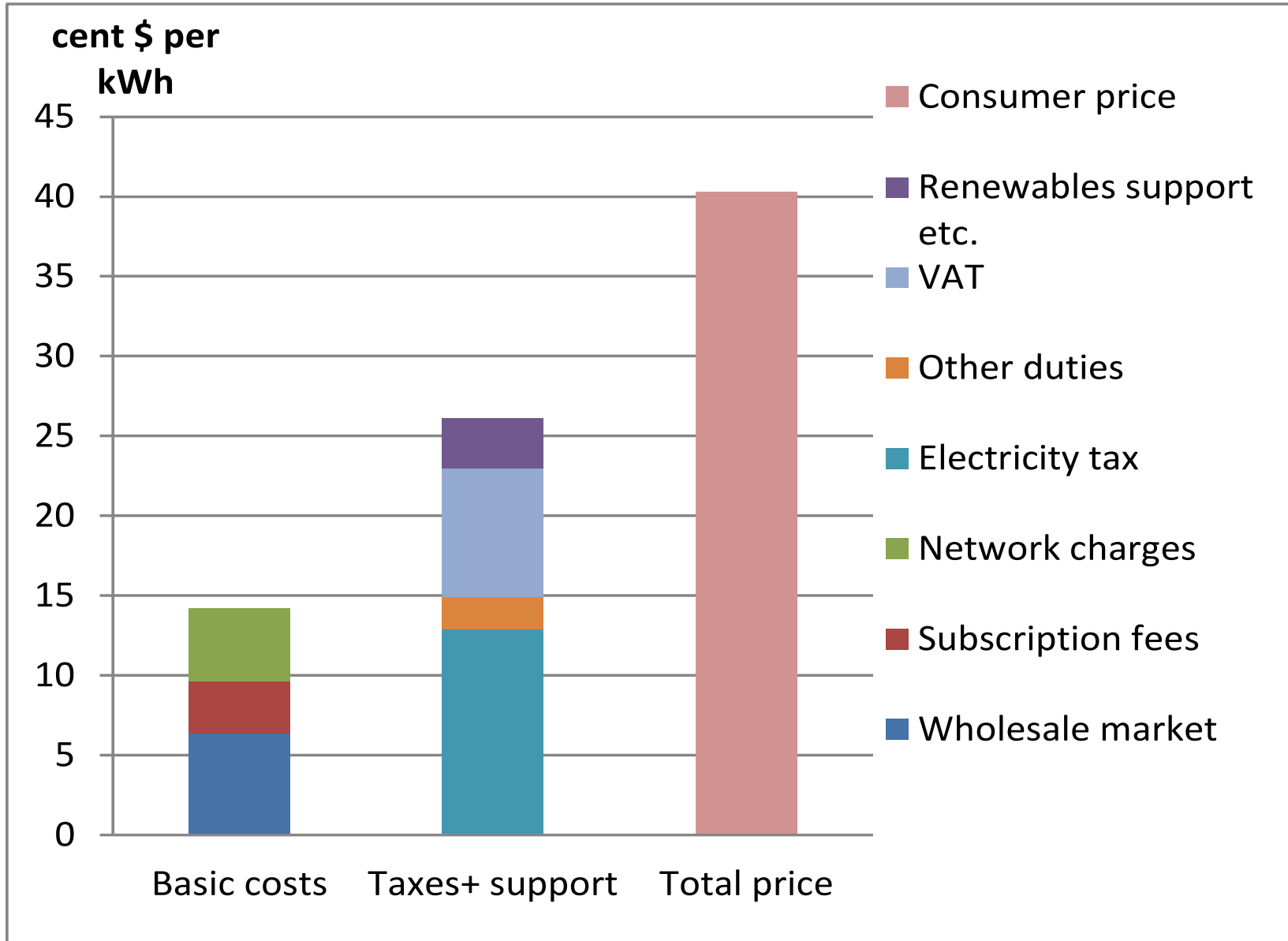
# On-shore and off-shore wind March 2013

MW



**The consumer is already paying considerable taxes and willingness to pay have not been a major issue**

# Electricity price for residential consumer in 2013





# West zone ERCOT

- Total installed power generation capacity around 12 GW, (compares to 14 GW in Denmark),
- Total installed wind power generation capacity around 9 GW, **75%**, (compares to 4GW and 30% in Denmark),
- Annual wind energy production as a fraction of electric energy consumption is more than **85%**, (compares to 27.1% in Denmark),
- Monthly wind energy production above **100%** in some months.

# DANISH ENERGY STRATEGY 2050

- Political agreement adopted in February 2011 (conservative government coalition)
- At time of adoption, the first of its kind in the world:

Declared target: **Denmark to become independent of fossil fuels in 2050**

- Reduction of Carbon emission by 30% until 2020
- Exports of clean-tech solutions
- New energy policy initiatives
  - Reduce energy consumption in 2020 by 6%      **new 2012 agreement: by 7.6%**
  - renewable energy in 2020 at 33%                      **new 2012: wind alone 50%**
- In 2035: 100% of electricity from renewable sources

***Thank you for your attention!***

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