A Smart Energy System designed to be compliant with COP21 visions for fast CO2 reduction

Smart Energy Systems and 4th Generation District Heating
AAU conference September 27-28'th 2016 at Nordkraft Aalborg

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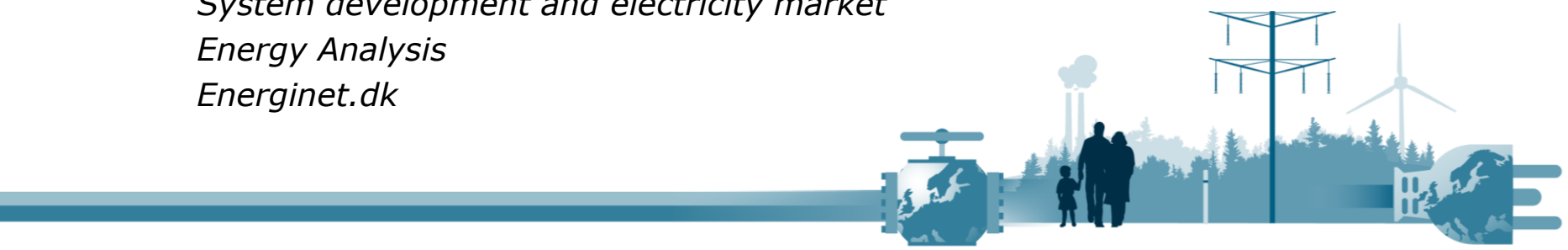
System development and electricity market
Energy Analysis
Energinet.dk



Disposition

1. Global context as a framework (COP21 etc.)
2. Danish energy system scenarios towards 2035
3. Some R&D issues towards a ”Smart Energy Systems”
4. Questions;)

Global contekst – IEA WEO and COP 21

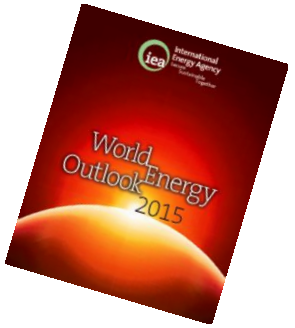
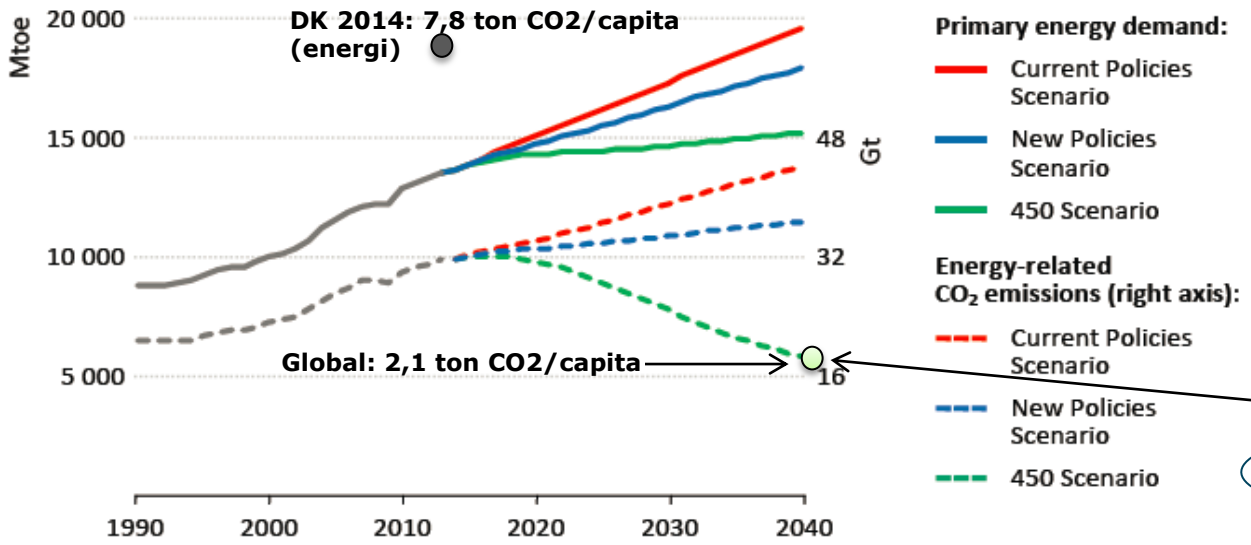


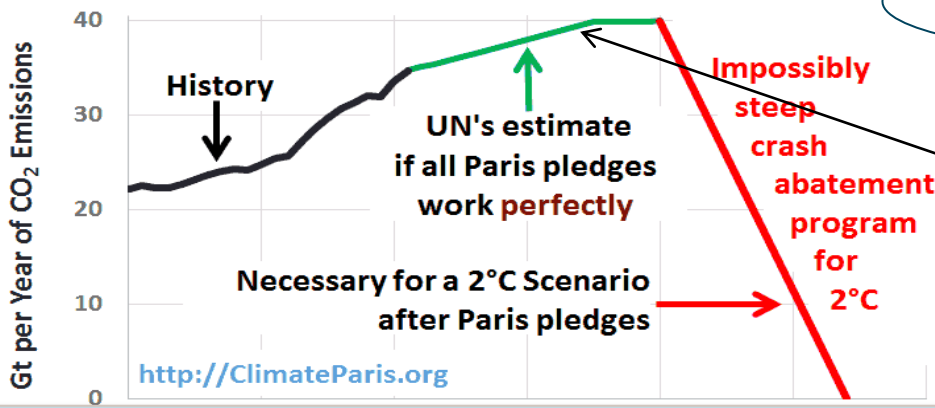
Figure 2.1 ▷ World primary energy demand and CO_2 emissions by scenario



IEA 450 PPM ≈ 2 degr.

Mission Innovation
More global R&D

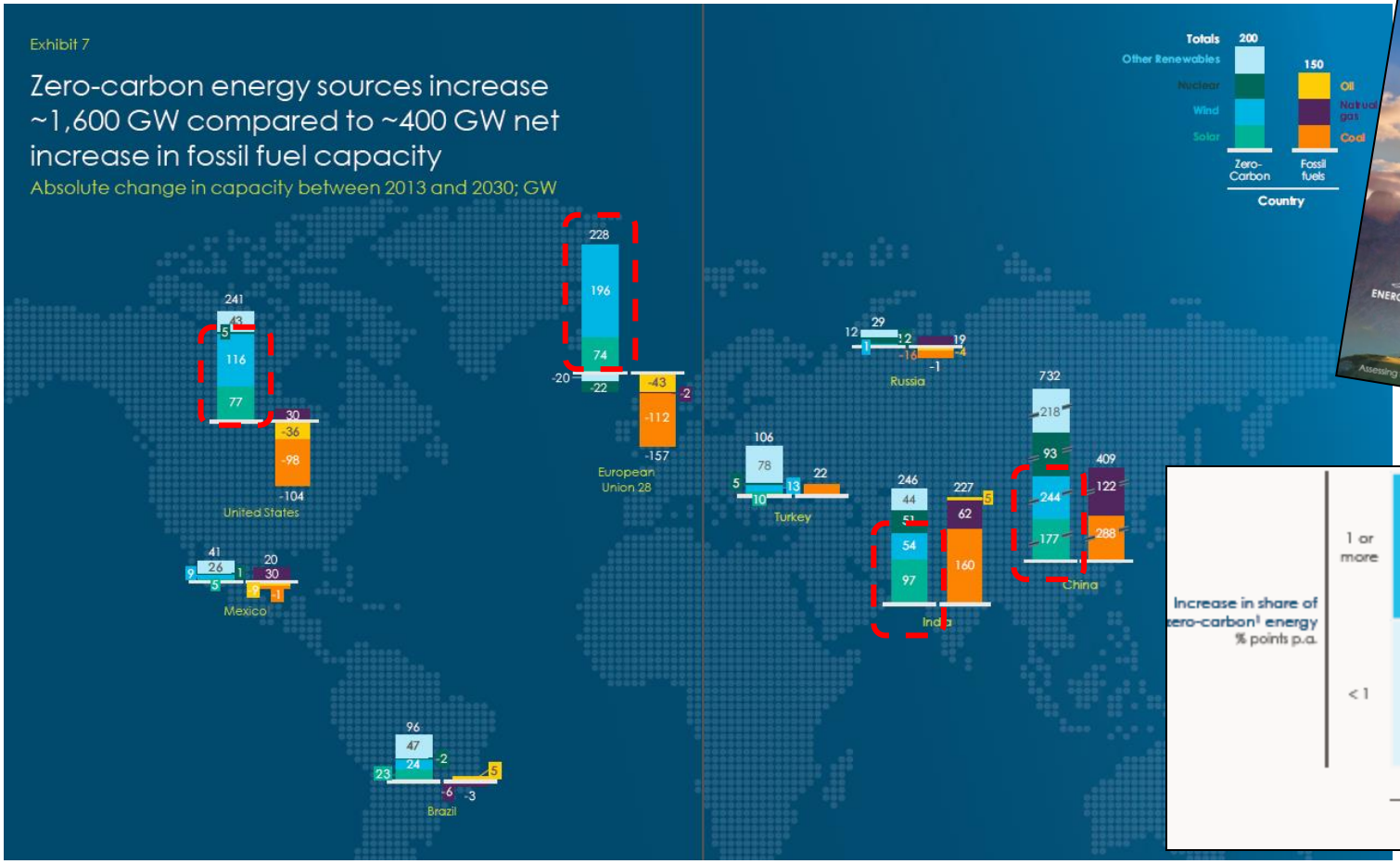
Target:
"Well below 2 degr."

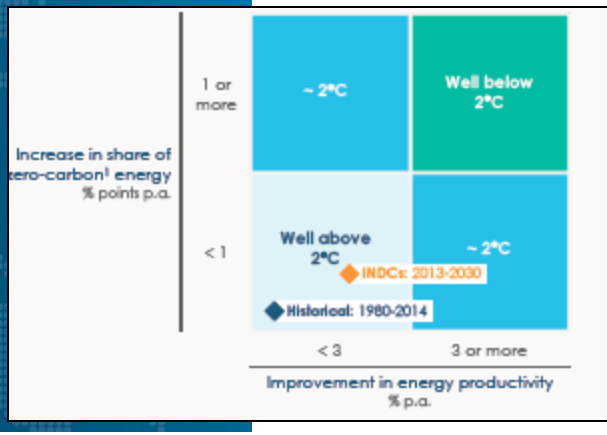


INDC's

A tough challenge to realise Paris COP21 targets
→ significant CO2-reduction needed

Global plans (INDC's) – significant grow in wind/solar

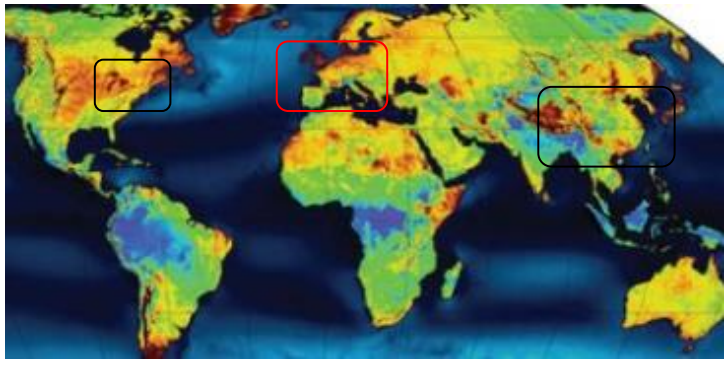




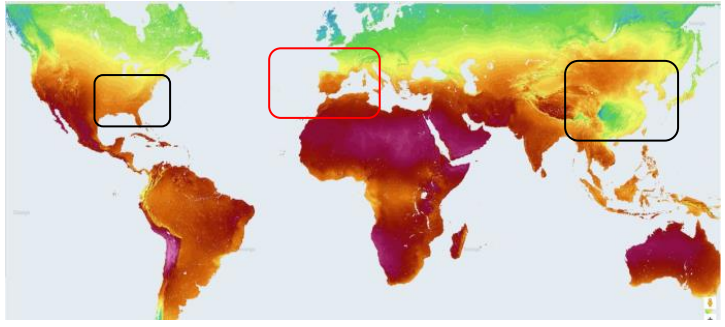
- INDC's does not lead to needed reduction in CO2 if "Well below 2 degr" should be realised
- A need for even more wind, solar, RE-fuels and energy efficiency

Europe – a case with wind and solar mix

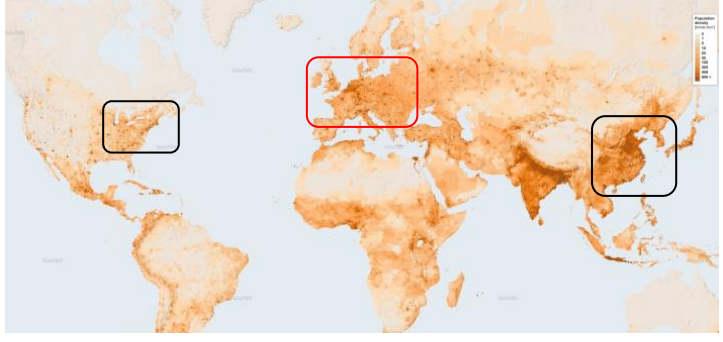
Wind ressources

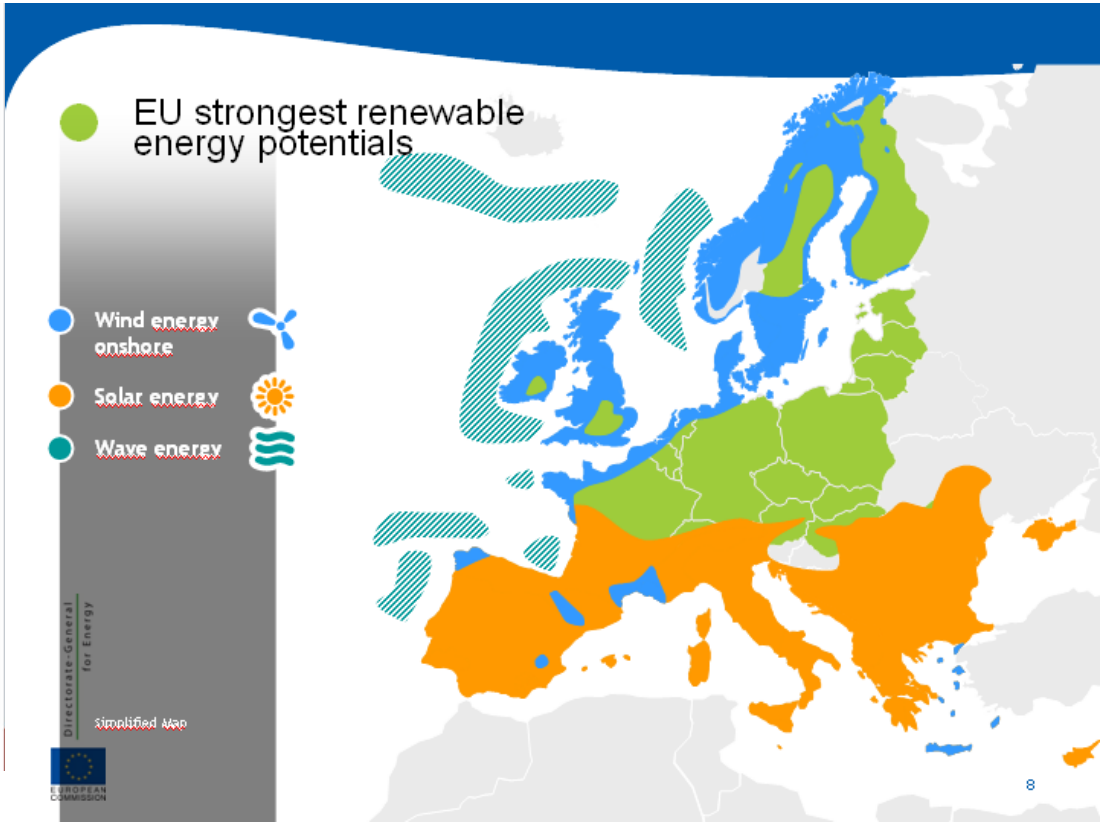


Solar ressources



Population densities

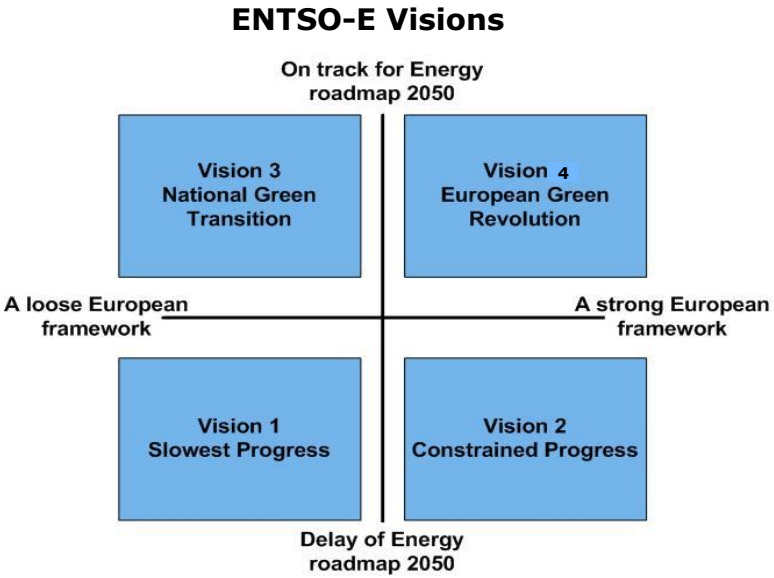




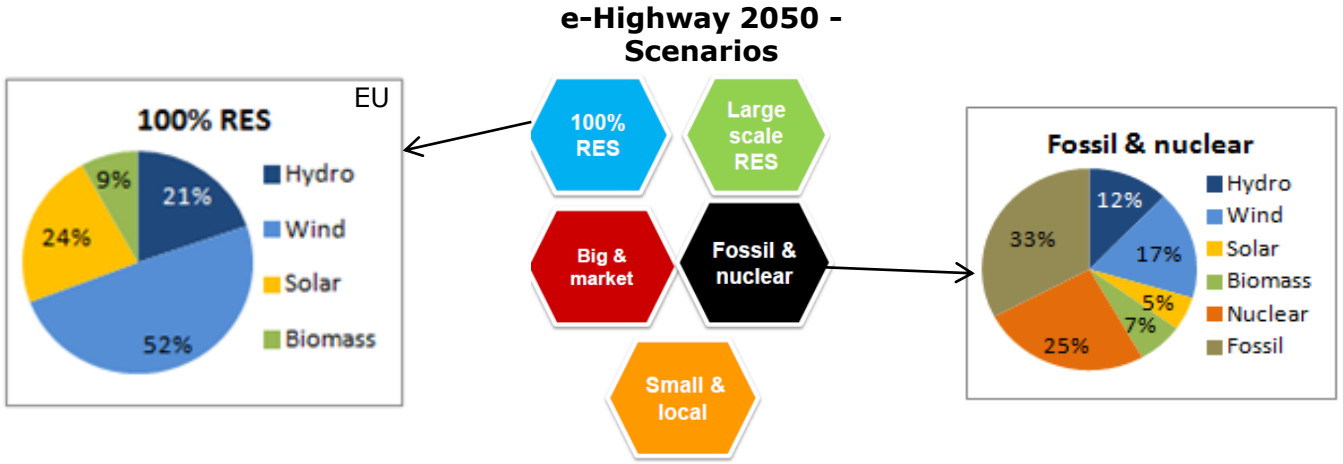
Europe – A region with a mix of wind and solar ressources

European Scenario Framework in the analysis

2030



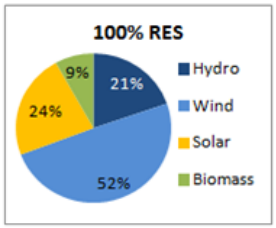
2050



A framework of international scenarios used to evaluate robustness of strategic choices

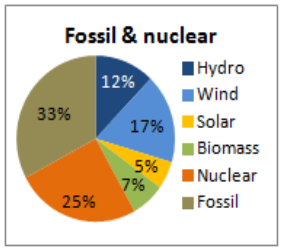
European transmission grid reinforcement towards 2050
An example from eHighway scenarios

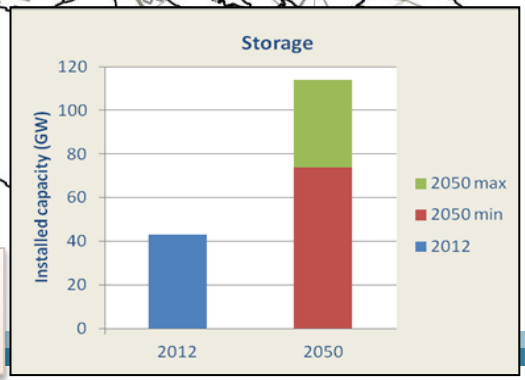
100% RES electricity



>100 GW windpower installed in North Sea region!

Fossil & nuclear





- *More transmission to integrate wind- and solar*
- *A need for more storage capacity (hydro etc.)*

Smart Energy system compliant with COP21 visions for CO2 reduction

Annual energy flow in energy system 2014

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Energy ressources | **Energy system** | **Energy services**

Transit

Import power

Power-system

Export power

Solar

Wind

Wave

Bio, waste etc.

Coal

Natural gas

Fossil Oil

Coal and bio CHP and boiler

Gas CHP

Electrolysis

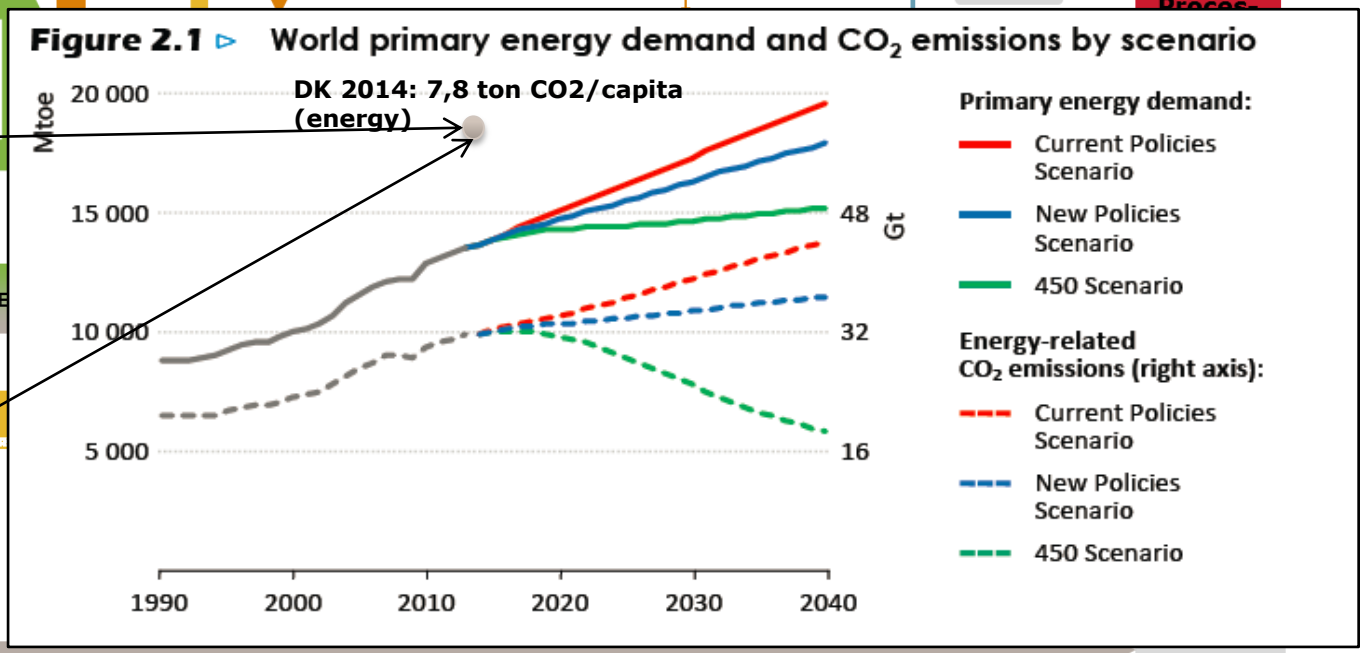
Heat pump and electric boiler

El-proces Light, it

HT-HP.

Proces-

Figure 2.1 ▷ World primary energy demand and CO_2 emissions by scenario



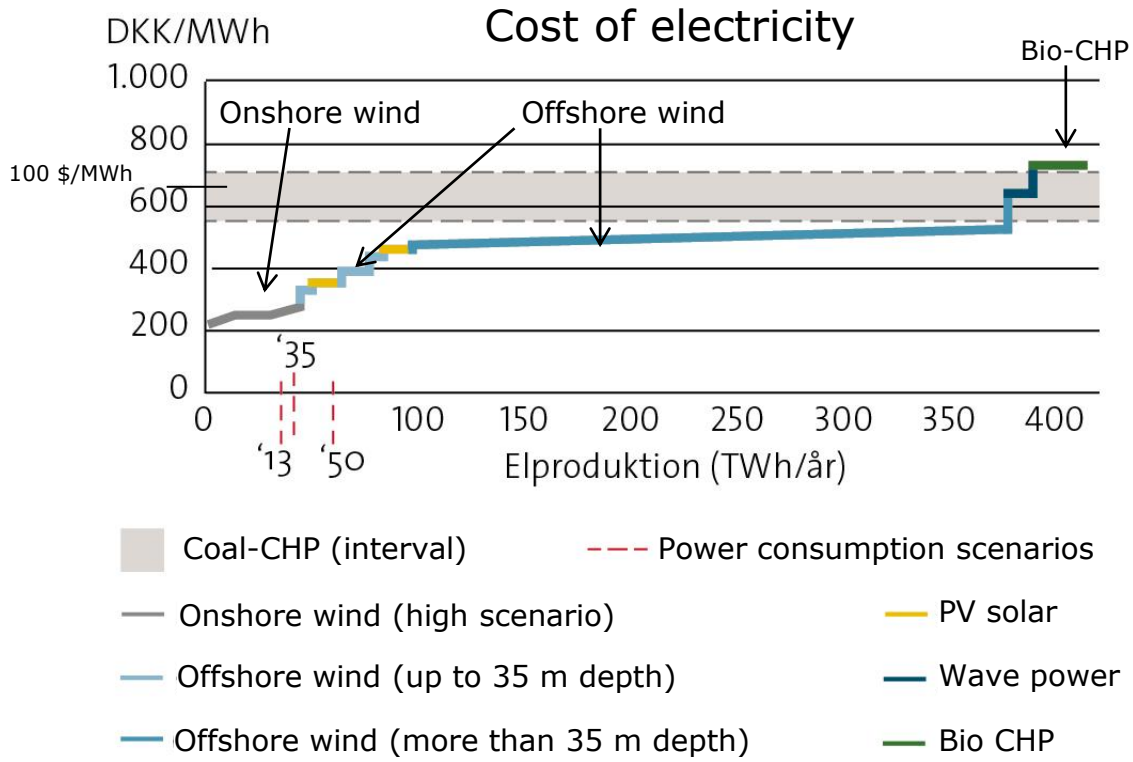
Liquid fuels fossil/RE (Gasoline, Diesel, Ethanol etc.)

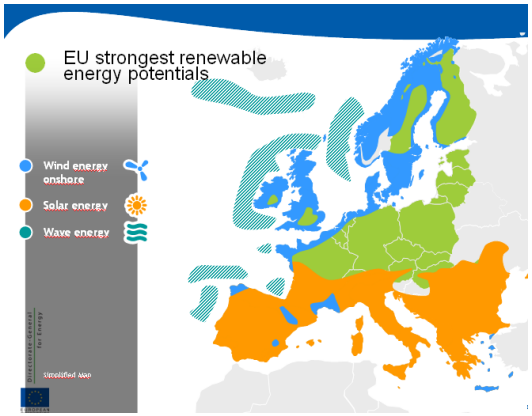
10 TWh=36 PJ

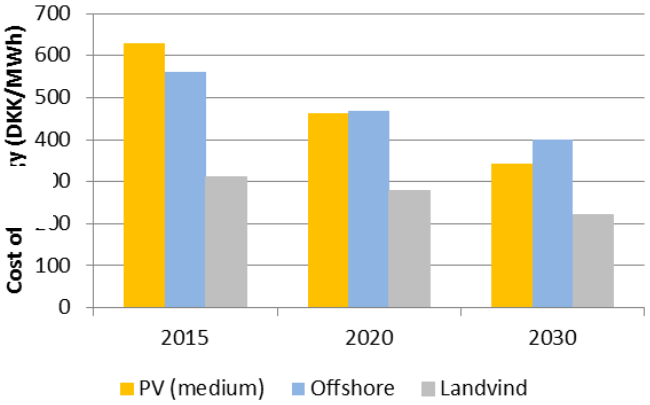
Transport almost totally based on fossil oil
– wind and solar still quite a small part of total gross energy

RE-electricity ressources DK

Socio-economic cost of energy 2030 excl. integration (LCOE)



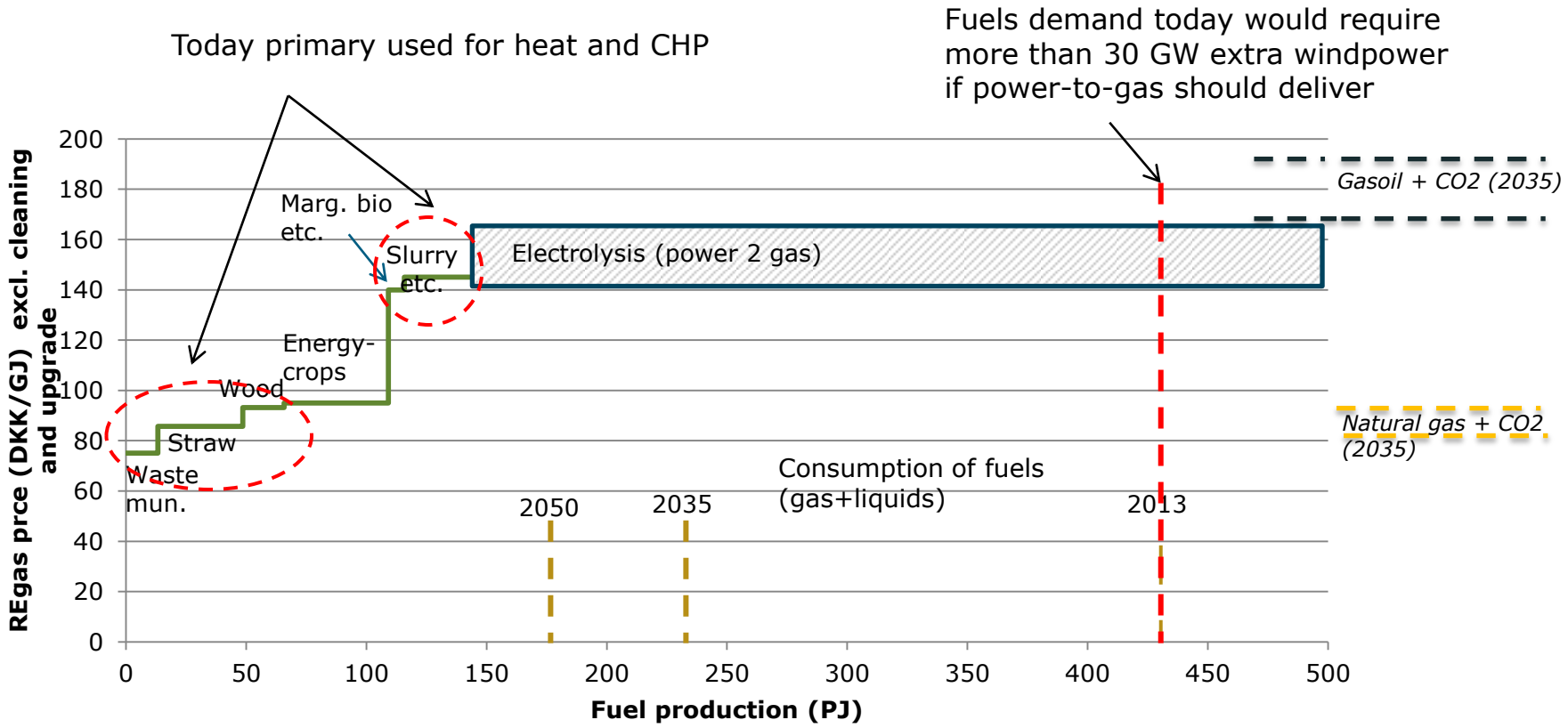




Technology data 2014/2015 and 4% discount
Solar large scale not illustrated

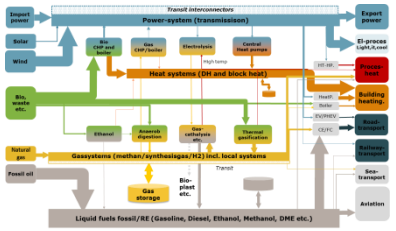
Ressources and cost for fuels

(2030 if all biomass is allocated to fuels)



A significant demand for fuels – electrification is needed to solve the "fuel" challenge

A scenario example towards RE-based energy supply



PJ/year

250
200
150
100
50
0

Power system | Gas system | District heating (ex plant) | Individual heating (netto) | Industrial process heat (netto) | Transport work (netto)

P2G
HP
HP
Industry-HP
EV/PHEV

Now 2025 2035 2050 | Now 2025 2035 2050 | Now 2025 2035 2050 | Now 2025 2035 2050 | Now 2025 2035 2050 | Now 2025 2035 2050

Wind, solar, etc. | Biomass/waste | Natural gas | Oil/coal | RE-gas/biofuels | DH/surplus heat | Electricity

2035 - Reference with fossil free power and heat system

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Import power

Transit

Power-system

Export power

Solar

Bio CHP and boiler

Gas CHP/boiler

Electrolysis

Central Heat pumps

El-proces Light,it,cool

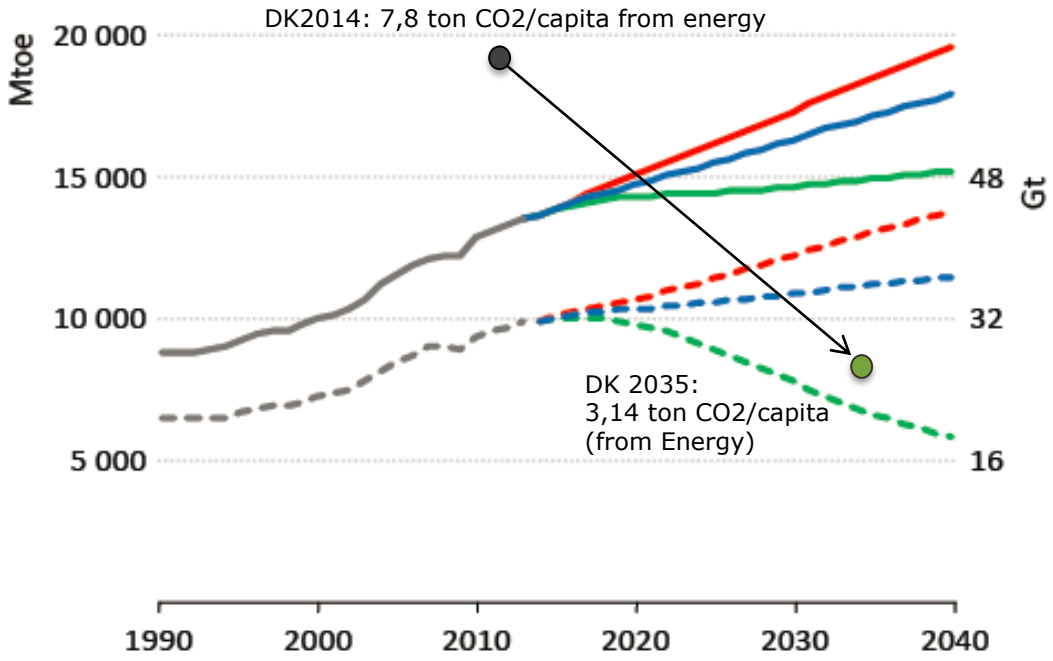
Wind

Bio, waste etc.

Natural gas

Fossil oil

Figure 2.1 ▷ World primary energy demand and CO_2 emissions by scenario



Liquid fuels fossil/RE (Gasoline, Diesel, Ethanol, Methanol, DME etc.)

14 mio ton CO2

10 TWh=36 PJ

Feasibility study 2035+ – reduced fossil oil demand

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Transit

Import power

Power system

Export power

Solar

Bio

Gas

Central heat

El-proces

Wind

Bio, waste etc.

Natural gas

Transit

Gas storage

Aviation

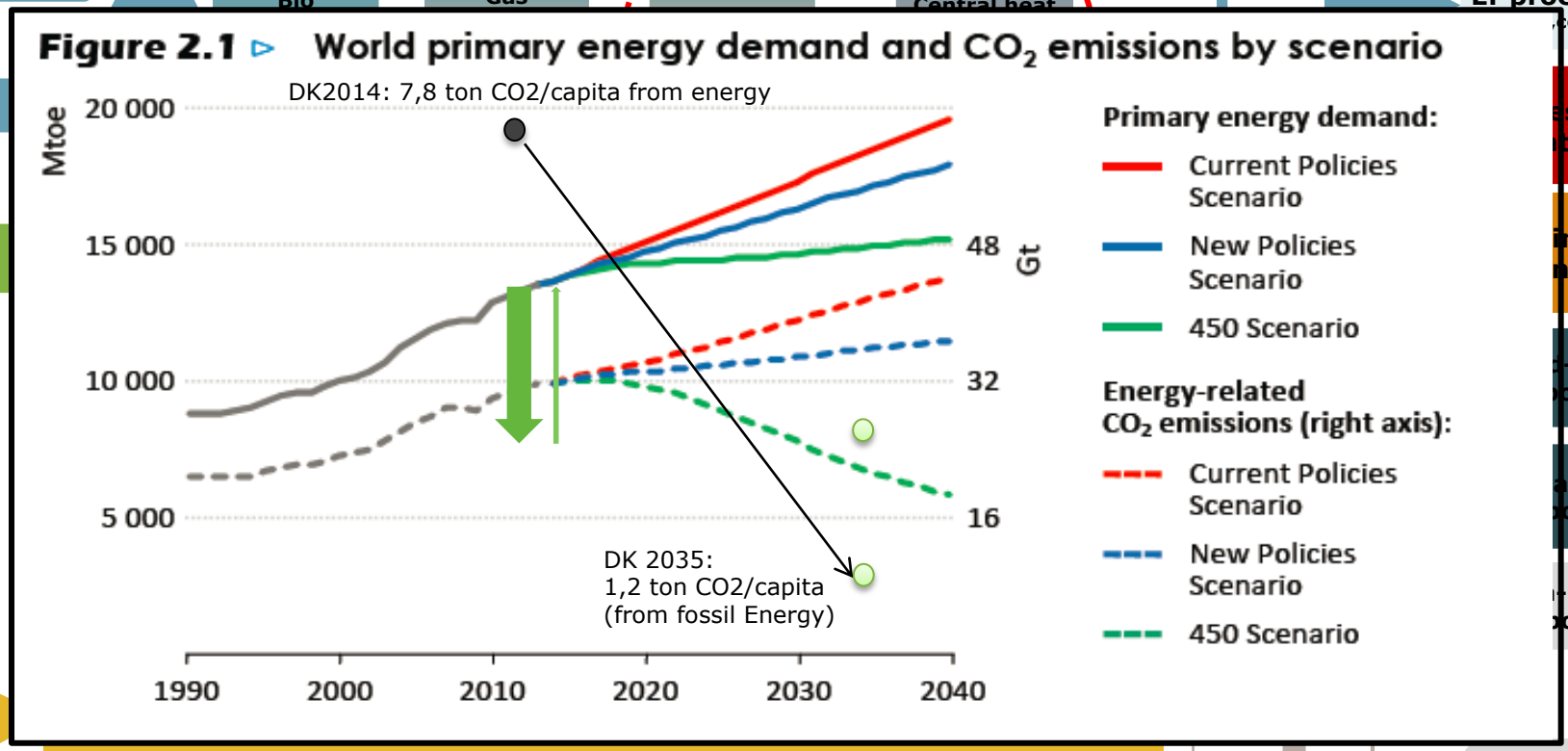
6 mio ton CO2

10 TWh=36 PJ

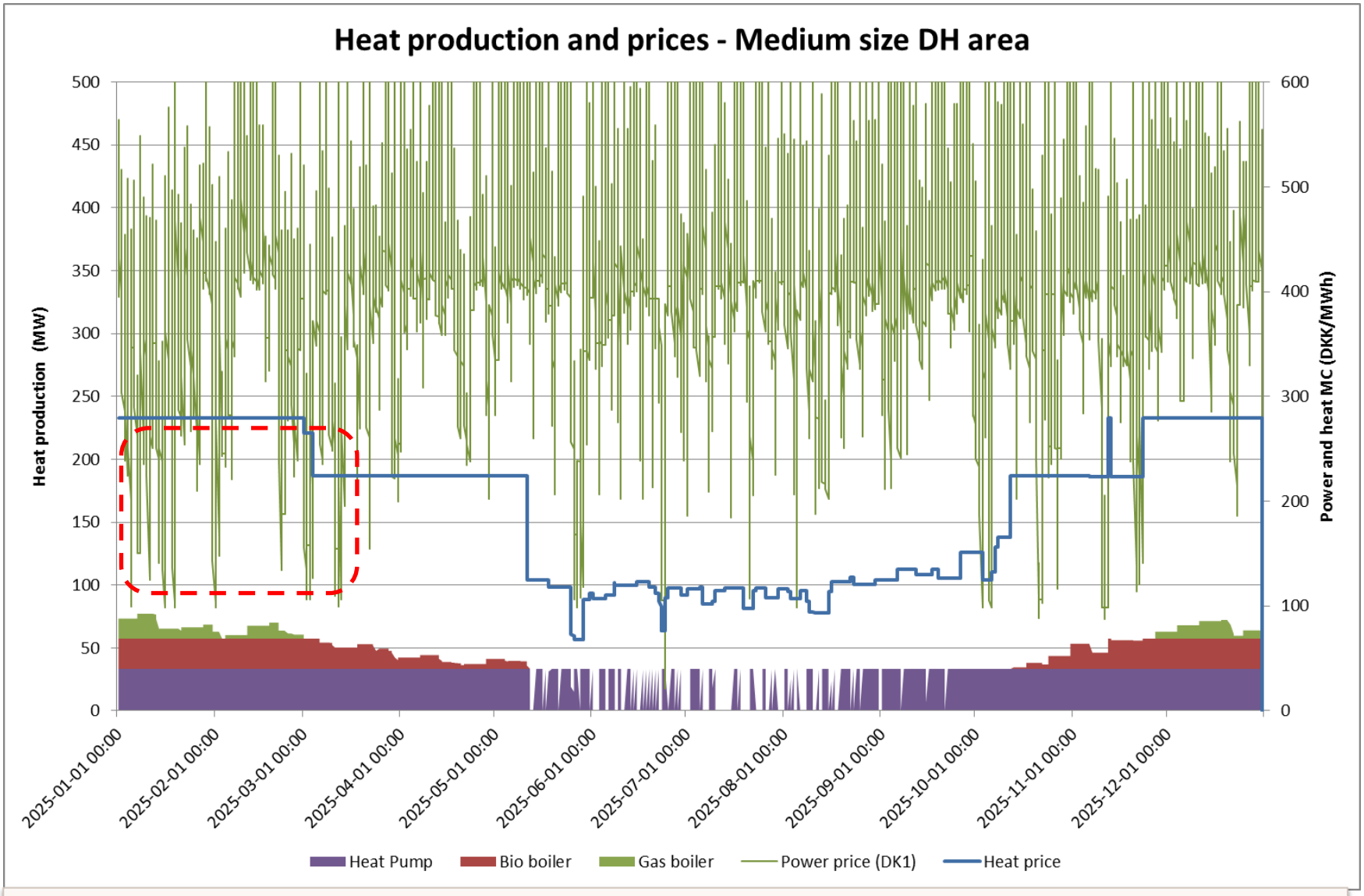
Liquid fuels fossil/RE (Gasoline, Diesel, Ethanol, Methanol, DME etc.)

Smart Energy system

Figure 2.1 ▷ World primary energy demand and CO_2 emissions by scenario

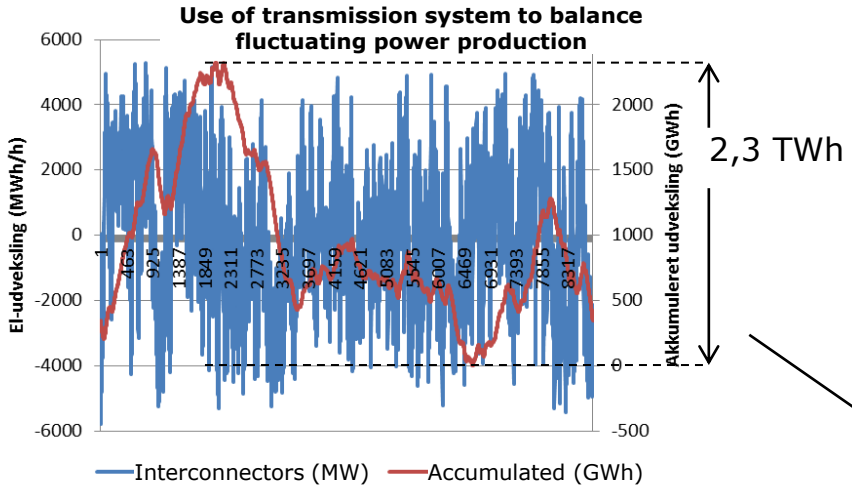


Case with straw used for biogas

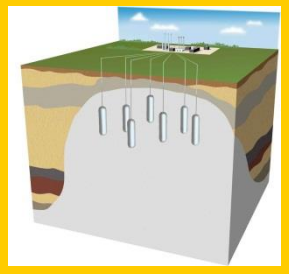


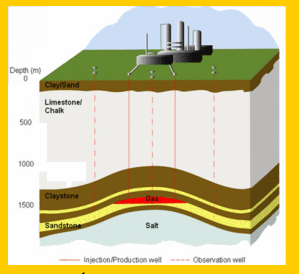
Fluctuating power and heat prices – a need for a price transparent heat and power market to get least cost operation (as found in simulation)

Use of transmission system to balance wind/solar



Gas storage (11 TWh methan-gas)
Energy input to power-to-gas





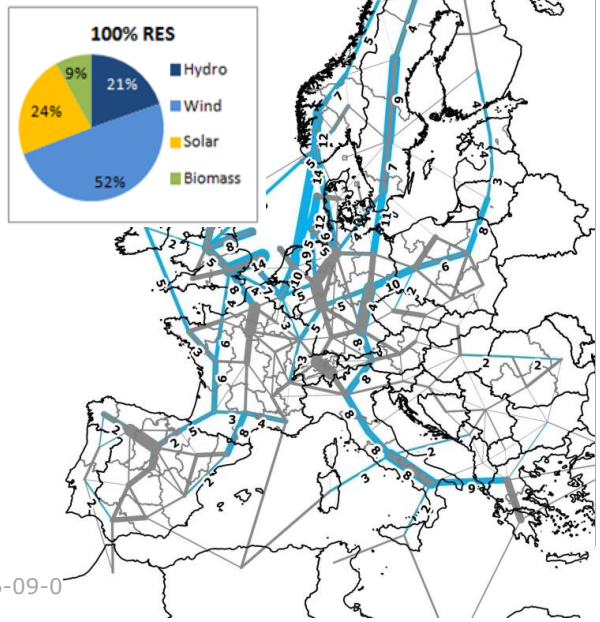
Transmission system:
Interconnectors yearly accumulated energy in 2035
(2,3 TWh)

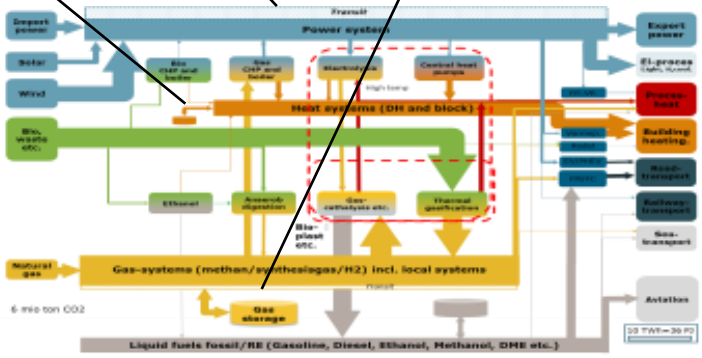
District heat+storage

Indivi. heat pump

El- og plugin hybrid case 2035

A 2050 EU scenario 100% RES





Smart Energy system compliant with COP21 visions for CO2 reduction

R&D focus areas –in a scenario realising COP21 ambition

- COP21 agreement very ambitious – fast reduction towards 2035 needed
- The analyzed scenario realises the fast CO2 reduction (not a zero carbon – but low carbon towards 2035 scenario)
- A need for R&D efforts in a number of areas identified: Mission Innovation ?

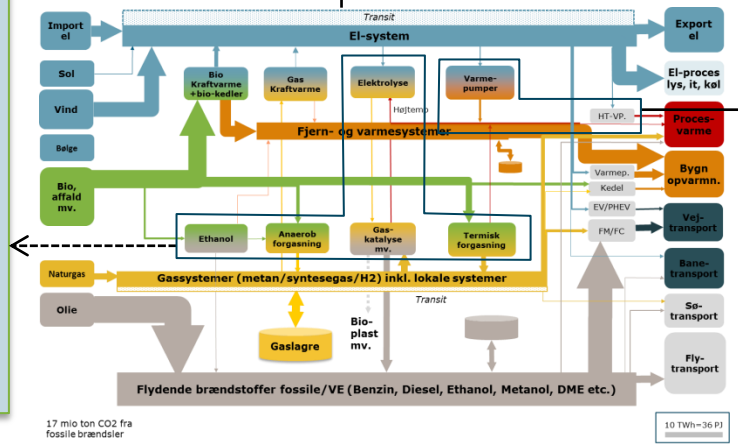
Grid and balancing

- Further development of market solutions
- Probalistic forecast of wind/solar
- Ancillary services from Wind, Solar, HP, EV, Power-to-gas etc.

- Low cost peak load power capacity from power units or storage integrated solutions (ETES/CAES mv.)
- Operation of low inertia power system

Energy Plants –Integrated power, fuel, heat

- Conversion of biomass and power to gas/liquid fuels
- Integration with agriculture and waste systems



Power to heat and cooling

- Large heat pumps (inkl. sea-water sourced)
- Process heat pumps (heating/cooling)
- Efficent use/storage high temp heat
- Market solutions fluctuating heat, power, gas prices


Thank you for attention
Link: www.energinet.dk/energianalyser

R&D focus areas –in a scenario realising COP21 ambition

Grid and balancing

- Dynamic line rating and new principles for use of power transmission
- Operation of low inertia power system
- Probalistic forecast of wind/solar
- Ancillery services from converterbased production and consumption. *(wind,solar,HP,EV,P2G)*

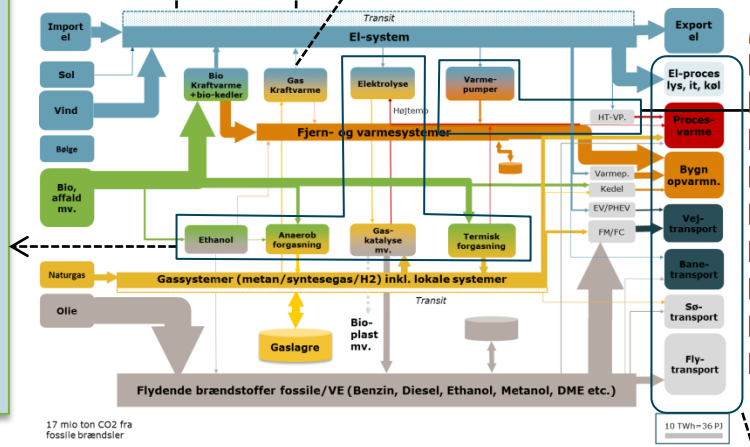
Market and operation

- Direct and indirect control strategies (control, stability, cost)
- TSO/DSO agregation in market solutions (incl. tarif)
- Big data and Internet-Of-Things use in market products

- Low cost <u>peak load</u> power capacity from power units or storage integrated solutions (ETES/CAES mv.)

Energy Plants –Integrated power, fuel, heat

- Conversion of biomass and power to fuels etc.
- Integration with agriculture and waste systems



Power to heat and cooling

- Large heat pumps (inkl. sea-water sourced)
- Process heat pumps (heating/cooling)
- Efficent use/storage high temp heat
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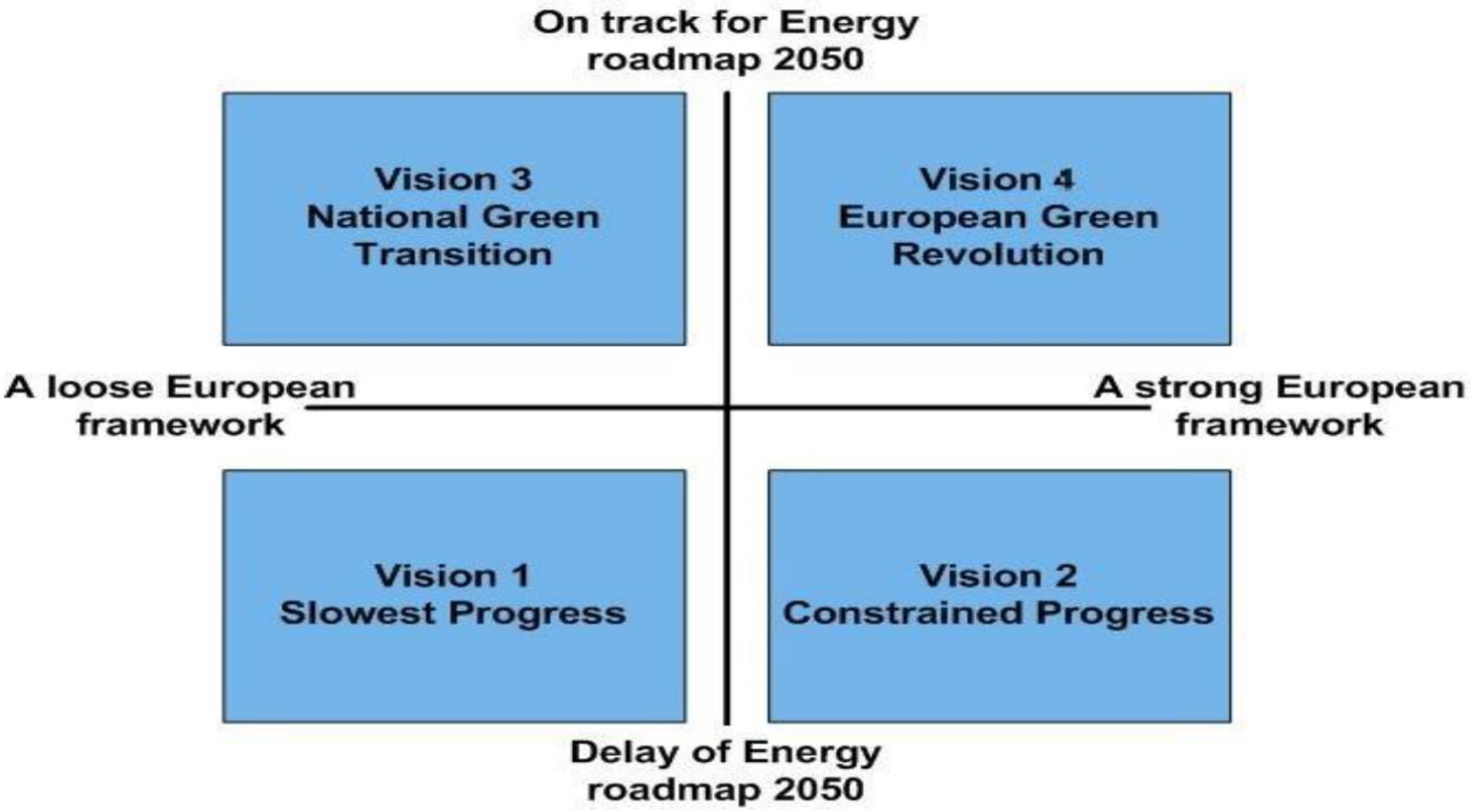
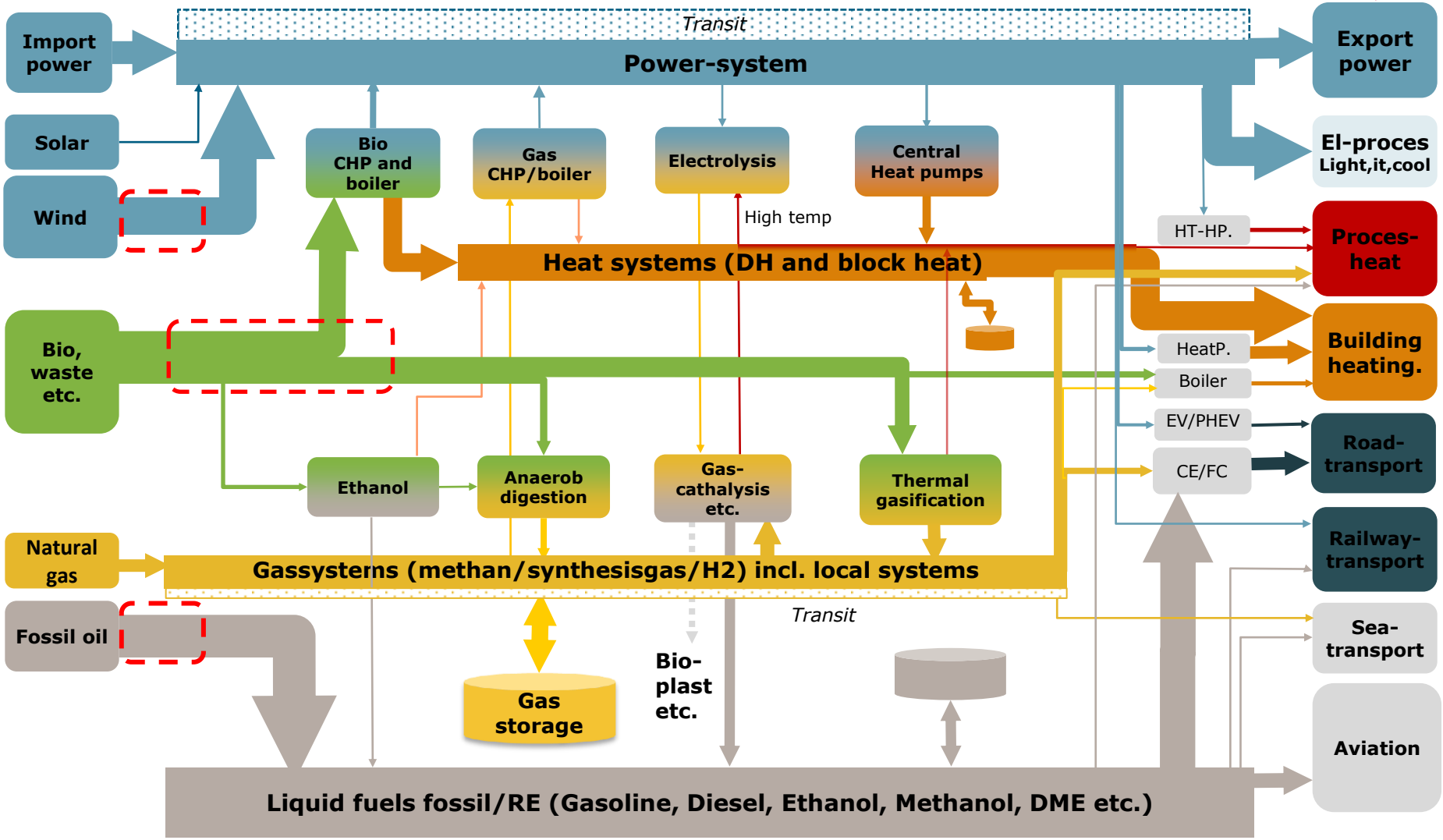
Demand response modelling

- Price elasticity, profiles
- Consumper preferences på variable energipriser


On track for Energy roadmap 2050
Vision 3 National Green Transition
Vision 4 European Green Revolution
A loose European framework
A strong European framework
Vision 1 Slowest Progress
Vision 2 Constrained Progress
Delay of Energy roadmap 2050

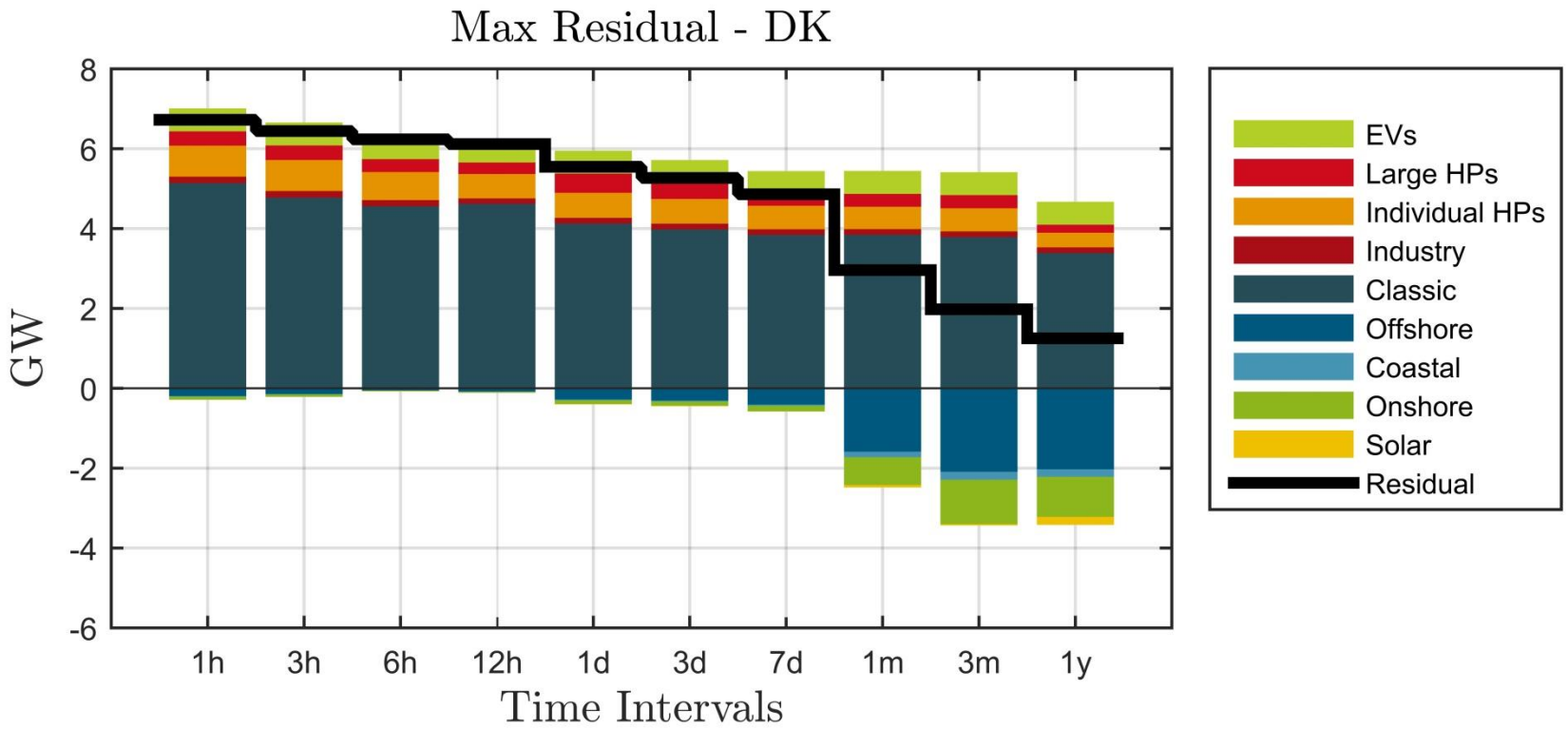
2035 - Reference with fossil free power and heat system



14 mio ton CO2

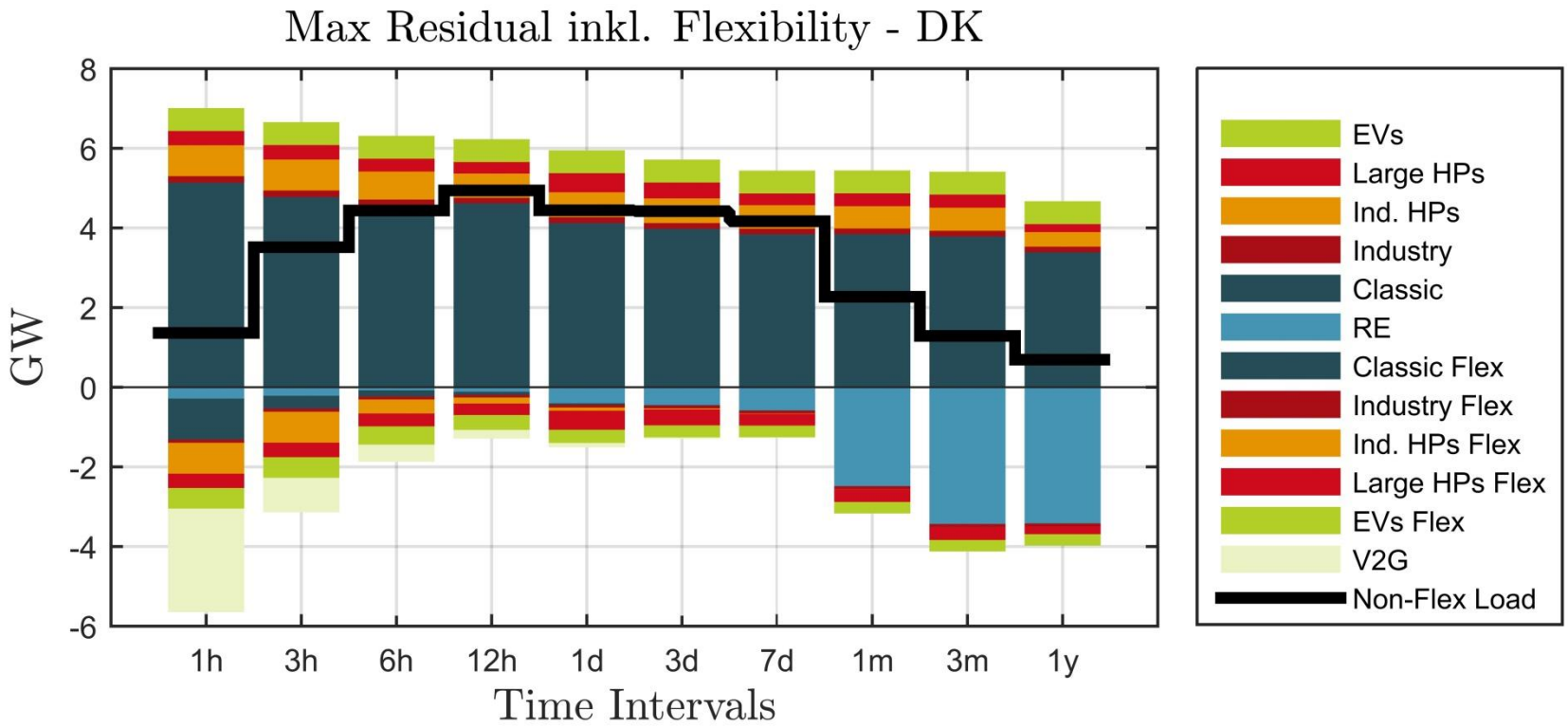
10 TWh=36 PJ

Max Residual load in Periods of 1 Hour to 1 Year (2035 scenario)
(analysis based on 10 year DTU wind time series)



Residual load = Consumption – wind/solar

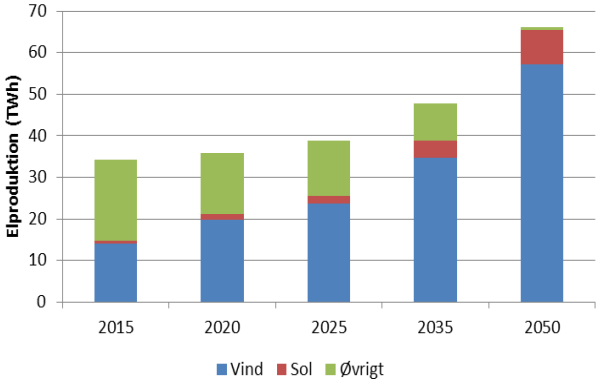
Use of flexible load to reduce peak demand

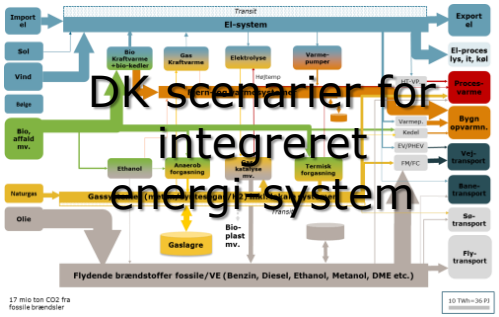


Now the max residual load is in a 12 hours period

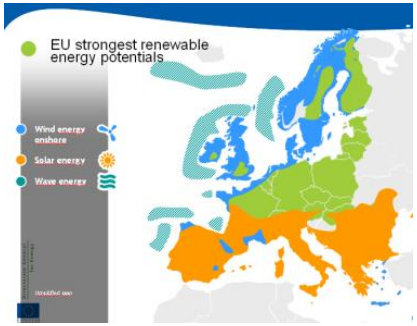
Fra DK og EU systemløsninger til globalt marked

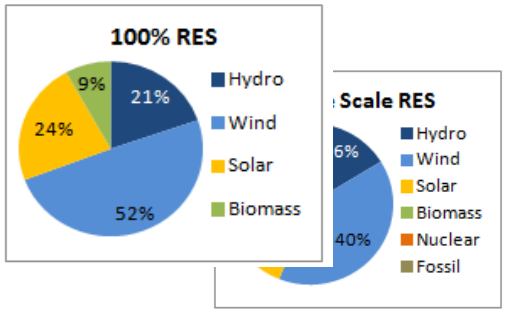
DK Scenarie eksempler





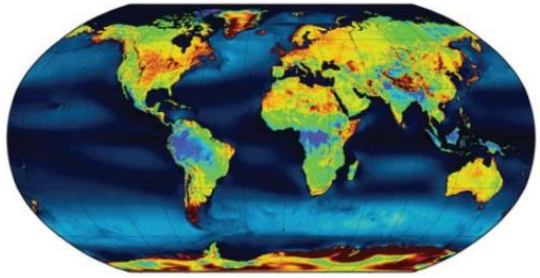
EU mod 2030/2050

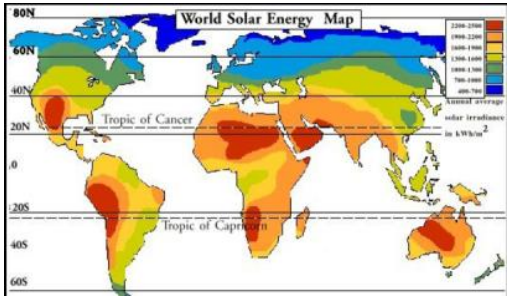




- System-integration (el,varme,gas,fuel,agro)
- Vind/sol/bio samspil – fleksibilitet og energieffektivitet
- Effektive markedsløsninger og stærk infrastruktur

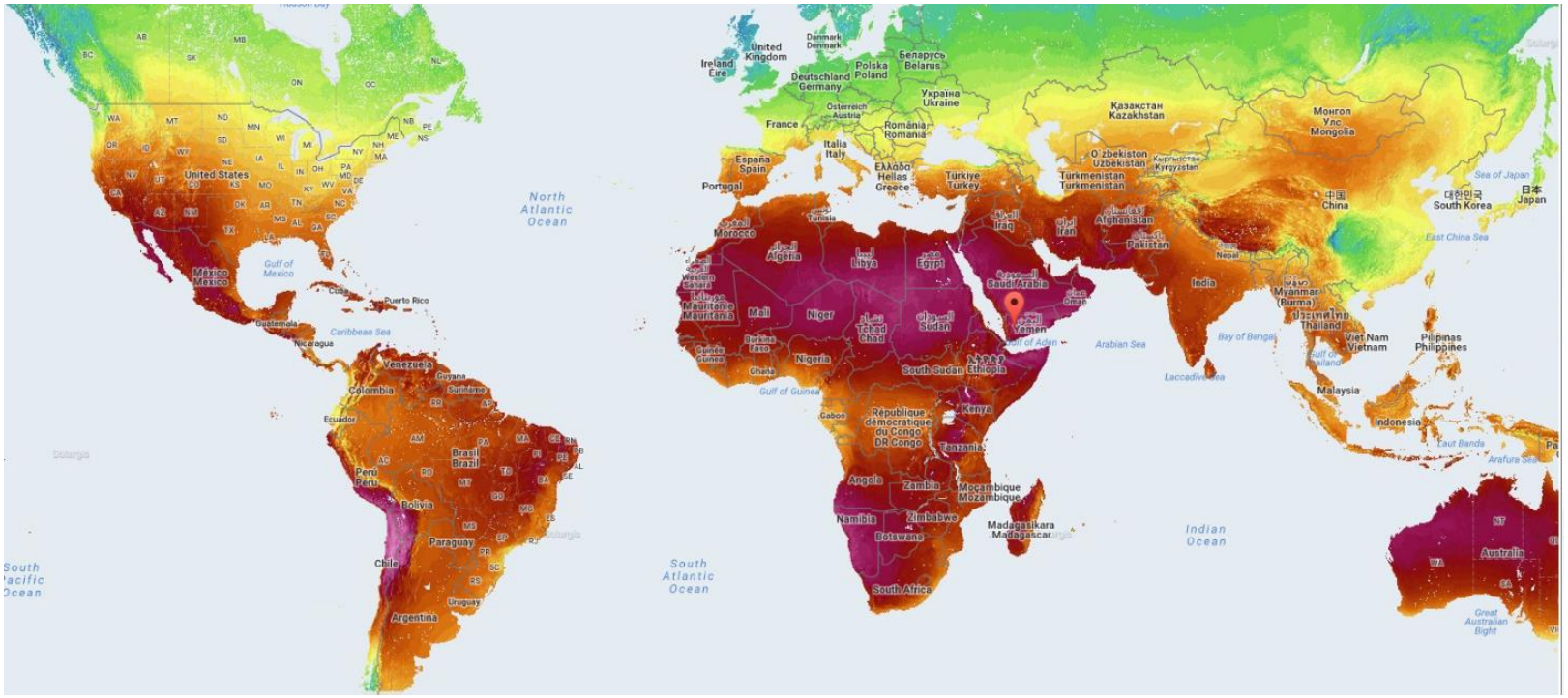
Global potentiale vind/sol

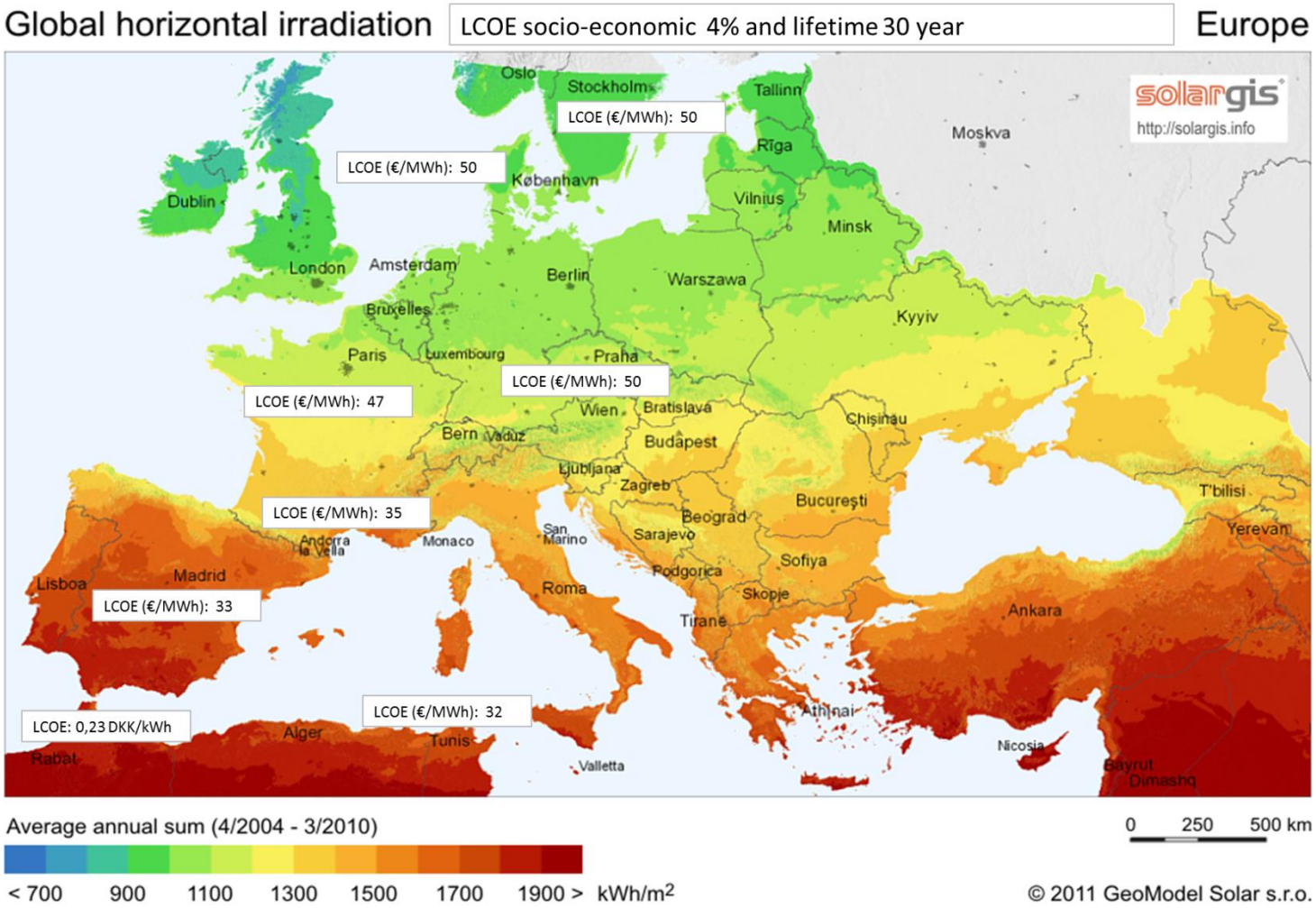




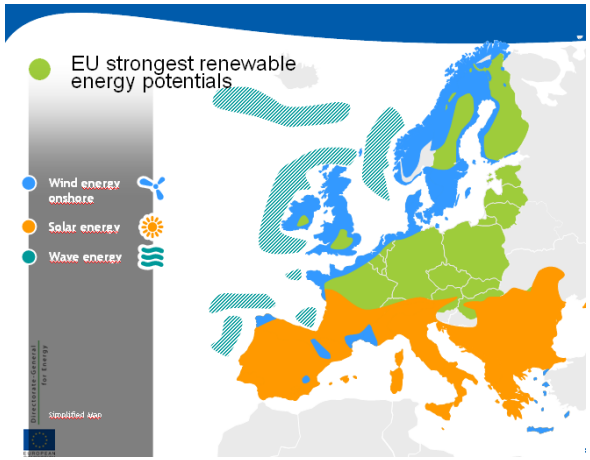
- Meget store vindpotentialer
- Vind/sol/bio samspil

- Potentiale for DK systemløsninger i både EU og global COP21 udvikling
- Hvilke FUD indsatser kræver det ?
- Hvilke indsatser er ”**særligt løfterige**” for DK ?


North Atlantic Ocean
South Atlantic Ocean
Indian Ocean
United States
México
Brazil
Argentina
Chile
Peru
Colombia
Venezuela
Bolivia
Paraguay
Ecuador
Guyana
Suriname
Puerto Rico
Guatemala
Nicaragua
Caribbean Sea
Gulf of Mexico
Ireland
United Kingdom
Denmark
Polska
Беларусь
Deutschland
Germany
Україна
Ukraine
France
Österreich
Austria
România
Romania
Italia
Italy
España
Spain
Portugal
Ελλάδα
Hellas
Greece
Türkiye
Turkey
Қазақстан
Kazakhstan
Монгол Улс
Mongolia
O'zbekiston
Uzbekistan
Türkmenistan
Turkmenistan
Кыргызстан
Kyrgyzstan
中国
China
대한민국
South Korea
日本
Japan
Sea of Japan
East China Sea
Afghanistan
Pakistan
Nepal
India
Myanmar
(Burma)
ประเทศไทย
Thailand
Việt Nam
Vietnam
Philipinas
Philippines
Malaysia
Indonesia
Laut Banda
Arafura Sea
Australia
Great Australian Bight
Bay of Bengal
Arabian Sea
Laccadive Sea
Gulf of Aden
Gulf of Guinea
Morocco
Algeria
Tunisia
Libya
Egypt
Mauritania
Mali
Niger
Nigeria
Burkina Faso
Guinea
Ghana
Gabon
Chad
Sudan
South Sudan
Ethiopia
Kenya
Somalia
République démocratique du Congo
DR Congo
Tanzania
Angola
Zambia
Moçambique
Mozambique
Namibia
Zimbabwe
Botswana
Madagasikara
Madagascar
South Africa
Saudi Arabia
Yemen
Iraq
Iran

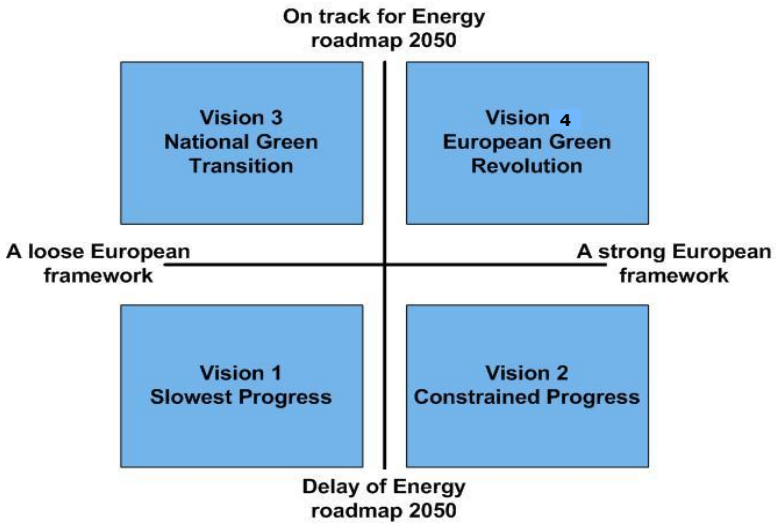

Global horizontal irradiation
LCOE socio-economic 4% and lifetime 30 year
Europe
solargis
http://solargis.info
LCOE (€/MWh): 50
LCOE (€/MWh): 50
LCOE (€/MWh): 50
LCOE (€/MWh): 47
LCOE (€/MWh): 35
LCOE (€/MWh): 33
LCOE (€/MWh): 32
LCOE: 0,23 DKK/kWh
Oslo
Stockholm
Tallinn
Moskva
Rīga
København
Dublin
Vilnius
Minsk
London
Amsterdam
Berlin
Warszawa
Bruxelles
Kyyiv
Paris
Luxembourg
Praha
Wien
Bratislava
Chişinau
Bern
Vaduz
Budapest
Ljubljana
Zagreb
T'bilisi
Bucureşti
Beograd
Yerevan
Andorra la Vella
Monaco
San Marino
Sarajevo
Sofiya
Podgorica
Lisboa
Madrid
Roma
Skopje
Ankara
Tirane
Athinai
Alger
Tunis
Nicosia
Rabat
Valletta
Bayrut
Dimashq
Average annual sum (4/2004 - 3/2010)
< 700
900
1100
1300
1500
1700
1900 >
kWh/m²
0
250
500 km
© 2011 GeoModel Solar s.r.o.

European Scenario Framework in the analysis



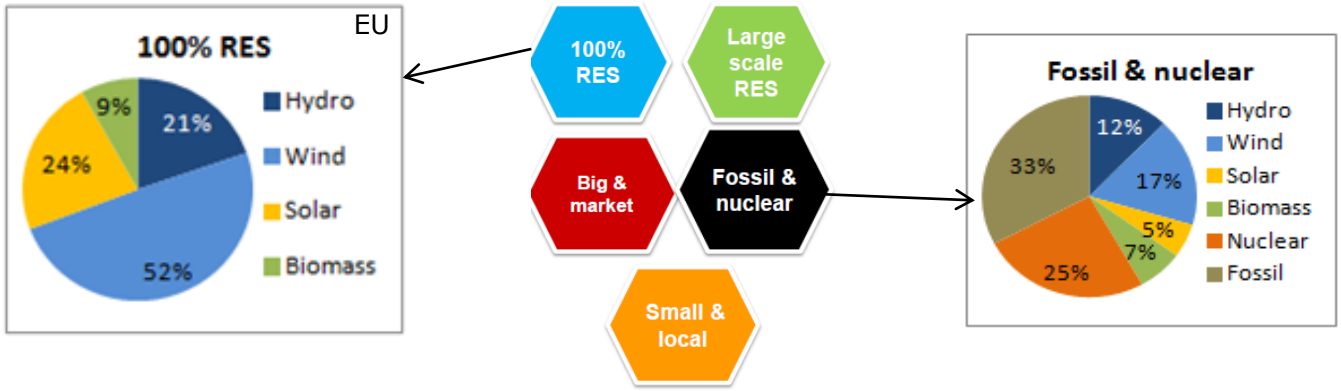
ENTSO-E Visions

2030



e-Highway 2050 – Scenarios towards 80-95% reduction of climate gasses

2050



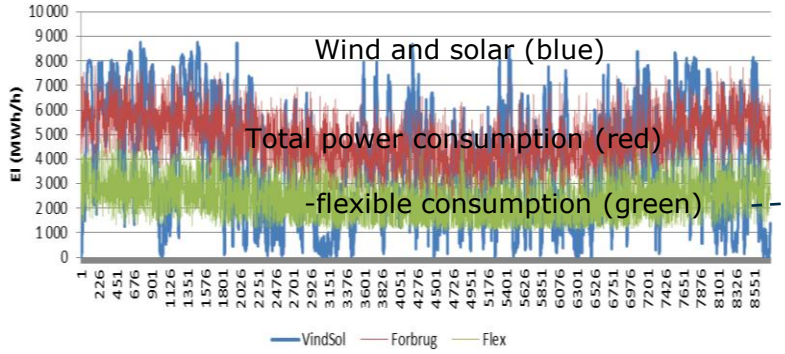
A framework of international scenarios used to evaluate robustness of strategic choices

system compliant with COP21 visions for CO2 reduction

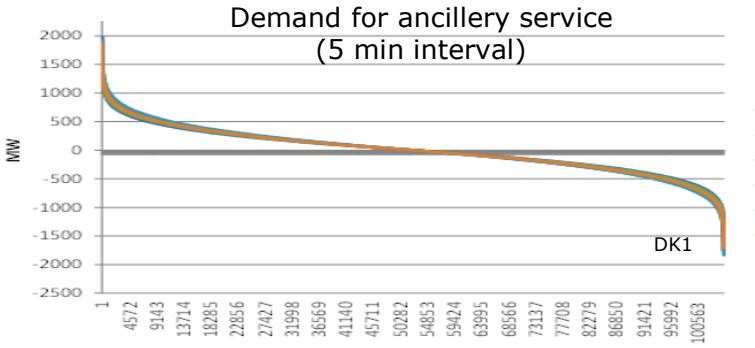
Balancing the power system

Flexible consumption as ancillary service and grid backup (n-1)

Flexible consumption analysed as grid reserve (n-1)

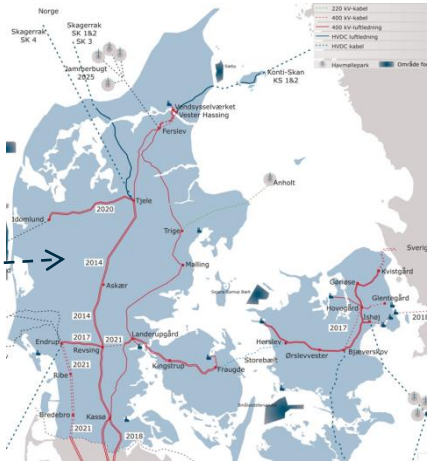


Flexible consumption as ancillary service



Flexible consumption as grid reserve can increase the use of transmission (long horizon solution)

Flexible consumption as grid reserve



- Flexible consumption essential as:
  - Grid reserve (TSO/DSO)
  - Ancillery services
  - Intraday balancing

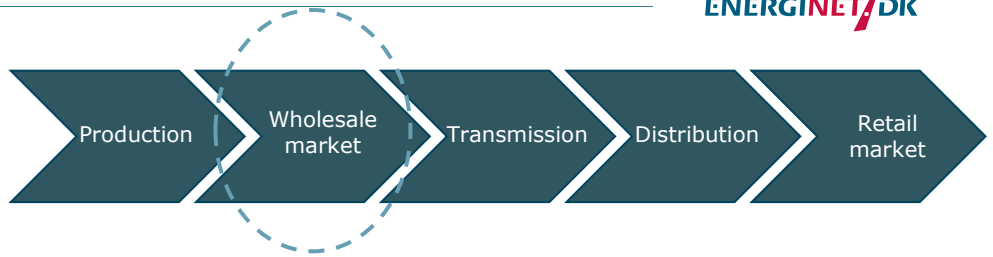
Danish perspectives on system support from different technologies

	Generator >100 kV	Generator <100 kV	WT >100 kV	WT <100 kV	Classical HVDC	New HVDC	SVC/ STATCOM	Synch. comp
Inertia	++	+	(+)	÷	(+)	(+)	÷	++
Short circuit power	++	+	(+)	÷	÷	(+)	÷	++
Black start	(++)	(+)	÷	÷	÷	(++)	÷/(+)	÷
Continious voltage control	++	(+)	(+)	÷	÷	++	++	++
Dynamic voltage support	++	÷	++	÷	÷	++	++	++
Damping of system oscillations (PSS)	+	÷	(+)	÷	(++)	(++)	(+)	÷

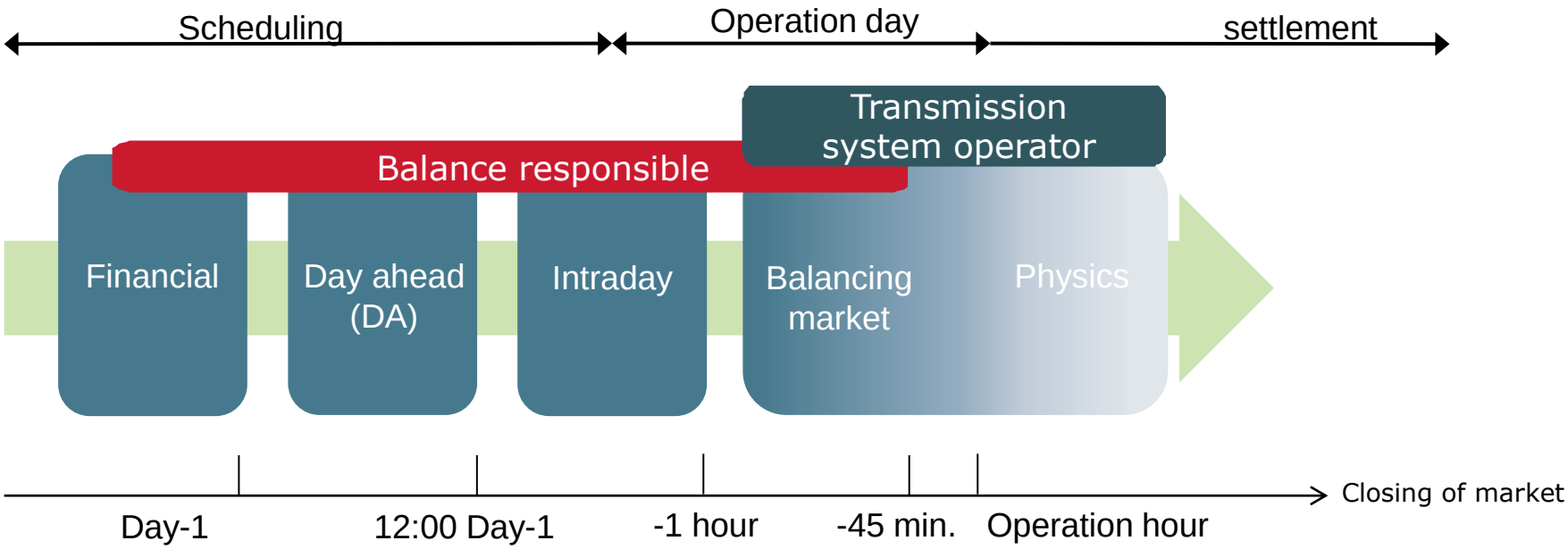
++	*Large contribution*
+	*Minor contribution*
(+/++)	*Conditionally available*
÷	*Unavailable*

System control and market

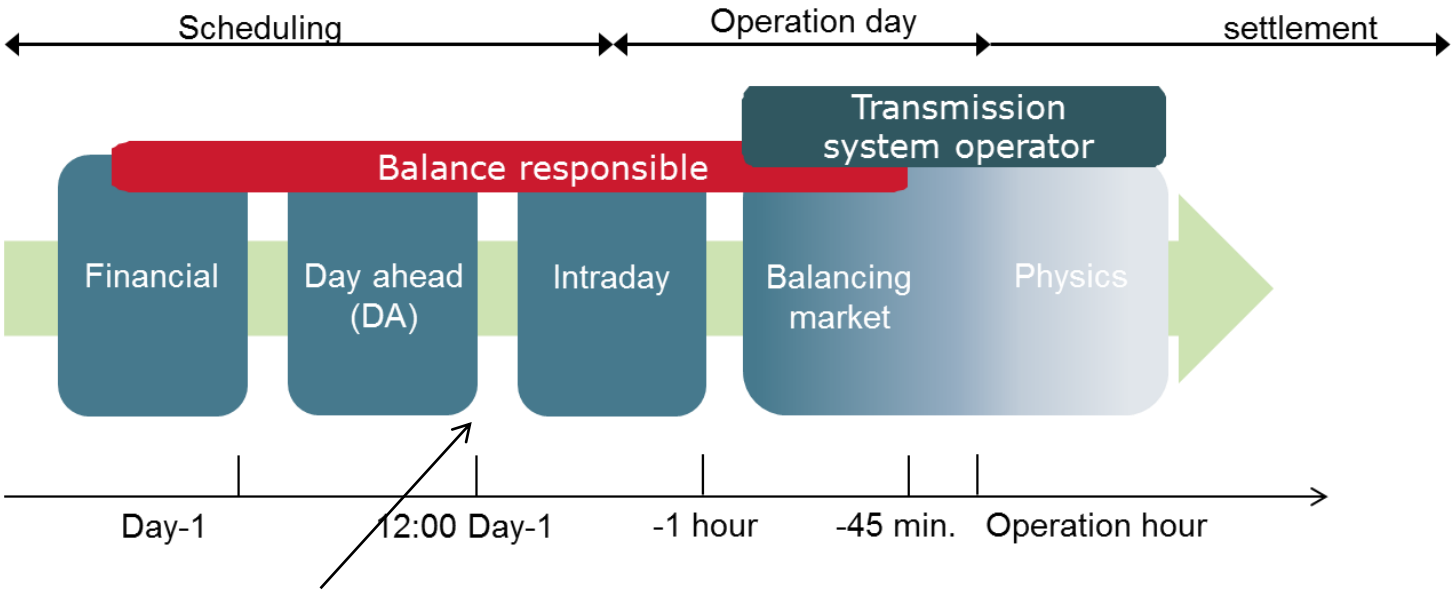
The wholesale market



The wholesale market is no just one market, but a number of markets



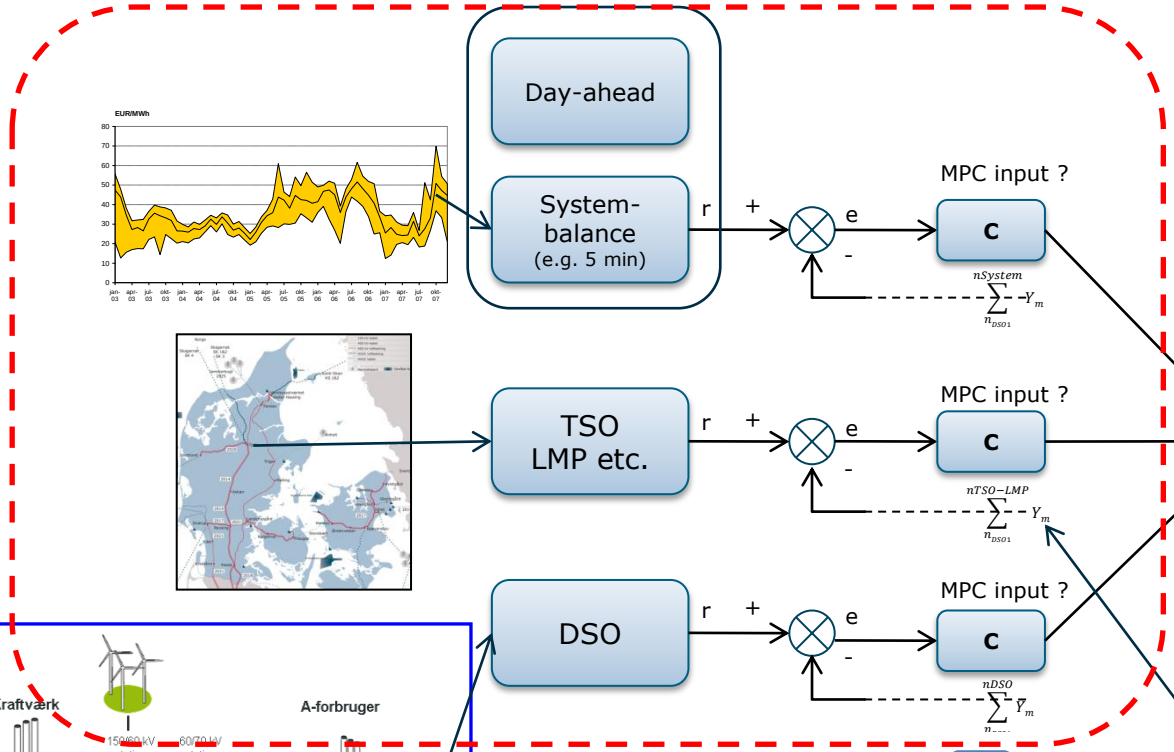
R&D investigation in a pilot

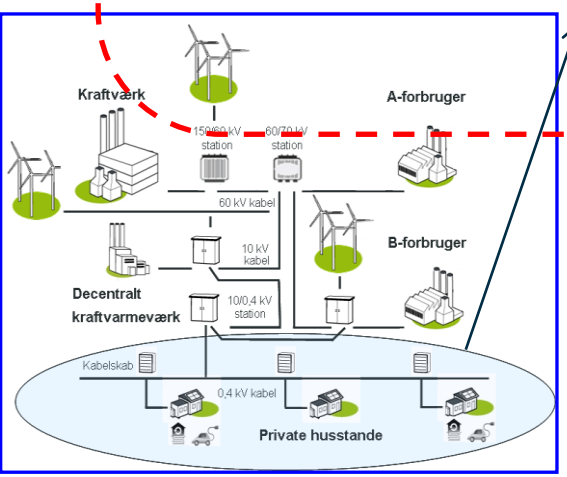


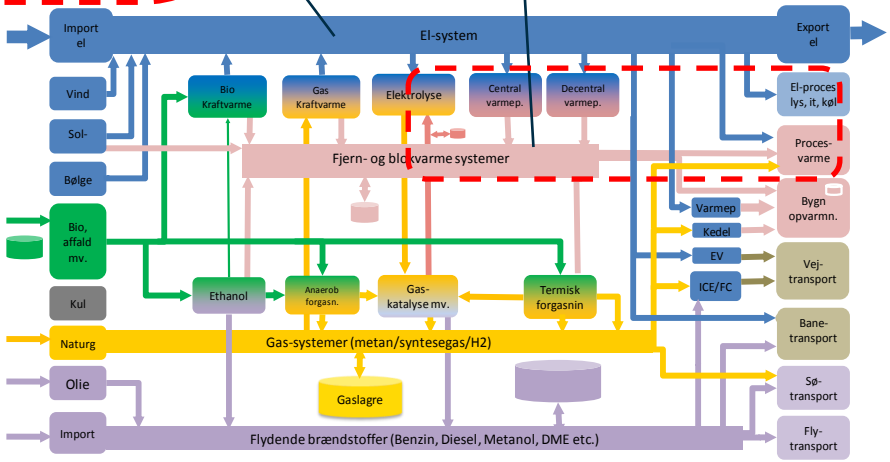
- Microtrade
  (small units can via trader/webservice operate on wholesale)
- Intraday price public and gives an indicative forecast of energyprice and tarif

- Balancing market (5 min) with real-time price public and used as settlement price
- Realtime tarif (nodal) in situations with congestion is published

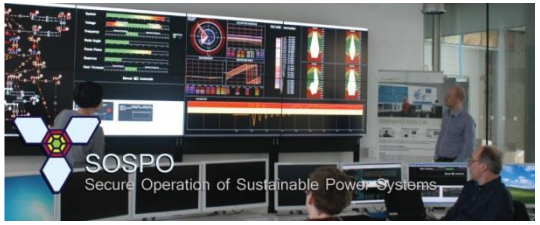
Analysis of Energy System dynamics
- including power TSO/DSO (and potentially heat market)

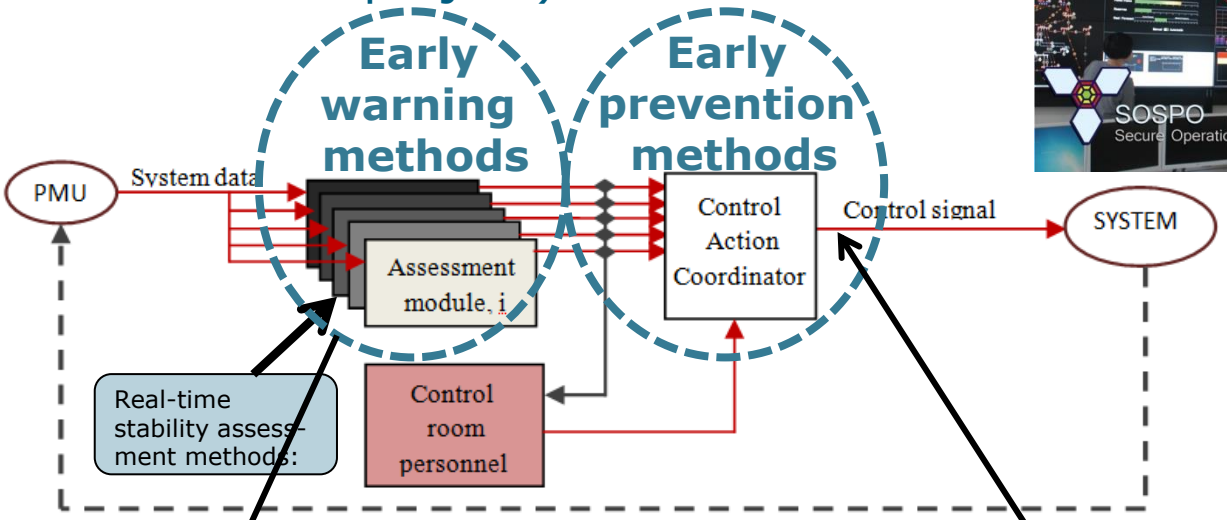


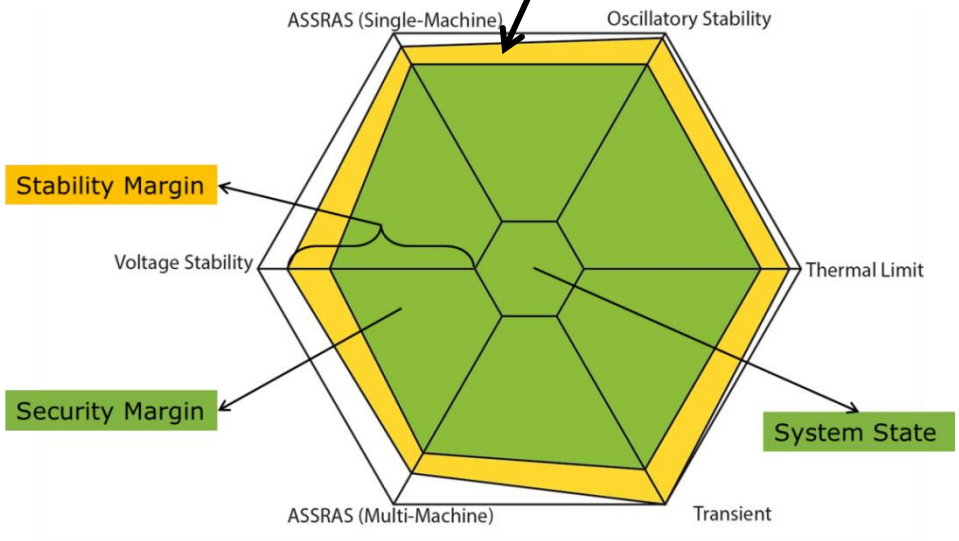




System awareness – PMU/WAMS
(example from SOSPO projekt)







With better state estimation from PMU/WAMS a higher utilization of the grid can be realised
– maintaining high security of supply

R&D issues to be discussed (how is US experiences)

- **Market solutions integrating Energy and grid (Transmission/Distribution level)**
  - DER's acting directly in wholesale market (intraday, day ahead)
  - Nodal pricing down to low voltage feeder
  - Broadcast of realtime price (stability issues etc.)
  - Use of DER's as grid-reserve at transmission level (n-1)
  - Dynamic line rating used in operation and market
  - Network tariff principles

- **Converter based power system (with low/no rotating mass)**
  - Delivery of ancillary services from wind/solar (virtual inertia, reactive power etc.)
  - Strategies for voltage/reactive power control to be used for power-flow control

- **Use of syncrophasor PMU/WAMS for system state estimation**
  - How to get access to all small DER's in case of alert situations
  - Strategies for use of WAMS/PMU and coupling to market solutions

- **Cost of technology and forecast** (does DEA have cost projections, bench marking etc.)

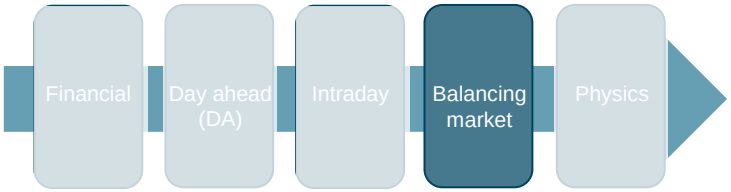
- **EV/PHEV/FCEV future situation** – and the challenge for the grid at low-voltage feeder
  - Standard EV/PHEV be in 2025 ? 63A 3-phase by use of main converter? V2G ?

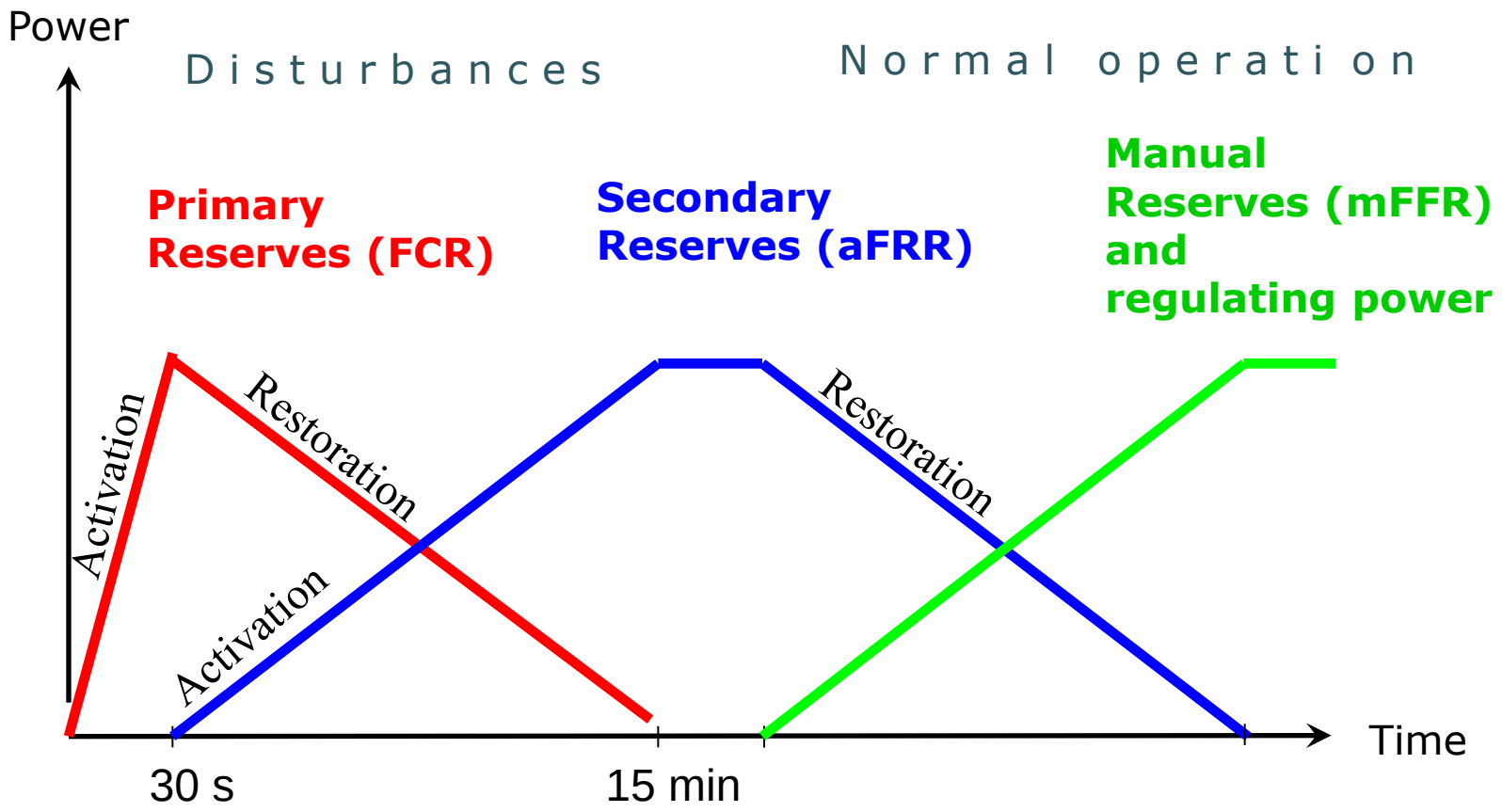
- **Solar/battery micro-grid future** (cost projections and role) – off/microgrid solutions

- **Utility scale batteries future situation** (cost projection and role in the grid/balancing/ac)

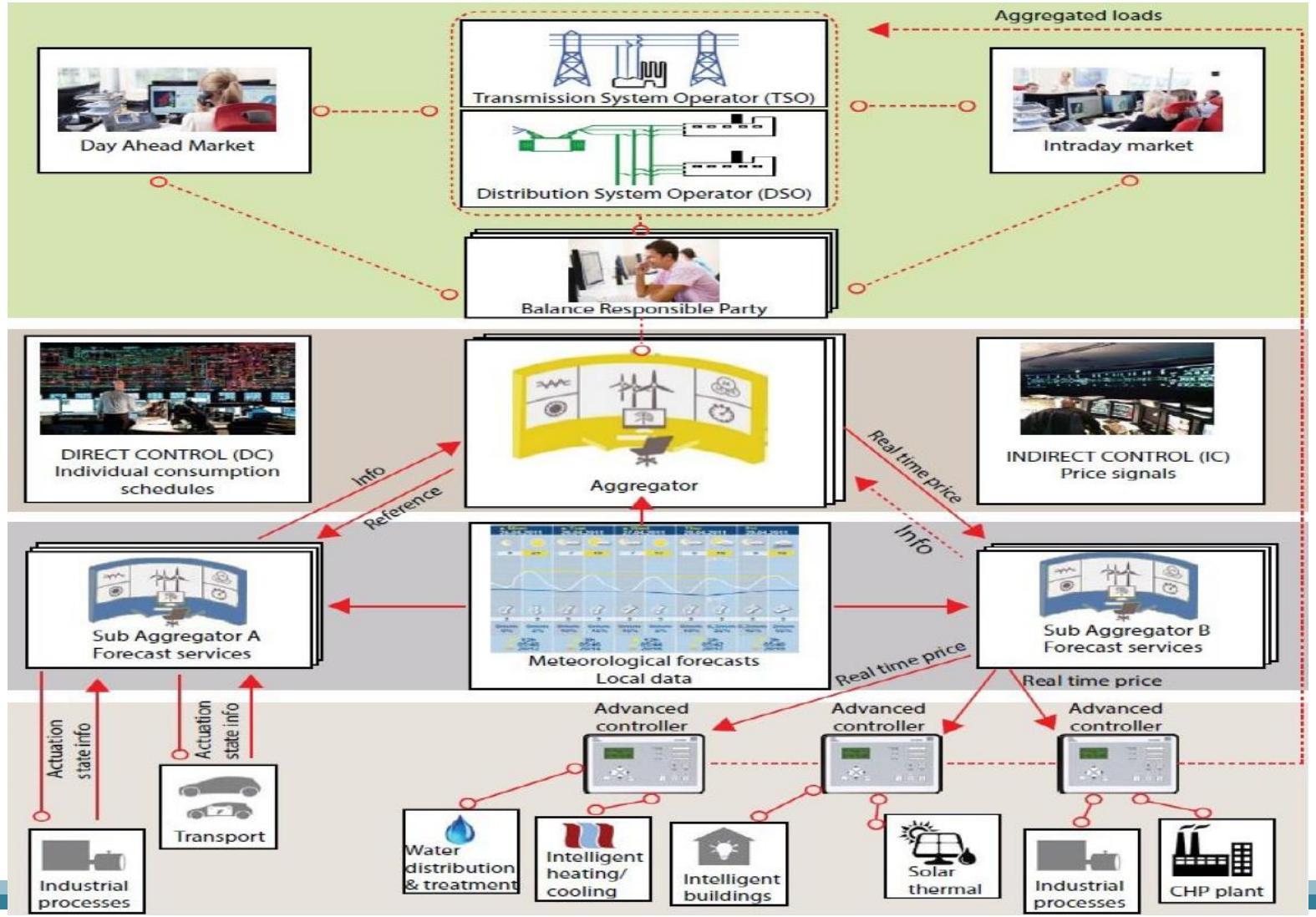
- **US scenarios and R&D strategies** for energy system technologies

The different reserves





Smart-Energy Operation system

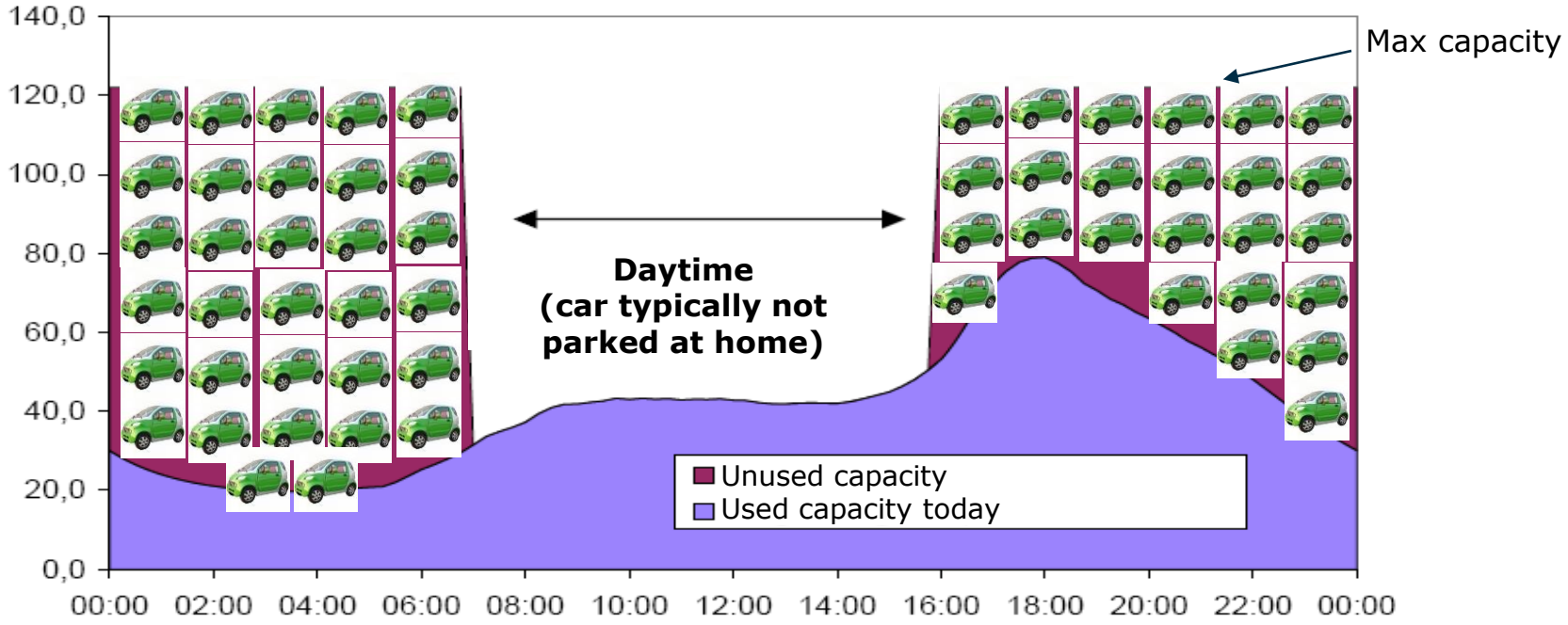


Capacity in the distribution grid to EV charging

Case study in a low voltage distribution net (0,4 kV in DK)

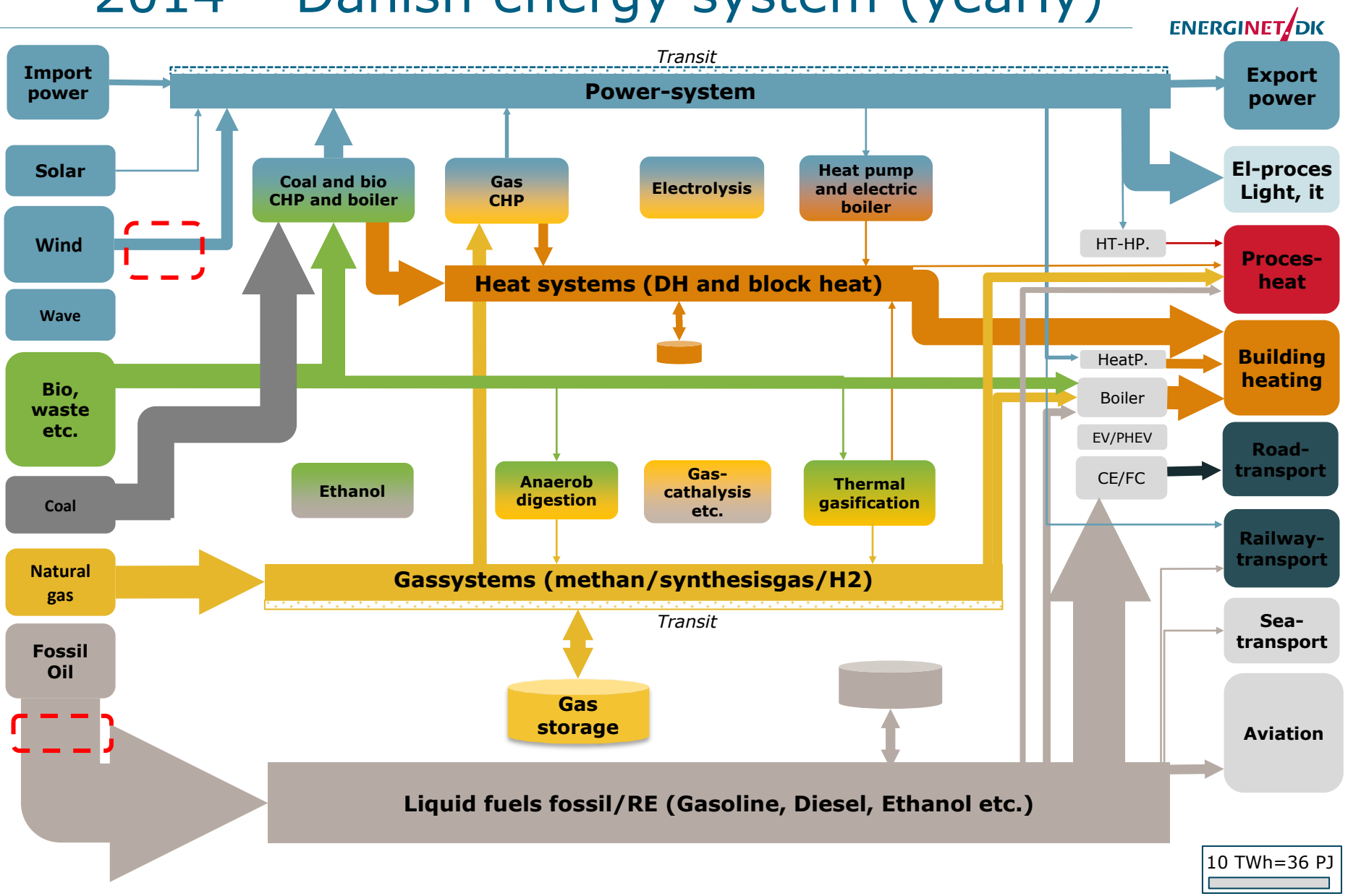
16 Amps 3-phase charging example for a local grid with low capacity

Current in radial [A]

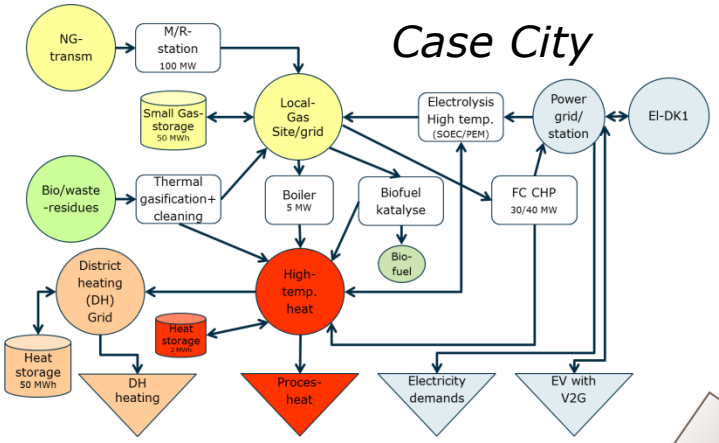


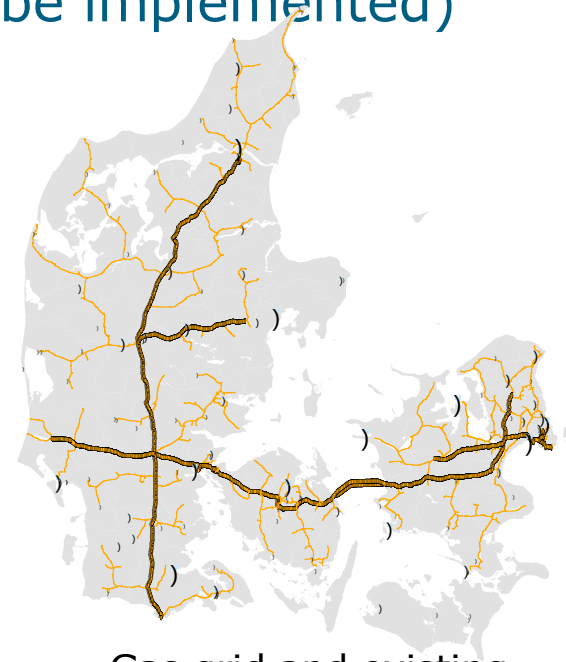
Only 3 cars with 16Amp 3-phase can charge in peak hours at 17-18
But: More than 50 cars evenly distributed
A high value of Smart Grid to control the charging !

2014 – Danish energy system (yearly)



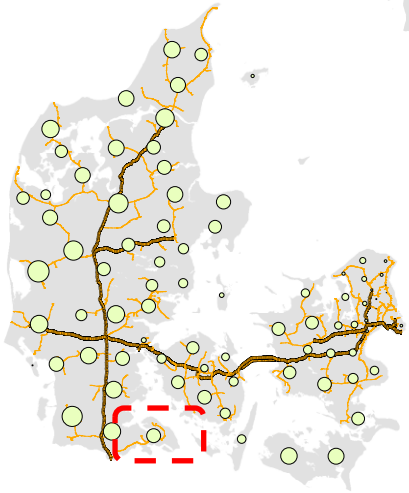
From case ”Cities” to national solutions (to be implemented)



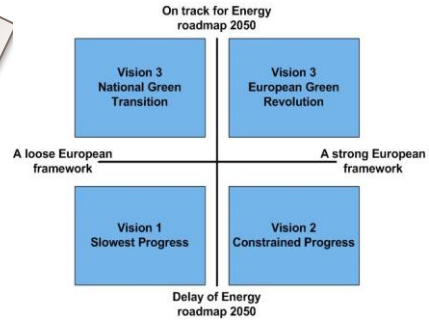


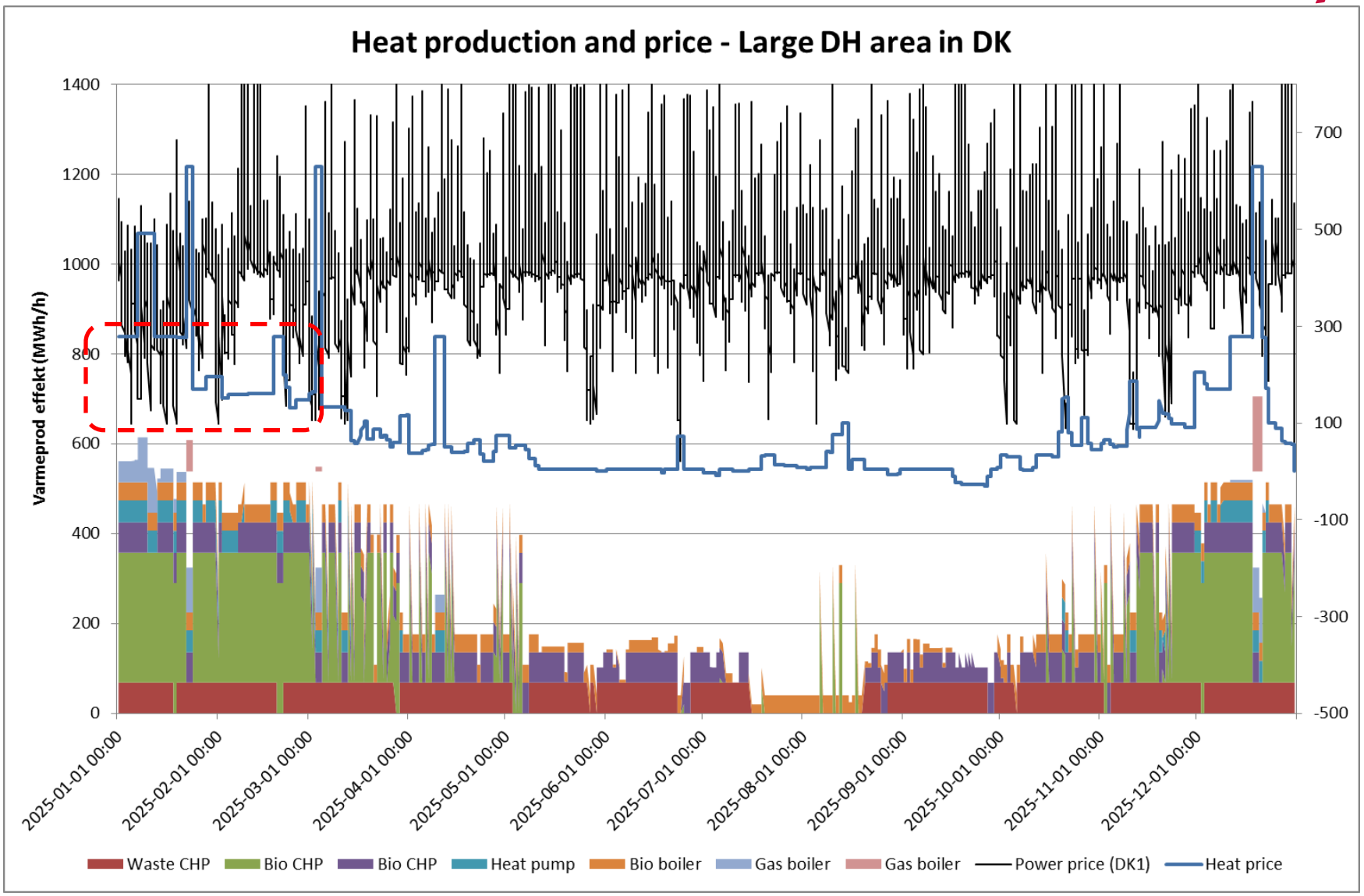
Gas grid and existing
Power plant capacity

Heat demands
(In Sifre reduced to 40 areas)



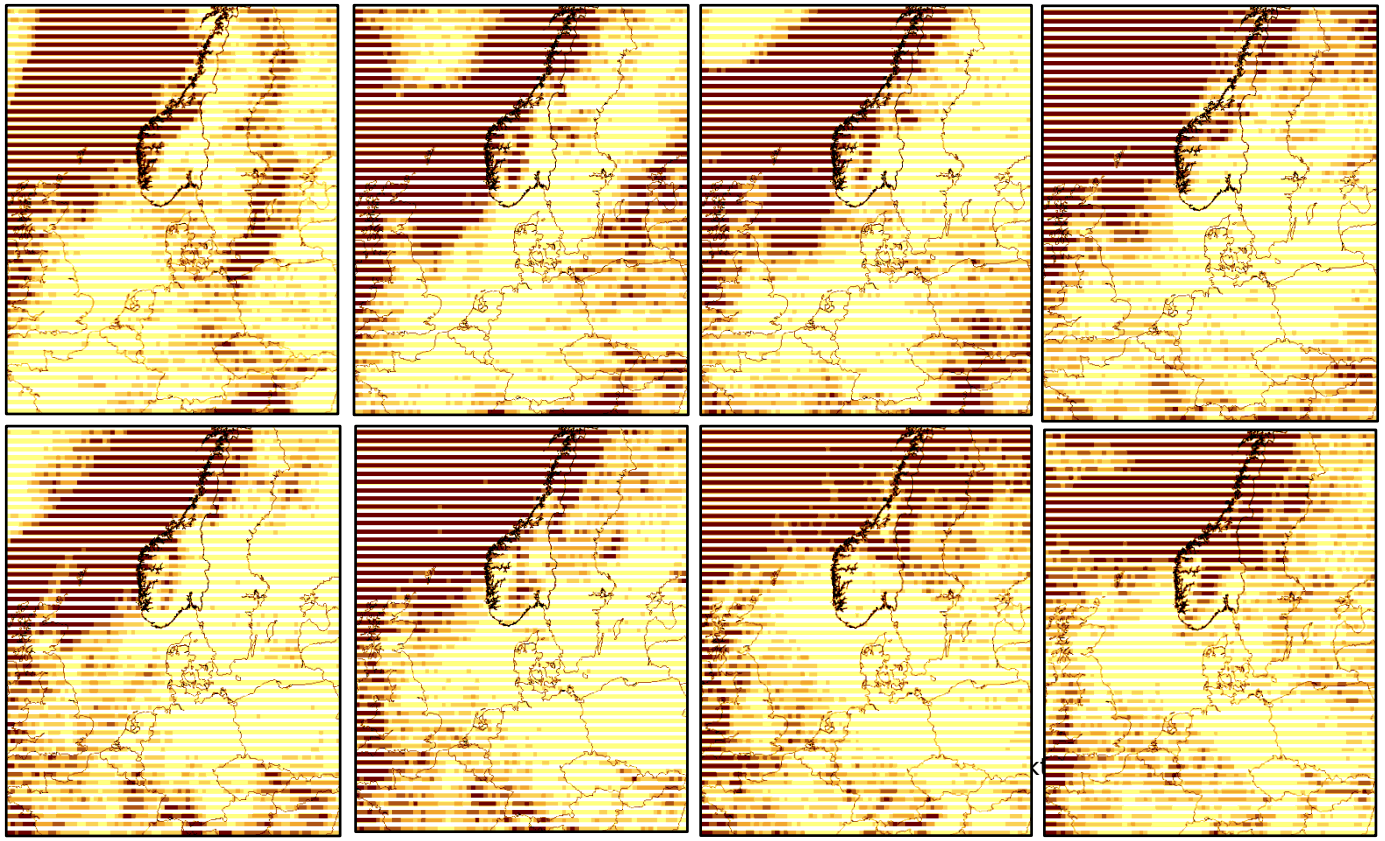
Biogas ressources

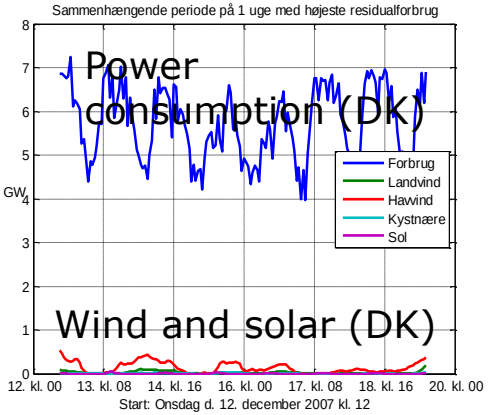


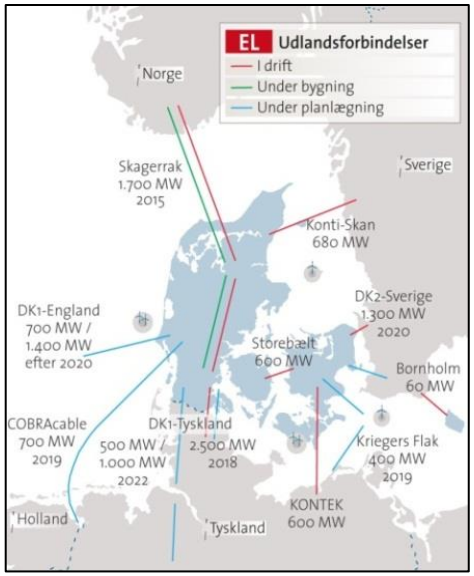

Heat production and price - Large DH area in DK
Varmeprod effekt (MWh/h)
1400
1200
1000
800
600
400
200
0
700
500
300
100
-100
-300
-500
2025-01-01 00:00
2025-02-01 00:00
2025-03-01 00:00
2025-04-01 00:00
2025-05-01 00:00
2025-06-01 00:00
2025-07-01 00:00
2025-08-01 00:00
2025-09-01 00:00
2025-10-01 00:00
2025-11-01 00:00
2025-12-01 00:00
Waste CHP
Bio CHP
Bio CHP
Heat pump
Bio boiler
Gas boiler
Gas boiler
Power price (DK1)
Heat price

Windpower in North sea region in a week with ”Worst case i DK”

From 12/12 kl. 24.00 and 7 days ahead







	0 - 0,14
	0,14 - 0,33
	0,33 - 0,55
	0,55 - 0,81
	0,81 - 1

- *Essential to use the geographical spread of windpower*