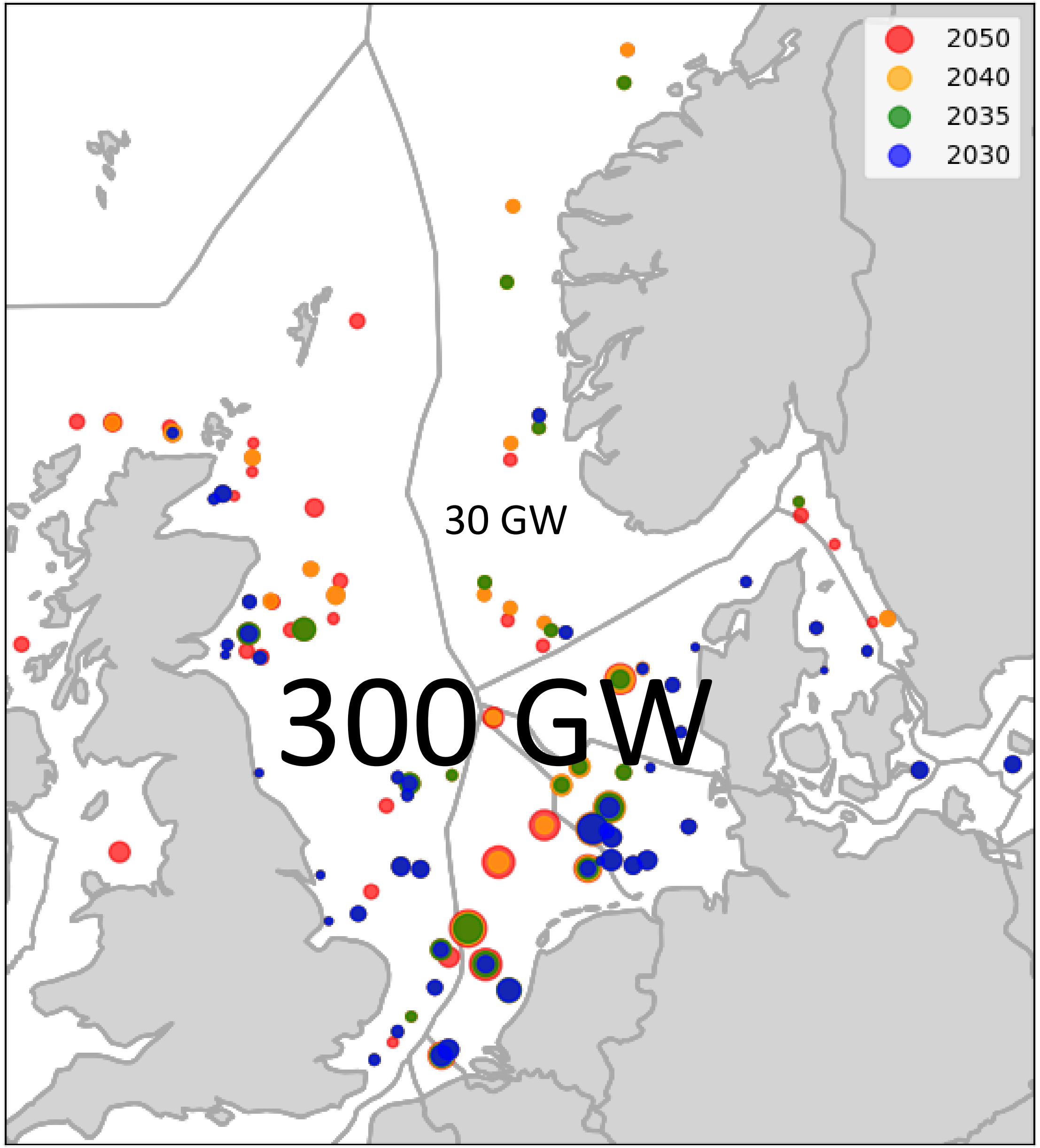
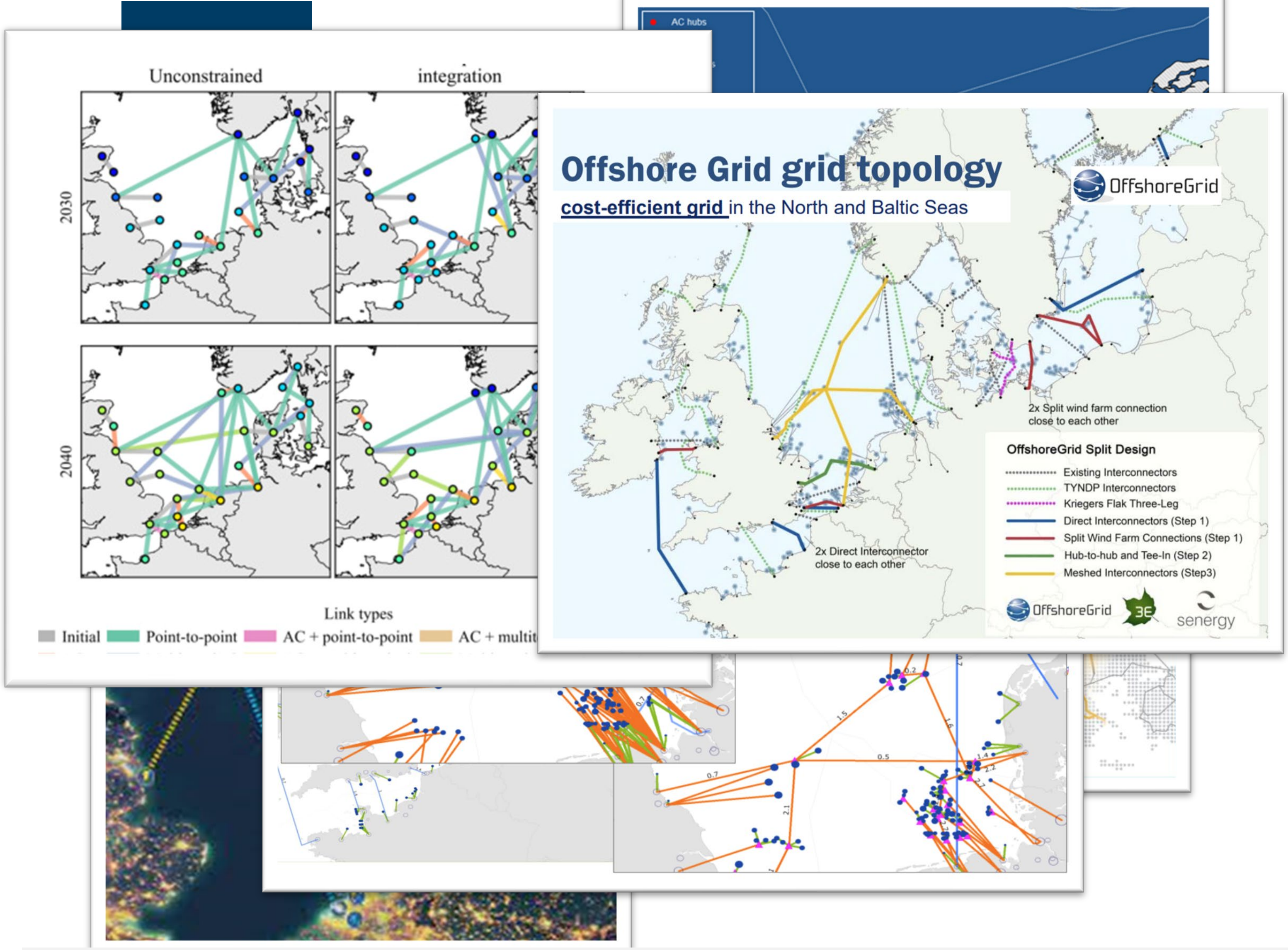
SINTEF

Offshore grid optimisation for 30 GW of Norwegian offshore wind

Harald G Svendsen, Spyridon Chapaliglou
SINTEF Energy Research
harald.svendsen@sintef.no





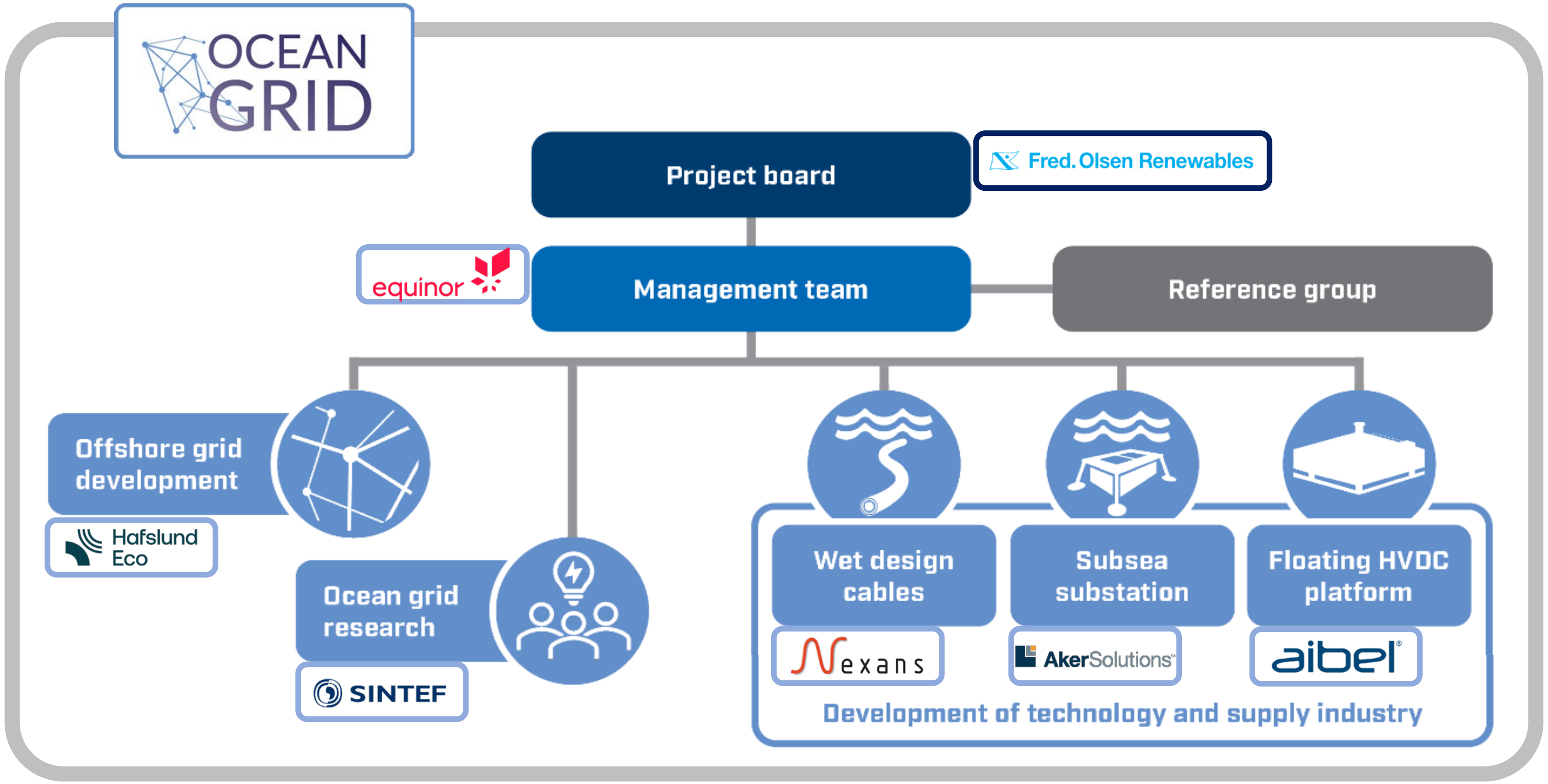
New in our study

Case study with mainly Norwegian (30 GW) perspective

Emphasis: extract generic conclusions

Ocean Grid project (2022-2024)

https://oceangridproject.no/



Develop new technology, knowledge, and innovations enabling profitable deployment of offshore wind farms in Norway and internationally, both bottom-fixed and floating, new green jobs and international sales.

University of Oslo · NTNU · Benestad · ABB · Hitachi Energy · Aker Offshore Wind · DNV · Deep Wind Offshore · Å Energi · Statnett · SINTEF · AkerSolutions · Nexans · aibel · Fred. Olsen Seawind · Hafslund · equinor

Big question: What is the best offshore grid?
Is it possible to find (reliable) answers?

NO

- Very dependent on energy system scenario
- Large uncertainties in scenarios, costs, technology availability etc.
- Computationally too complex
- Impossible to compute ***the*** optimal grid towards 2050

YES

- Focus on the next step (2030-2035)
- Effects of changing values of input parameters (sensitivity analysis)
- Generic characteristics and conclusions
- Use modelling and optimisation to **explore** a large solution space

Modelling

Mixed-integer linear progamming (MILP)
Optimisation model

Minimise **ALL COSTS** such that **ALL CONSTRAINTS** are satisfied

ALL COSTS = Investment costs + Operating costs over 40 years

Investment costs = $\sum \text{hvdc costs} + \sum \text{hub costs}$

Operating costs = $\text{NPV}\{\sum \text{generator output} \times \text{cost} \ + \sum \text{investment} \times \text{maintenance factor}\}$

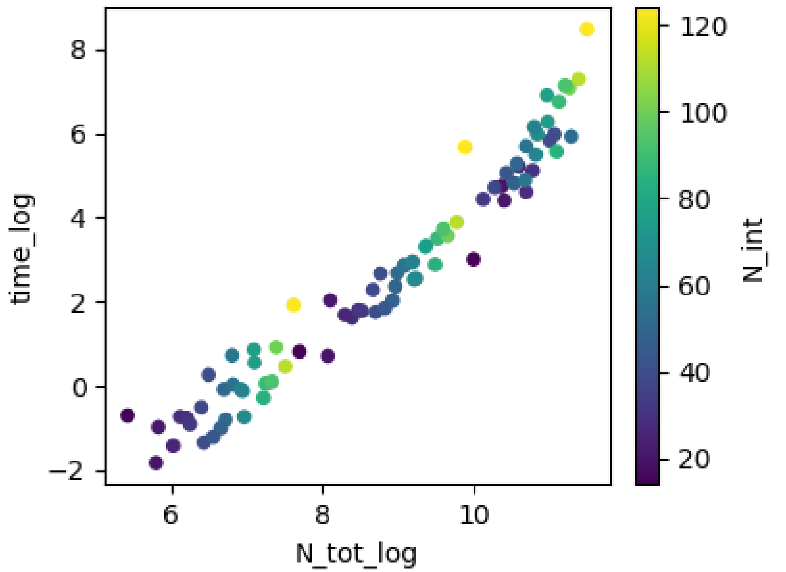
ALL CONSTRAINTS = Linear equations and inequalities describing the system

- Power balance in all nodes
- Power output and transmission limited by (available) capacities
- …

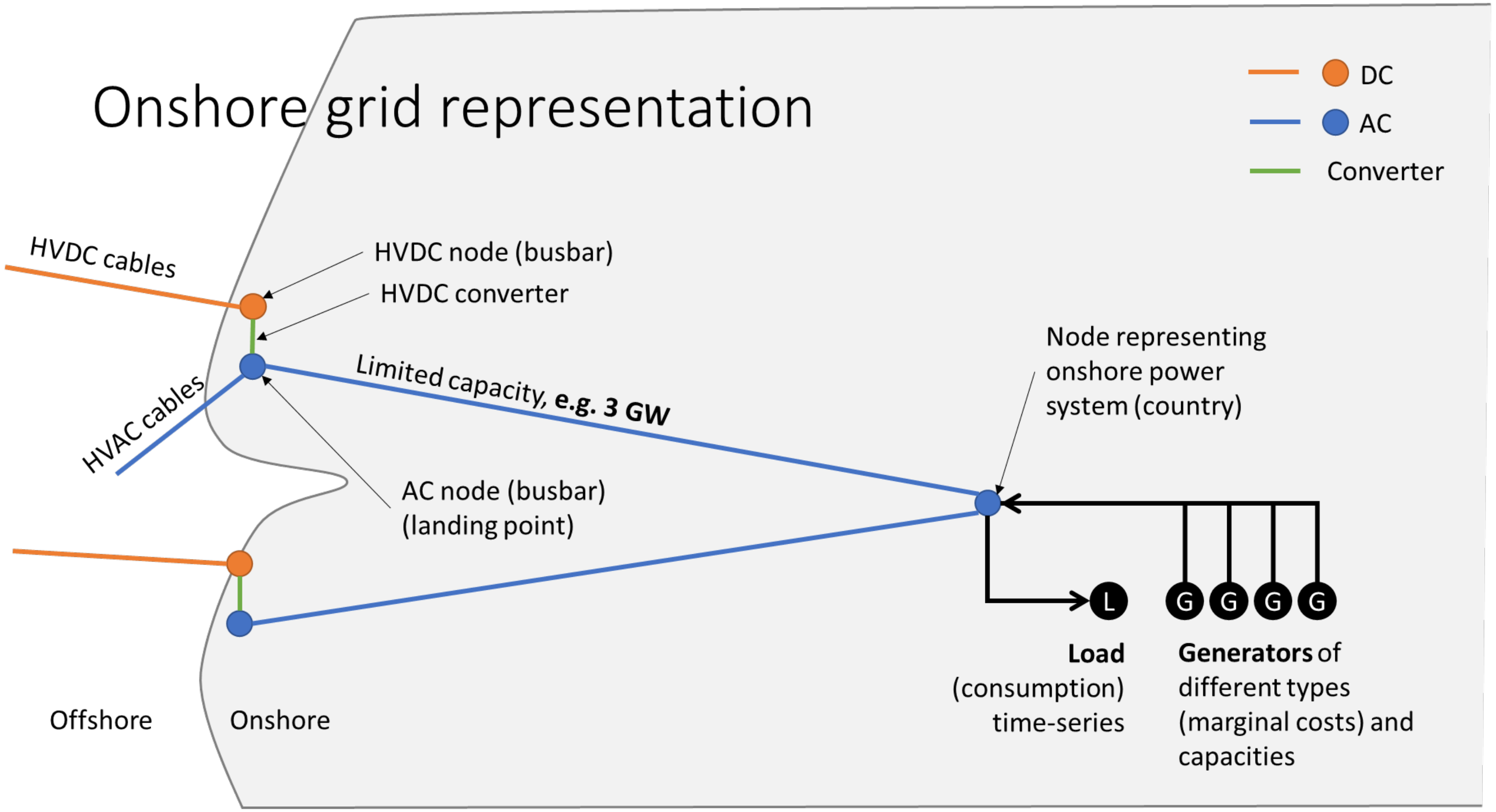
Variables:

- Number of cables (integer)
- Cable capacity (continuous)
- Generator dispatch
- Power flow

Exponentially increasing computation times



Onshore power system

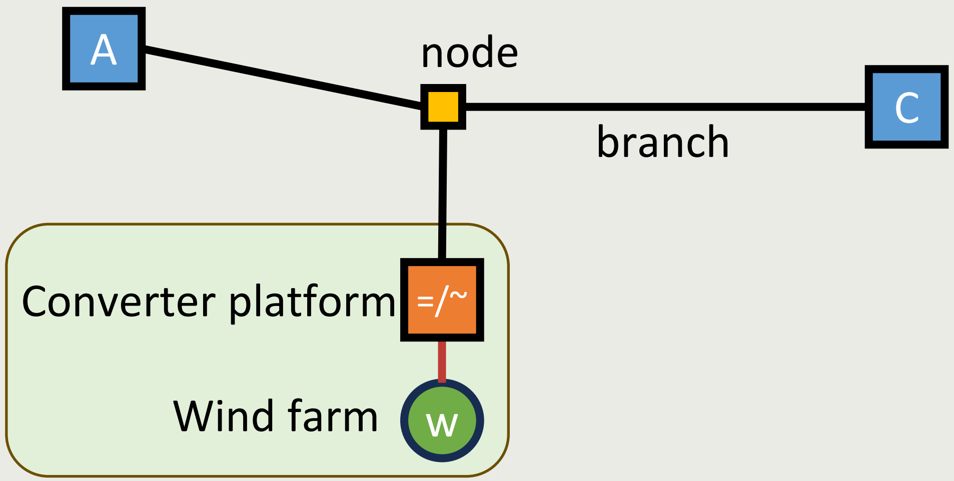


Power demand & production mix

Onshore grid bottlenecks

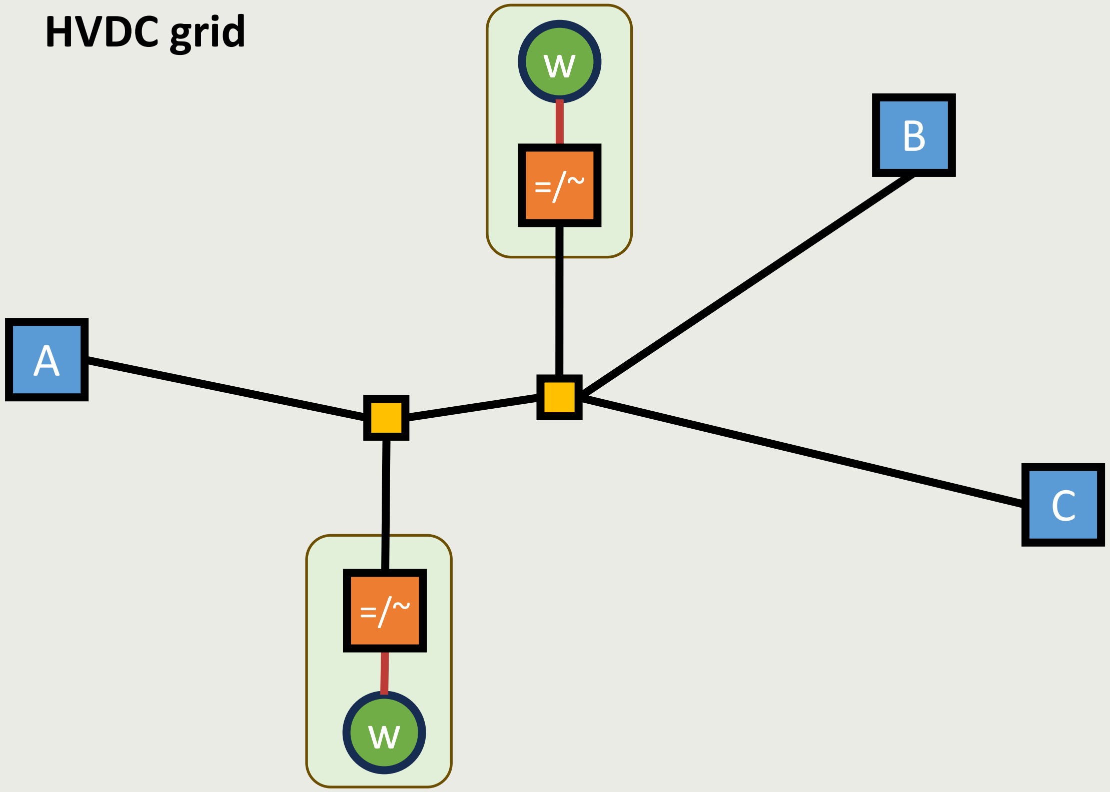
Offshore grid modelling

3-terminal multi-purpose interconnector



Wind farm – costs kept outside optimisation

Many-terminal HVDC grid

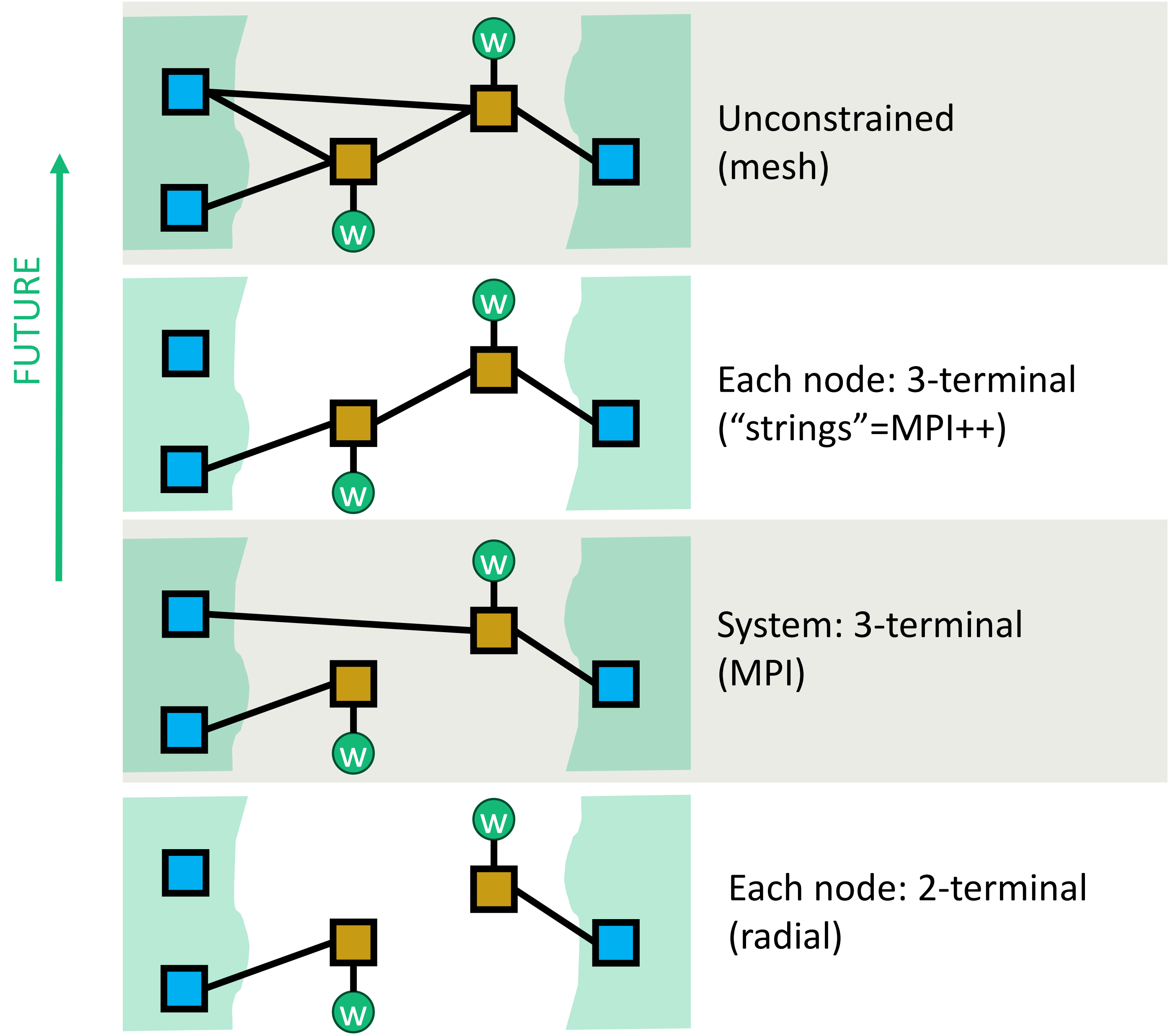


Topology constraints

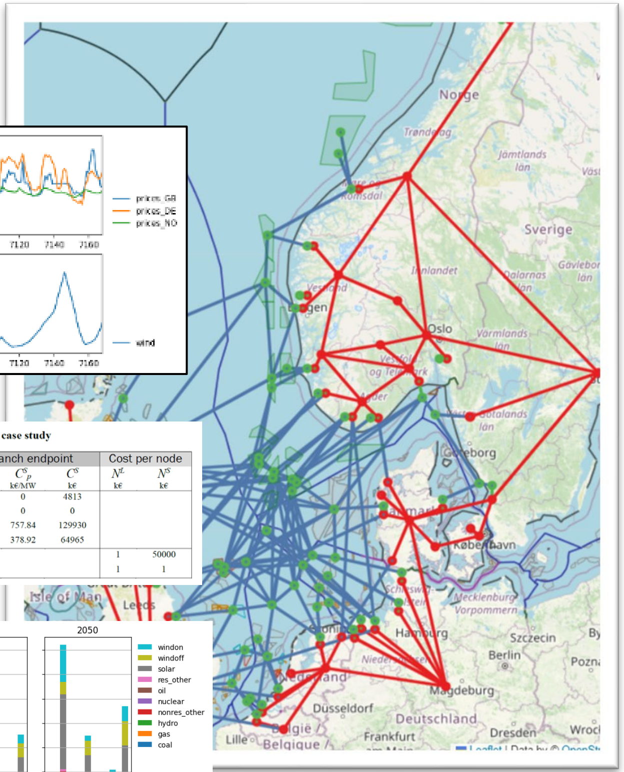
Technology in development

Meshed configurations unlikely in the near term.

We can add constraints in the optimisation model to reflect this



PowerGIM



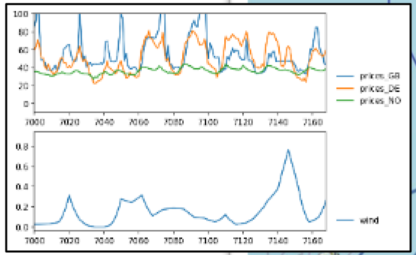
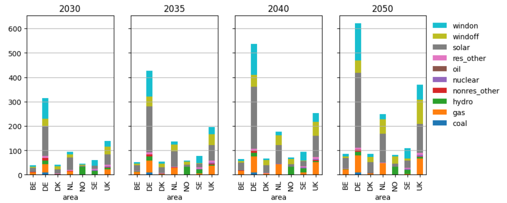
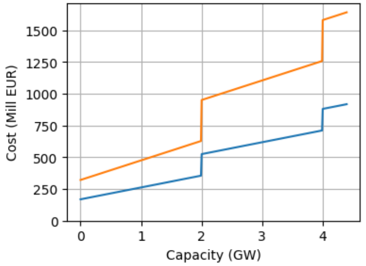


Table 11: Cost data assumed in case study

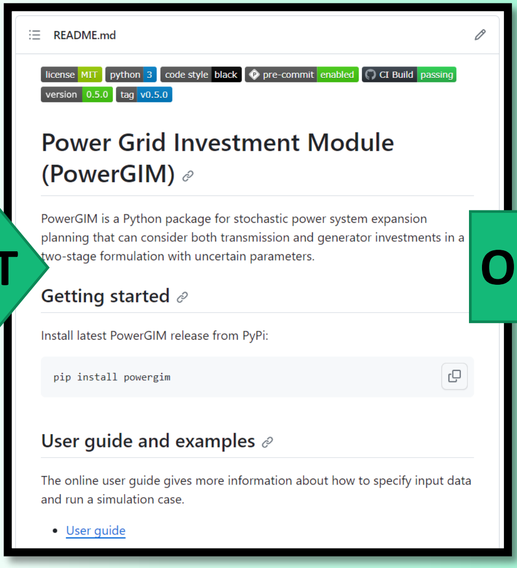
Type	Cost per branch			Cost per branch endpoint				Cost per node	
	B_d k€/km	B_{dp} k€/kmMW	B k€	C^L_p k€/MW	C^L k€	C^S_p k€/MW	C^S k€	N^L k€	N^S k€
AC	656	1.15	5000	0	1562	0	4813		
DC-mesh	680	0.47	5000	0	0	0	0		
DC-direct	680	0.47	5000	118.28	20280	757.84	129930		
Converter	0	0	0	59.14	10140	378.92	64965		
AC node								1	50000
DC node								1	1





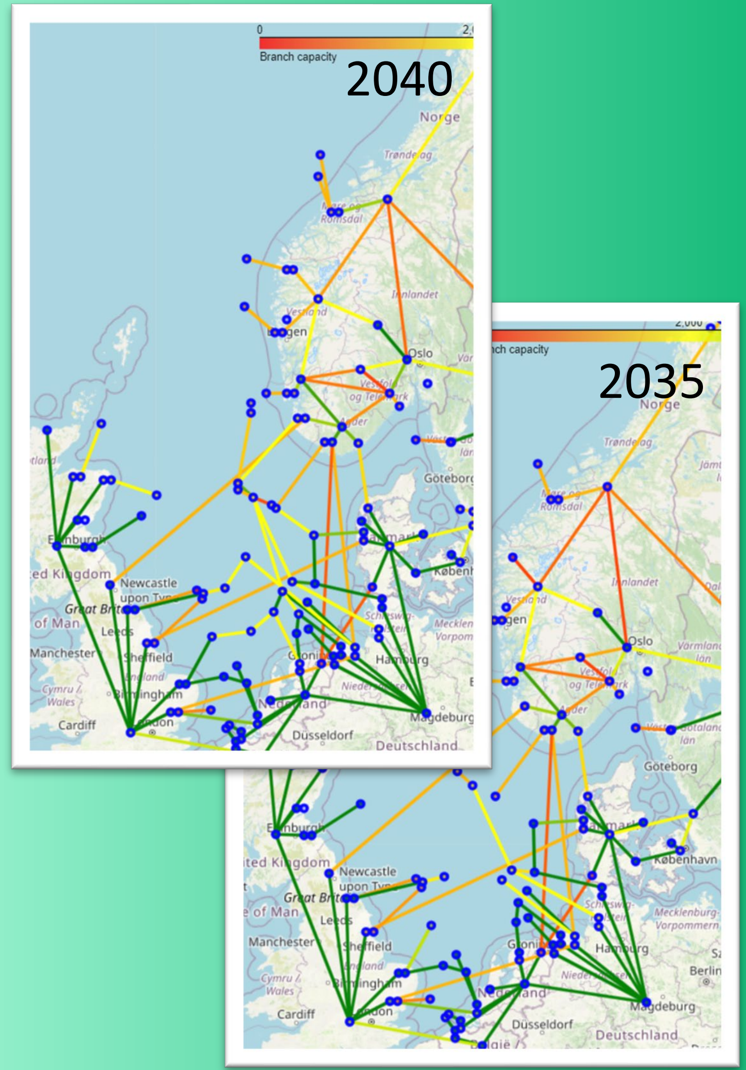
INPUT

PowerGIM
Grid
Investment
Module



https://github.com/powergama/powergim

OUTPUT



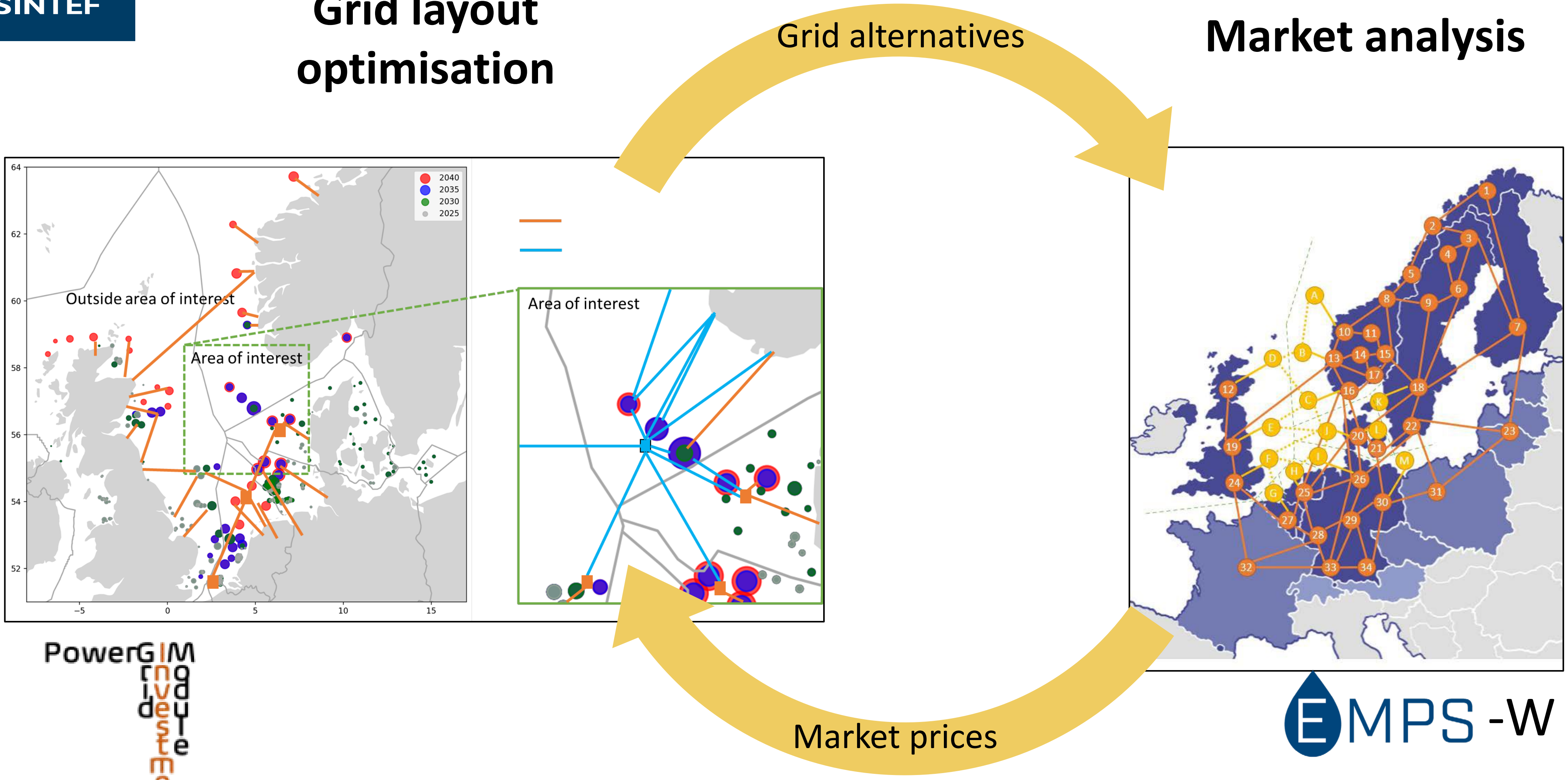
- power system scenario
- time-series
- cost and other parameters
- existing grid
- candidate investments

- what to build
- capacity to build
- total costs

SINTEF

Grid layout optimisation

Market analysis

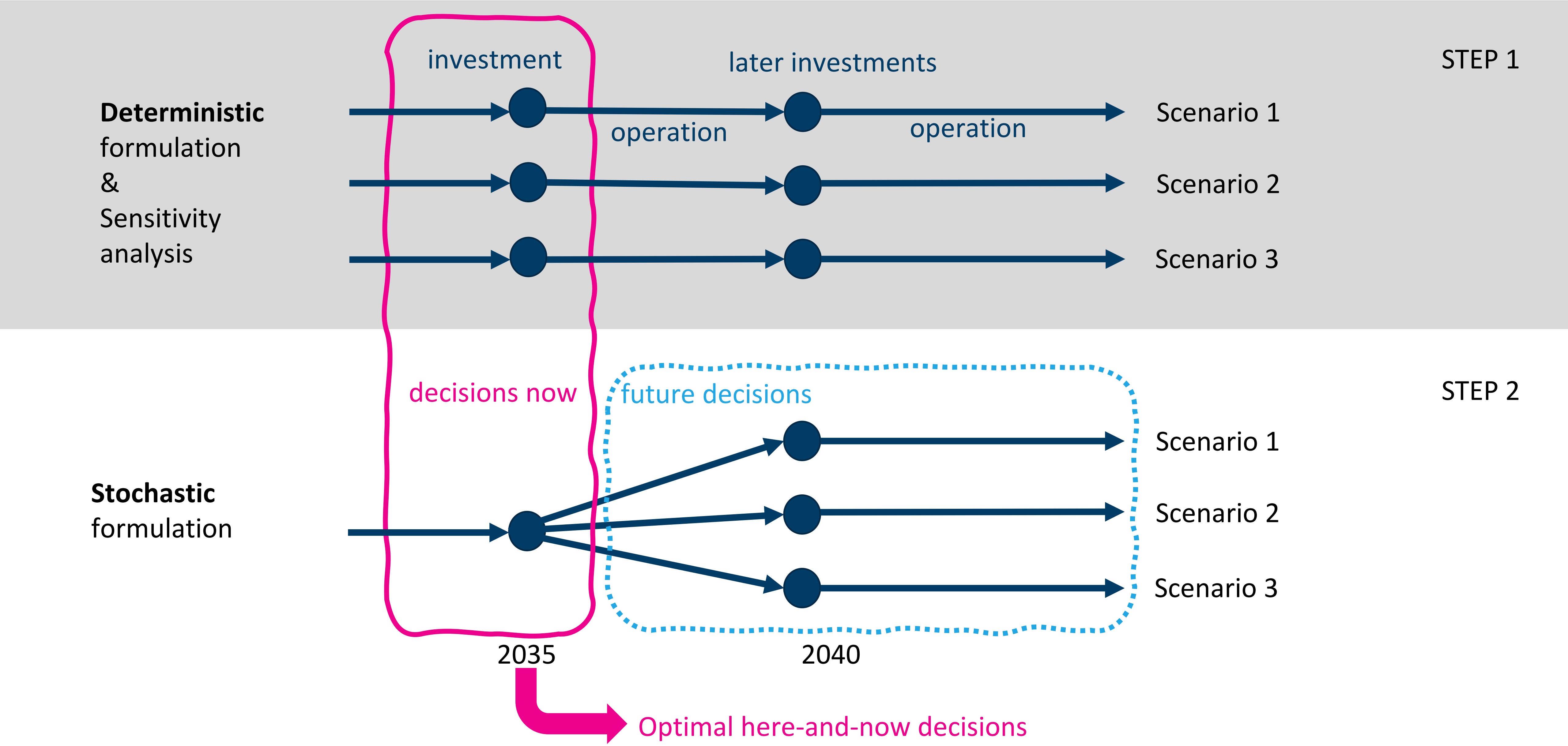


PowerGIM

Grid
Investment
Module

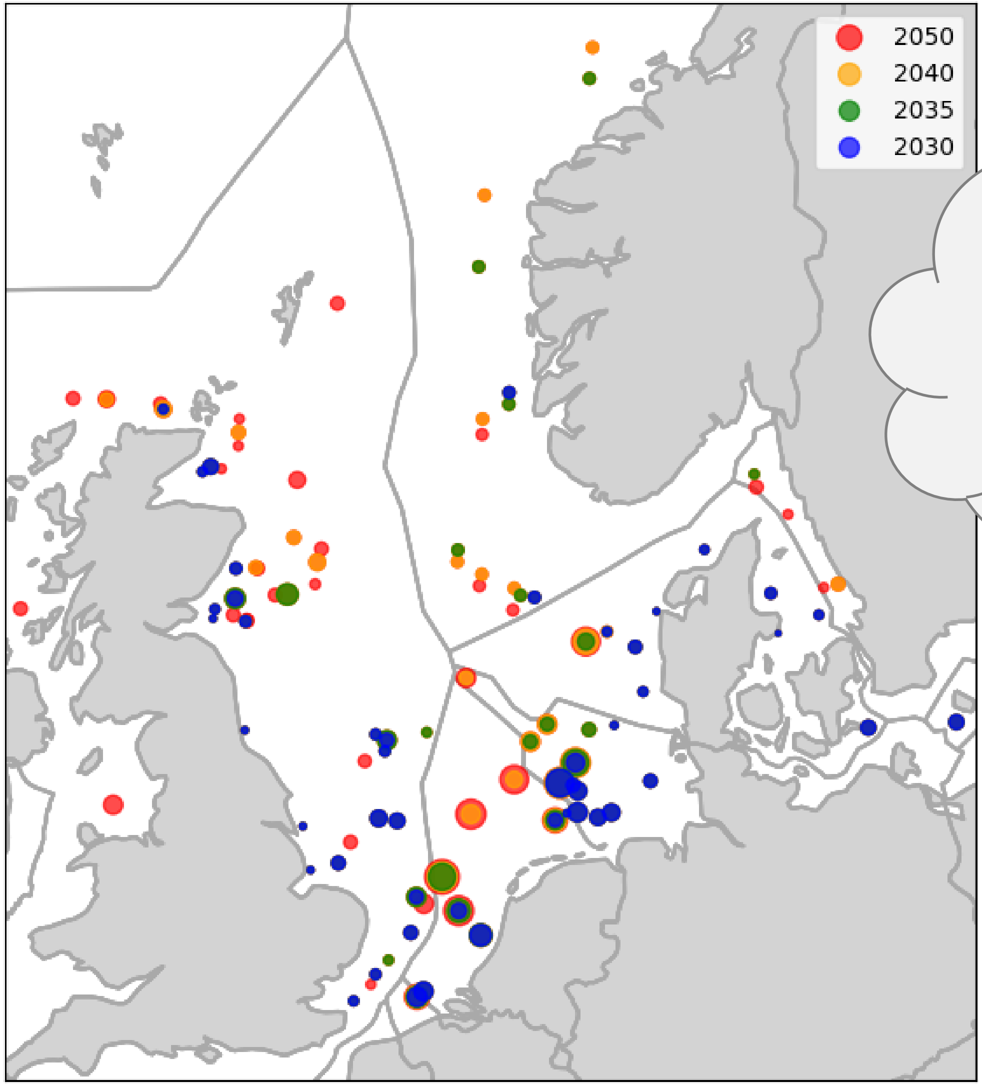
EMPS -W

Dealing with uncertainty



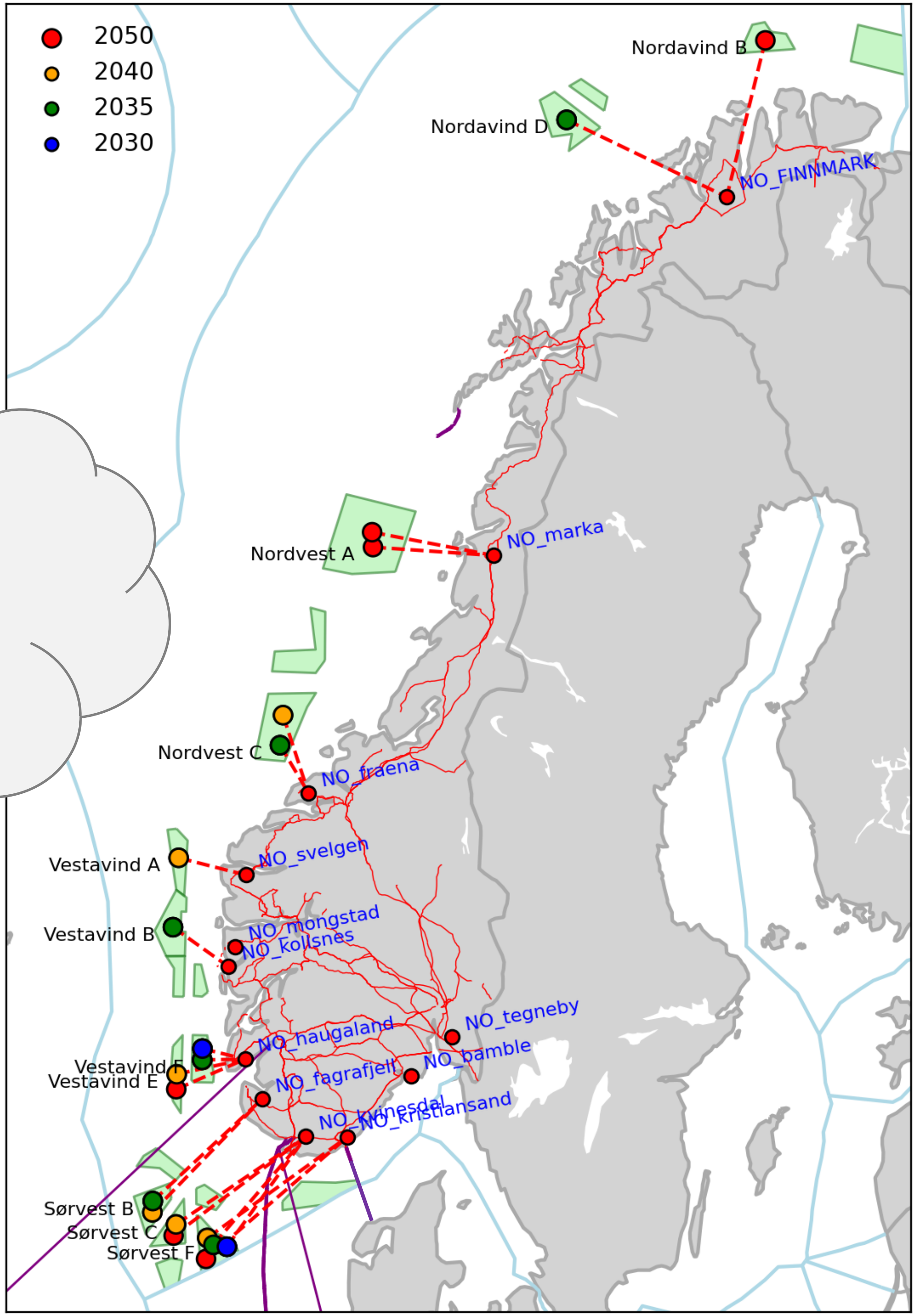
Case study

Offshore wind power capacity



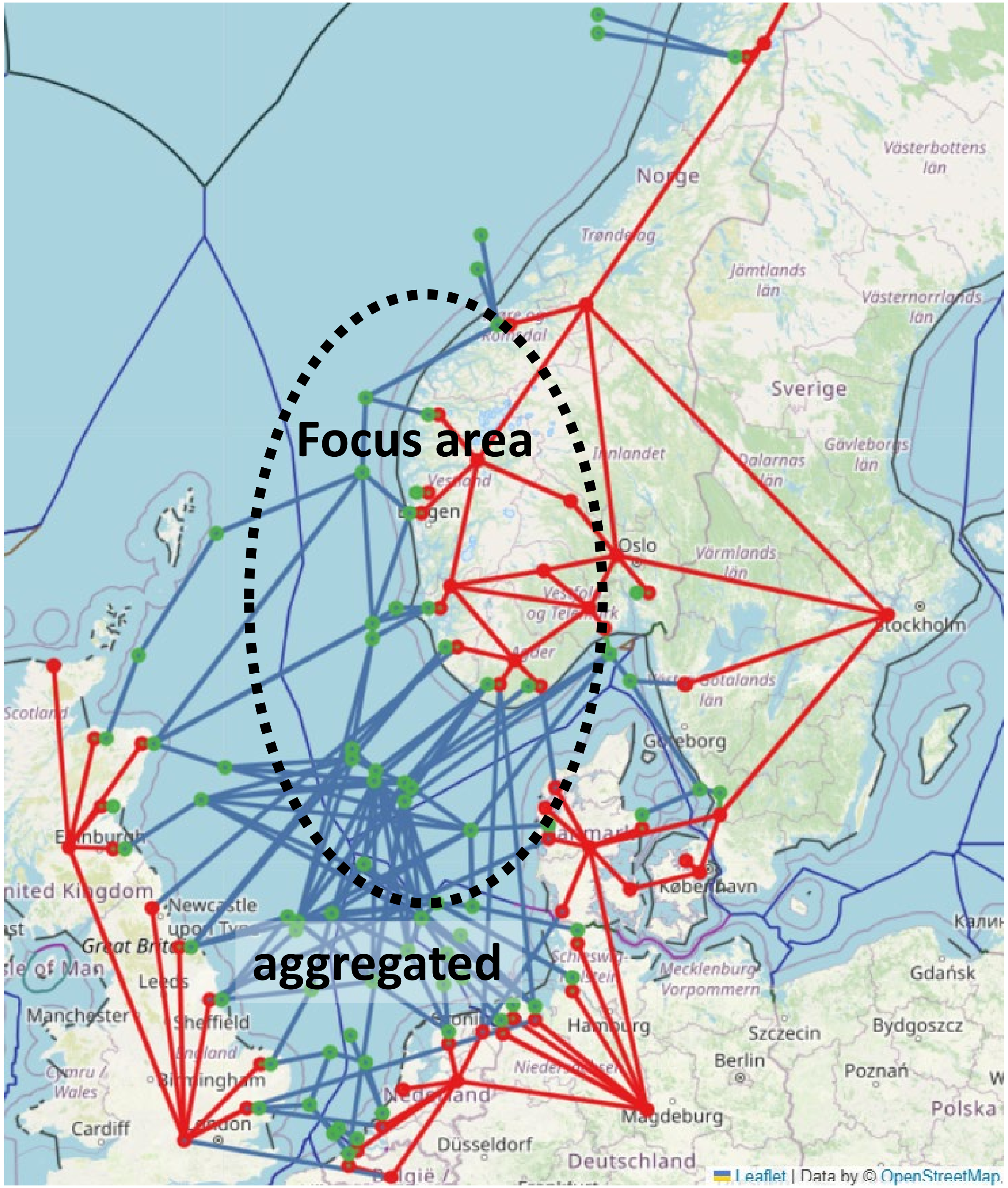
Which offshore grid is needed?

OceanGrid offshore wind scenario

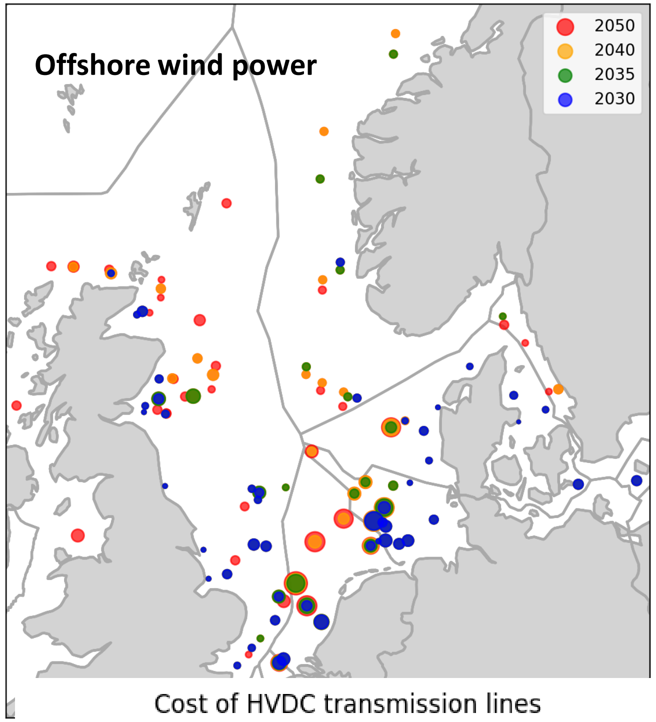


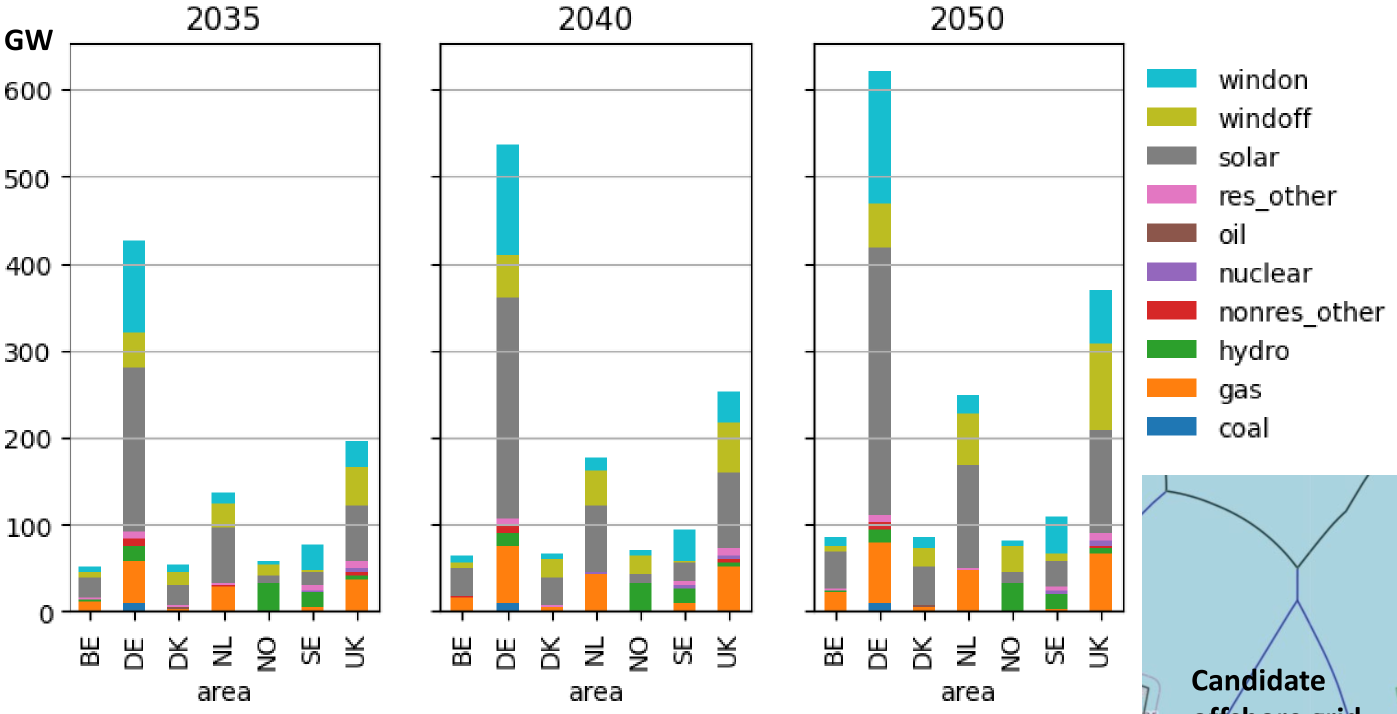
Case study

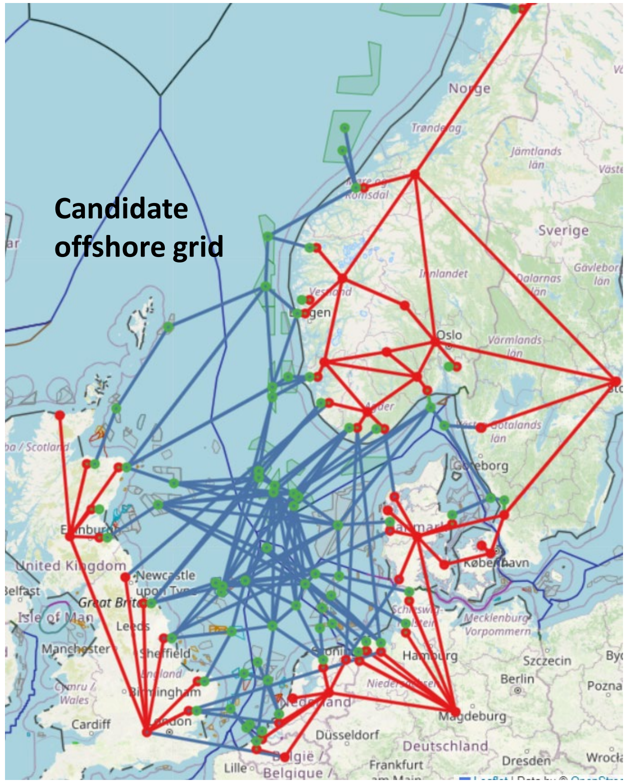
- North Sea
- 2035 – 2040 – 2050
  - Decisions must be made many years before
- Scenario for offshore wind power
  - 30 GW in Norway
  - 300 GW by 2050
- Energy system scenario based on ENTSO-E TYNDP 2022 “Distributed energy” storyline, adjusted for Norway



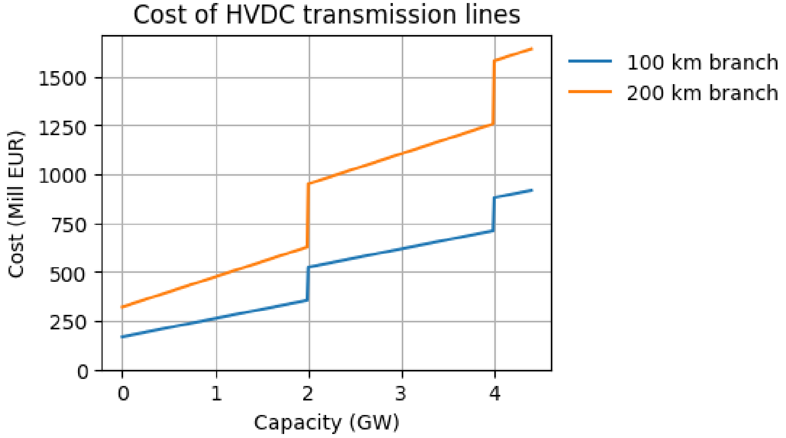
Input data







area	existing_2030	demand_2035	demand_2040	demand_2050
	TWh/year			
BE	118.8	160.8	202.7	260.7
DE	861.9	1098.8	1335.6	1563.1
DK	55.0	68.8	82.6	109.9
NL	211.0	254.7	298.4	402.8
NO	178.0	220.0	240.0	260.0
SE	164.5	188.5	212.5	243.3
UK	464.7	627.9	791.0	927.0

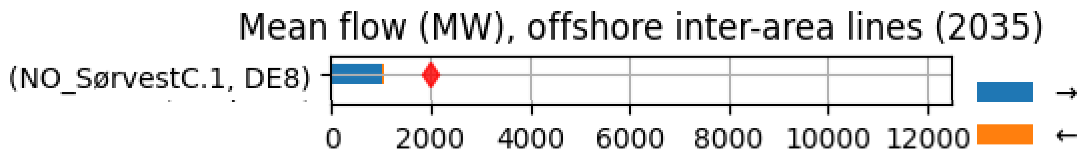


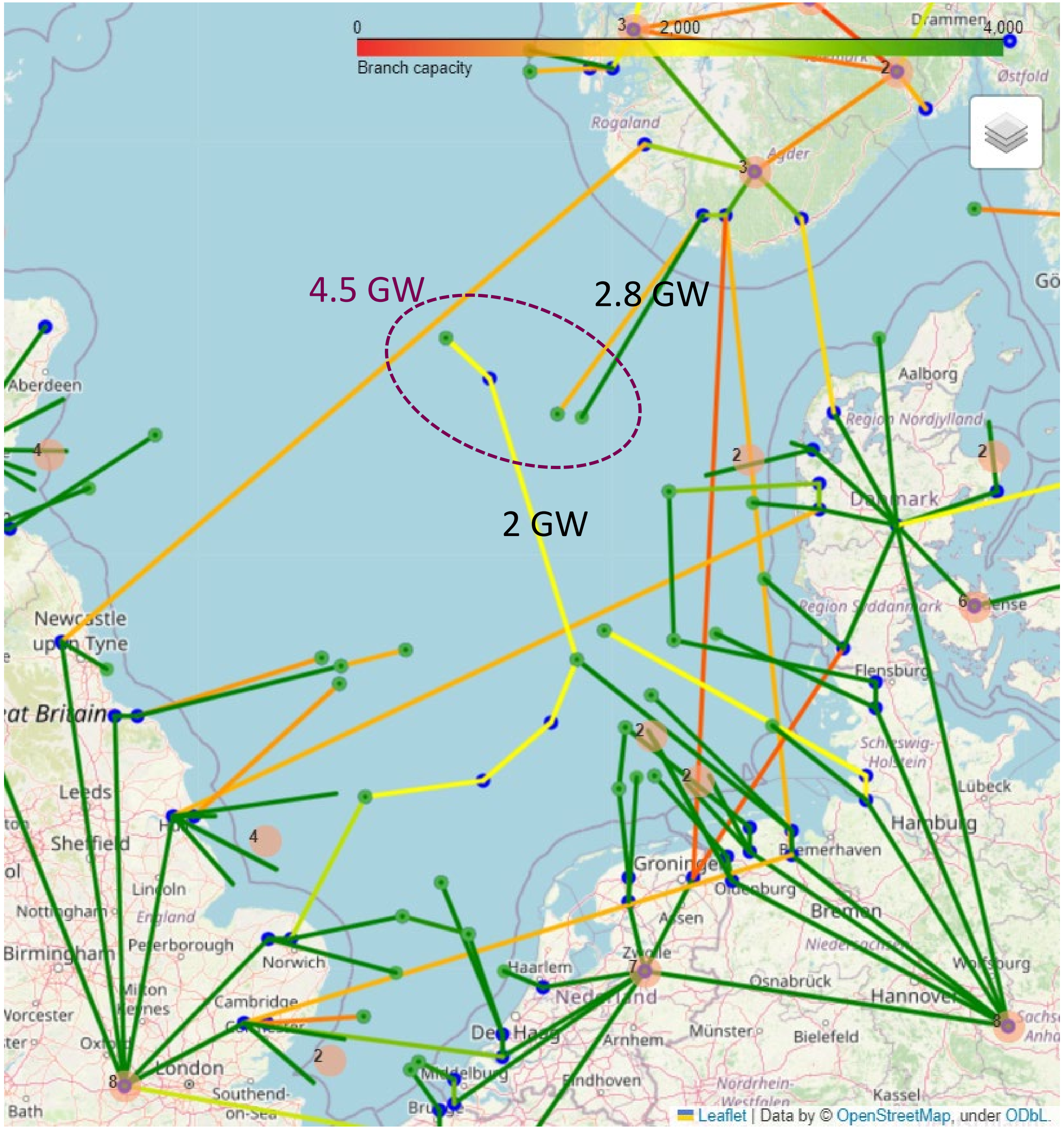
OceanGrid scenario results: base case

This is ongoing work

These results are preliminary, and for a specific scenario only

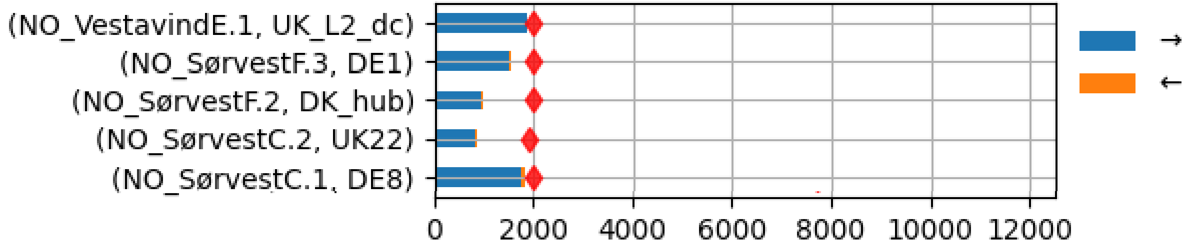
2035

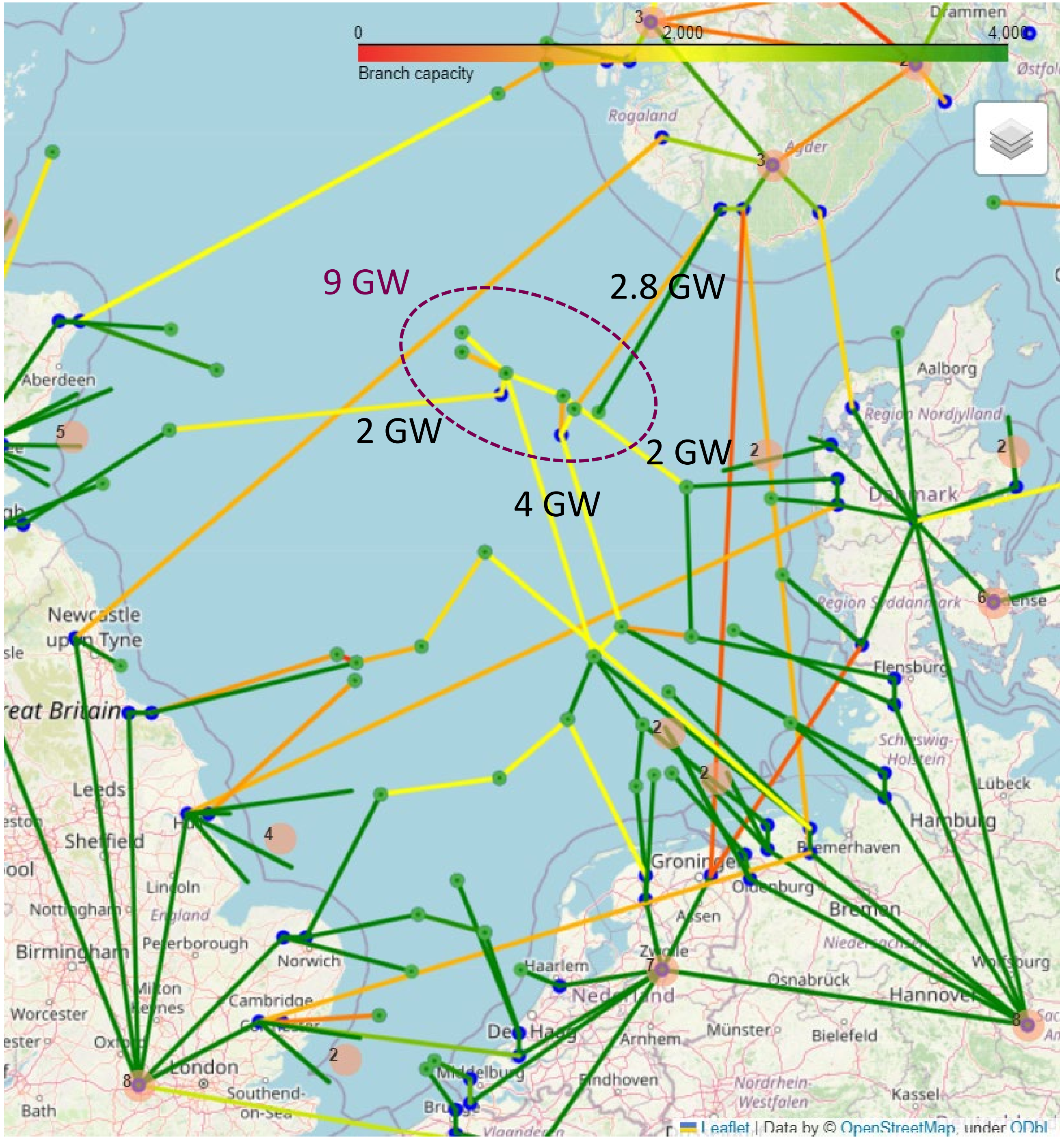

Mean flow (MW), offshore inter-area lines (2035)
(NO_SørvestC.1, DE8)
0
2000
4000
6000
8000
10000
12000
→
←


0
2,000
4,000
Branch capacity
4.5 GW
2.8 GW
2 GW
Drammen
Østfold
Rogaland
Agder
Aberdeen
Aalborg
Region Nordjylland
Danmark
Newcastle upon Tyne
Leeds
Sheffield
Lincoln
England
Nottingham
Peterborough
Norwich
Birmingham
Cambridge
London
Southend-on-Sea
Bath
Flensburg
Schleswig-Holstein
Lübeck
Hamburg
Bremerhaven
Groningen
Oldenburg
Bremen
Assen
Zwolle
Haarlem
Nederland
Den Haag
Middelburg
Arnhem
Eindhoven
Osnabrück
Münster
Bielefeld
Hannover
Wolfsburg
Kassel
Leaflet | Data by © OpenStreetMap, under ODbL.

2040

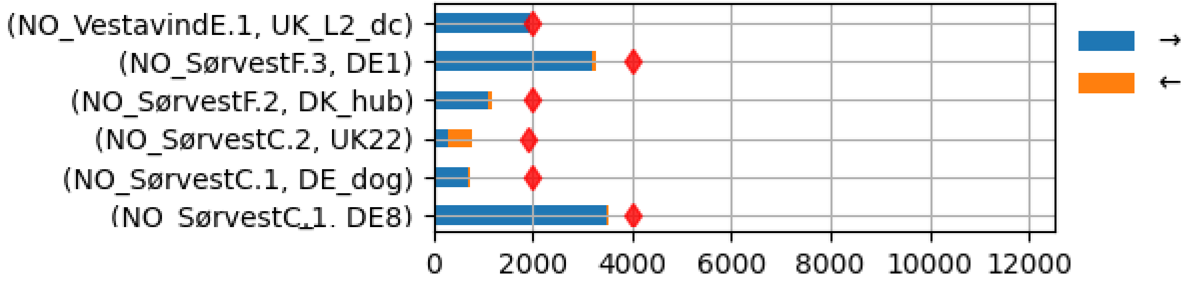
Mean flow (MW), offshore inter-area lines (2040)

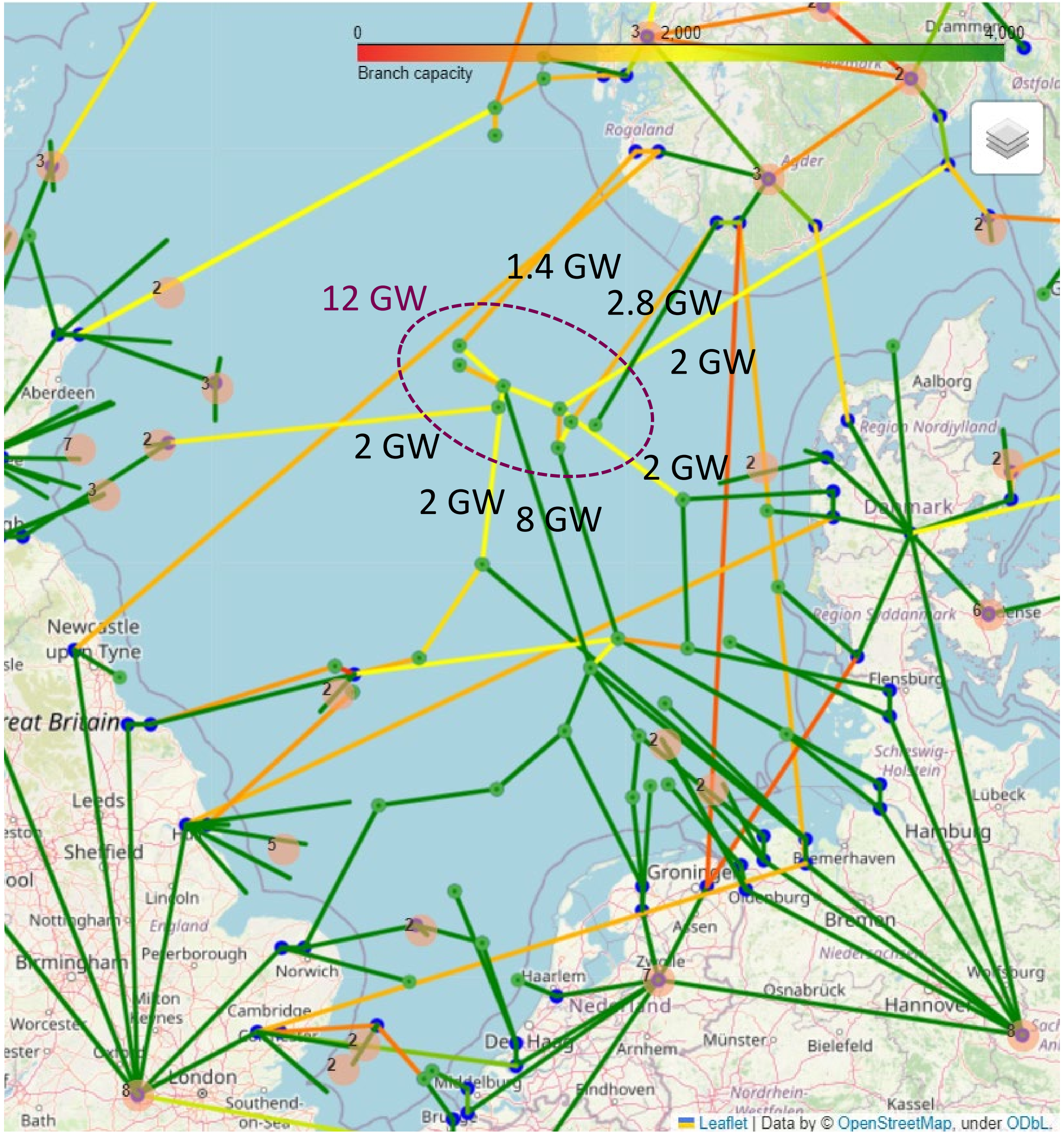




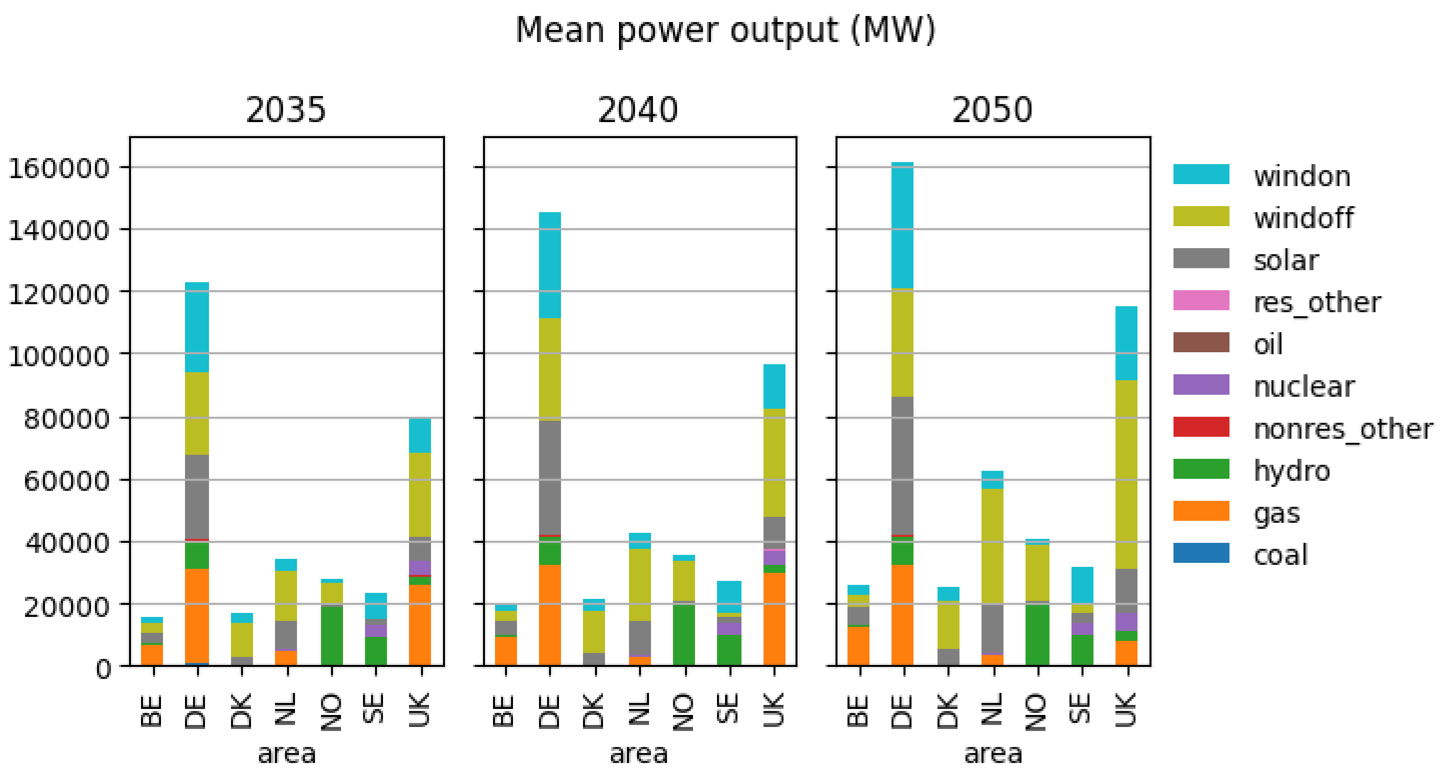
2050

Mean flow (MW), offshore inter-area lines (2050)





Why so much export from Norway?
Power balance



Energy mix

BE, DE, UK: Expensive gas power

Power flow

NO, SE, DK: Surplus areas

Conclusion

- Very large offshore grid investments are coming…
- Need for modelling **tools** and **datasets** to explore large space of possibilities
  - Prior to detailed project-specific studies
- Now
  - Main scenario analysis
- Next
  - Sensitivity analyses / focus analyses / what if..
  - Stochastic formulation
  - Extract generic conclusions
- Finally
  - Guidance for connecting 30 GW Norwegian offshore wind

SINTEF

Teknologi for et bedre samfunn