The Danish Experience with Integration of Variable Renewable Energy

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Anders Kofoed-Wiuff

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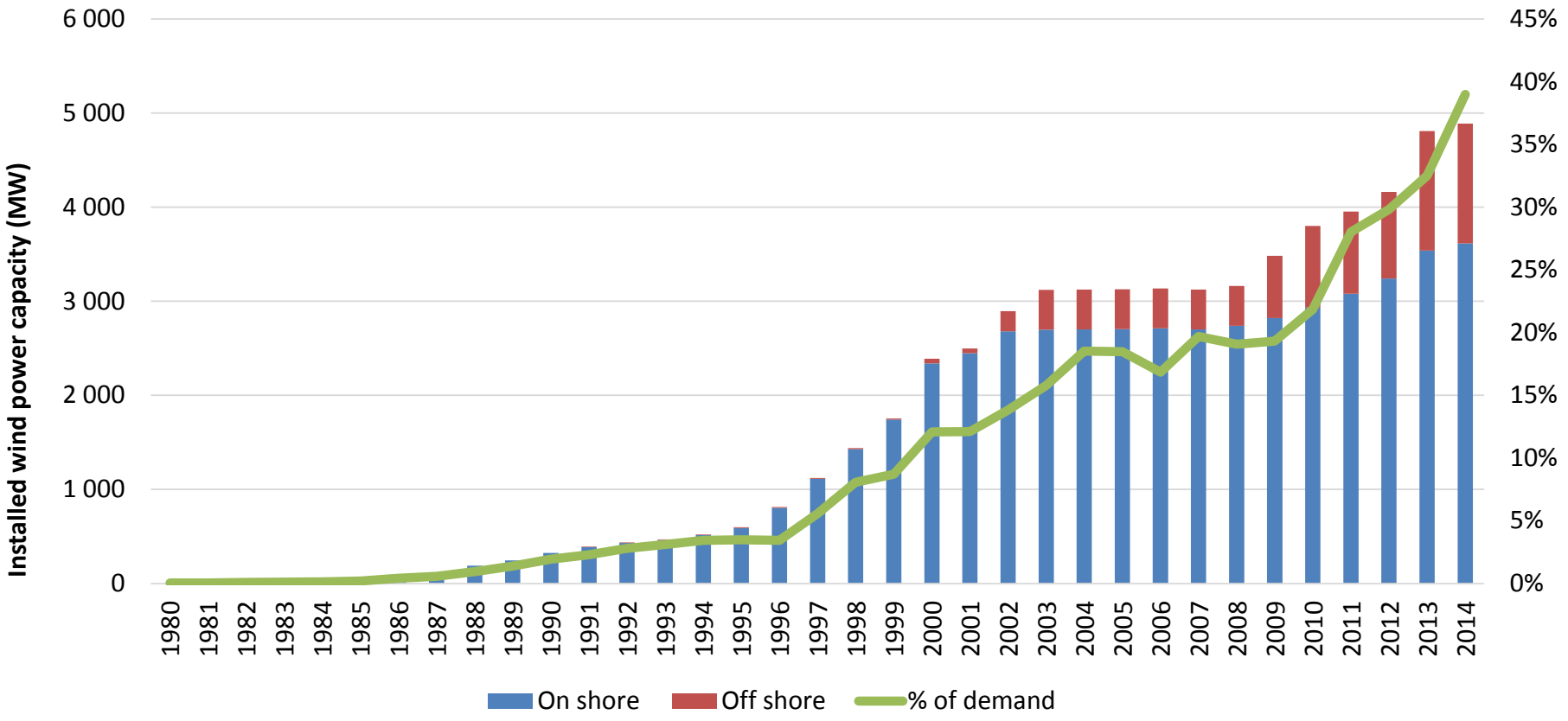
Development in Denmark: 39% wind power in 2014



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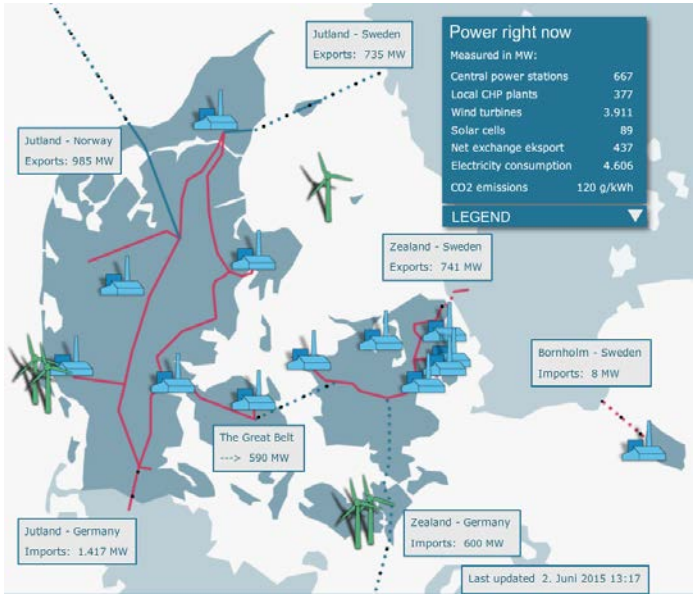
Danish power system in brief



- Electricity demand
  - 33 TWh/year
  - Peak: 6,000 MW
  - Min: 2,300 MW
- 4,800 MW wind and 600 MW solar
- Interconnectors to Sweden, Norway and Germany: 6,400 MW
- 60 % of all thermal power generation is produced in CHP mode

- More than 100% wind and solar in 400 hours
- In January 2014: 63% wind and solar

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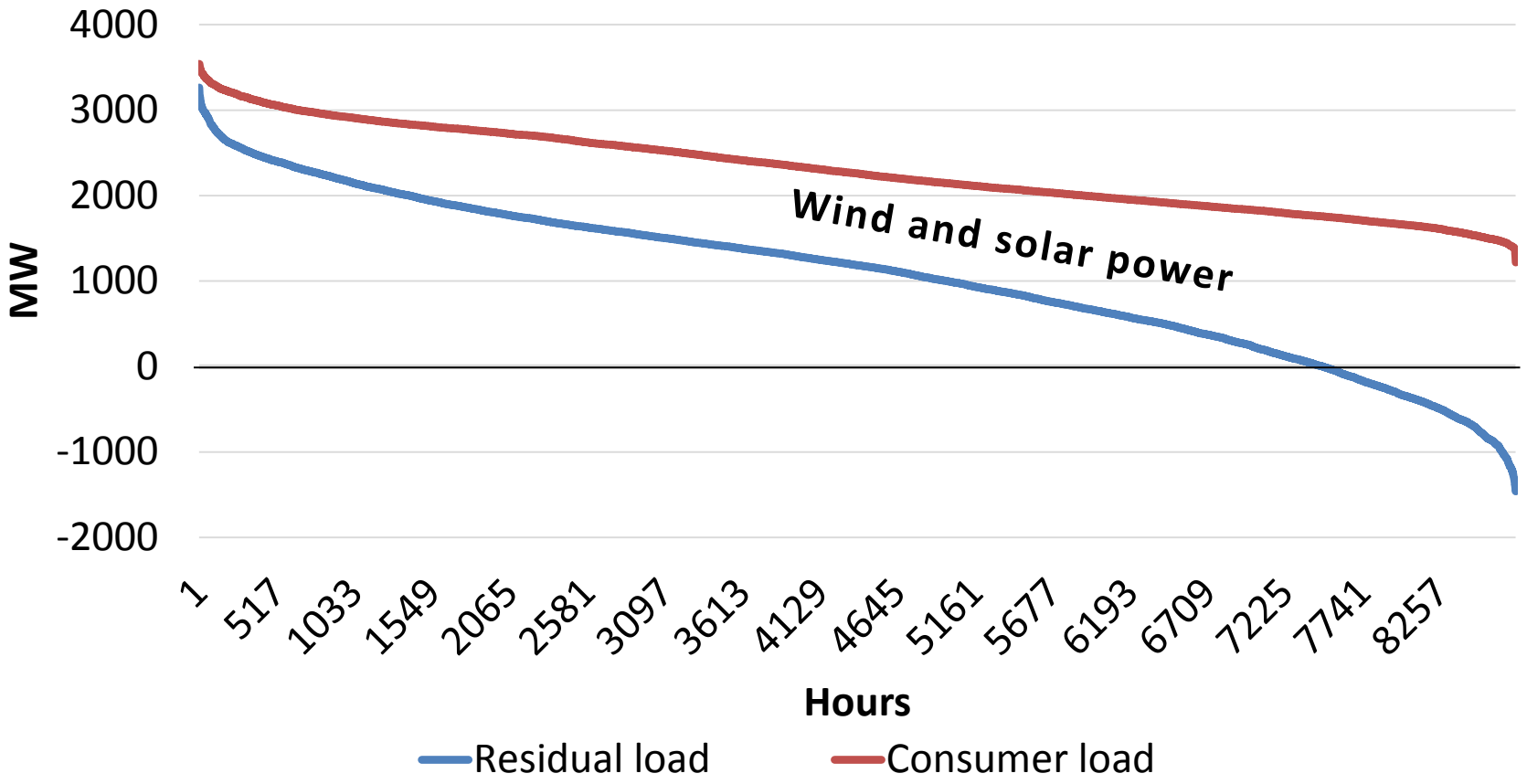
Load and residual load in Western Denmark



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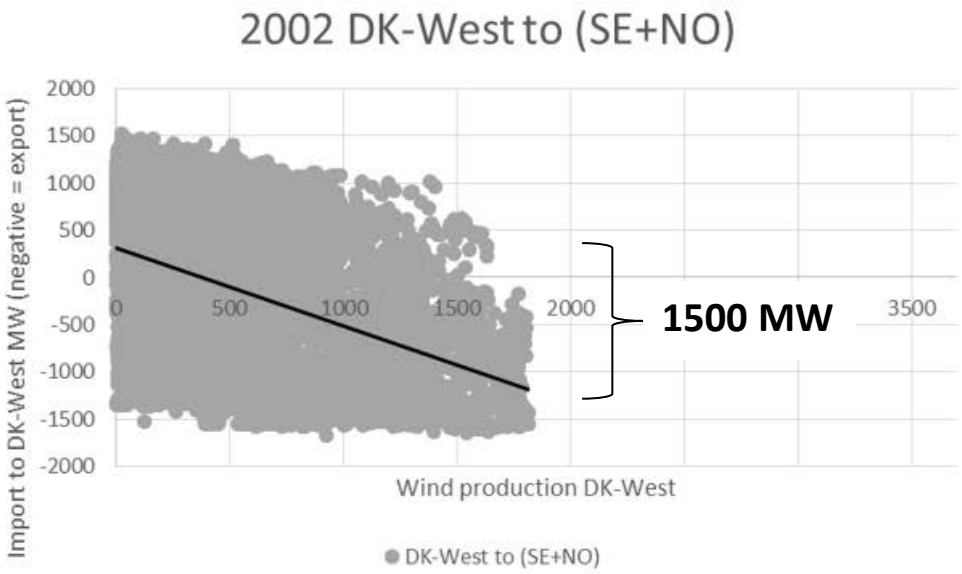
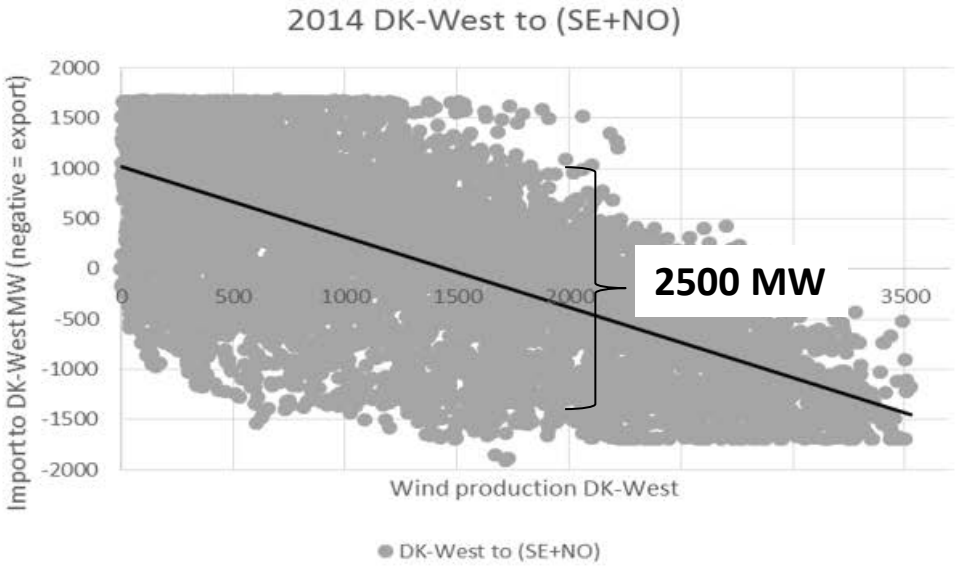
Wind power integration: Three main challenges

1. To ensure the value of the electricity generated by wind and solar when generation is high
   - Electricity price: Indicator of wind value
   - Curtailment = Waste of potential generation
2. To ensure sufficient production capacity when there is no wind.
   - Wind power expansion makes it less attractive to build thermal (base load) plants.
3. To balance wind power production
   - To manage wind power's partly unpredictable generation

Selected flexibility measures

- Efficient utilization of interconnectors
- More flexible power plants
- Power – heat integration
- System friendly wind power
- New sources of ancillary services
- Demand response and smart grid





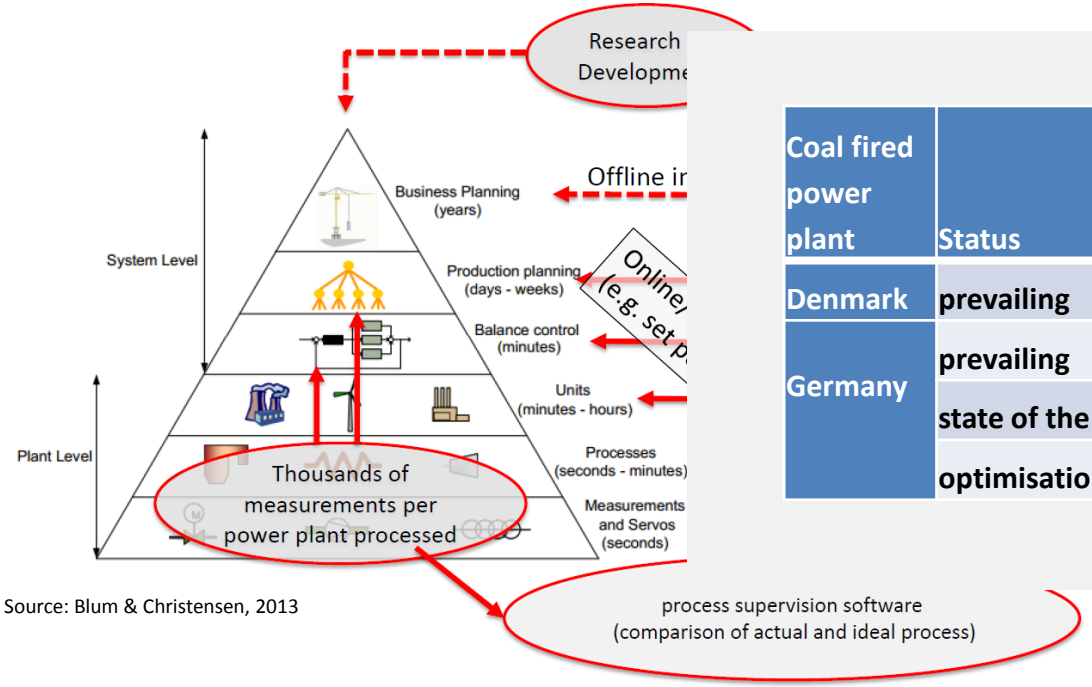
Spot market --- market coupling --- negative spot prices --- new interconnectors

More flexible power plants

Opposition to wind power among Danish power producers in the 1980s and 1990s

Scenario analyses used to describe different possible futures. Quantify operation patterns via model analyses.

Large wind peneration => change in focus from high efficiency to **high flexibility**



Coal fired power plant	Status	Positive load gradients ($\%P_N$/min)	Min. stable generation ($\%P_N$)
Denmark	prevailing	3-4	10-20
Germany	prevailing	1.5-3	40-55
	state of the art	4	25
	optimisation	6	20

Source: Blum & Christensen, 2013

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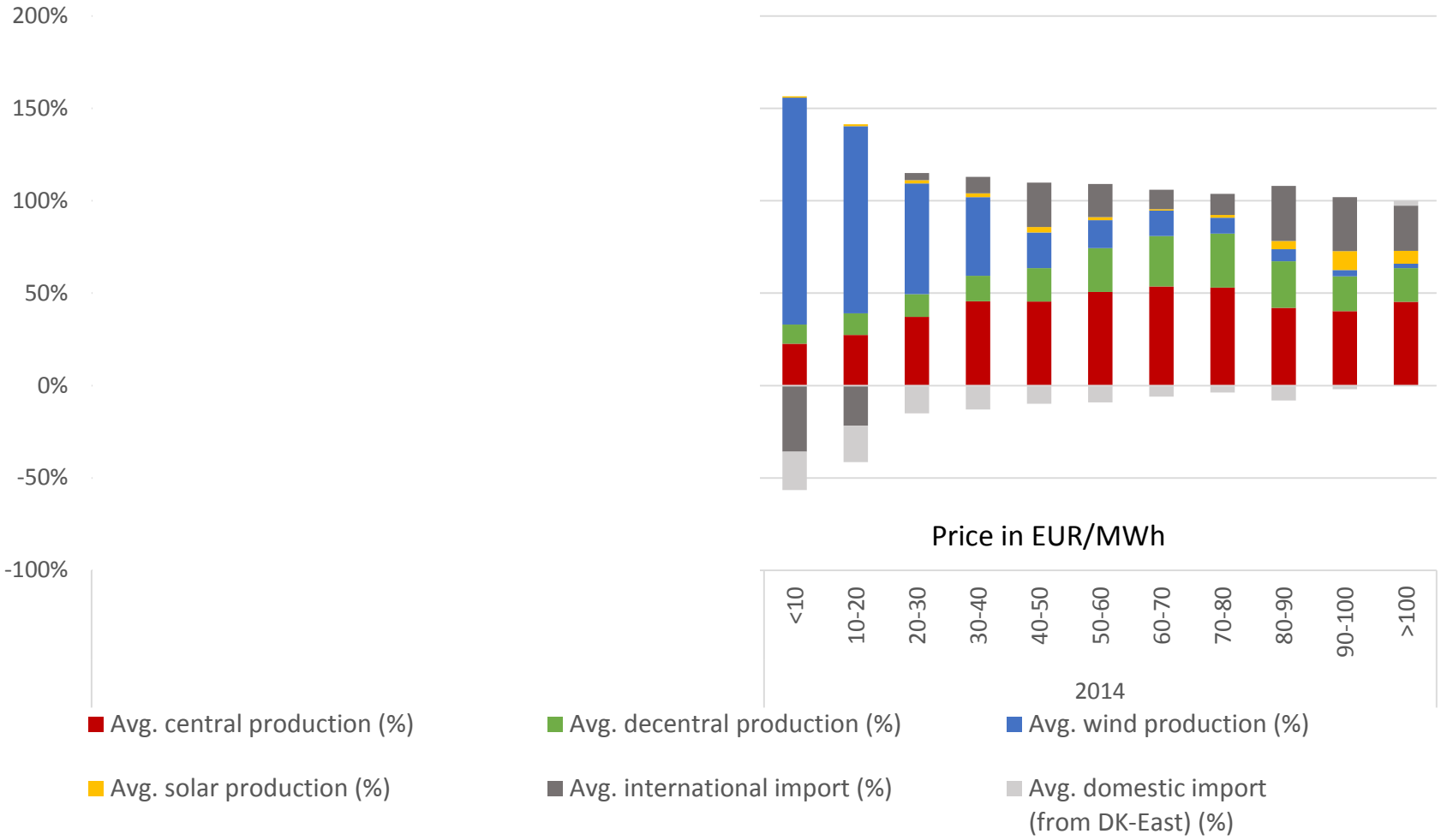
Dynamics of power plants



Denmark West. Data from Energinet.dk

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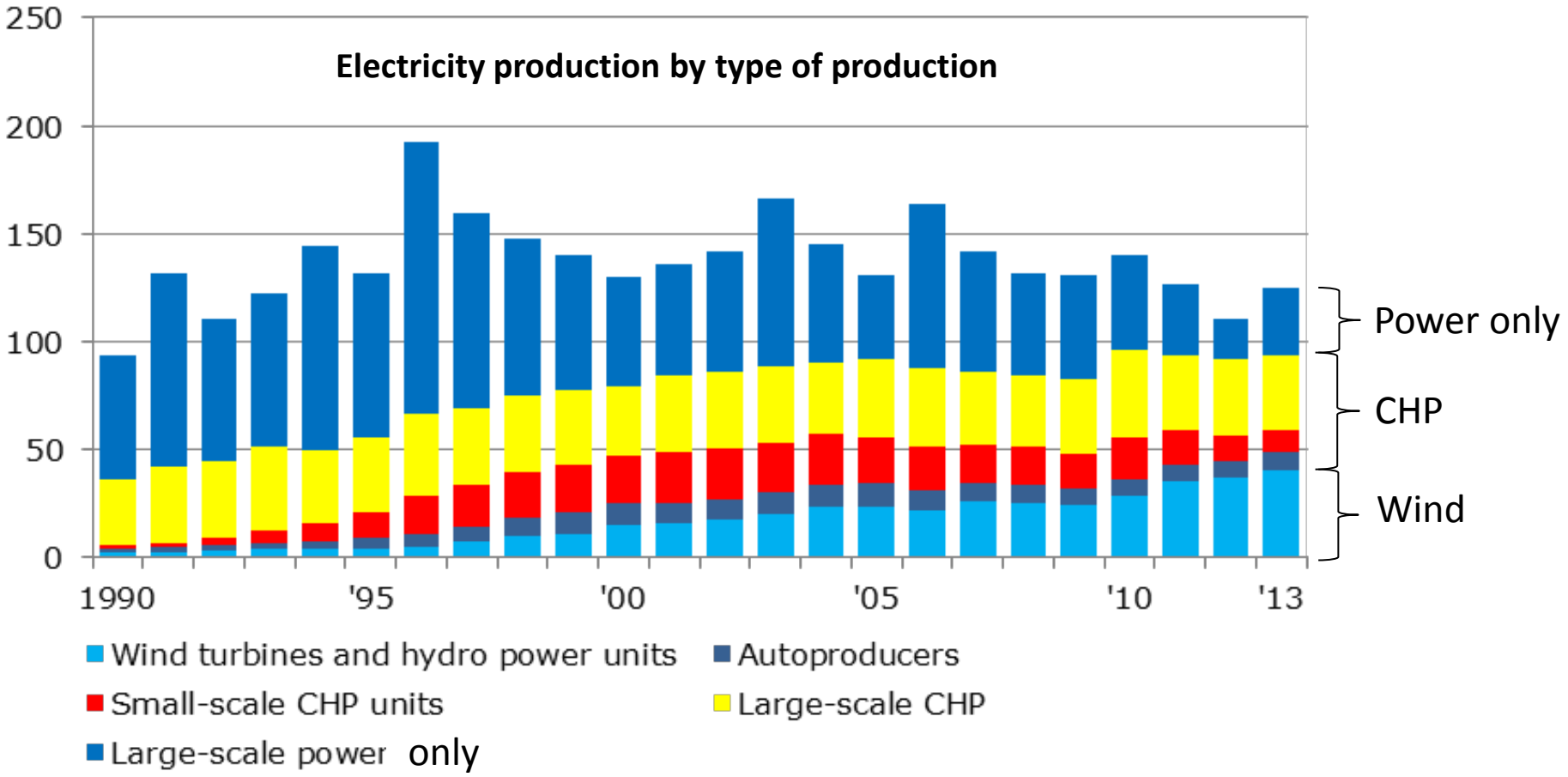
Combined heat and power plays a key role in Danish electricity and heat supply



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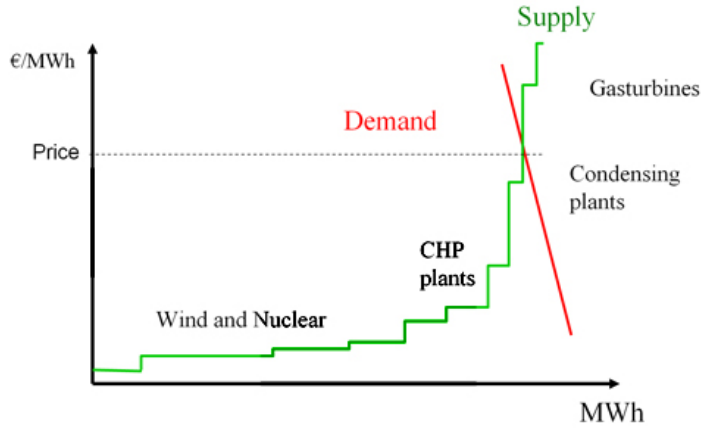
Power & heat integration



- **Drawback of district heating coupling**: Heat bound electricity generation has lower marginal electricity generation costs than condensing power
- **Advantage**: District heating is potentially a large electricity consumer
- Historically Danish regulation has favoured district heating generation
  - Time of use tariffs =>> Market price + production independent subsidy
  - Tax discounts to CHP =>> expanded to cover heat boilers in CHP systems

Measures for integration of wind and district heating

- Technological measures to improve flexibility
  - Heat storage
  - Bypass of turbines
  - Electricity to heat : Heat pumps, Electric boilers

- Heat pumps use electricity to produce heat with high efficiency (~ 300 %)
- Heat source can be air, sea water, industrial waste heat…
- Higher investment costs than electric boilers

1 MW heat pump in Brædstrup

400 MW of electric boilers today – driven by market for ancillary services

Very little heat pump capacity due to high electricity taxes and tariffs

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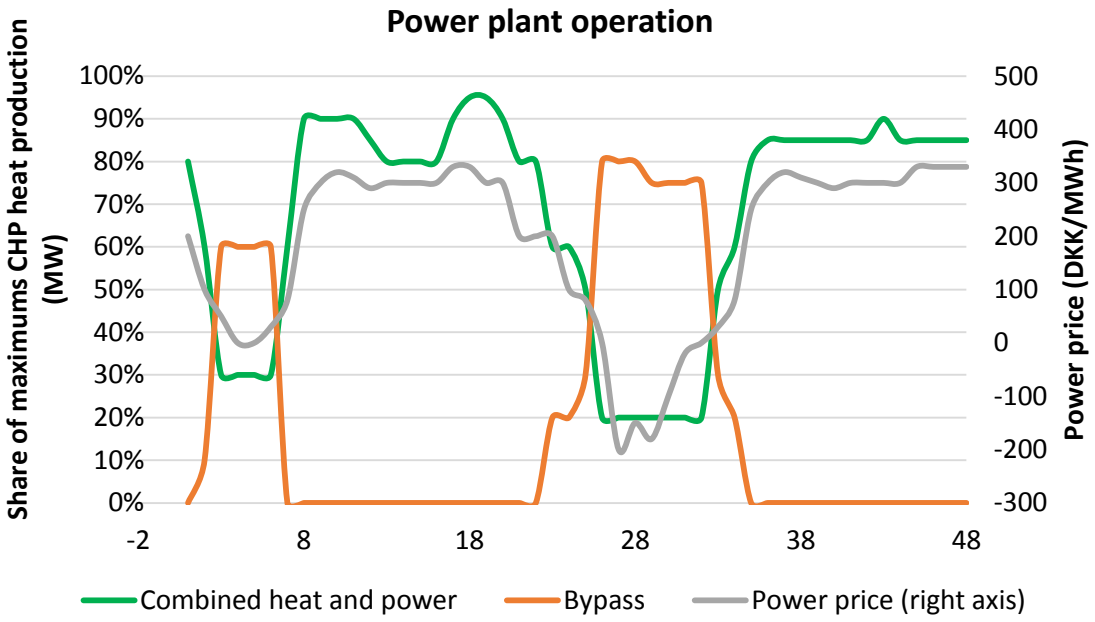
Bypass of turbines

- Turbine bypass is possible on steam turbine plants.
- Instead of feeding steam from the boiler to the turbine the steam is used directly for heat production
- => electricity production can be reduced when there is a need for regulating down in the electricity system.
- Avoid start-up/shut-down



During christmas 2012 the value of power was very low because of high wind and relatively low power consumption => Bypass limited power production on CHP plant

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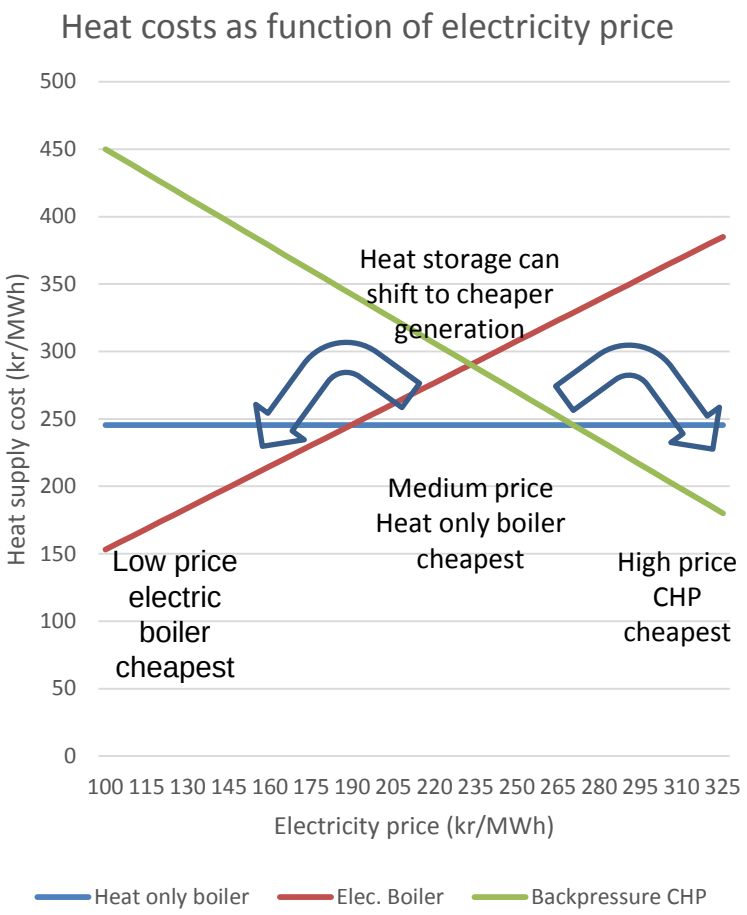
Economically efficient DH is flexible

- Priority of heat units based on power system balance
  - Wind curtailment implies very low market price
  - Cost efficient for district heating companies to respond
  - Promotes needed flexibility
- **If power price is always the same -> no incentive to be flexible**



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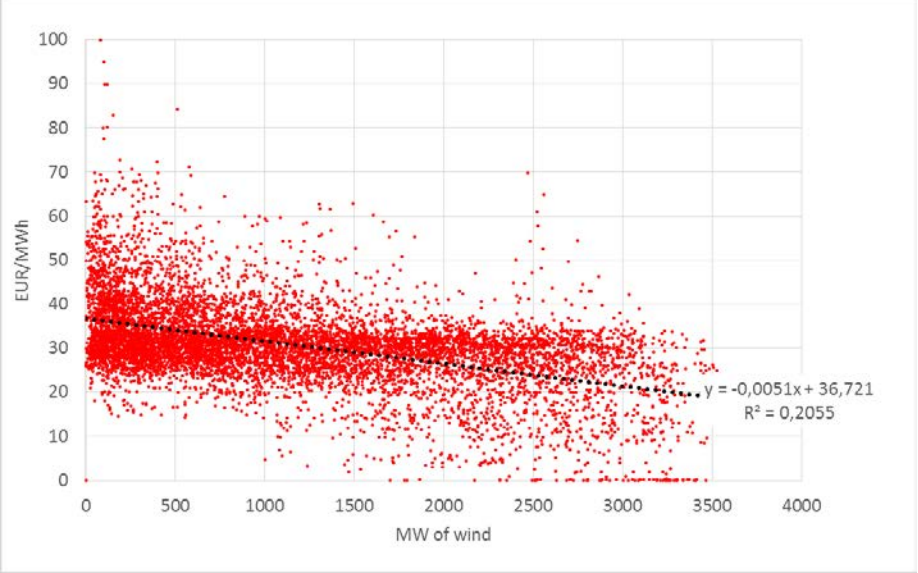
System friendly wind power



- Original regulation:
  - feed-in premium on top of the spot market price for the first 22,000 full-load hours.
    (Subsidy = Capacity in MW*22,000 hours*250 DKK/MWh)
  - Incentive to invest in turbines with **high rated capacity**
- New regulation
  - the feed-in-premium is dependent on both the turbine generator size and the rotor size

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Ancillary services

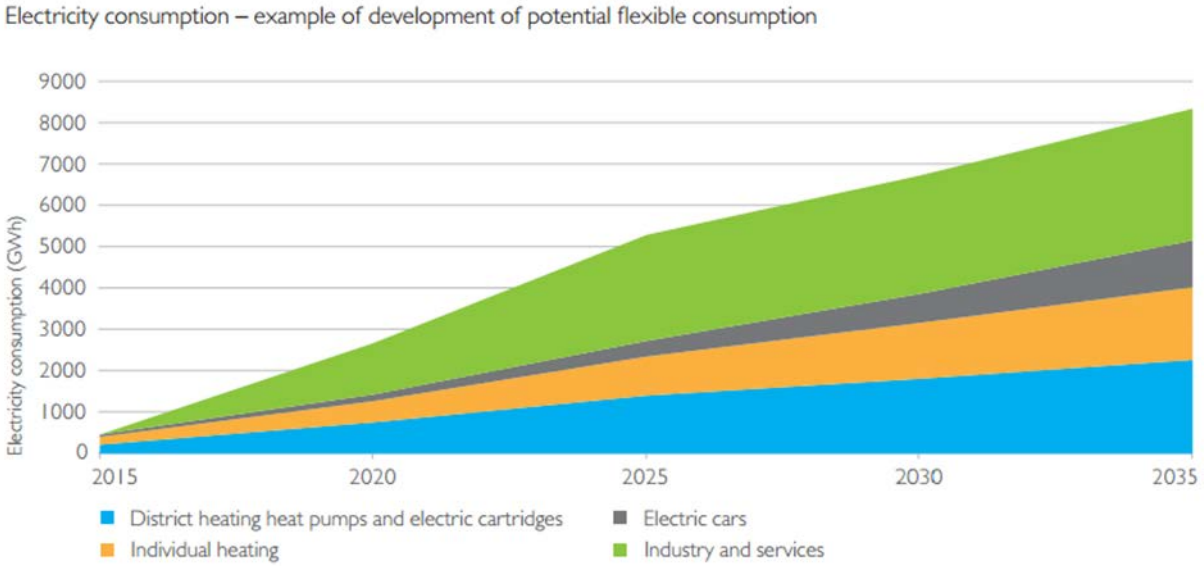
- **Common Nordic market for balancing power since 2002.** Most bids a voluntary, i.e. without payment for availability.
- Energinet.dk's strategy for regulating power
  - **International markets for regulating power** both increase the opportunities for suppliers and guarantee Energinet.dk an increased amount of regulating resources.
  - **More flexible product definitions** (e.g. longer notice) ensure that more resources can be exploited to balance the power system.
  - **No separate reserves for balancing wind power**. In concrete terms this means that Energinet.dk will not purchase more manual reserves as a result of the wind power expansion
  - **Manual reserves will be shared over larger areas –** both nationally across the two price areas and internationally – thus reducing the total amount of reserves in the system.
- Build the **system stability components into the grid** when this is economically advisable

The need for must run capacity has been reduced from 3 large units to 0-1 units in Western Denmark

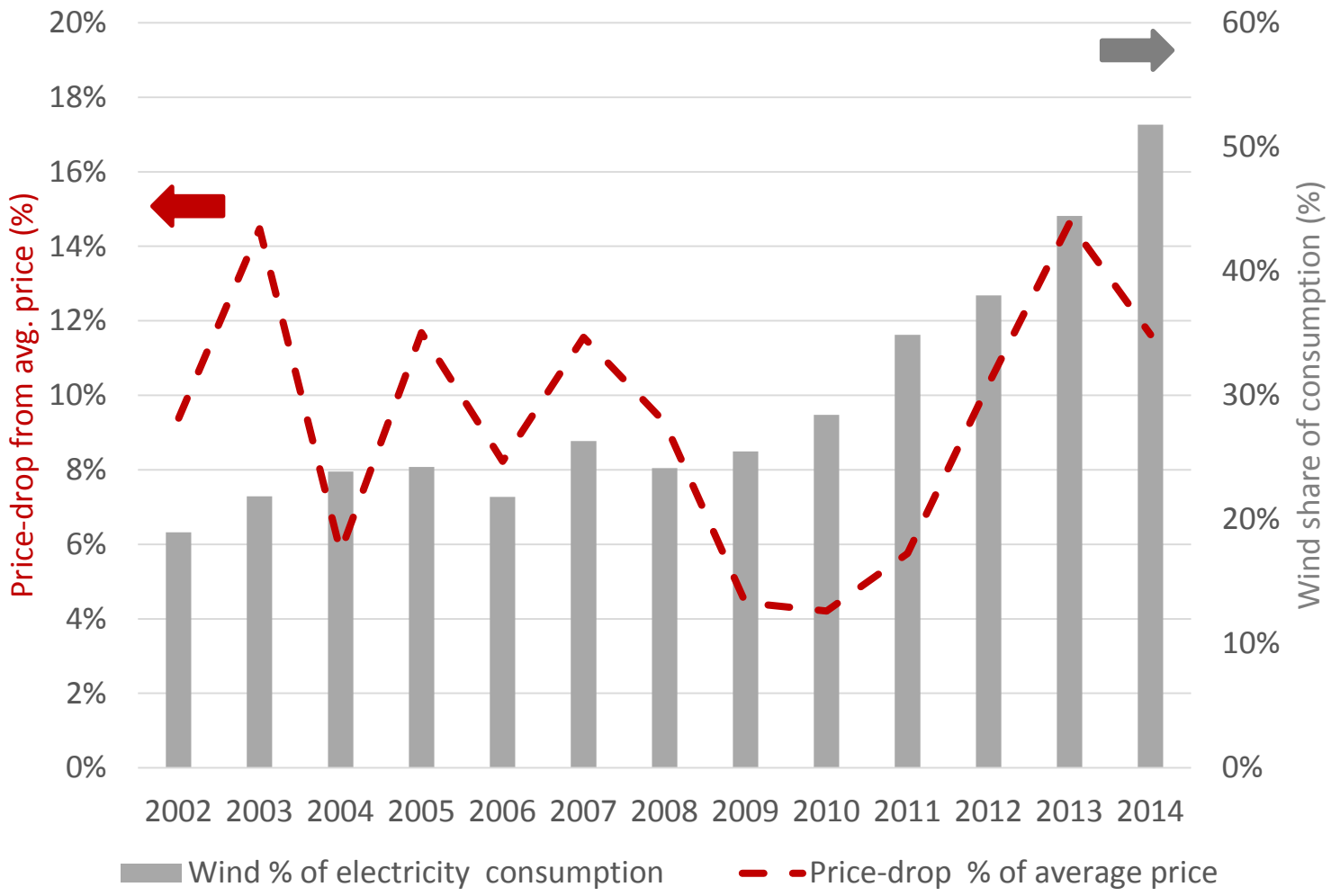
Demand response and smart grid

- Consumers should have hourly meters installed that can be accessed remotely
- The electricity market should allow consumers to be settled on an hourly basis instead of the fixed-price settlement (known as template settlement) used today
- Electricity tariffs should reflect the benefits of flexible load
- Access for small consumers to the market for ancillary service

Expectation are high but the potential has yet to be realised



An indicator in successful integration



Data for West Denmark

Source: Data from Energinet.dk

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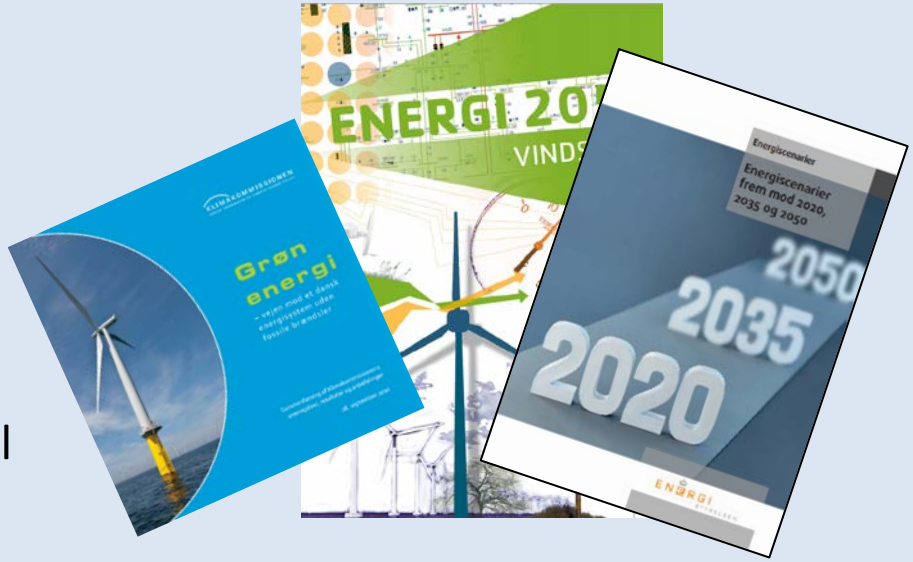
Summary

Measure	When?
Denmark joins Nordic spot market	1999/2000
Joint Nordic market for regulating power	2002
More flexible power plants	Continually
Changed taxation of CHP plants, boilers and electric boilers	2005
Additional interconnector to Norway (Skagerrak 4)	2014

Future options

- Further interconnections
- Power to heat
- Realize demand response potential
- Fuel-shift in industries
- Power to-gas
- ...

Integrated sectoral approach to fossil free energy system by 2050



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THANK YOU!

Anders Kofoed-Wiuff, akw@eaea.dk