Offshore Grids

Large scale integration of offshore wind power

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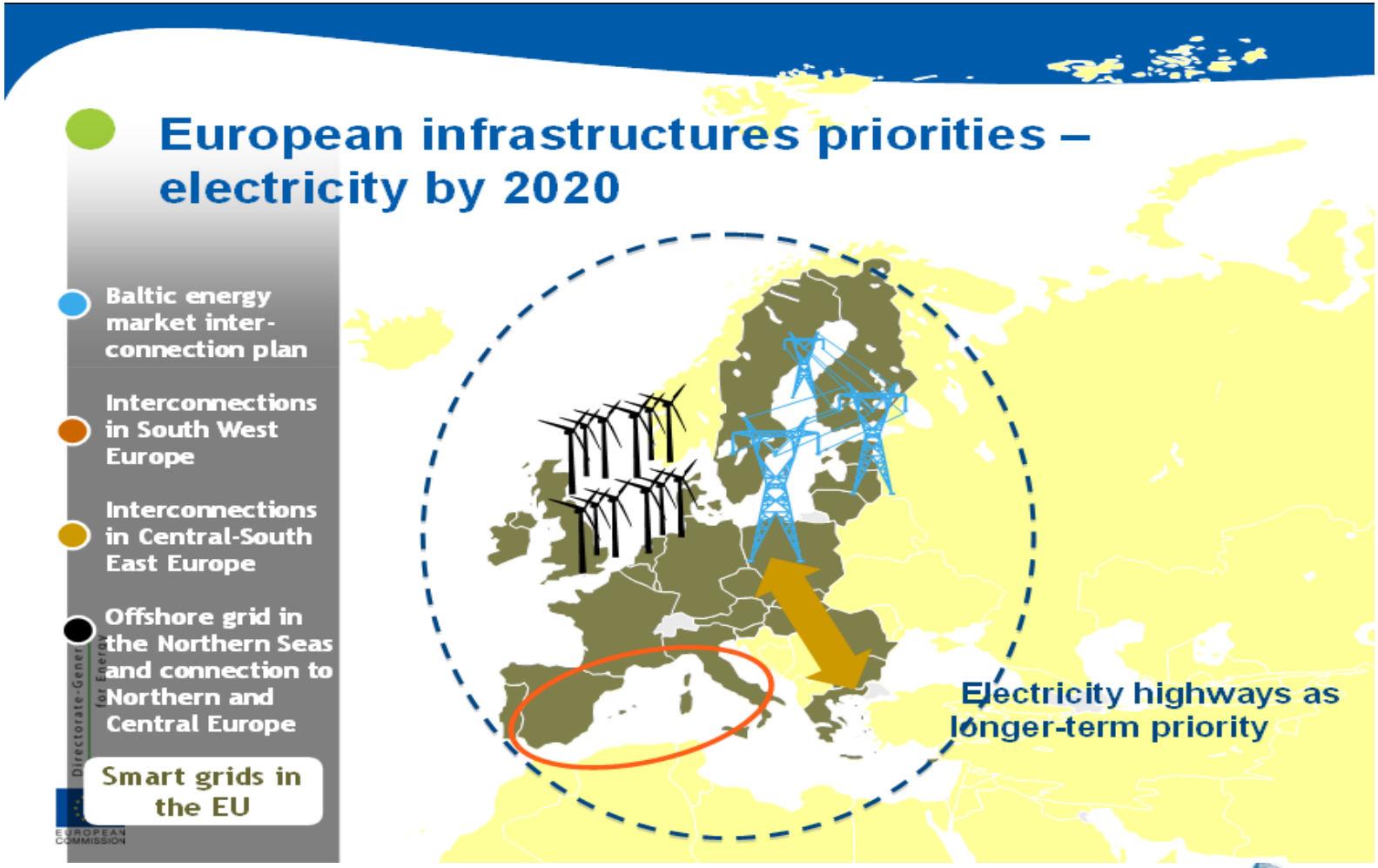
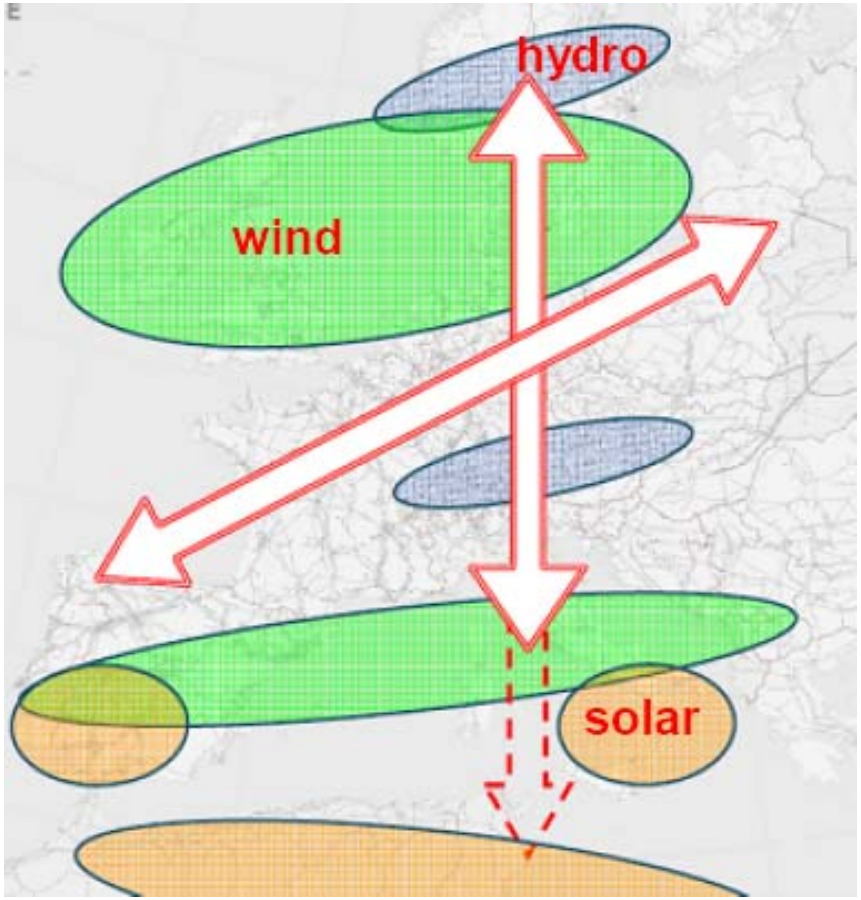
European Cooperation – EU / ENTSO-E / Regions



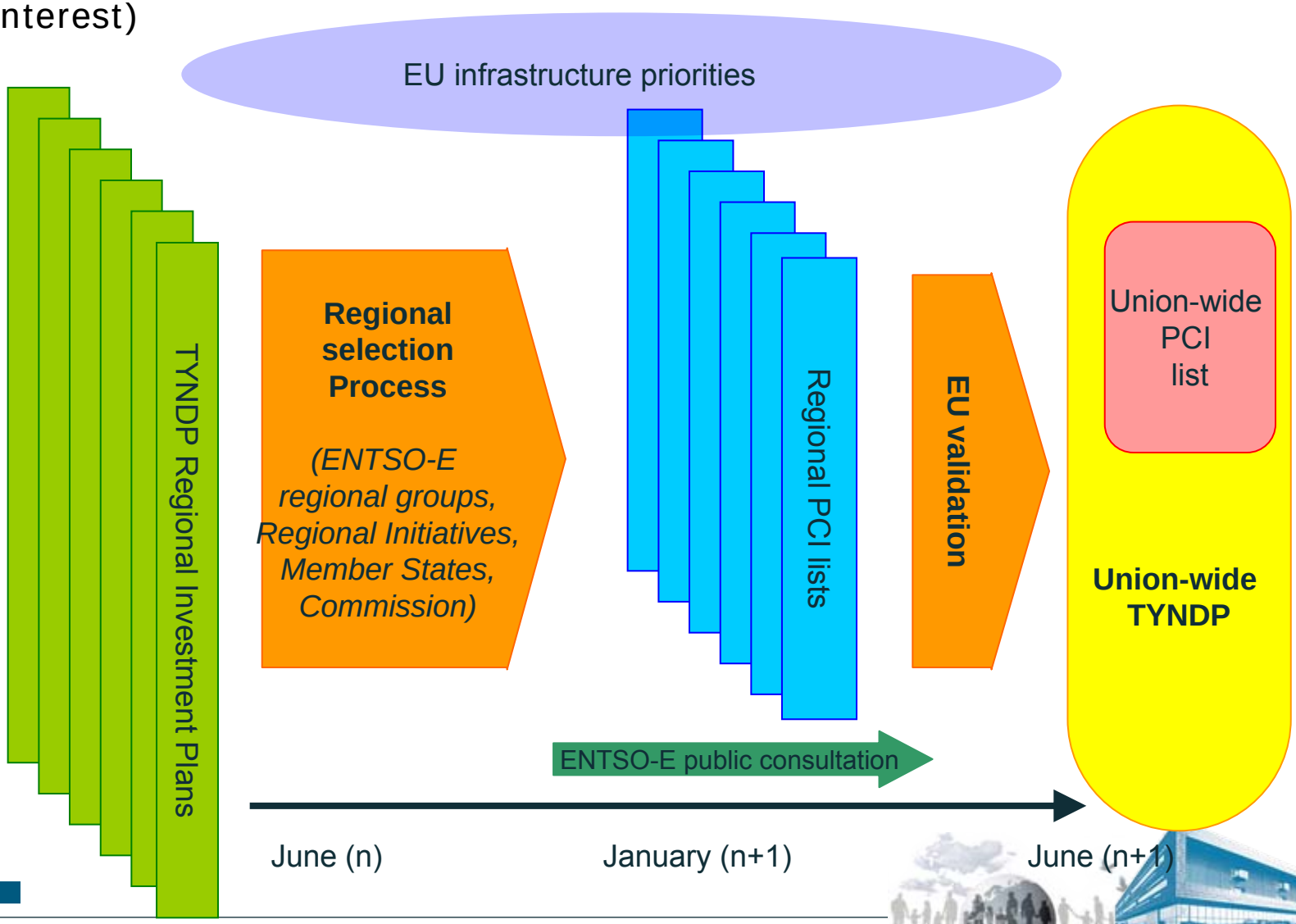
source: European Commission, DG ENER (March 2011)

The challenge: Need for increased transmission capacity



- More REN calls for increased transmission capacity
  - EU: more Wind and PV
- Investment needs until 2020 of 140 bill. EUR in the power grid (Commission)
- The solutions must be found on a European level

Project selection approach (PCI: Projects of Common Interest)



Power balance 2011

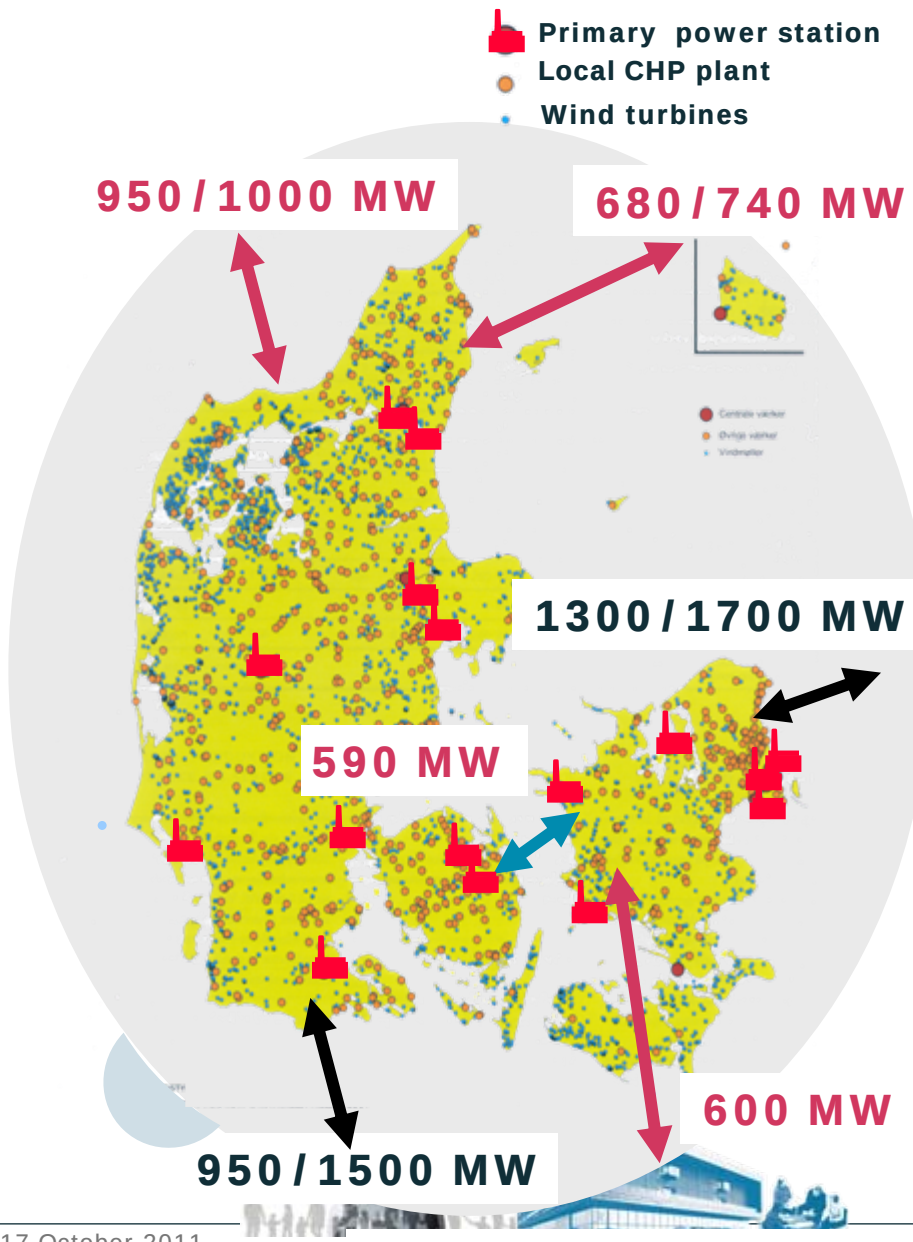
Two synchronous areas

West:

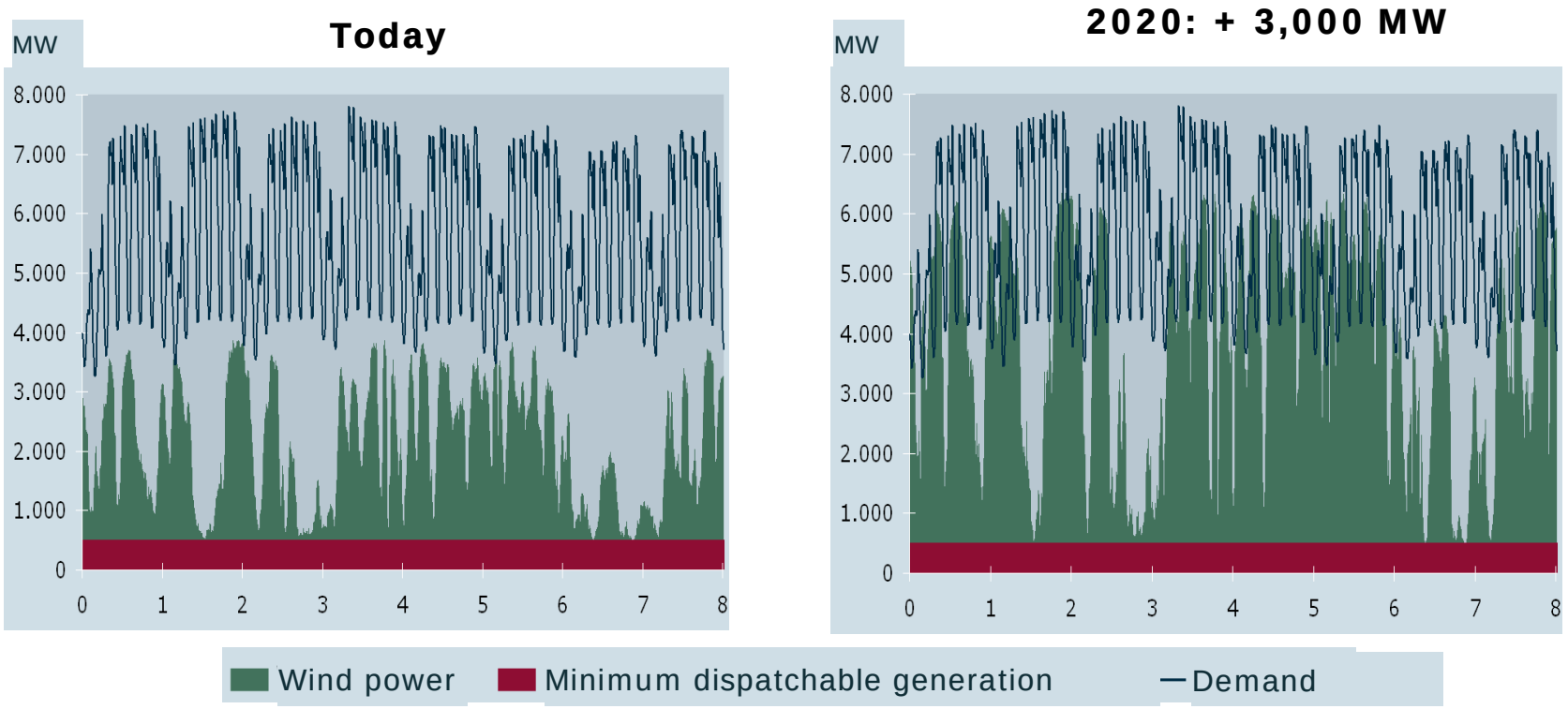
Consumption	1400 - 3700 MW
Primary power stations	3400 MW
Local CHP plants	1850 MW
Wind turbines	2850 MW

East:

Consumption	900 - 2700 MW
Primary power stations	3800 MW
Local CHP plants	650 MW
Wind turbines	950 MW



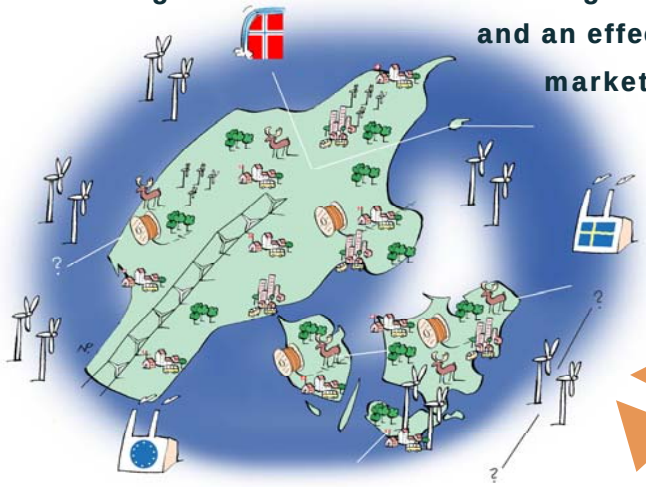
Additional 3,000 MW wind power by 2020



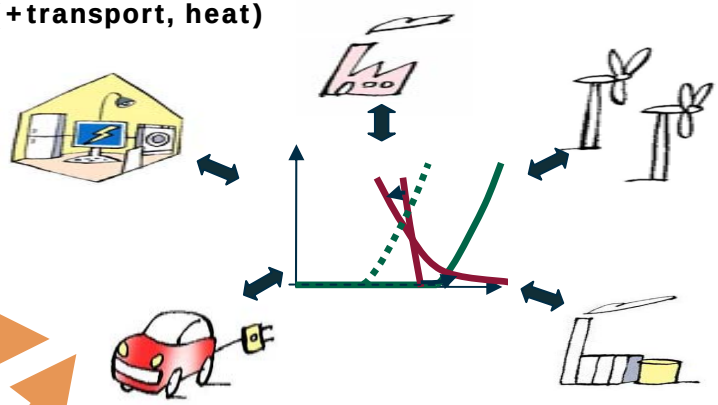
Optimum utilisation of **domestic flexibility** and **international electricity markets** is a precondition for maintaining security of supply and maximising the value of wind power

Efficient integration of wind power

A strong international transmission grid and an effective market



Market based mobilization of flexible resources (+transport, heat)



Smart Grids / integration of users' actions

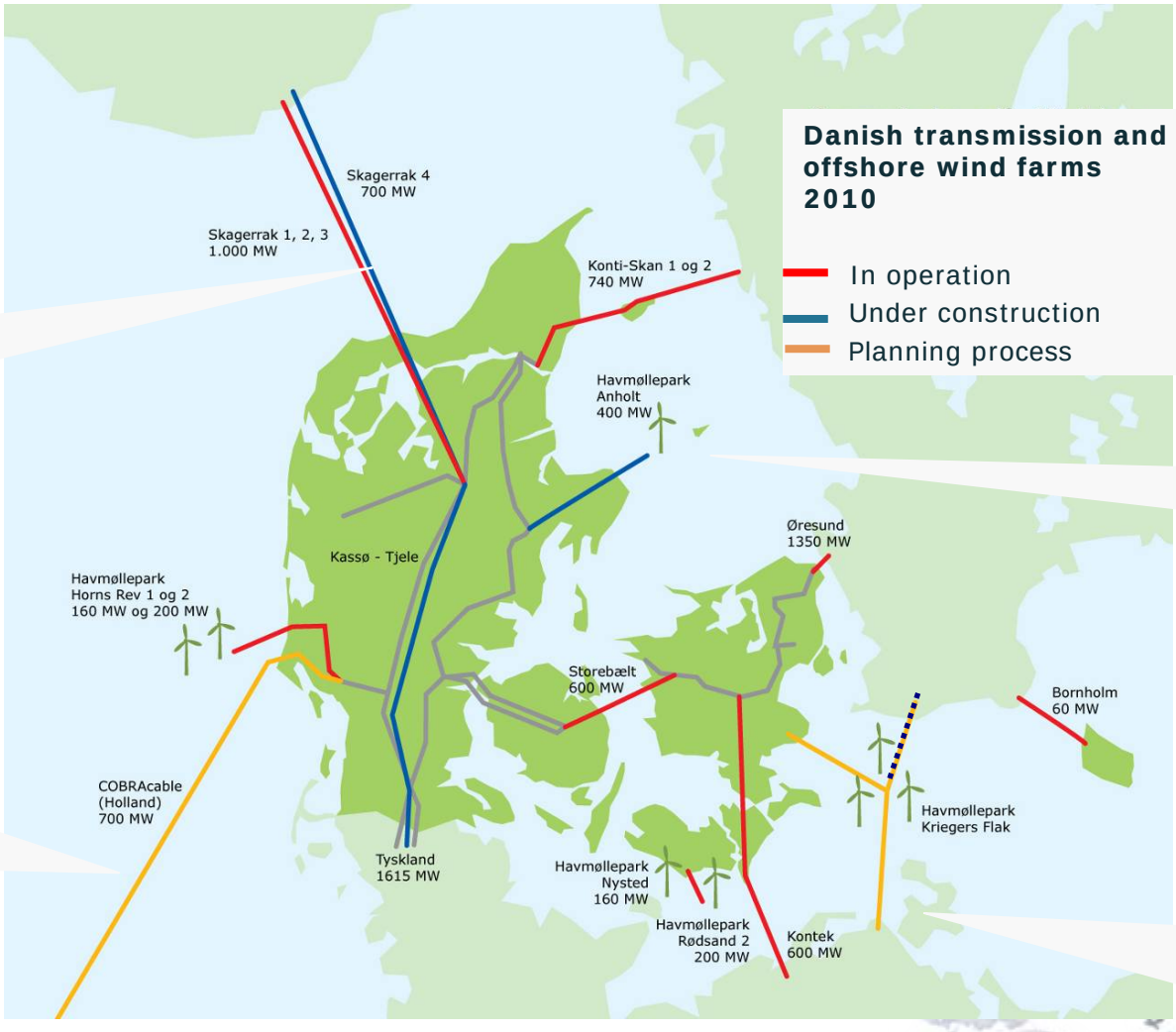
Reinforcements of the transmission grid and interconnectors

Skagerrak 4

700 MW - HVDC

NO-DK1

HVDC - VSC



Anholt 1+2

400 MW

Wind farm offshore

COBRA

700 MW - HVDC

NL-DK1

EC co-funding

HVDC - VSC

Kriegers Flak

600 MW Wind farm offshore

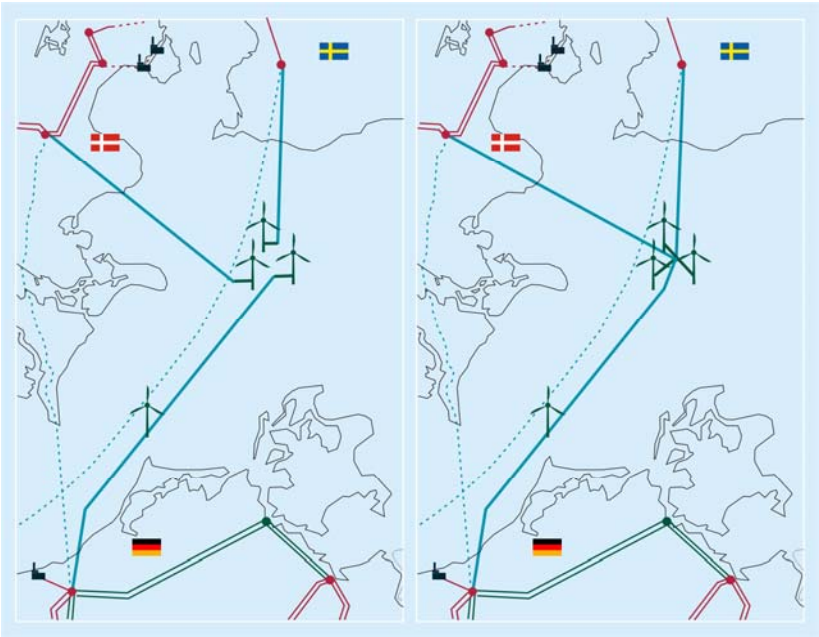
600 MW – HVDC

HVDC - VSC

DE-DK2

EC co-funding

Kriegers Flak:
Joint TSO Project for Combined Grid Solution



- **How** would future wind power plants (1600 MW) at Kriegers Flak **best be connected**?

- **Dual-purpose concept**:
  - Both wind energy and cross-border electricity trade on the same grid connection

- **Joint TSO study**
  - 50herz
  - Swedish National Grid (SVK)
  - Energinet.dk

Status and possible combinations

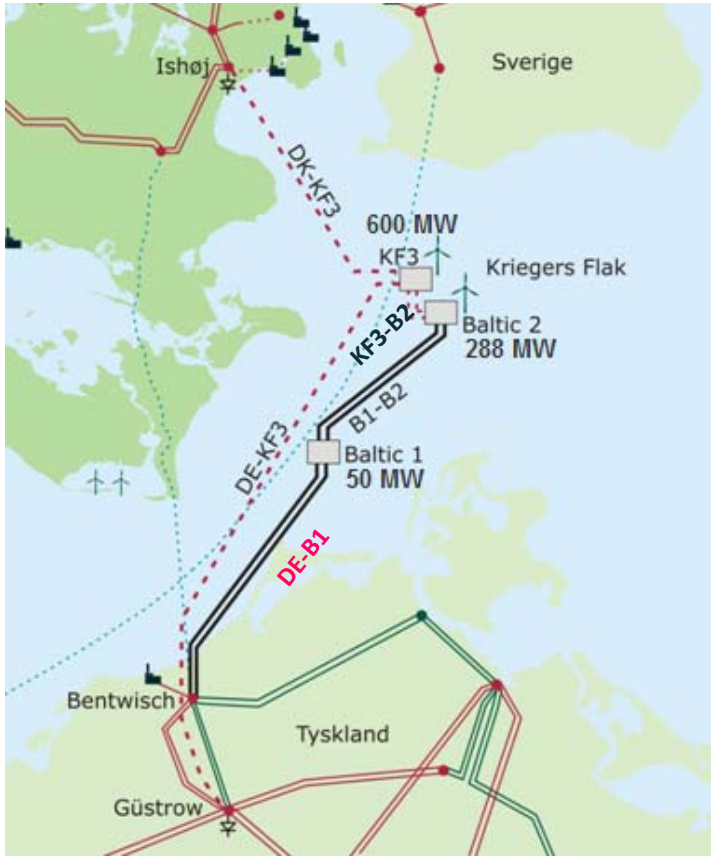
Offshore Wind Farms

- Baltic 1 50 MW *in operation*
- Baltic 2 288 MW *decided*
- Kriegers Flak 3 600 MW to be decided

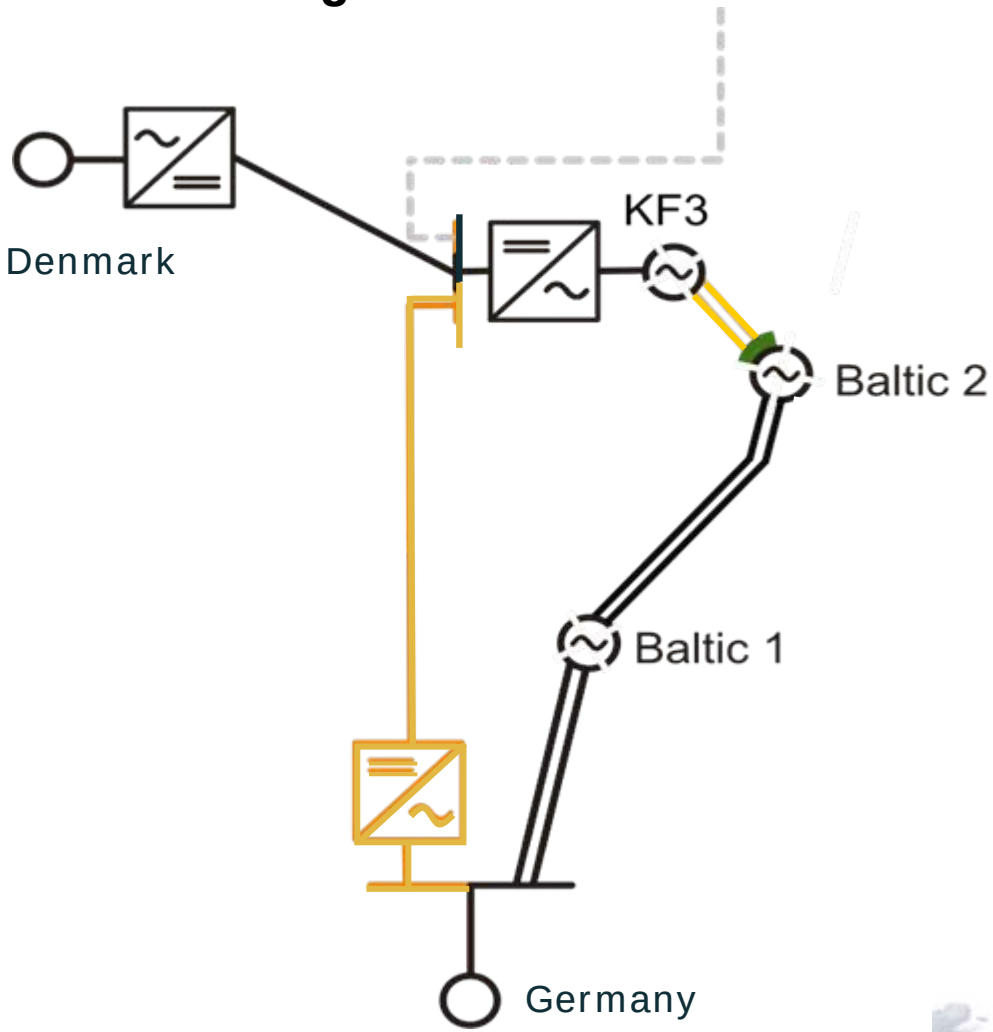
Cables

- DE - Baltic 1 ~400 MW AC *in operation*
- Baltic 1 - Baltic 2 ~400 MW AC *ordered*
- DK - KF 3 ??? MW DC VSC to be decided
- Baltic 2 - KF3 ??? MW AC to be decided
- DE-KF3 ??? MW DC VSC to be decided

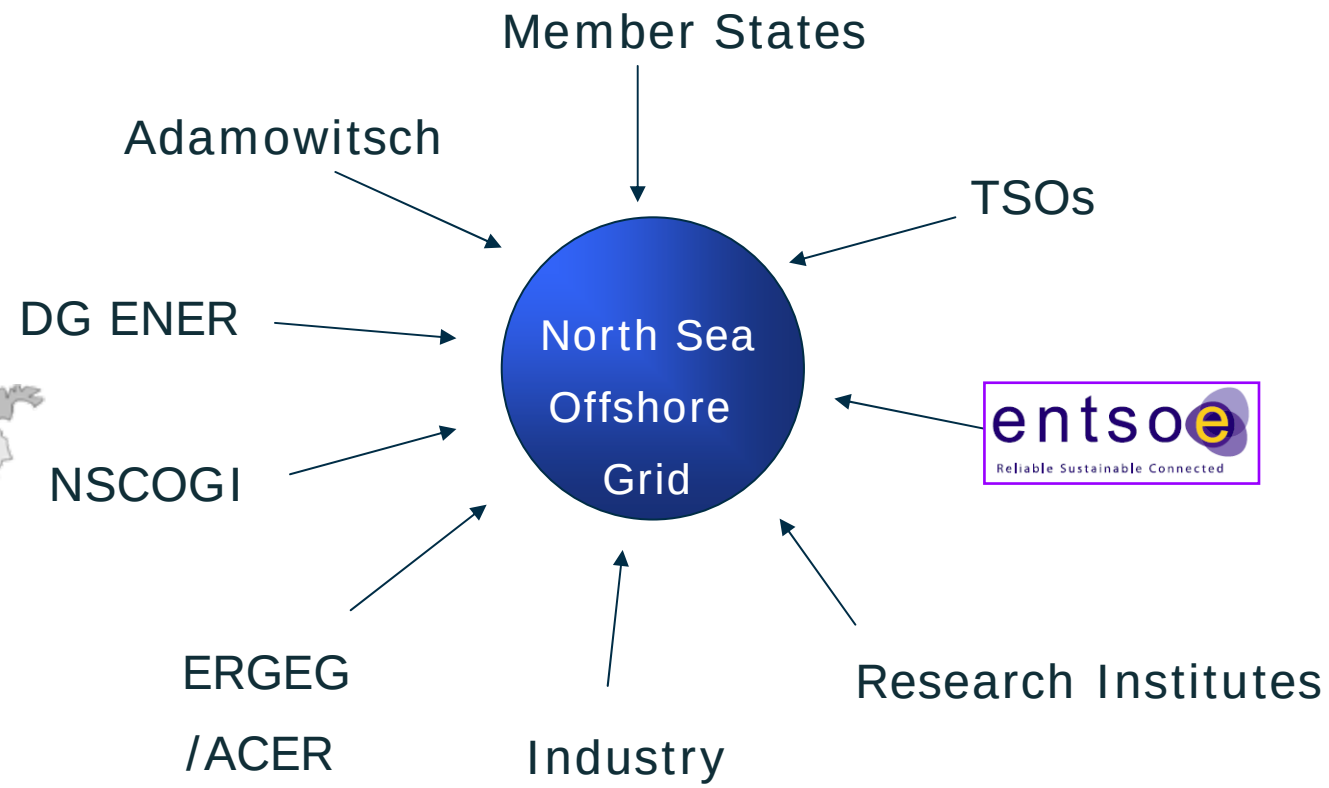
Option for Swedish OWF and cable at a later stage



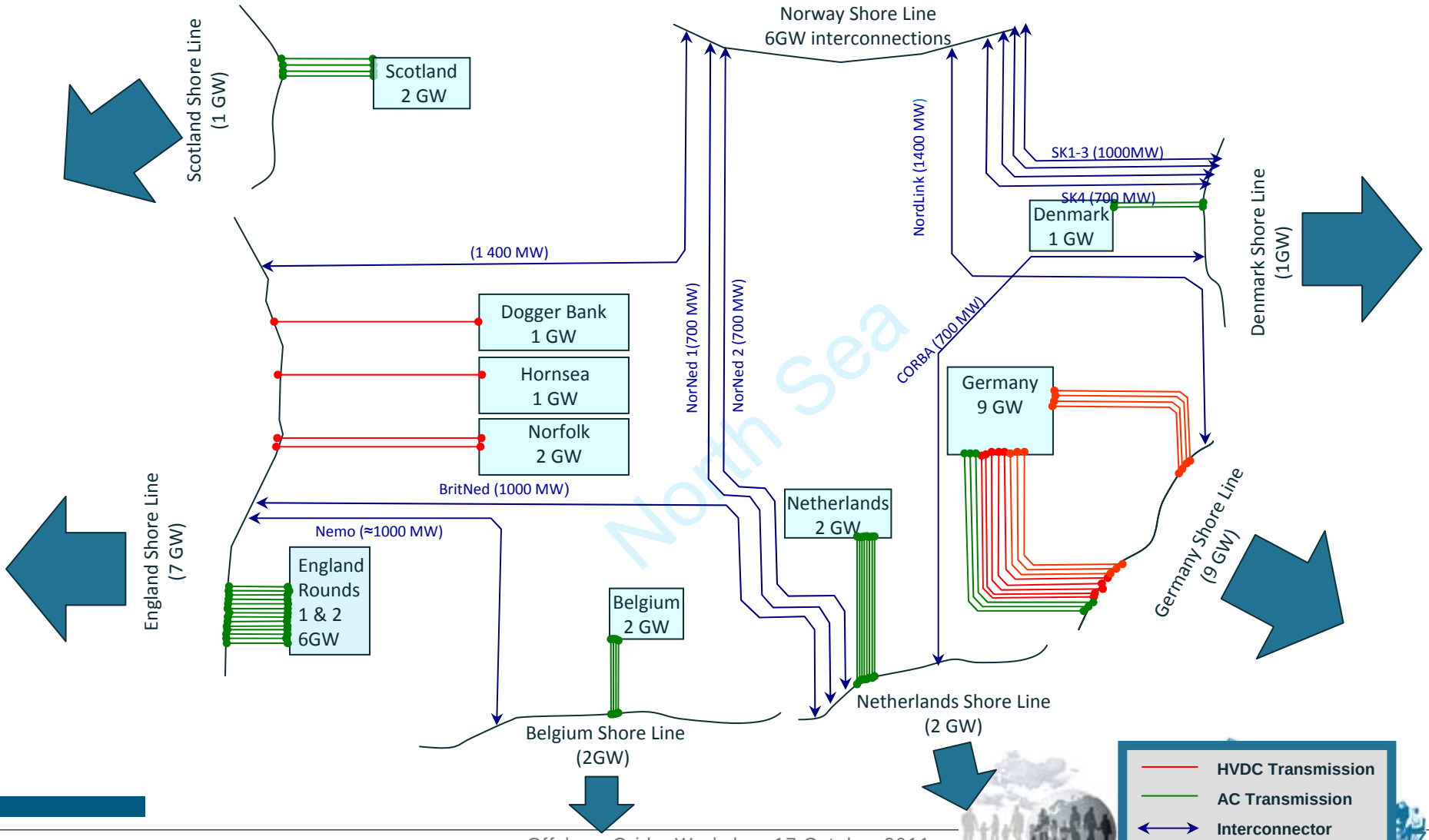
Possible Final Configuration



Stakeholders of ”North Sea Offshore Grid”



North Sea 'in flight' and operational large projects up to 2020



2030 wind volumes demand different thinking

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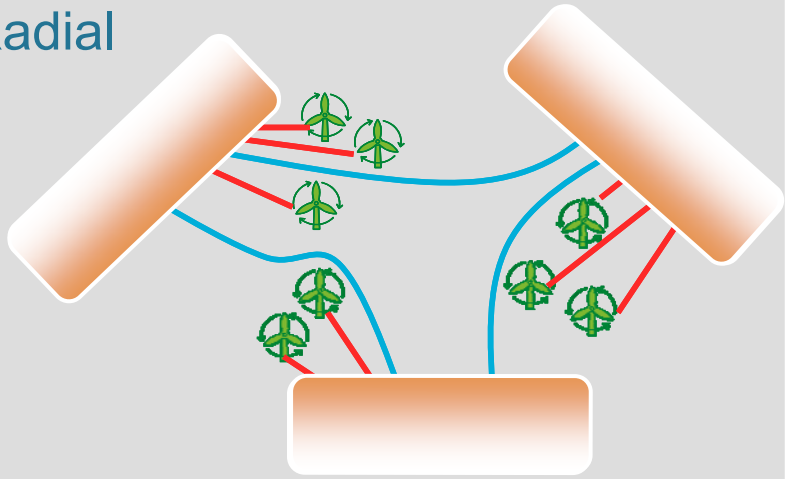
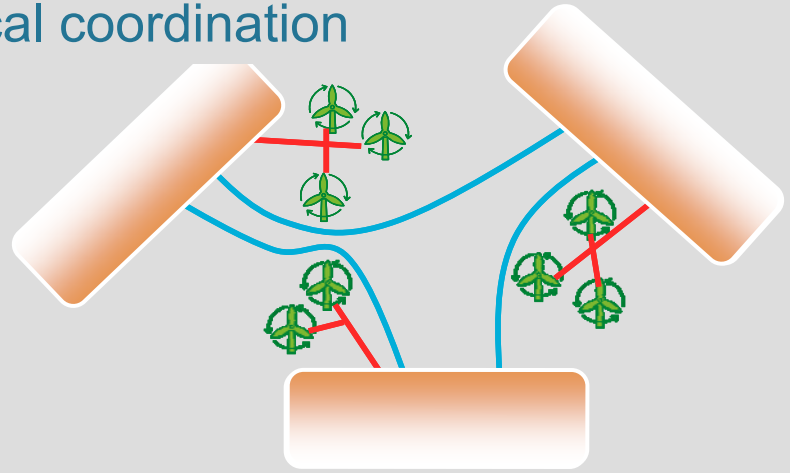
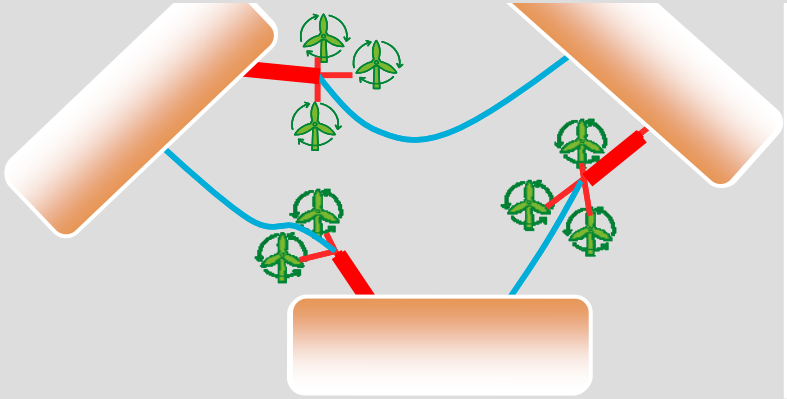
Radial



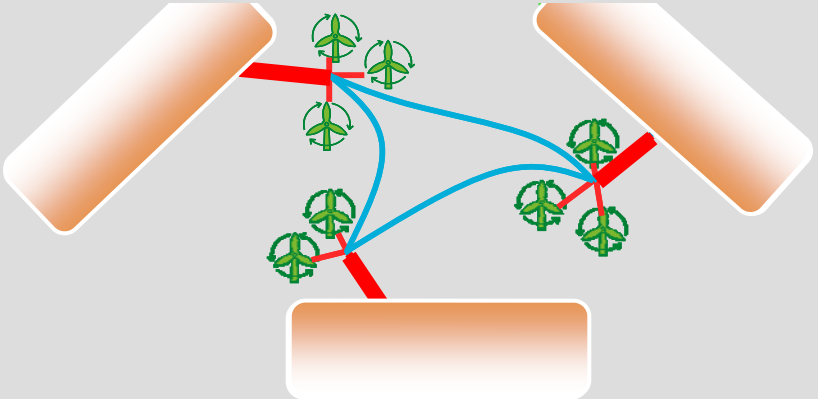
Local coordination



International coordination

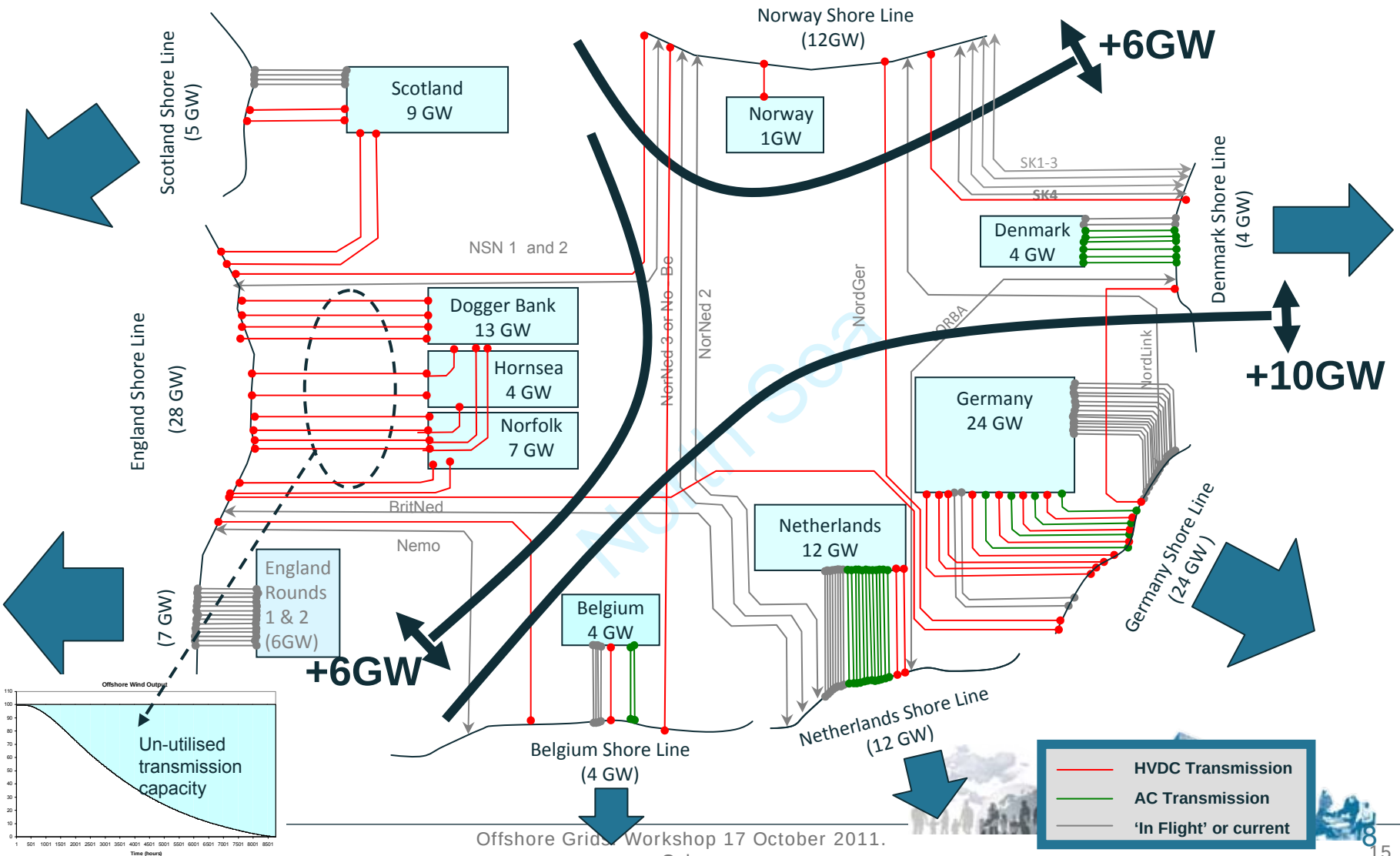


Fully integrated solution

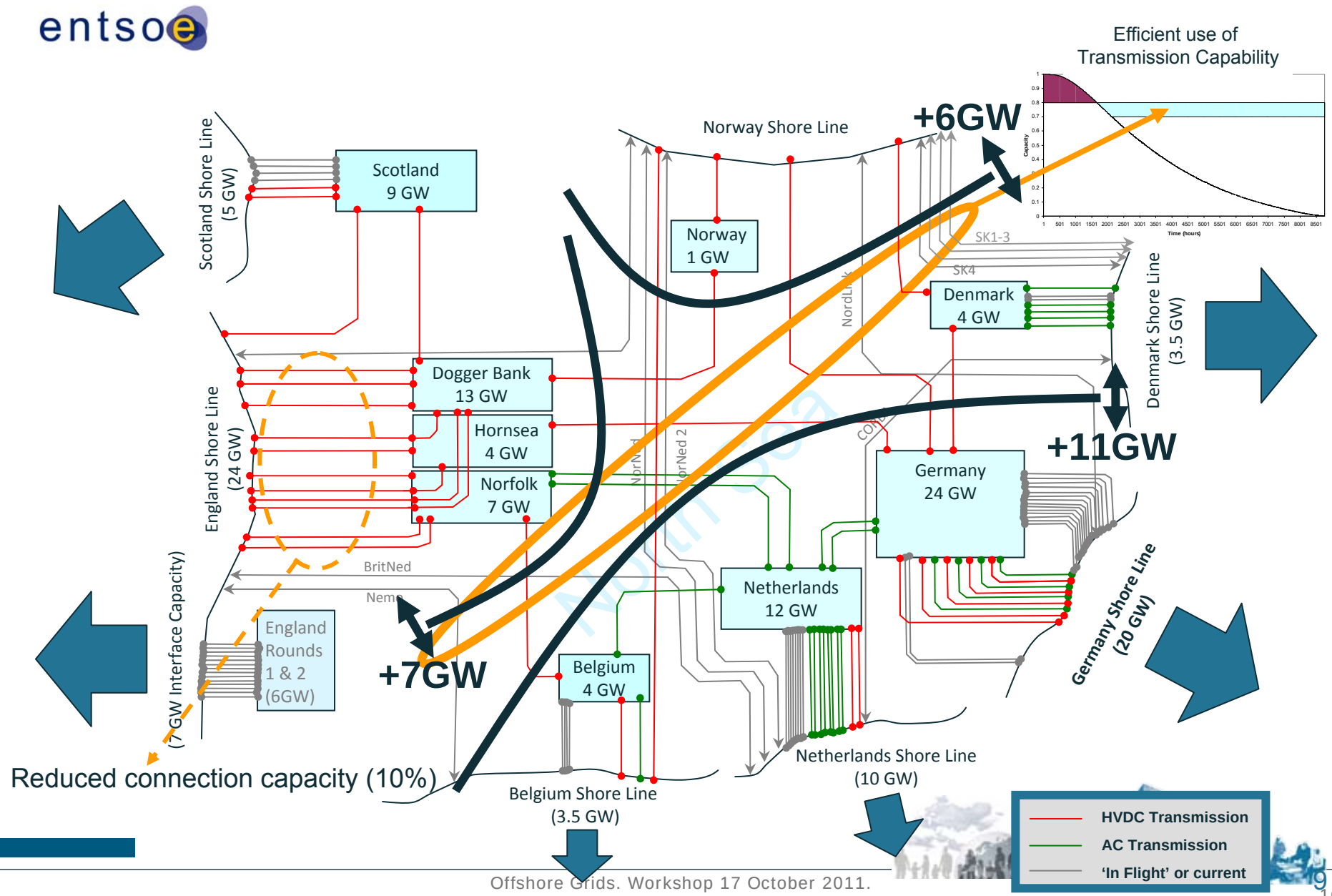


Conceptual design for 2030

Accelerated **radial** offshore circuits by 2030 with additional interconnection on top of 'in flight' interconnections



Integrated offshore grid development by 2030

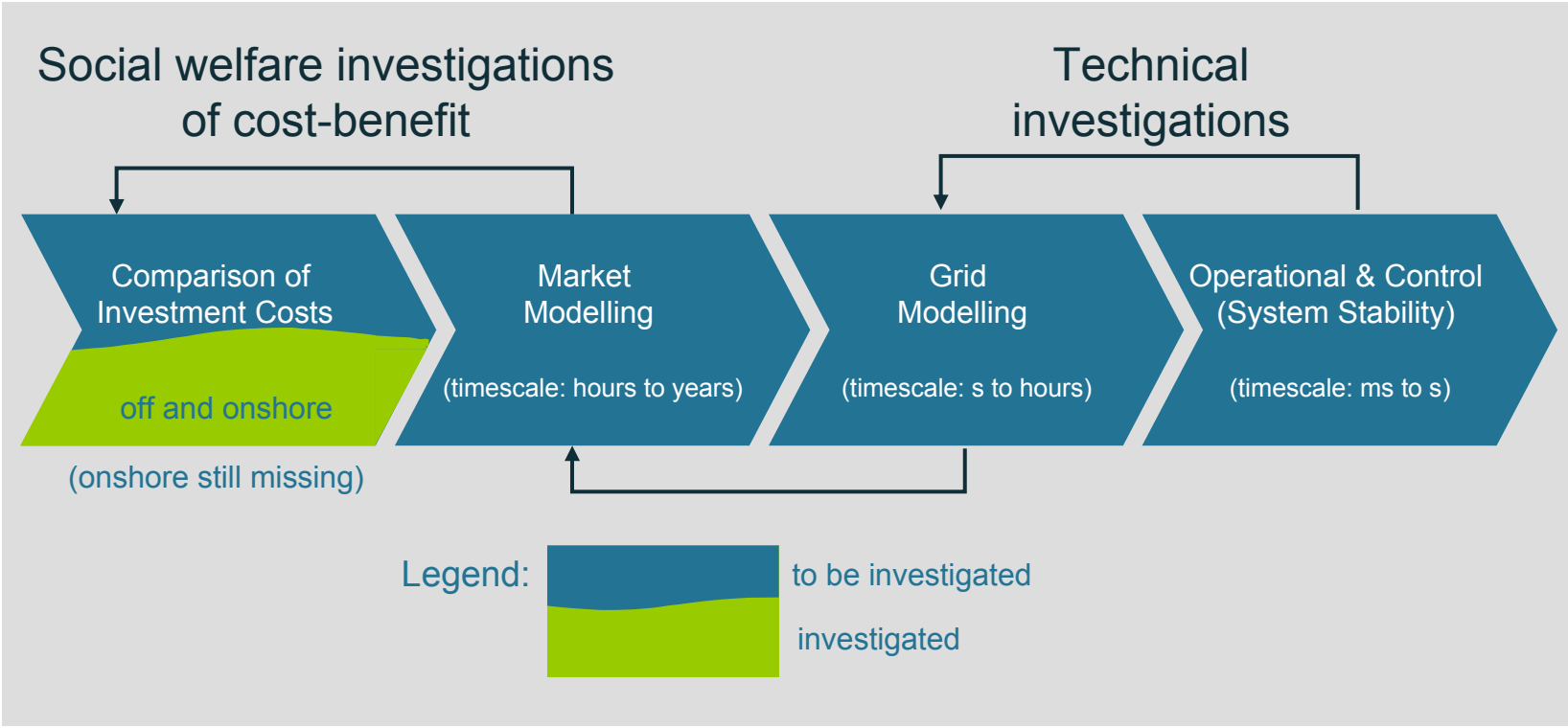


Comparison of network designs

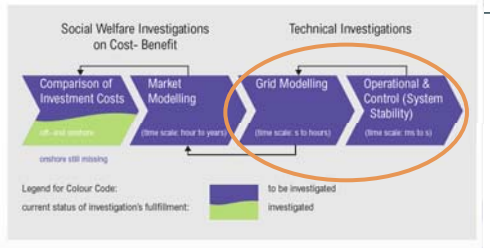
* Remark:
figures would be identical, if interconnection capacities would be the same
– but we have slightly different (2 GW) interconnector capacities between the investigated radial and integrated solutions…

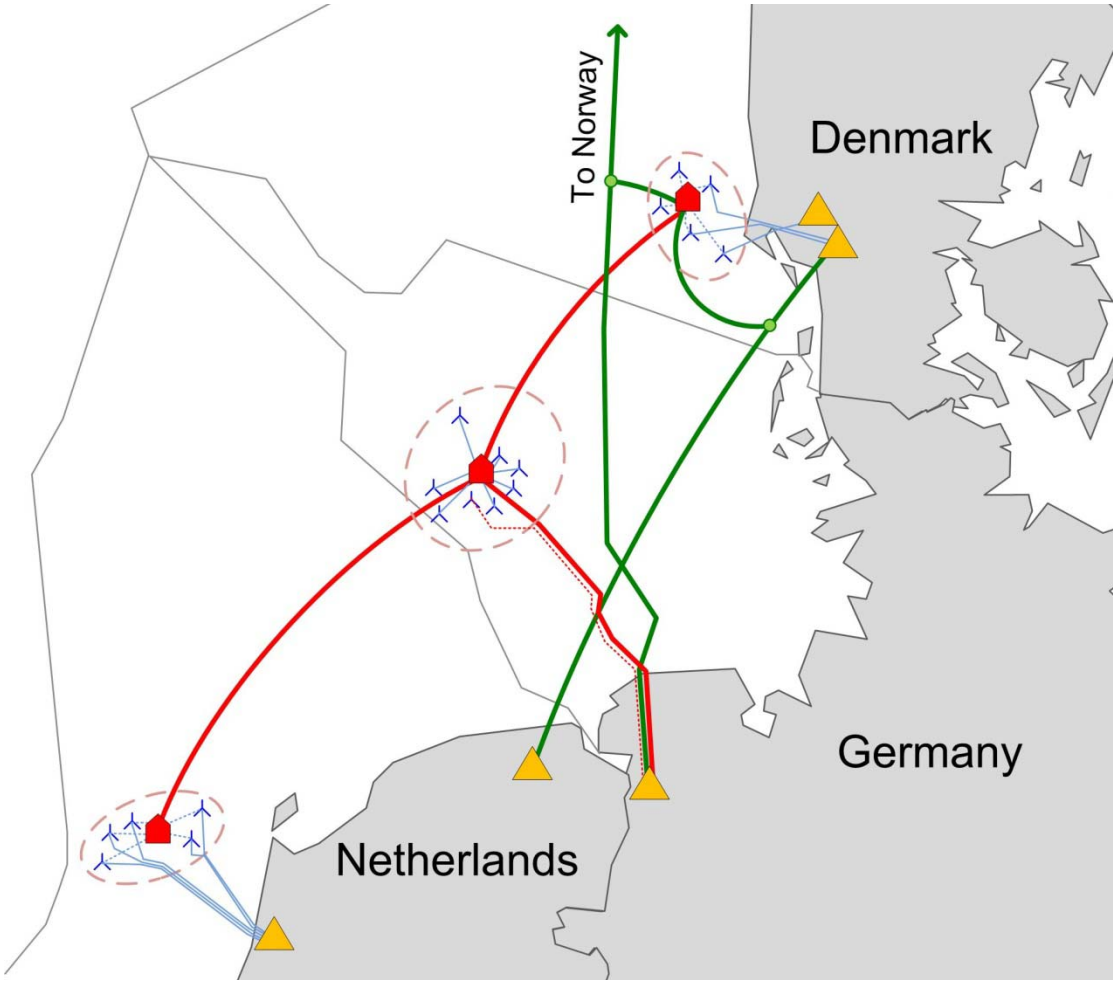
	Radial		Integrated (with ~ 6-10 GW interconnector capacity)	
	No additional Interconnector Capacity	Additional Interconnector Capacity BASE CASE	Transmission Capacity to meet 100% wind output	Network Optimised Capacity to meet 90% wind output
CAPEX (€bn) Additional to 2020 TYNDP	67.5	70.5	68.5	63
Cross border trade (TWh) (With no wind curtailment)	75	180*	195	190
Max Cross border trading (TWh) (with wind curtailment)	75	180*	202	202*
Wind curtailment to facilitate Max border trading (% of output)	0%	0%	3.5% 7TWh	6% 12TWh
Annual Wind Energy lost due to outages (TWh)	14.5TWh	14.5TWh	~ 1TWh	6TWh

Status of investigations



Offshore Test System



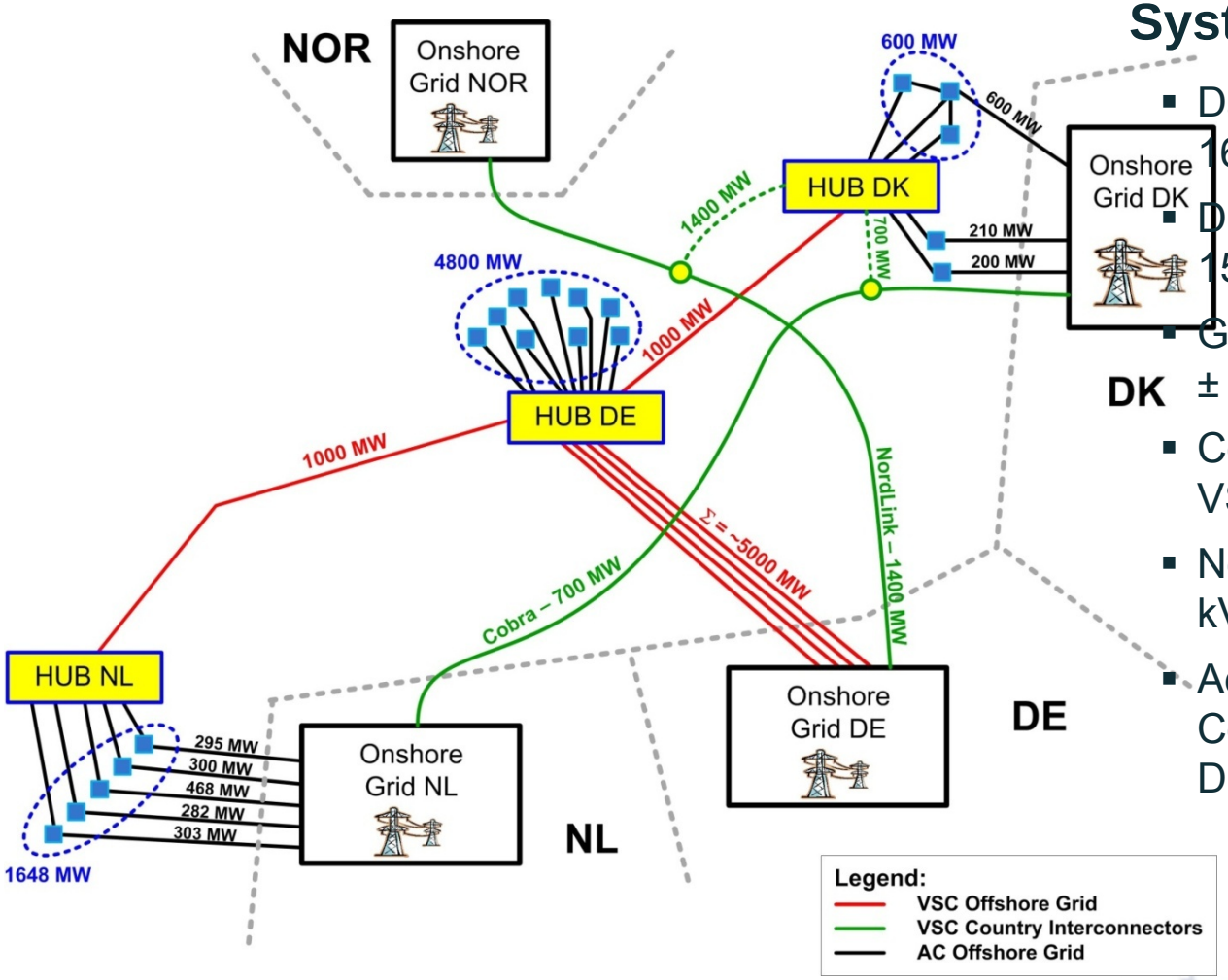


Legend:

- DC links interconnecting wind farms with onshore system as well as interconnecting offshore DC hubs to each other
- DC links interconnecting two countries as e.g. Cobra or Nord-Link
- Onshore interconnection points
- Offshore DC hubs
- Offshore wind farms
- AC interconnectors of offshore wind farms

Offshore Test Syste

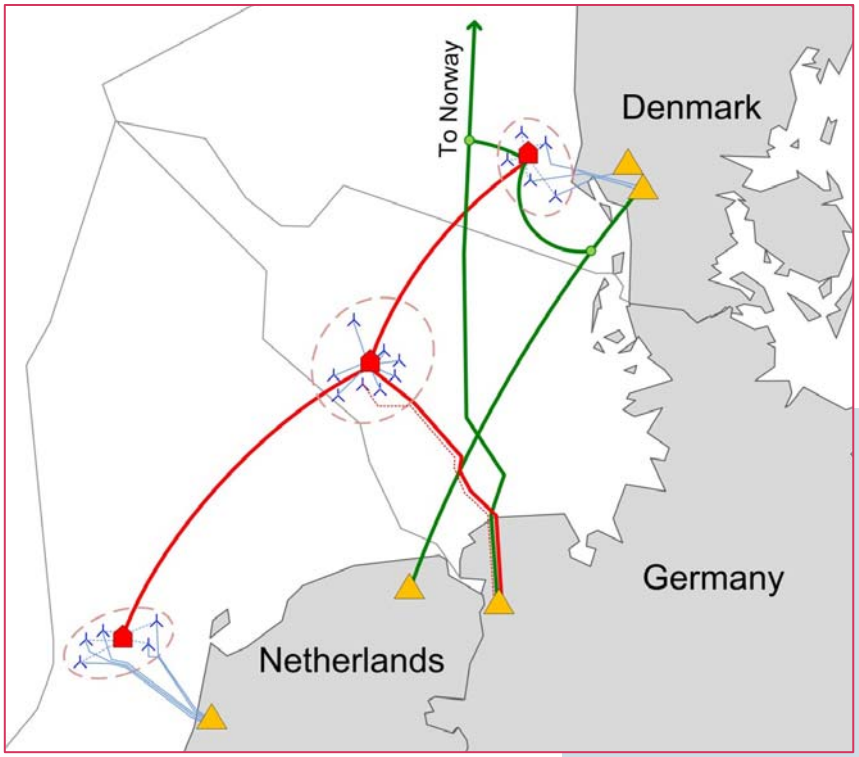
General Structure

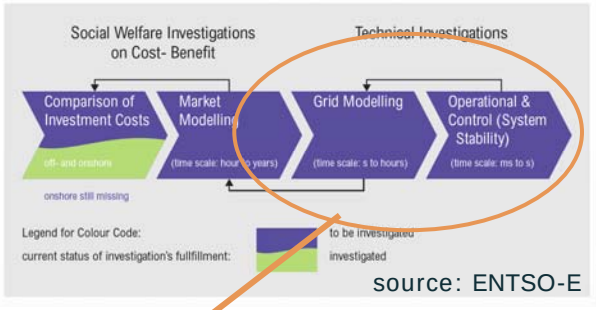


System Parameters:

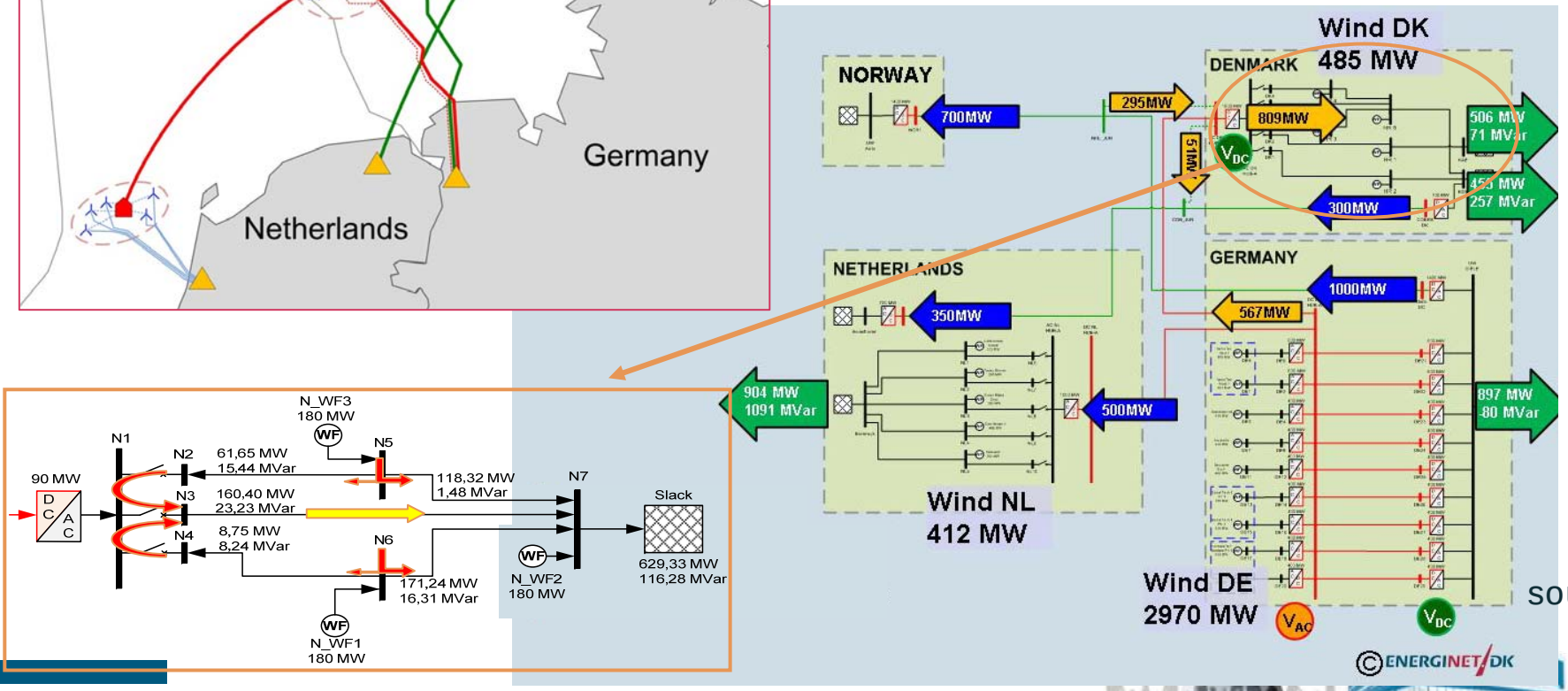
- Danish farms connected with 165 kV AC cables
- Dutch farms connected with 150 kV AC cables
- German farms connected with ± 320 kV VSC HVDC
- Cobra link DK-NL → ± 320 kV VSC HVDC
- NordLink NOR-DE → ± 320 kV VSC HVDC
- Additional interconnectors Cobra-DK hub and NordLink-DK hub assumed

Offshore test system – example of results



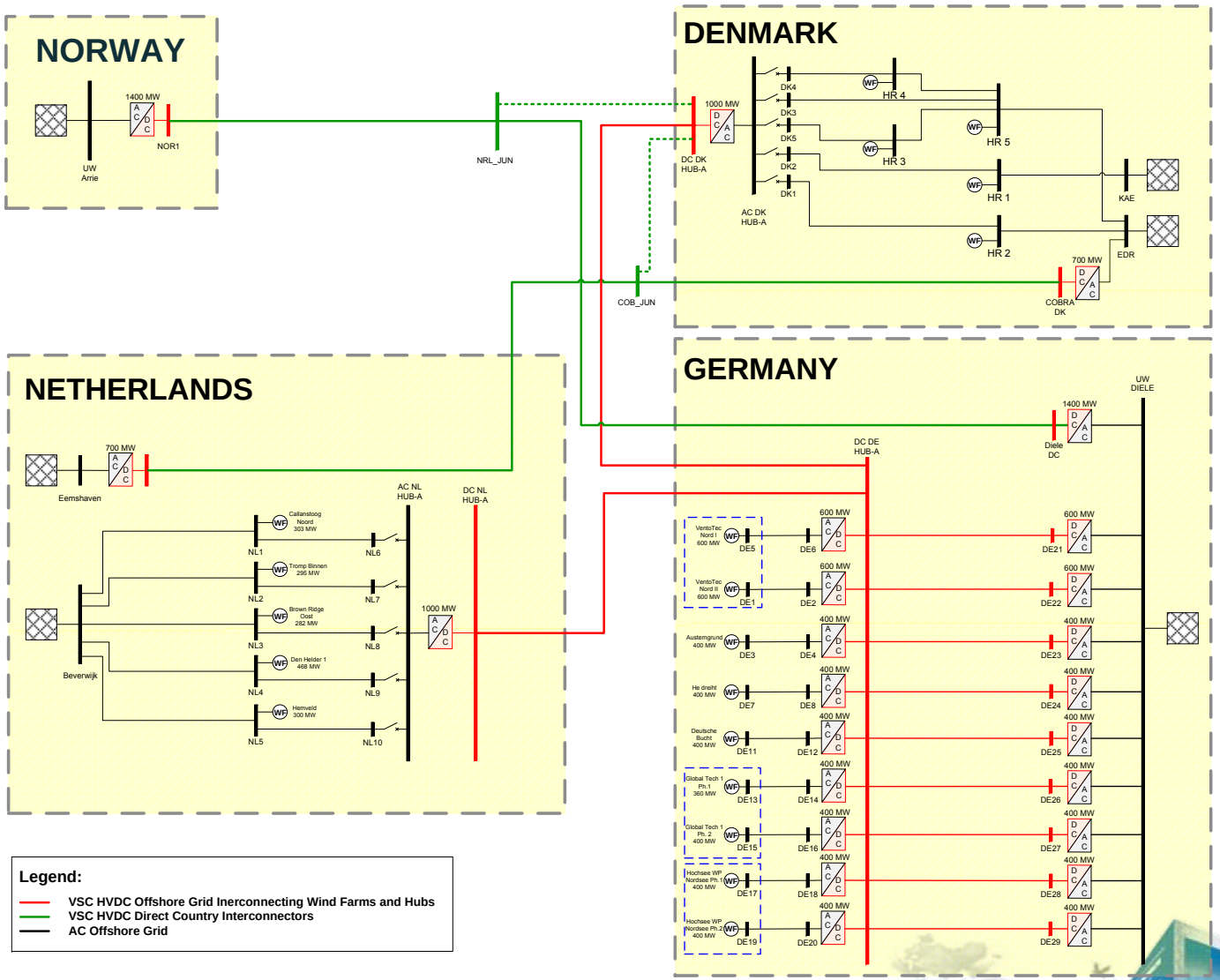


source: ENTSO-E

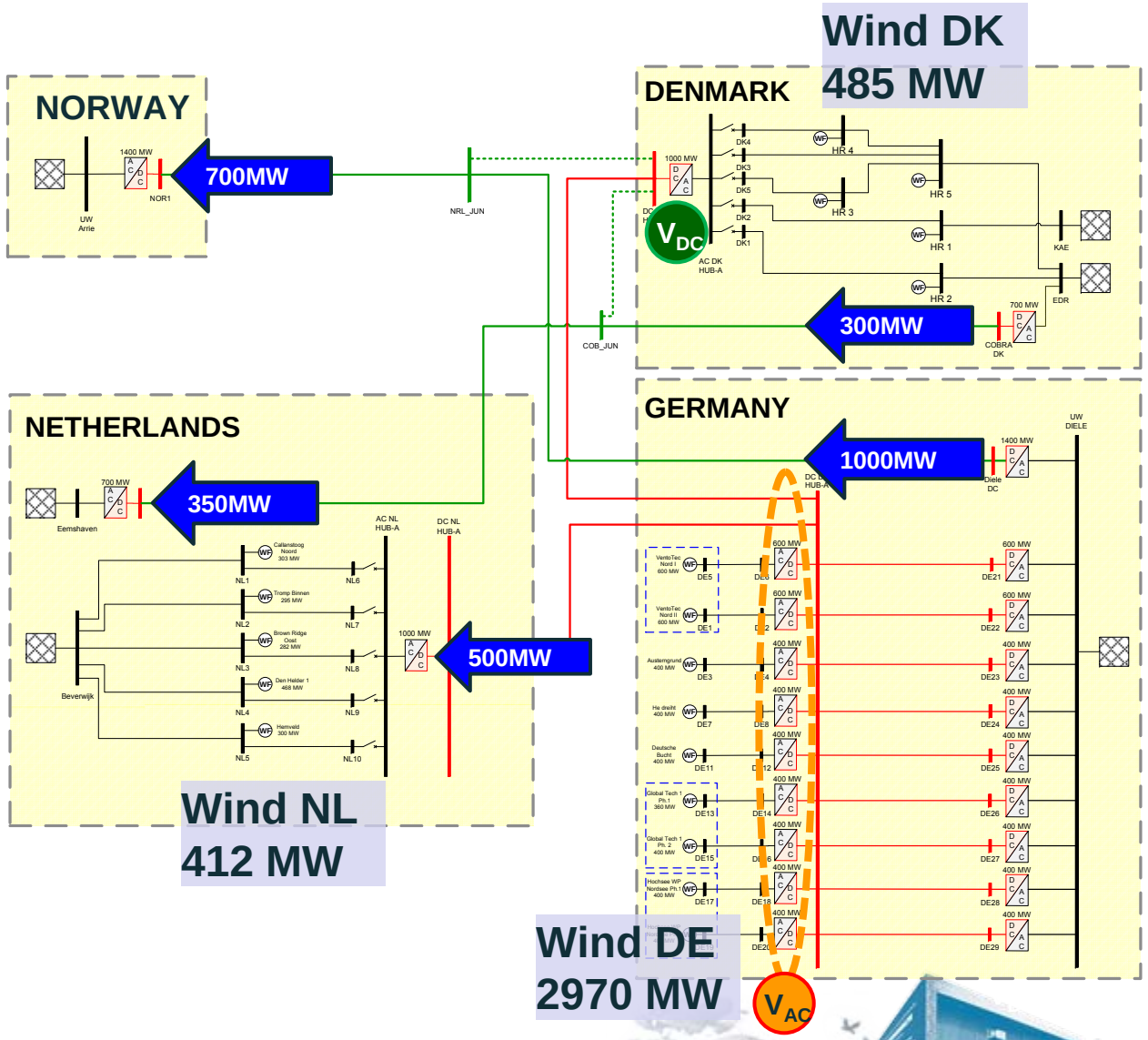


source: OPSA

Offshore test system – example of results



Offshore test system – example of results

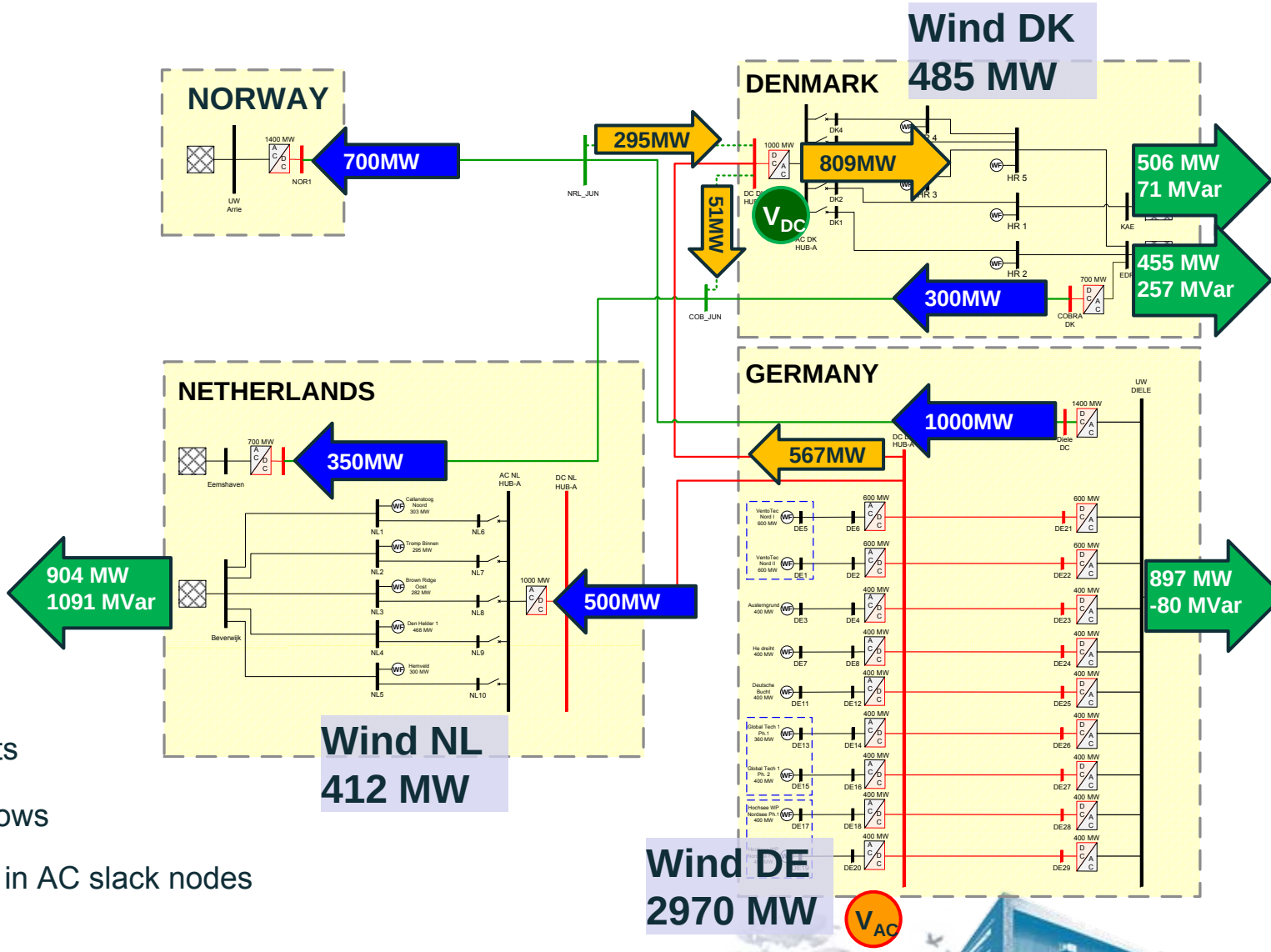


V_{DC} V_{DC} operation mode

V_{AC} V_{AC} operation mode

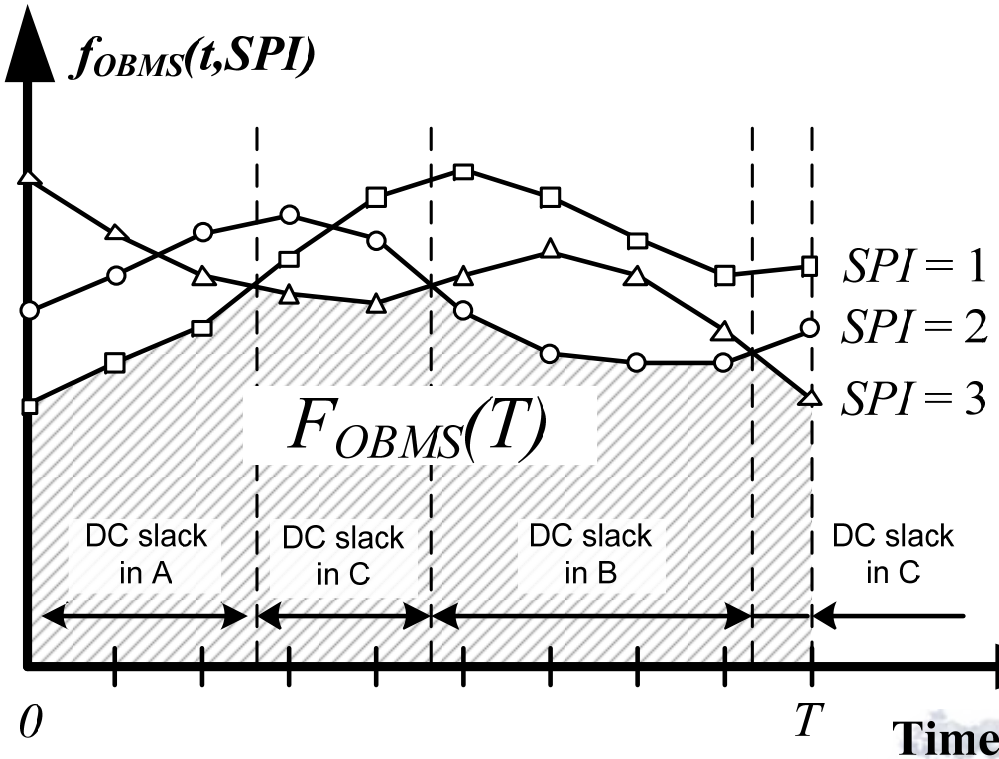
Power set-points

Offshore test system – example of results



Optimal DC slack position in offshore grid

Objective: Minimize deviations between DC grid flows and market dispatch
Constraint: voltage limits must be must be satisfied



Offshore Grids – Summary (1)

- Benefits of international integration of large scale offshore wind e.g. in the Nord Sea (compared to national radial connection concept)
  - more cost effective cross border trade (combining the connection of wind power and interconnectors)
  - fewer and larger assets reduce the number of seabed routes, landing points and converter sites
  - coordinated plan provides basis for cost effective modular development
- Coordination of load flows in complex offshore power system requires sophisticated control methods
- As in AC systems unwanted power flows can be expected in meshed multi-terminal DC systems

Offshore Grids – Summary (2)

Knowledge gaps and challenges:

- Operation and control of meshed DC-grids for large-scale offshore wind power need special attention (R&D)
- A working VSC multi-terminal HVDC systems has not been demonstrated
- Control and protection of offshore grid systems with a high share of HVAC and/or HVDC cables is a challenge
- HVDC circuit breaker – will it be developed for high voltages? It there a work-around..?
- Development of standards & technology :"plug & play" of components from different vendors is crucial. Presently, any proposed multi-terminal solution would be supplier specific.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