The upcoming role of energy storage in Denmark and Europe

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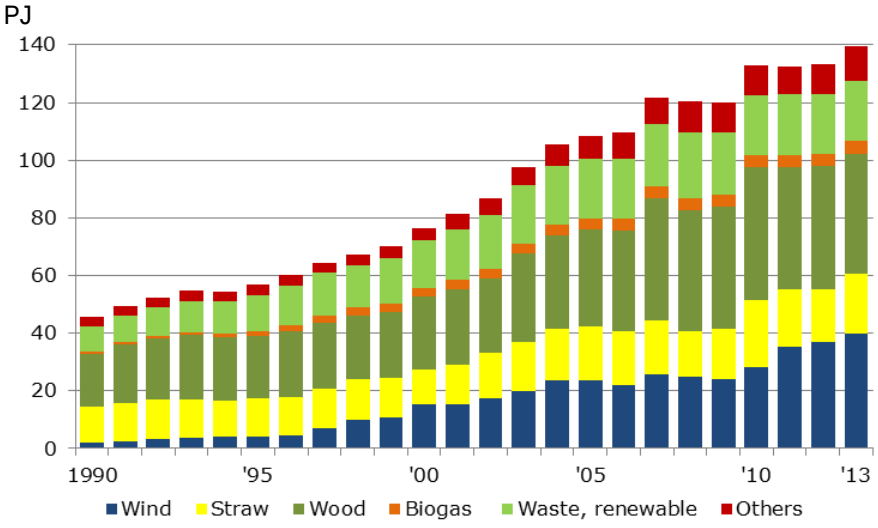
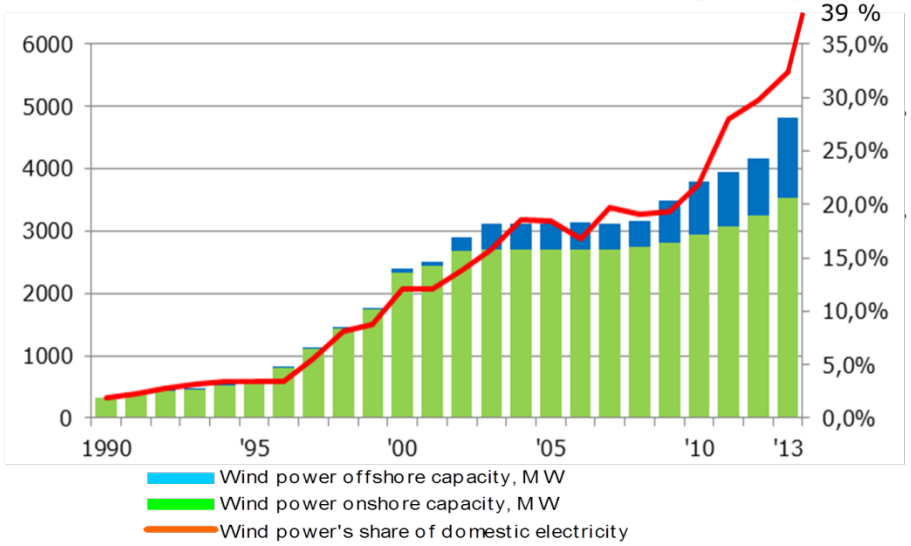
Energy supply targets for Denmark

- **50 % of electricity supply should come from wind power in 2020** (Parliament agreement)
- **In 2035 all domestic electricity and heat demand should be supplied by non-fossil sources** (Former government policy)
- **By 2050 Denmark should be completely independent of fossil energy** (Former government policy)

Production of renewable energy by energy product



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

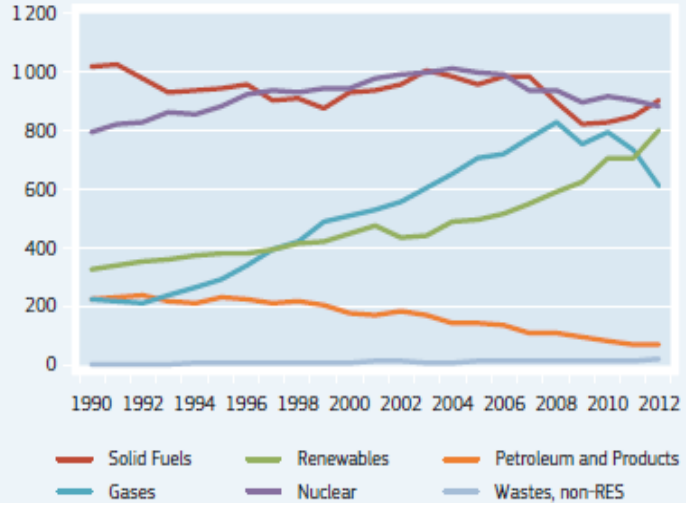


Source: Danish Energy Agency

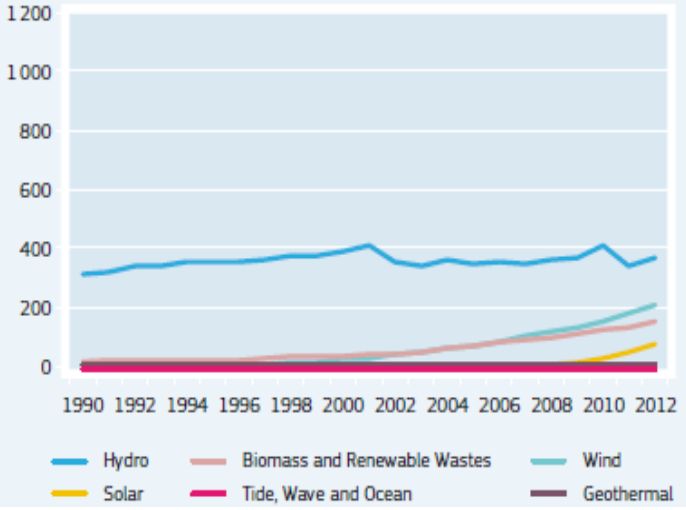
Electricity generation in the EU-28

Gross Electricity Generation

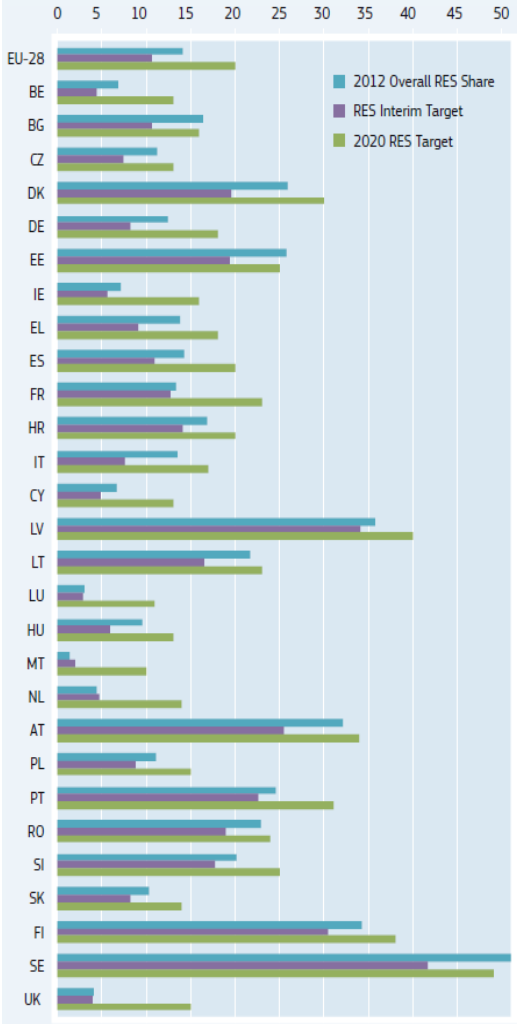
EU-28 – Gross Electricity Generation by Fuel – 1990-2012 (TWh)



EU-28 – Gross Electricity Generation – Renewables – 1990-2012 (TWh)



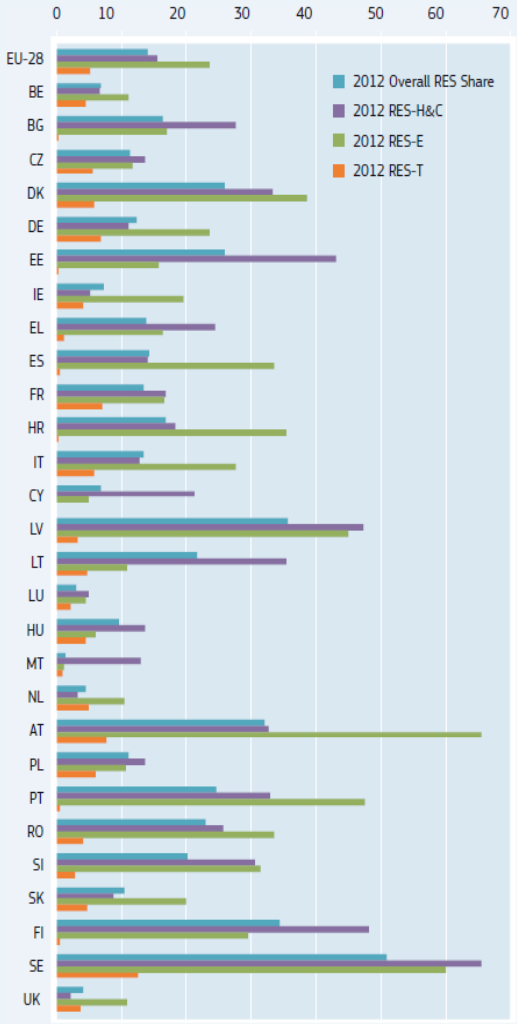
Renewable Energy Targets* (%)



* In Gross Final Energy Consumption
Source: Eurostat, May 2014

Renewable Energy Shares* (%)

Overall, Heating and Cooling (H&C), Electricity (E), and Transport (T) Shares



* In Gross Final Energy Consumption
Source: Eurostat, May 2014

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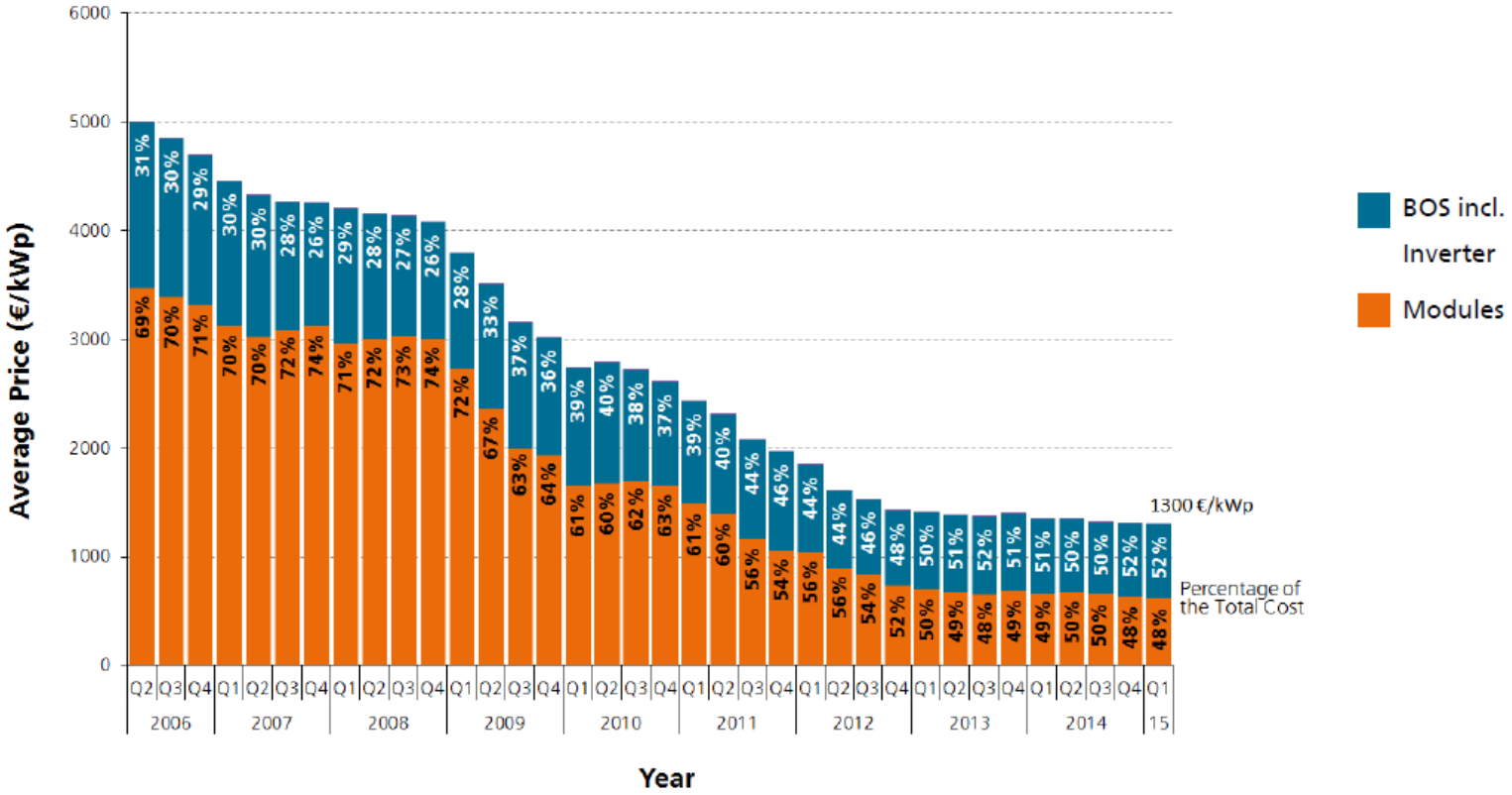
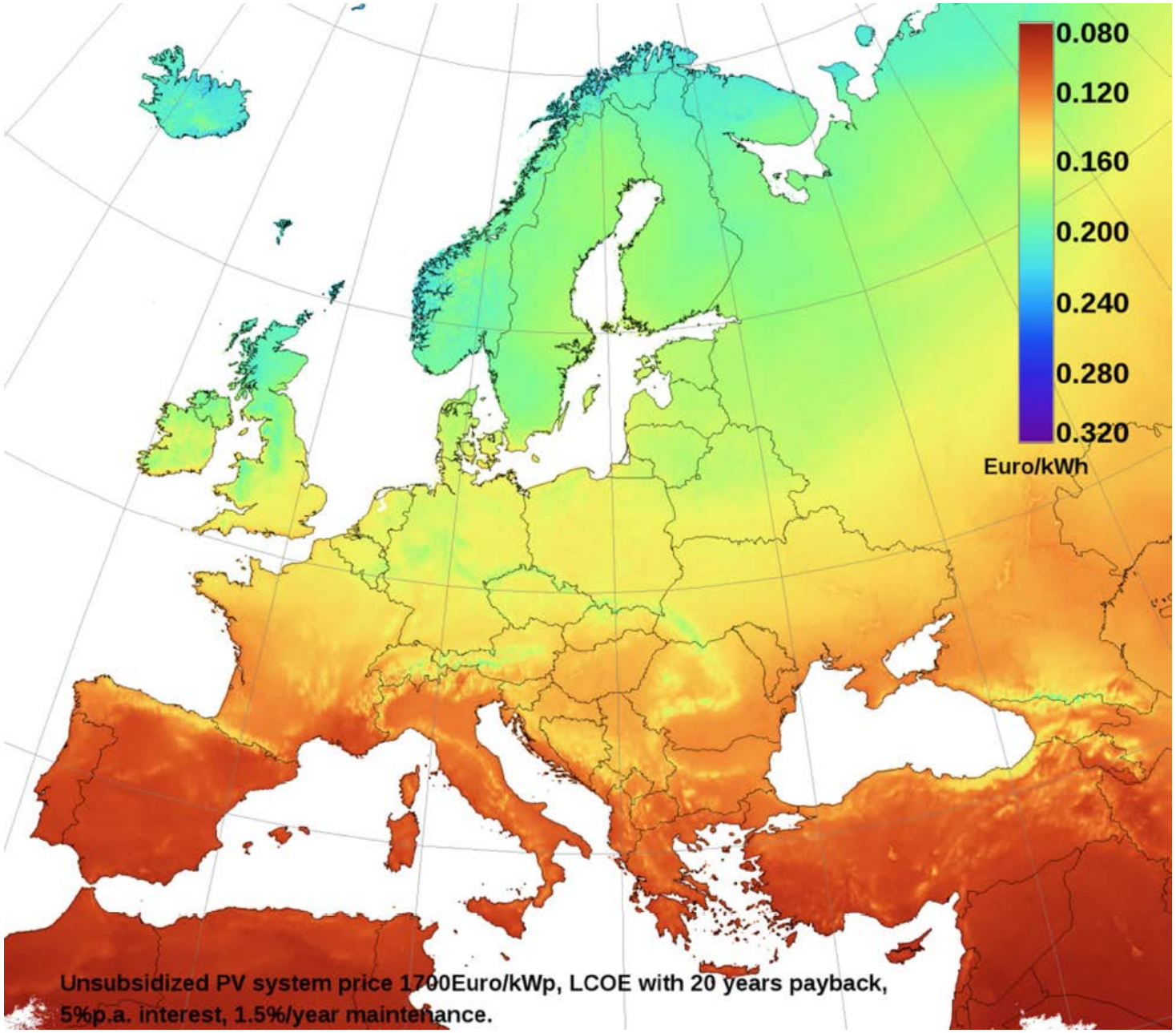
Average Price for PV Rooftop Systems in Germany
(10kWp - 100kWp)



Data: BSW-Solar. Graph: PSE AG 2015



Today in DK:

~1 DKK/kWh

Today in ES:

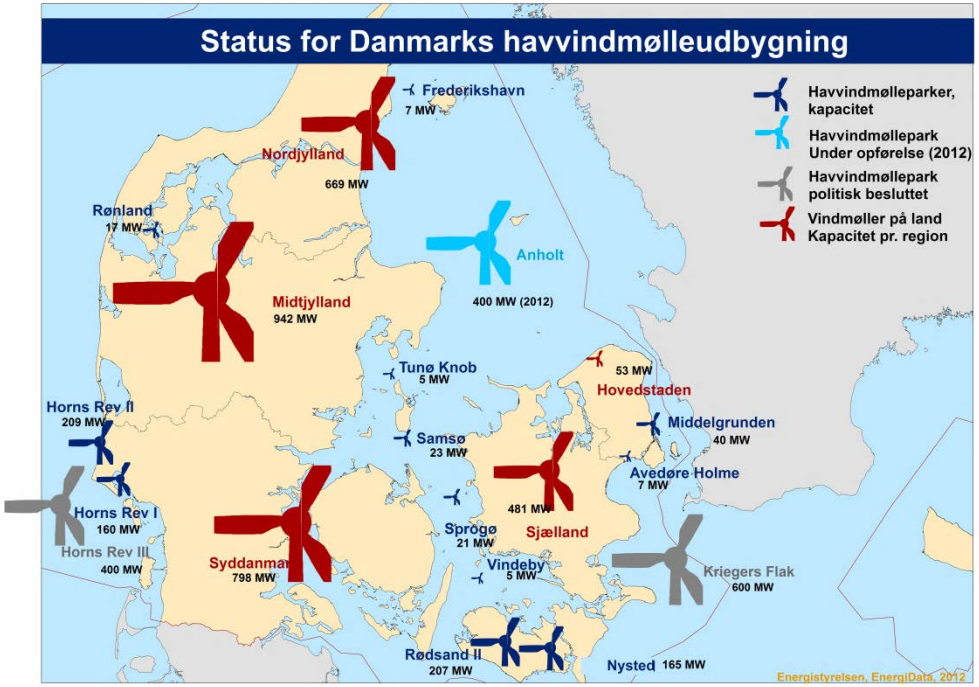
~ .08 EUR/kWh

~ .56 DKK/kWh

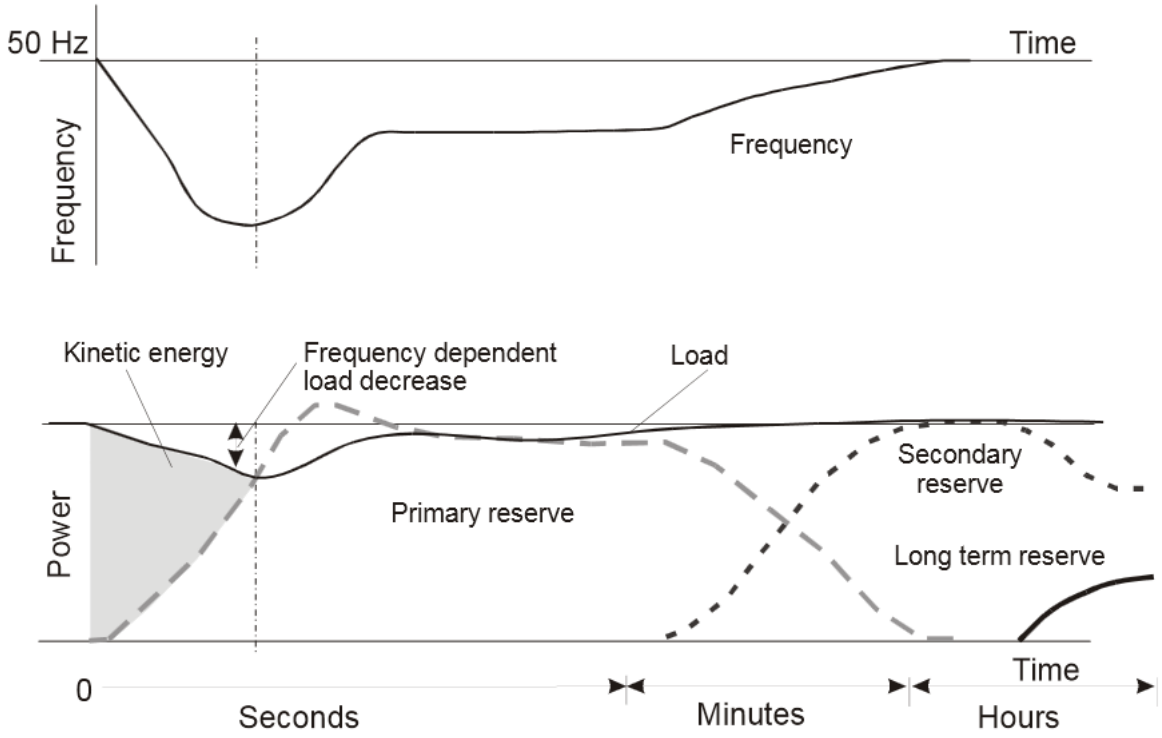
Source: Photovoltaic Electricity Cost Maps, JRC, 2013

Generation capacity in Denmark

- After commissioning the Anholt Off-Shore wind mill farm (400 MW) Denmark now has 4500 MW installed wind power capacity
- New capacity is planned to reach 50% electricity from wind in 2020
- Present thermal generation capacity in Denmark is about 6000 MW



Cascading contingency reserve arrangement

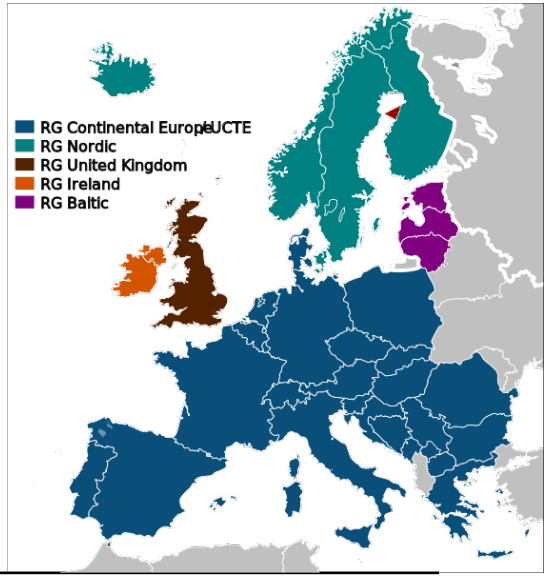


Activation of power reserves and frequency of power system as a function of time when a large power plant is disconnected from the power system (Holttinen, VTT PUBLICATIONS 554)

Ancillary services

Are services required for the security and stability of the transmission system and for maintaining the quality of electricity supply.

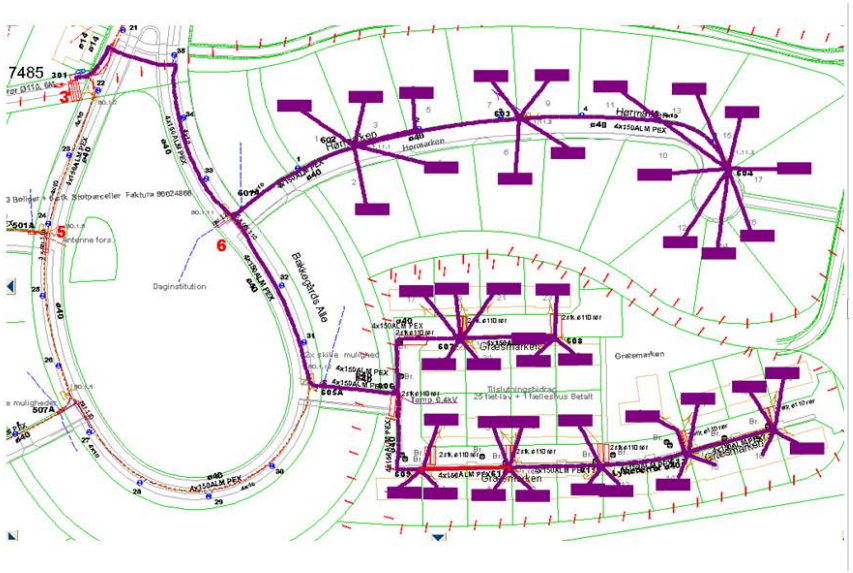
Presently, Energinet.dk buys the below ancillary services



DK1 – West Denmark	DK2 – East Denmark
• Primary reserves - +/- 23 MW Proportional to frequency deviation, 50% 15 s, 100% 30 s, maintain 15 min	• Frequency controlled normal operational reserve - +/- 22 MW Proportional to frequency deviation and completely within 150 s
• Secondary reserves (LFC) - 100 MW	• Frequency controlled operational disturbance reserve (DK+S) - +450 MW
• Manual reserves +268 MW	• Manual reserves +600 MW
• Black start services	• Black start services
• Short circuit power, reactive power and voltage control	• Short circuit power, reactive power and voltage control

Storage in distribution grids – an example

- The electricity system originally designed to distribute energy from central plants to the consumers
- In a future scenario a substantial part of the electricity will be generated at lower voltage levels from distributed sources
- Many 0.4 kV feeders are insufficiently dimensioned for this purpose
- Congestions and voltage variations



In periods of calm and no sun:

What should provide the power?

…. and how about mobility

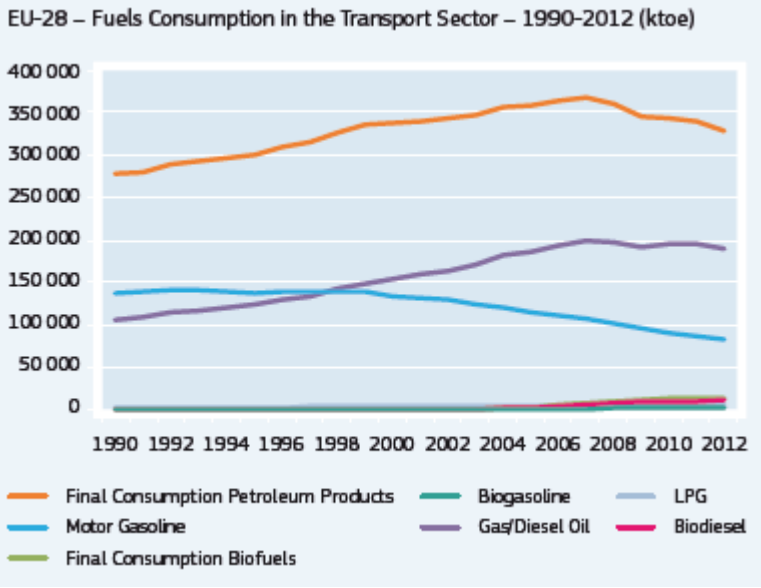
Energy storage for transport

Batteries will have numerous applications in the future energy system:

- Cars, two-wheelers and off-road
- Ferries
- Trains

Chemical fuels for

- Aviation
- Marine transport
- Heavy truck transport
- Long distance transport



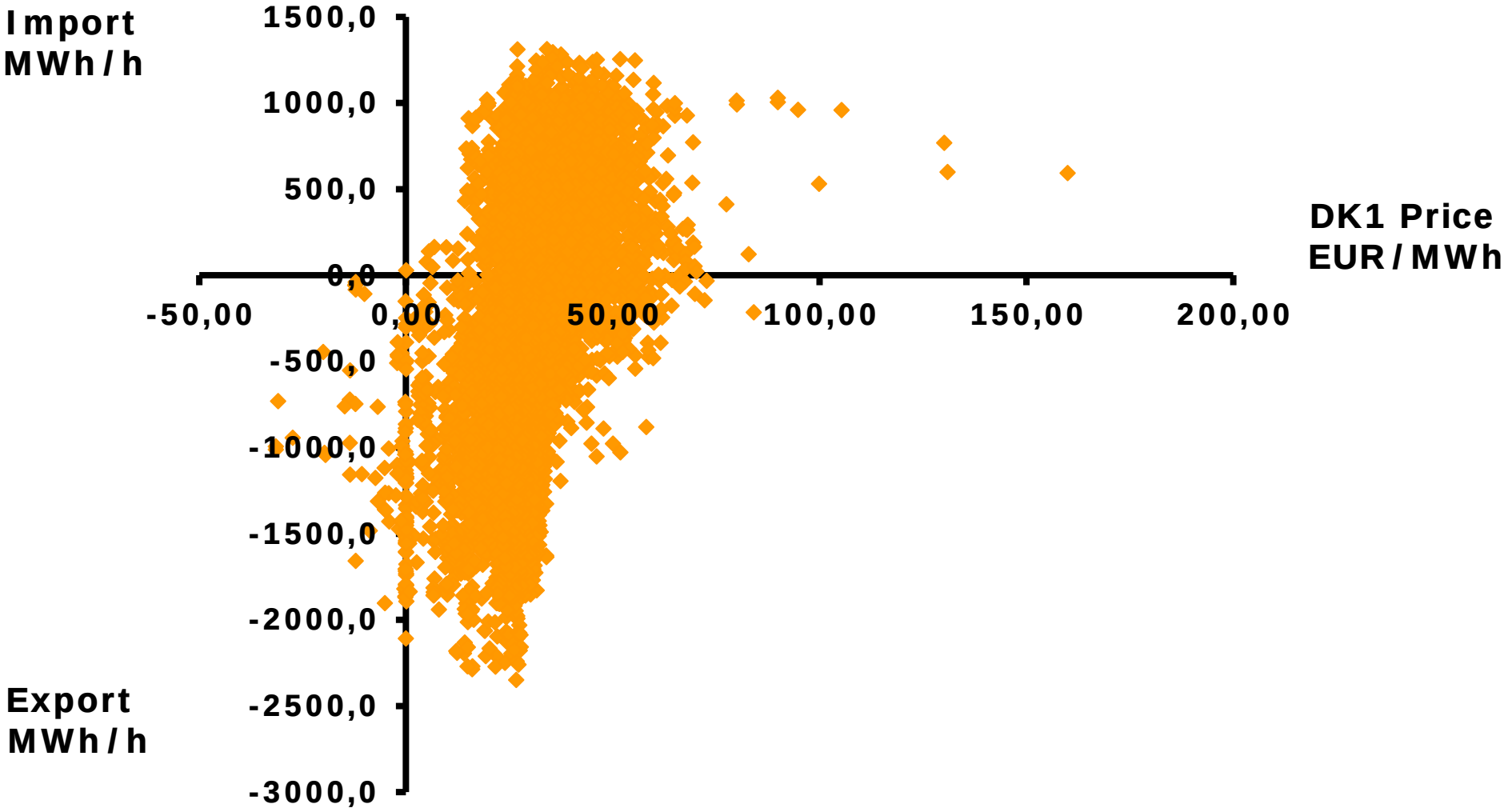
Storing energy

Energy density for different energy carriers

	w-% H	g H/l	kJ/ml	kJ/g
Hydrogen at 200 bar	100.0	17	2.4	141.0
Magnesium Hydride	7.6	101	14.4	10.9
Complex Hydride	12.0	120	16.9	17,0
Methane at 200 bar	25.0	64	7.0	55.7
Liquid Hydrogen	100.0	70	10.0	141.0
Methanol	12.5	99	18.0	22.7
Gasoline			33.4	47.6
Lead/Acid Battery			0.3	0.2
Advanced battery			1.0	0.7
Liquid Methane	25.0	106	25.0	55.7
Liquid Ammonia	17.6	120	17.9	25.2
Fly Wheel				0.5

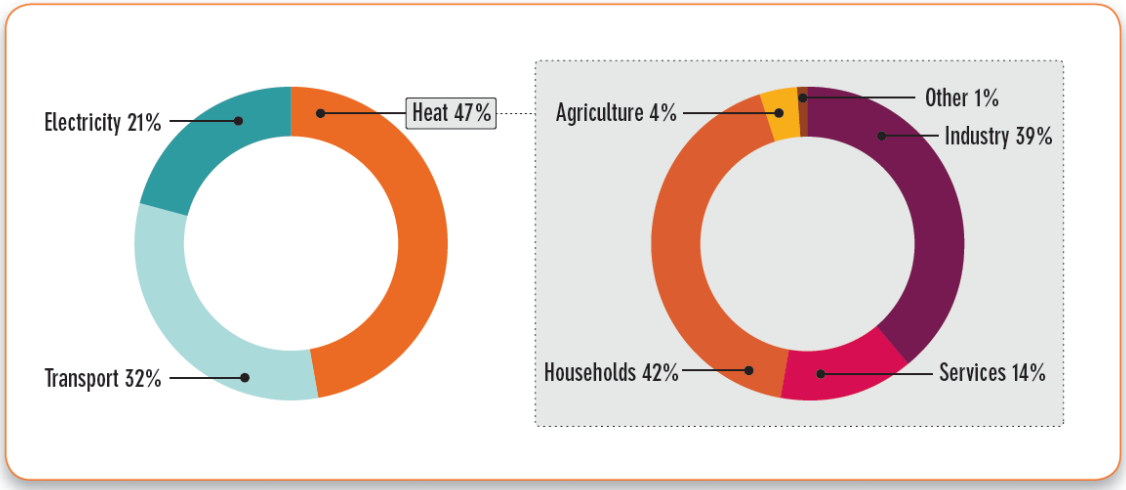
Numbers do not include weight of containment and system components

Exchange of electricity vs electricity spot price in DK1. April 2014-March 2015



Let´s not forget about heat !

- Worldwide heat accounts for almost 50 % of energy consumption
- Electricity is (currently) 18 % in DK and 21 % in EU
- In Denmark approx. 60 % of households are supplied by district heating
- Power-to-heat including heat pumps is anticipated to grow significantly in Denmark
- Large-scale heat storage can be foreseen



Final energy use in the the EU27 by type of use (left) and by sectors (right)

Source: European Technology Platform on Renewable Heating and Cooling

Solar-thermal heat store for district heating in DK

Vojens Fjernvarme – operation started in 2015

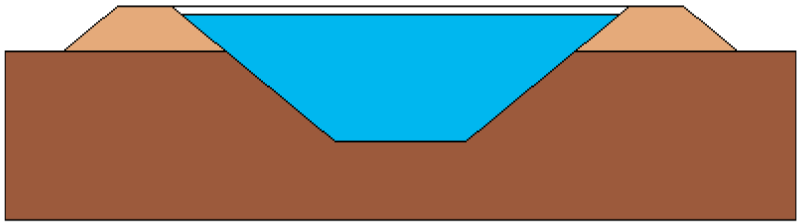
70.000 m2 solar heating - 203.000 m^3 storage volume

23.500 m^2 - 14 m deep, 200 m wide - 70 cm lid (Leca)

45% of annual consumption for 2000 consumers - 10-15% saving on bill

Charge Apr - Sep: 80-90 ºC

Discharge Oct – Jan: 40-45 ºC



Requested by the European Commission to prepare a joint European industry / research roadmap for energy storage

EASE – The European Association for Storage of Energy

Siemens, EdF, SAFT, Alstom, FIAM, E.ON, RWE, Glen Dimplex, ….

EERA – The European Energy Research Arena

Joint Programme on Energy Storage

ENEA, DLR, KIT, SINTEF, Uni Sheffield, …..

DK funding programmes identified Energy Storage as priority RD&D area for reaching the energy political goals towards 2050

The funding program committees asked for:

- **Status of relevant energy storage technologies**
- **Evaluation of their potentials in a Danish context**
- **Overview of Danish actors**
- **Applications in the (Danish) energy system**
- **TRL level**
- **Danish competences**

In summary

- **Energy storage will be required – for transport it is mandatory**

  – Thermal energy storage is of significant interest for Europe and Denmark
    - Heating
    - Cooling
    - Re-electrification
    - Make reversible conversion processes more efficient

  – Chemical energy storage has many comfortable and convenient properties

  – Batteries – although still of low energy density – hold very attractive useful qualities

  – Note market terms and regulatory issues for energy storage technologies