BaltHub final workshop:

Offshore energy hubs in the Baltic Sea

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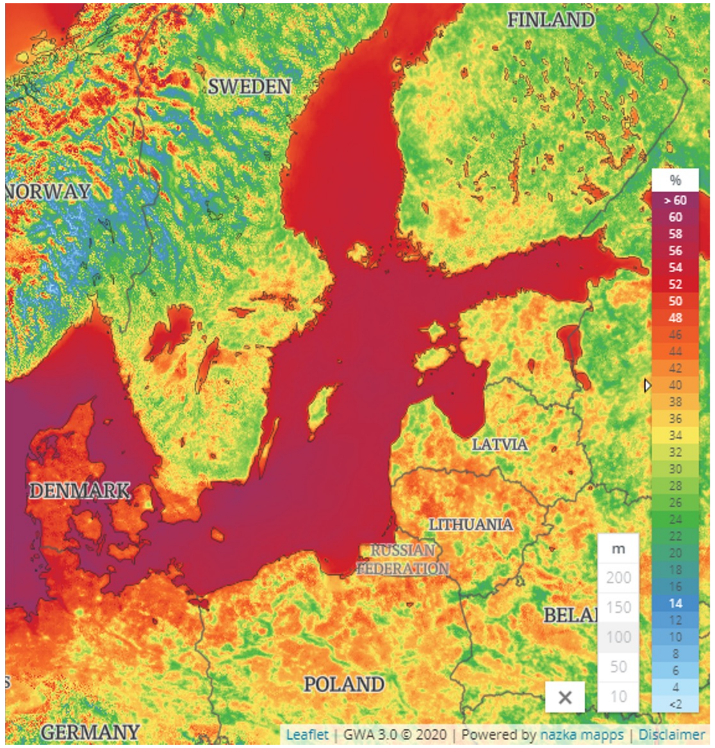
Online presentation
25 Jan 2023

Agenda

- Introduction to the BaltHub project and research questions
- **Results:** Role of offshore energy islands in the Baltic Sea towards 2050
- **Methods:** Modelling offshore energy islands for energy system analyses



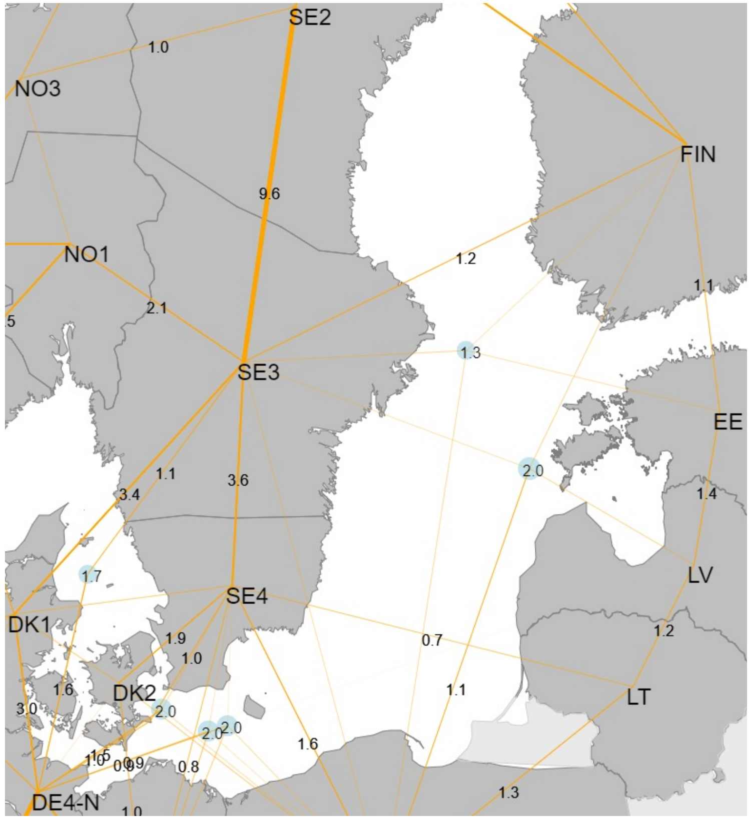
Baltic Sea offers capacity factors only slightly lower than the North Sea

Source: https://globalwindatlas.info/en

Interconnecting the Baltic Sea countries via offshore energy hubs (BaltHub)

- **BaltHub analyses the cost-effectiveness of Baltic Sea energy hubs**
  - Wind power connected far offshore where wind speeds are high
  - Hubs interconnect the onshore energy systems of the Baltic Sea countries

- **Funded by the Nordic Energy Research**
  - 2021-2022
  - Via the Baltic-Nordic Energy Research Programme



Offshore energy hubs can be used to integrate the onshore power systems of the region

BaltHub:
Partners and Observers

- **Partners:**
  - Technical University of Denmark (DTU), Denmark
    - » DTU Wind Energy & DTU Management
  - SINTEF, Norway
  - Tallinn University of Technology (TalTech), Estonia
  - Kaunas University of Technology (KTU), Lithuania

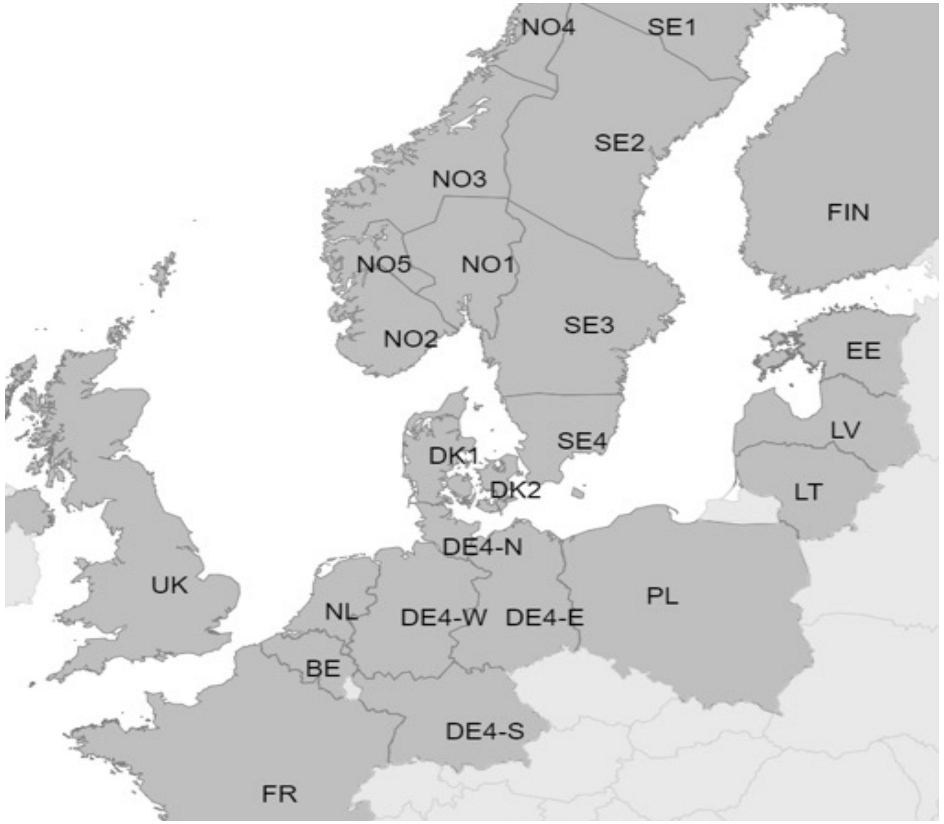
- **Observers**
  - Fingrid, Finnish TSO
  - Energinet, Danish TSO
  - Elering, Estonian TSO
  - LITGRID, Lithuanian TSO

BaltHub:
Research questions

1. **Are offshore energy hubs a cost-effective solution for driving green transition in Baltic Sea countries?**
   - How is this impacted by key input parameters?
2. **Do large-scale wake losses jeopardize the cost-effective buildout of such hubs?**
3. **Are the hubs beneficial in interconnecting the Baltic Sea region's countries?**
4. **What are the optimal here-and-now offshore infrastructure investment decisions?**
   - Considering uncertainty of the future

BaltHub results

Studied scenarios

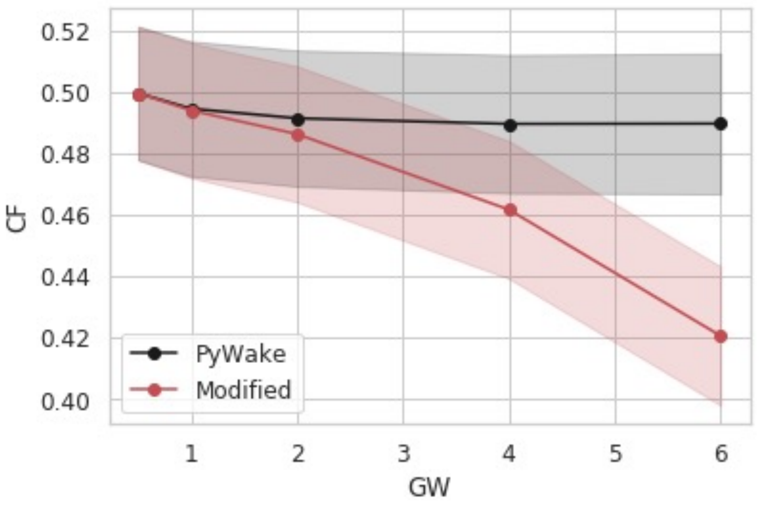


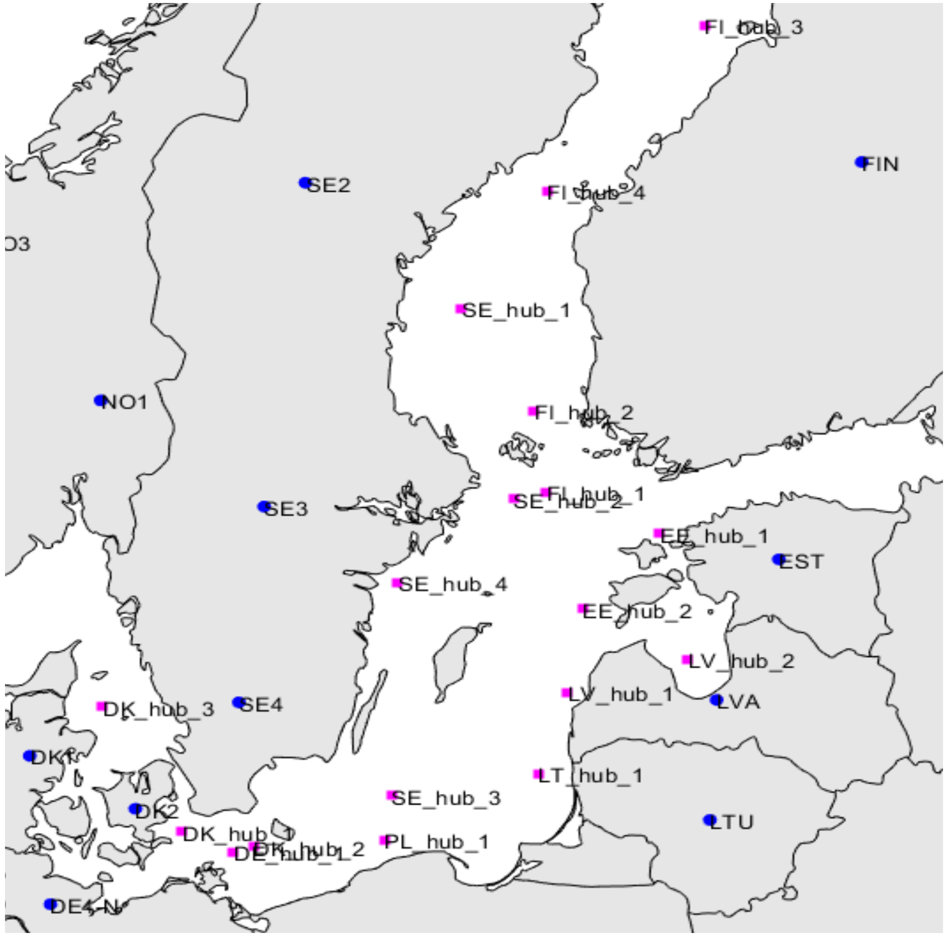
All analysed countries shown in dark grey. The Baltic Sea region countries are: Denmark (DK), Sweden (SE), Finland (FI), Estonia (EE), Latvia (LV), Lithuania (LT), Poland (PL), and Germany (DE).

More electrification

Scenario	**Heating (household & industry)**	**Electric mobility**	**Hydrogen demand (industry & transport fuels)**
Heat only	Optimized	-	-
Heat and elec. mobility	Optimized	Operation optimized	-
All Electrified	Optimized	Operation optimized	Operation optimized

Results:
Wake losses

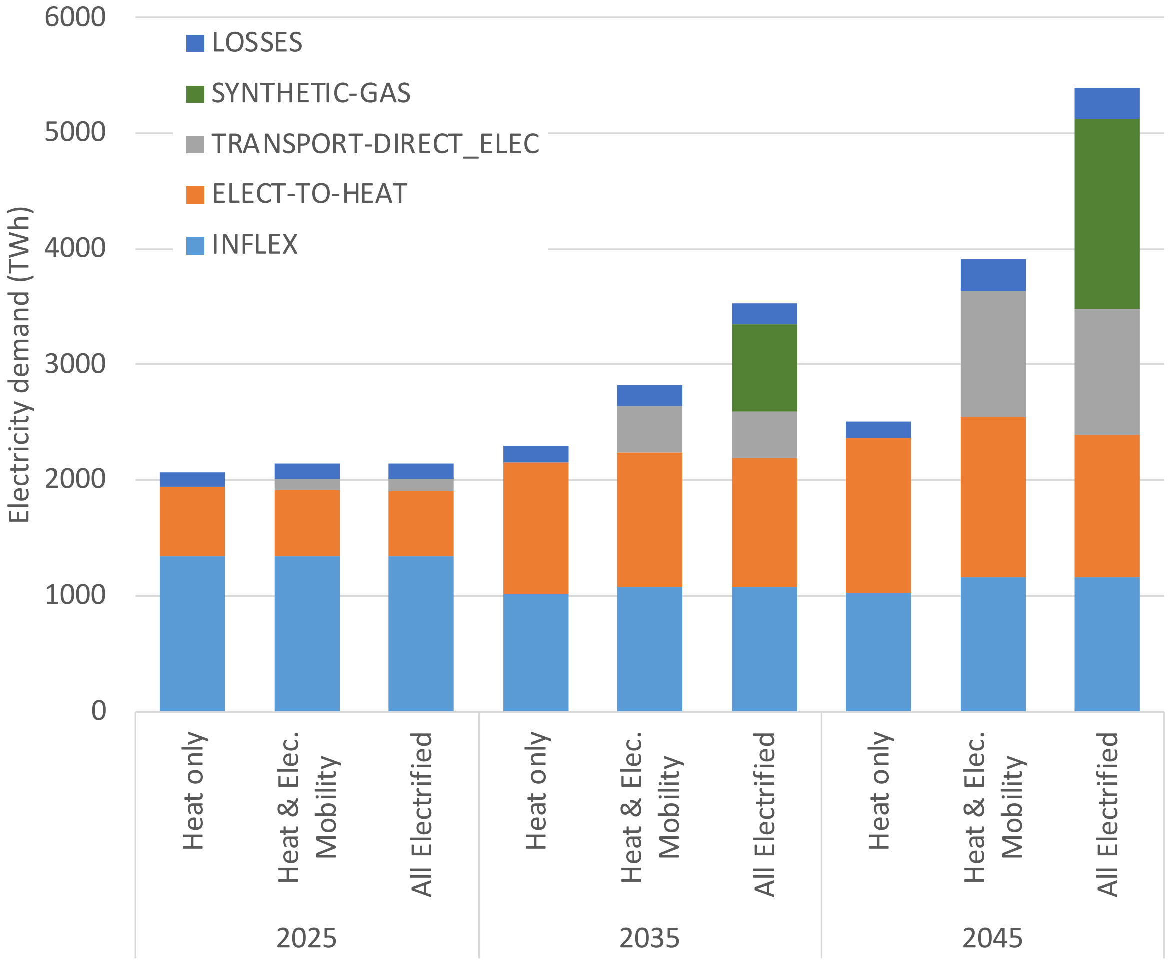




- **The red (Modified) curve shows losses when also the large-scale (mesoscale) wakes are considered**
  - Significant impact after 2 GW size
  - Note: uncertainty remains in estimating wake losses for very large hubs

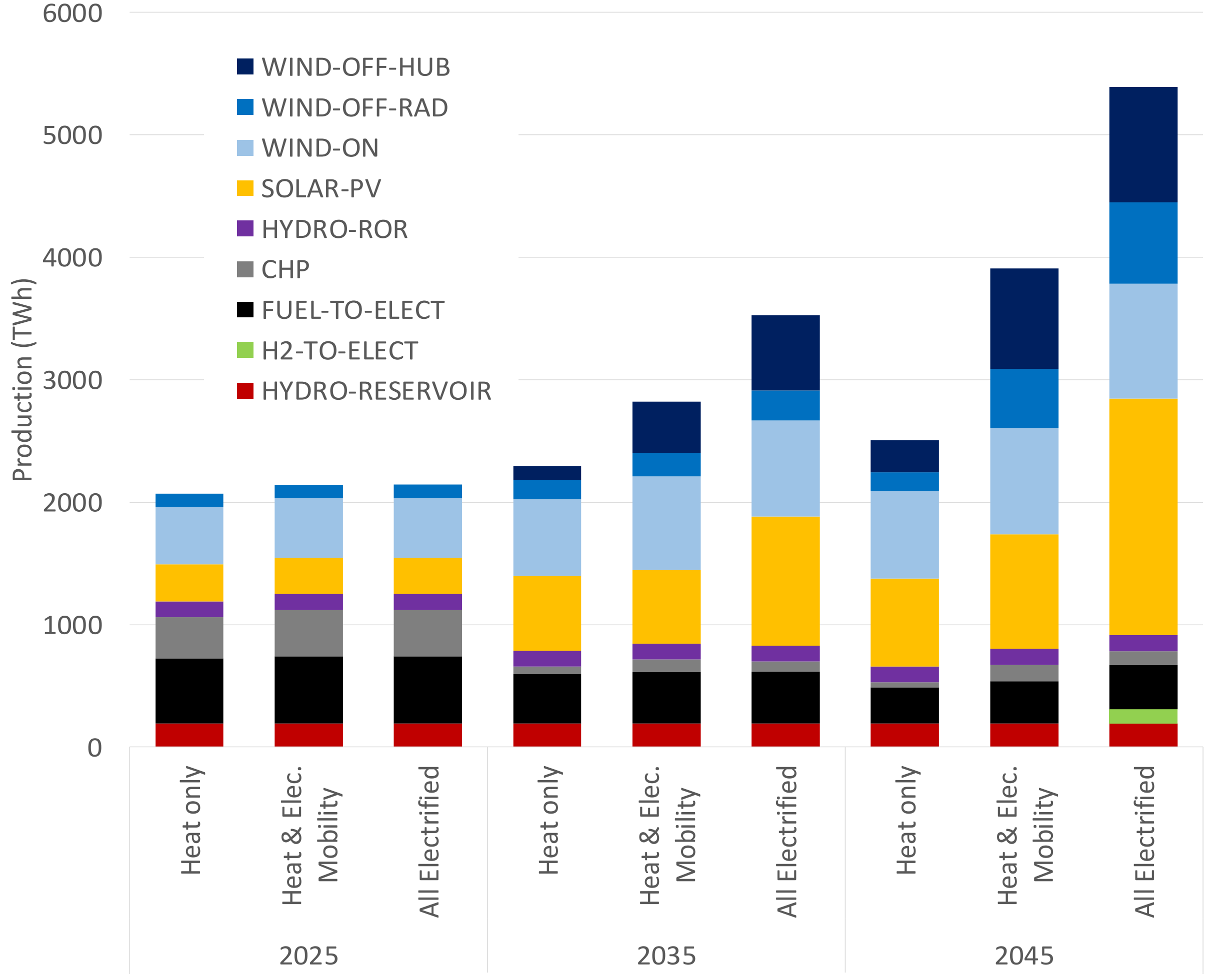
M. Koivisto, et al., "Offshore energy hubs: Cost-effectiveness in the Baltic Sea energy system towards 2050, "*Wind Integration Workshop*, 2022

Results (all analyzed countries): Electric Load



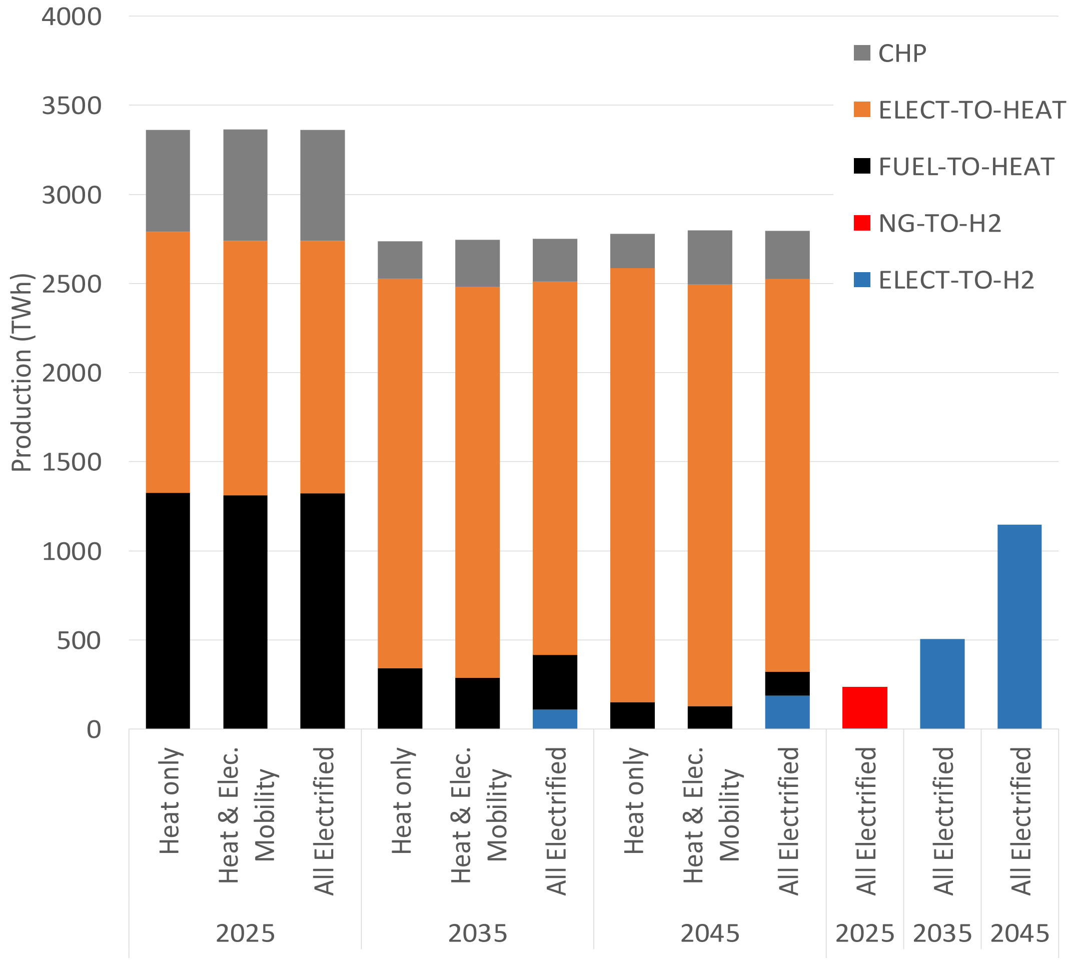
M. Koivisto, et al., "Offshore energy hubs: Cost-effectiveness in the Baltic Sea energy system towards 2050, "*Wind Integration Workshop*, 2022

Results (all analyzed countries): Electricity Generation



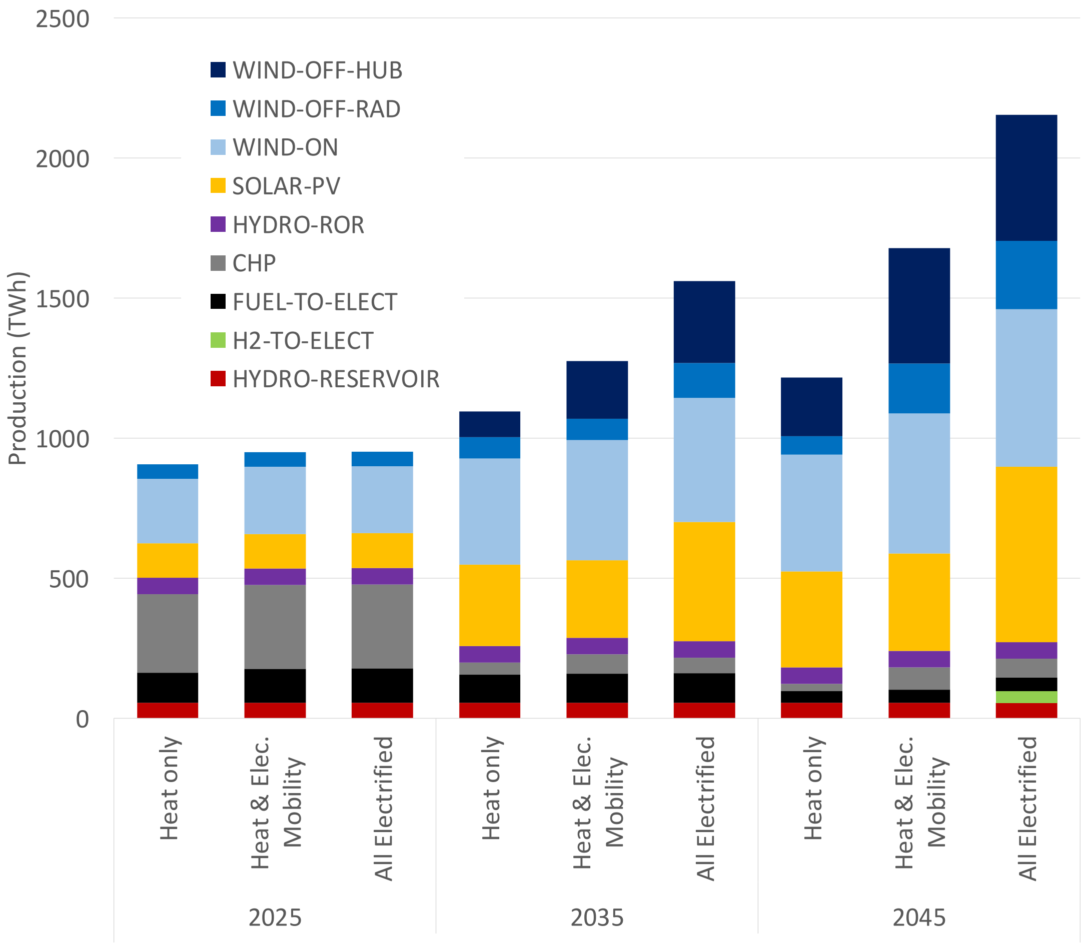
M. Koivisto, et al., "Offshore energy hubs: Cost-effectiveness in the Baltic Sea energy system towards 2050, "*Wind Integration Workshop*, 2022

Results (all analyzed countries): Heat and hydrogen Generation



M. Koivisto, et al., “Offshore energy hubs: Cost-effectiveness in the Baltic Sea energy system towards 2050, “*Wind Integration Workshop*, 2022

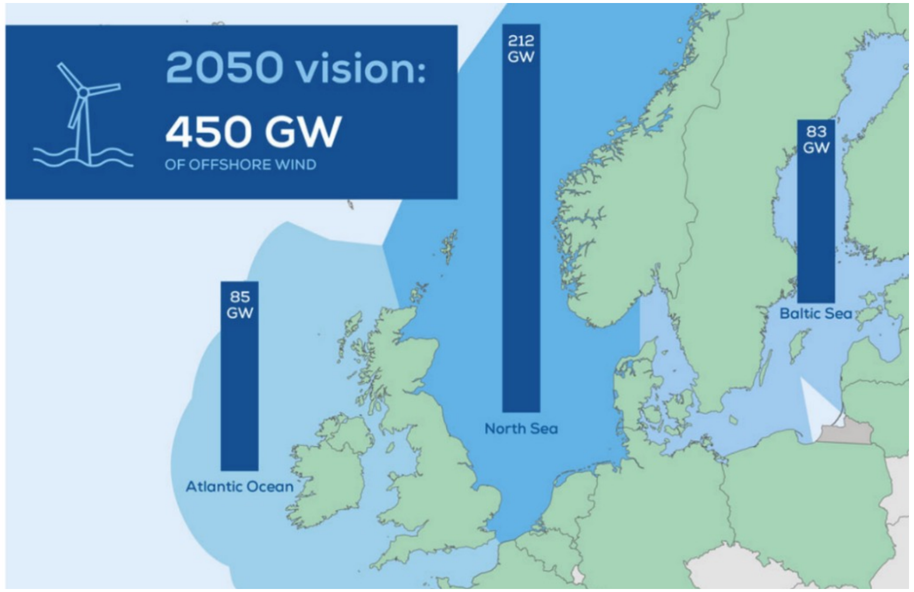
Results:
Baltic Sea region



Offshore GWs per sea area in the most electrified scenario:

Sea area	2025 (GW)	2035 (GW)	2045 (GW)
North Sea	**15**	**158**	**238**
Radial	15	35	53
Hub		123	186
Baltic Sea	**6**	**32**	**82**
Radial	6	14	47
Hub		17	35
Atlantic Ocean	**7**	**13**	**65**

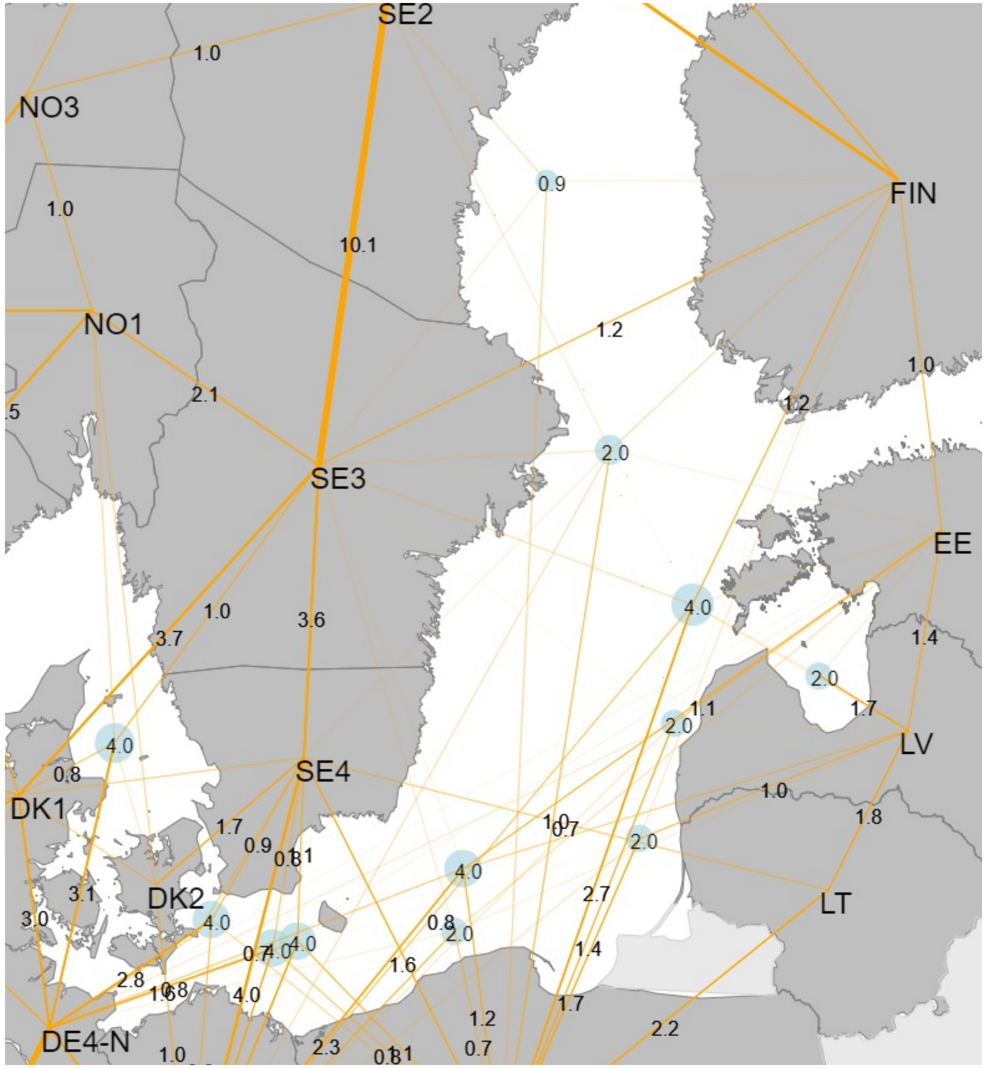
Comparison to WindEurope numbers:



https://windeurope.org/intelligence-platform/product/our-energy-our-future/

M. Koivisto, et al., "Offshore energy hubs: Cost-effectiveness in the Baltic Sea energy system towards 2050, "*Wind Integration Workshop*, 2022

Hubs Invested:
All Electrified



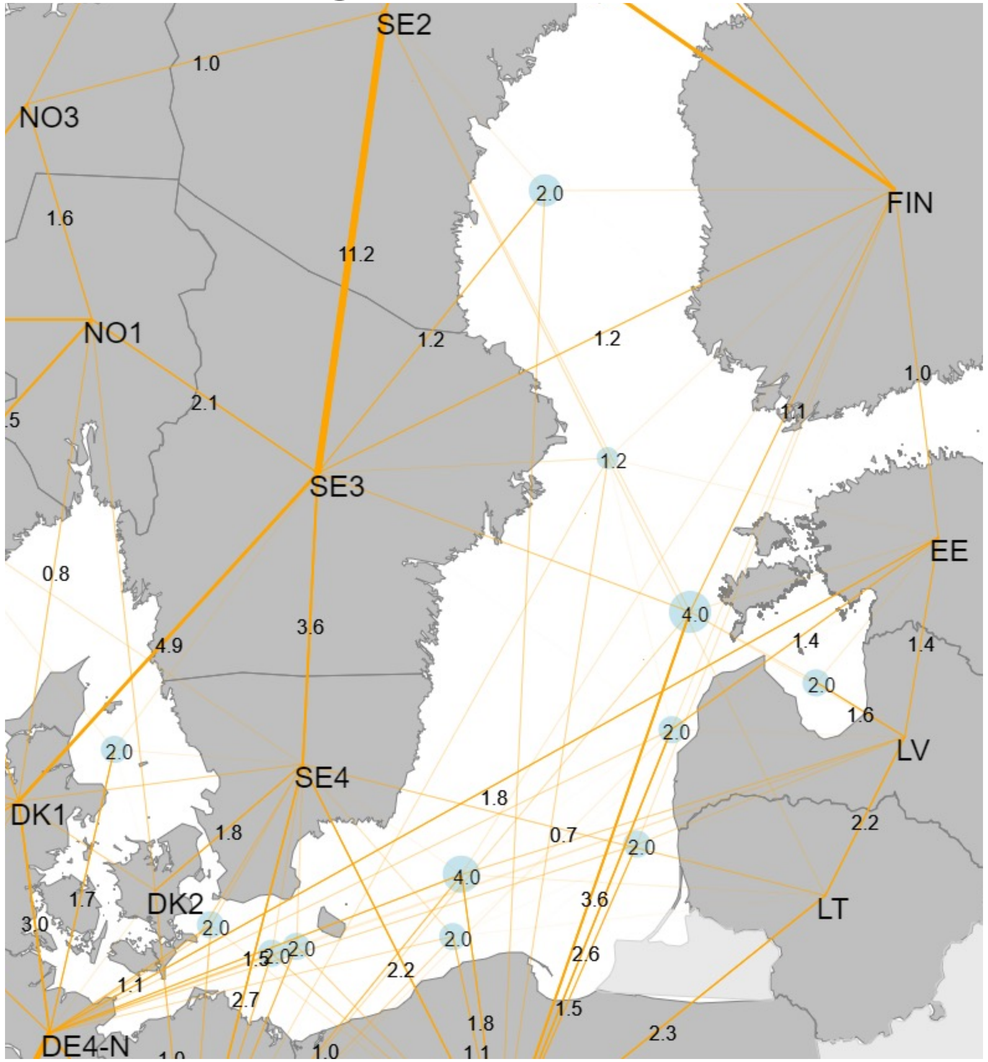
Very high electrification scenario

Installed offshore wind:

	2045 (GW)
Baltic Sea	**82**
Radial	47
Hub	35

- Note: unfeasible small lines may appear in the maps, as the results are from linear optimisation
- MIP optimisation, to find more realistic line sizes, is being carried out

Hubs Invested:
Heat & Elec. Mobility



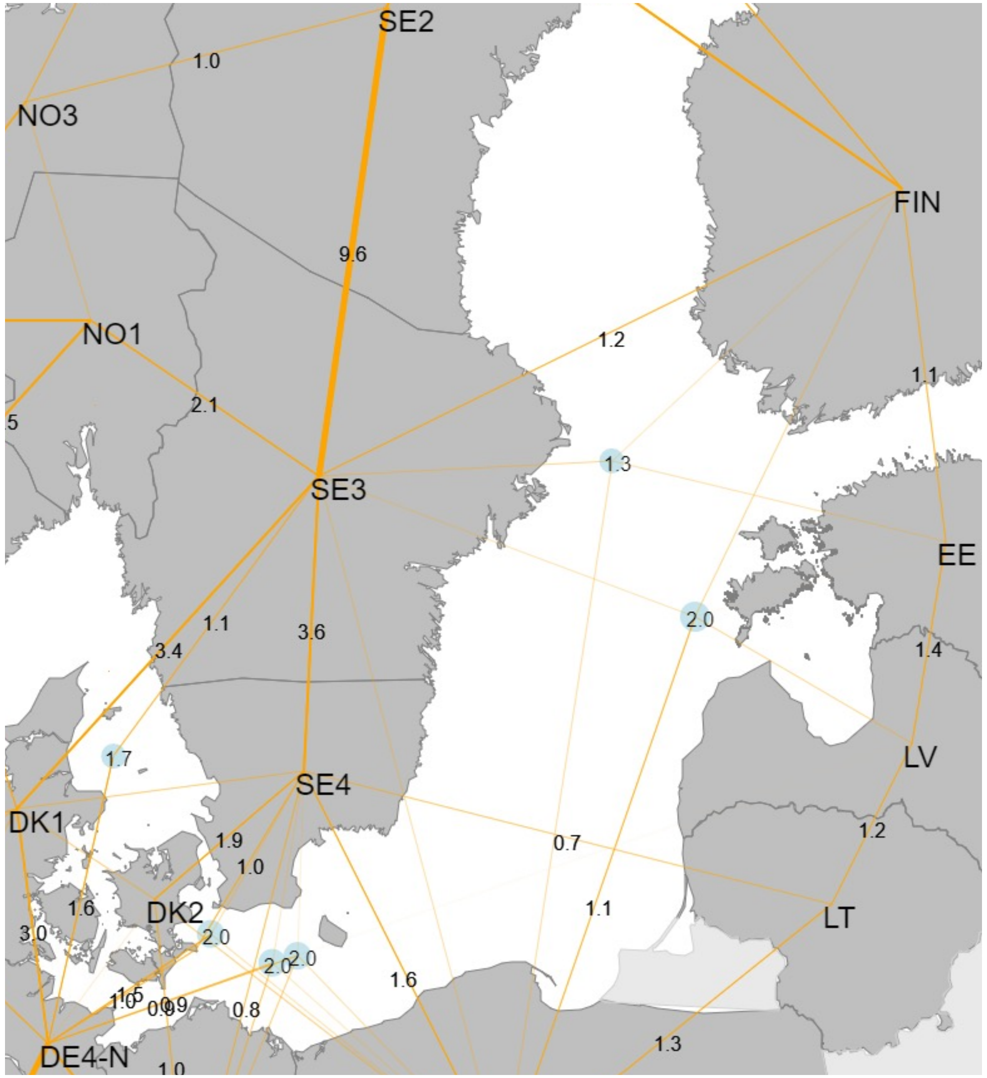
Medium electrification scenario

Installed offshore wind:

	2045 (GW)
Baltic Sea	**58**
Radial	31
Hub	27

- Note: unfeasible small lines may appear in the maps, as the results are from linear optimisation
- MIP optimisation, to find more realistic line sizes, is being carried out

Hubs Invested: Heat only



Low electrification scenario

Installed offshore wind:

	2045 (GW)
Baltic Sea	**15**
Radial	4
Hub	11

Some of the hubs remain competitive compared to radially connected offshore wind even in the least electrified scenario

- Note: unfeasible small lines may appear in the maps, as the results are from linear optimisation
- MIP optimisation, to find more realistic line sizes, is being carried out

Hydrogen Pipes Development: All Electrified

Installed electrolysers:

	2045 (GW)
Baltic Sea region	**117**
Onshore	115
Offshore	2

Electrolysers are mostly installed onshore

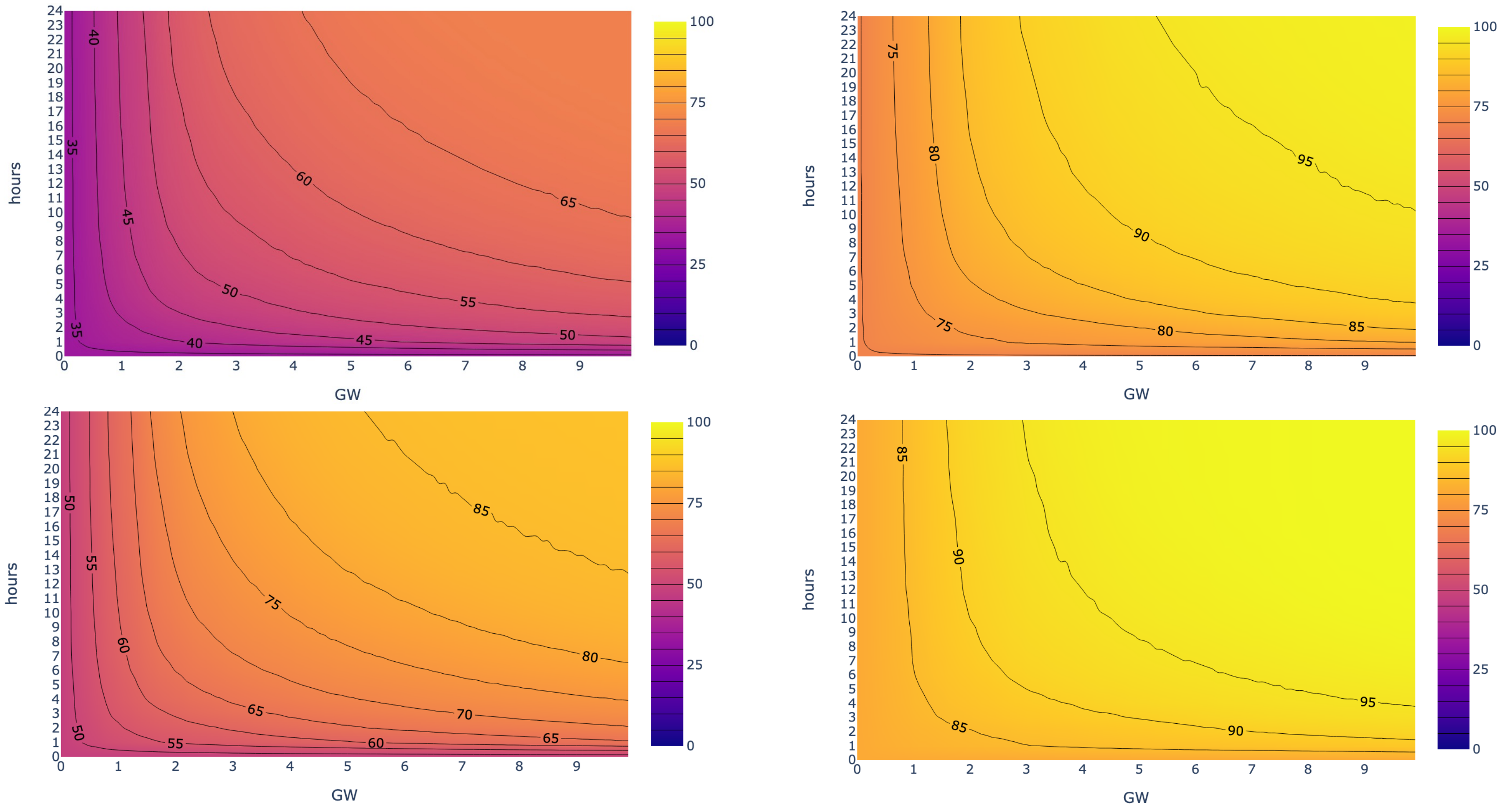
- The placement of electrolysers onshore is aligned with results from similar modelling in the North Sea region[1]
- Many factors impact the onshore vs. offshore placement of hubs
    - As it is not in the focus of this study, it is not analysed further
    - Note: In these runs, solar PV in Central/Southern Europe is driving hydrogen investments and production

[1]J. Gea-Bermúdez, R. Bramstoft, M. Koivisto, L. Kitzing, A. Ramos, "Going offshore or not: Where to generate hydrogen in future integrated energy systems?", *Energy Policy*, vol. 174, March 2023 (https://doi.org/10.1016/j.enpol.2022.113382).

Focus on the Baltic States: Renewable generation share and flexibility needs

2035 | 2045

Without the hubs and meshed grid



With the hubs and meshed grid

-> higher renewable generating share with less flexibility required from within the Baltic States

Focus on the Baltic States: Renewable generation share and flexibility needs

1. The most electrified scenario (All Electrified) was analyzed with focus on the Baltic States
   - It is the most ambitious scenario, including reaching challenging goals in transport and heating transition and hydrogen expansion
2. **Offshore energy hubs and related grid help to reach larger renewable generation share (share of total consumption)**
   - 15-20 percentage point higher in 2035 (for the same flexibility requirement)
   - With the hubs and currently installed flexibility technologies in the Baltic States, a 60-65 % renewable generation share could be reached in 2035
3. **The hubs enable to reach up to 100 % renewable generation share by 2050**
   - But requires additional energy storage installations (compared to today)
   - Without the hubs, the maximum renewable generation share, even when installing additional energy storage of up to 24 hours duration, would be 85-92 %

Conclusions on BaltHub results

1. **Most hubs seen when the energy system is highly electrified**
   - And offshore wind becomes the dominant wind technology by 2050
   - The hubs are a cost-effective technology
2. **Southern part of the Baltic Sea sees the strongest development of hubs**
   - Poorest wind resource locations seen unsuitable for offshore energy hubs
   - Impacted by large-scale wake losses
3. **Overall deployment of offshore wind less compared to the North Sea**
   - Hub sizes in the Baltic Sea are foreseen to be smaller than in the North Sea
4. **The hubs are utilised to interconnect the onshore power systems of the Baltic Sea region's countries**
   - More detailed MIP runs required to analyse optimal line sizes (next presentation)
5. **The hubs enable to reach up to 100 % renewable generation share in the Baltic States by 2050**

Modelling offshore energy islands

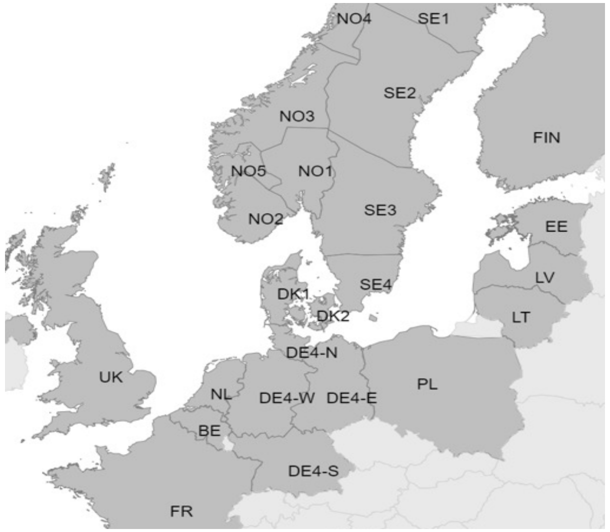
Methodology overview

CorRES → **Balmorel** → **Scenarios**

CorRES: VRE time series

Balmorel: Energy system optimisation

Scenarios: Towards 2050



For example for studying:

- **Offshore energy hubs & meshed grids[1,2]**
- **Impact of sector coupling[3]**

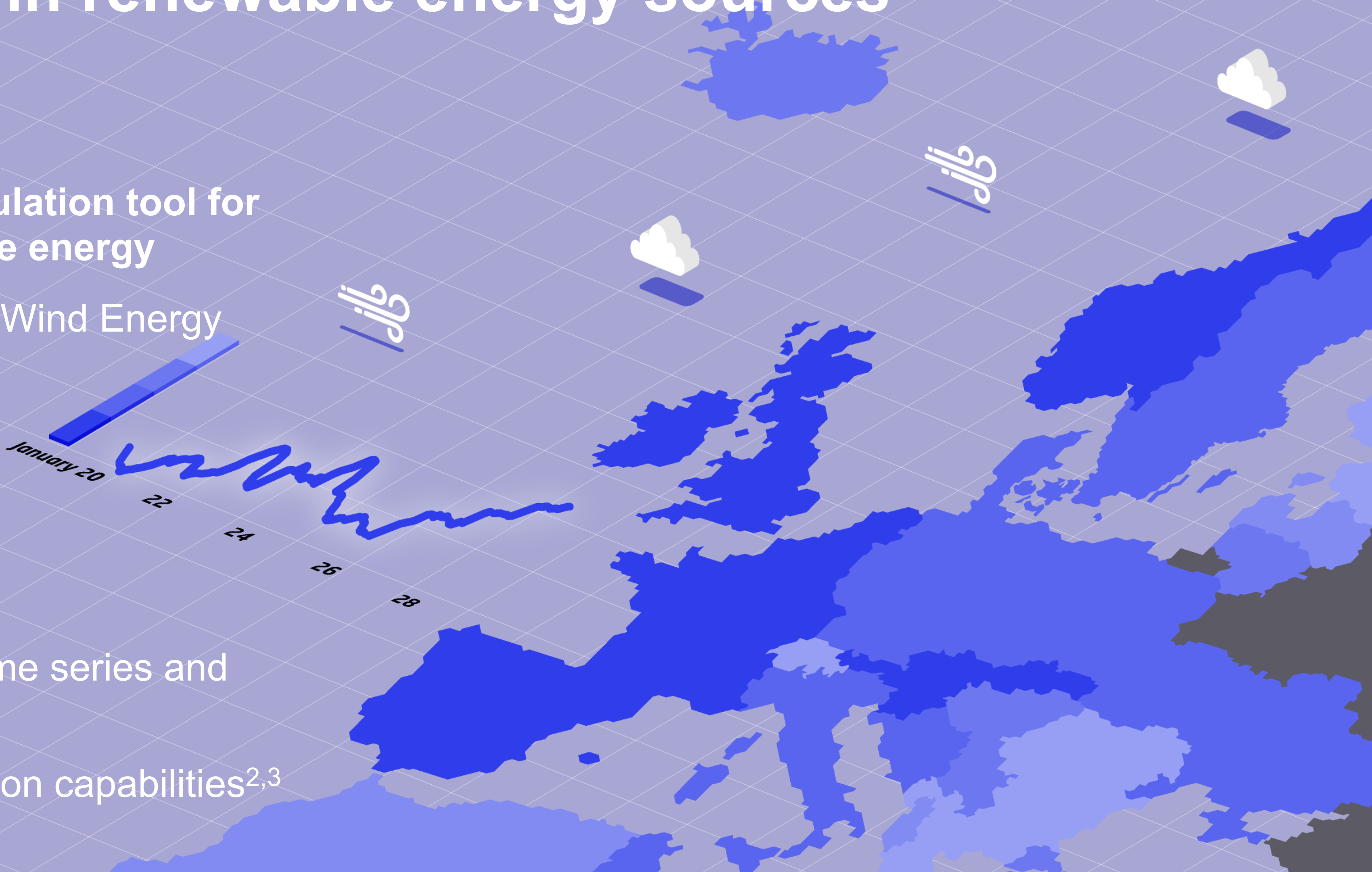
[1] J. Gea-Bermúdez et al., “Optimal generation and transmission development of the North Sea region: impact of grid architecture and planning horizon”, *Energy*, 2020 (https://doi.org/10.1016/j.energy.2019.116512)

[2] M. Koivisto, et al., “North Sea offshore Grid development: Combined optimization of grid and generation investments towards 2050”, *IET Renewable Power Generation*, 2020 (https://doi.org/10.1049/iet-rpg.2019.0693)

[3] J. Gea-Bermúdez, et al., “The role of sector coupling in the green transition: A least-cost energy system development in Northern-central Europe towards 2050”, *Applied Energy*, 2021 (https://doi.org/10.1016/j.apenergy.2021.116685)

Correlations in renewable energy sources (CorRES)

- **A time series simulation tool for variable renewable energy**
- Developed at DTU Wind Energy



- Using reanalysis time series and microscale data[1]
- Sub-hourly simulation capabilities[2,3]

[1]J. P. Murcia, et al., "Validation of European-scale simulated wind speed and wind generation time series", *Applied Energy*, 2022 (https://doi.org/10.1016/j.apenergy.2021.117794)

[2]J. P. Murcia Leon, et al., "Power Fluctuations In High Installation Density Offshore Wind Fleets", *Wind Energy Science*, 2021. (https://doi.org/10.5194/wes-6-461-2021)

[3]M. Koivisto, et al., "Combination of meteorological reanalysis data and stochastic simulation for modelling wind generation variability", *Renewable Energy*, 2020 (https://doi.org/10.1016/j.renene.2020.06.033)

https://corres.windenergy.dtu.dk/

CorRES: Modelling VRE generation variability

Meteorological data

- WRF runs
- NEWA
- ERA5
- ERA5-Land (irradiance)
- Global Wind Atlas (for statistical downscaling)

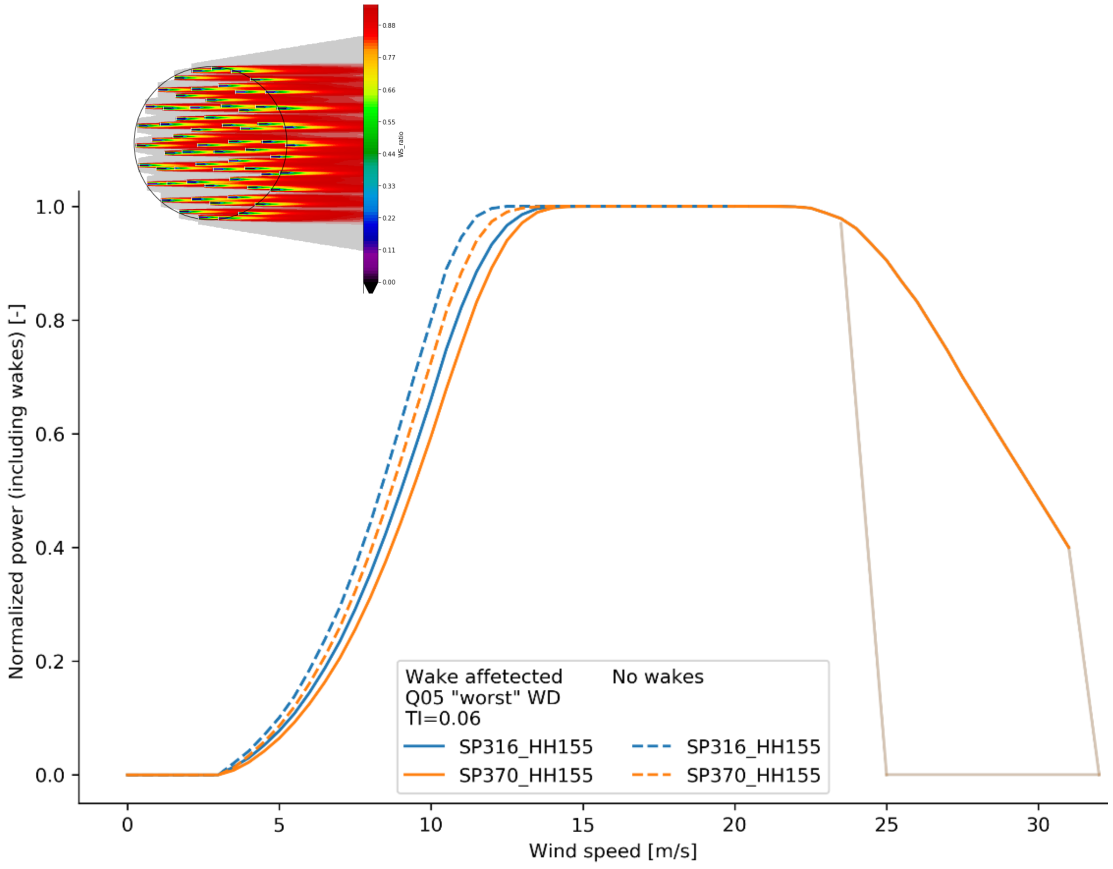
Conversion to power generation

- Wakes (if not part of meteorological data)
- Storm shutdown model
- PVLib for solar PV
- Turbine data
- Wind power plant data

VRE time series

CorRES: Modelling wakes

- **Micro-scale wake models available in PyWake[1]**
  - The main approach used in CorRES
  - Can be applied in energy system optimisation[2]
- **Meso-scale wake models[3]**
  - Include the impact of very large plants removing kinetic energy from the atmosphere
  - Use in energy system optimisation quite new (used in the BaltHub)



[1]M. M. Pedersen, et al., DTUWindEnergy/PyWake: PyWake, 2019 (https://doi.org/10.5281/zenodo.2562662)

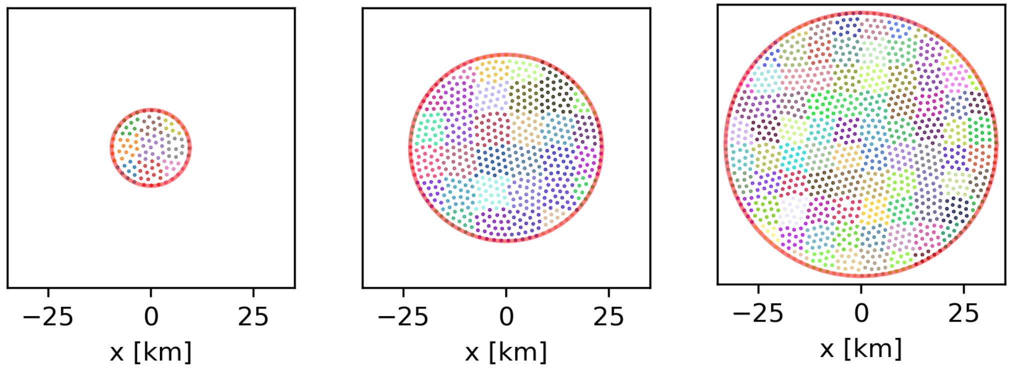
[2]J. Gea-Bermúdez, et al., “The Value of Sector Coupling for the Development of Offshore Power Grids”, *Energies*, 2022 (https://doi.org/10.3390/en15030747)

[3]P. J. H. Volker, et al., “Prospects for generating electricity by large onshore and offshore wind farms”, *Environmental Research Letters*, 2017 (https://doi.org/10.1088/1748-9326/aa5d86)

CorRES:
Modelling hubs for energy system analyses

- We want to considered hub size in the energy system optimisation
  - **Economies of scale[1] (+)**
  - **Required cable length[2] (+/-)**
  - **Increasing wake losses[2] (-)**

- **Each hub is modeled in detail in CorRES**
  - Variation in resource
  - Ramps in detail using sub-farms
  - Storm shutdown[3]



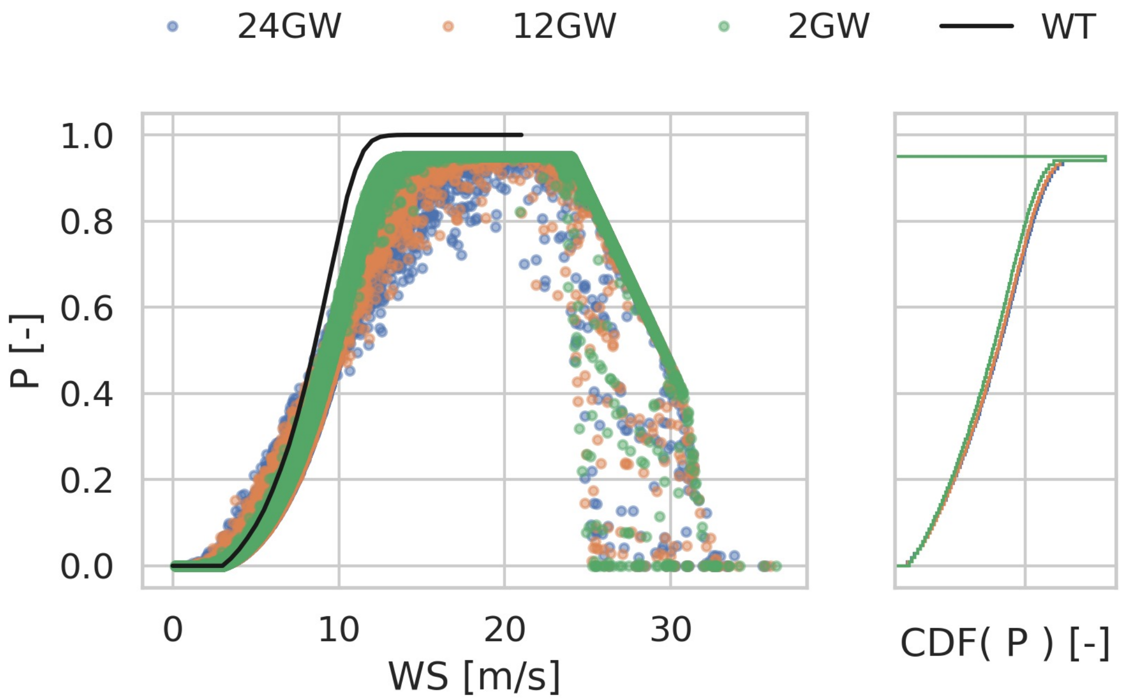
Layouts for 2GW, 12GW and 24GW hubs. Each sub-farm is shown in different color.

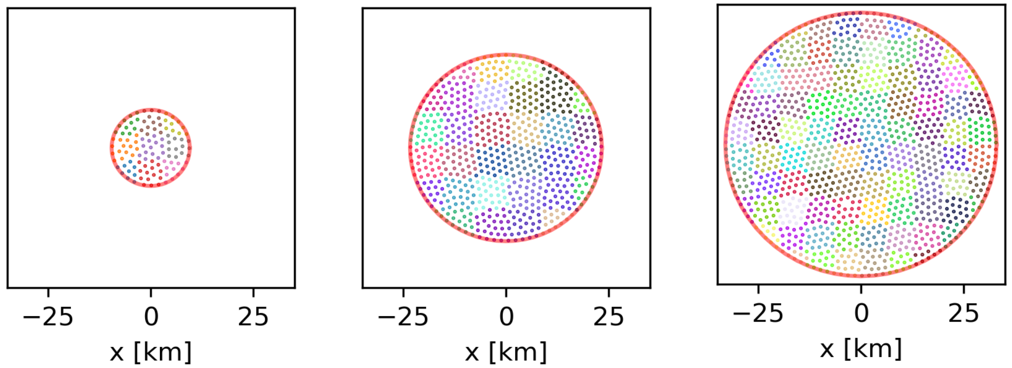
[1] J. Gea-Bermúdez, et al., "Optimal generation and transmission development of the North Sea region: impact of grid architecture and planning horizon", *Energy*, 2020 (https://doi.org/10.1016/j.energy.2019.116512)

[2] J. Gea-Bermúdez, et al., "The Value of Sector Coupling for the Development of Offshore Power Grids", *Energies*, 2022 (https://doi.org/10.3390/en15030747)

[3] J. P. Murcia Leon, et al., "Power Fluctuations In High Installation Density Offshore Wind Fleets", *Wind Energy Science*, 2021. (https://doi.org/10.5194/wes-6-461-2021)

CorRES:
Why consider sub-farms?

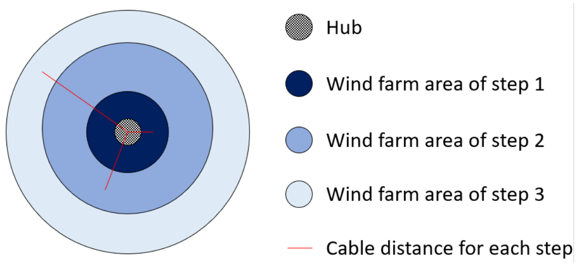




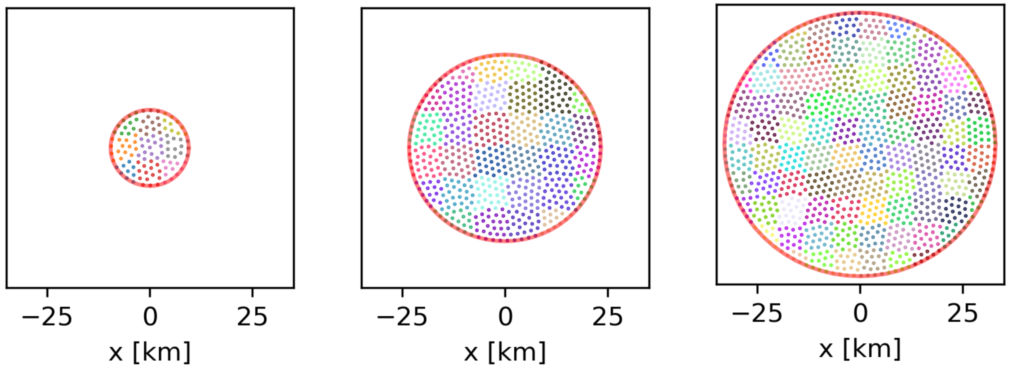
Layouts for 2GW, 12GW and 24GW hubs. Each sub-farm is shown in different color.

- **With very large hubs, the hub-level power curve starts to smoothen significantly**
  - Captured by having the GW split to sub-farms

CorRES to Balmorel:
The specific hubs modelled



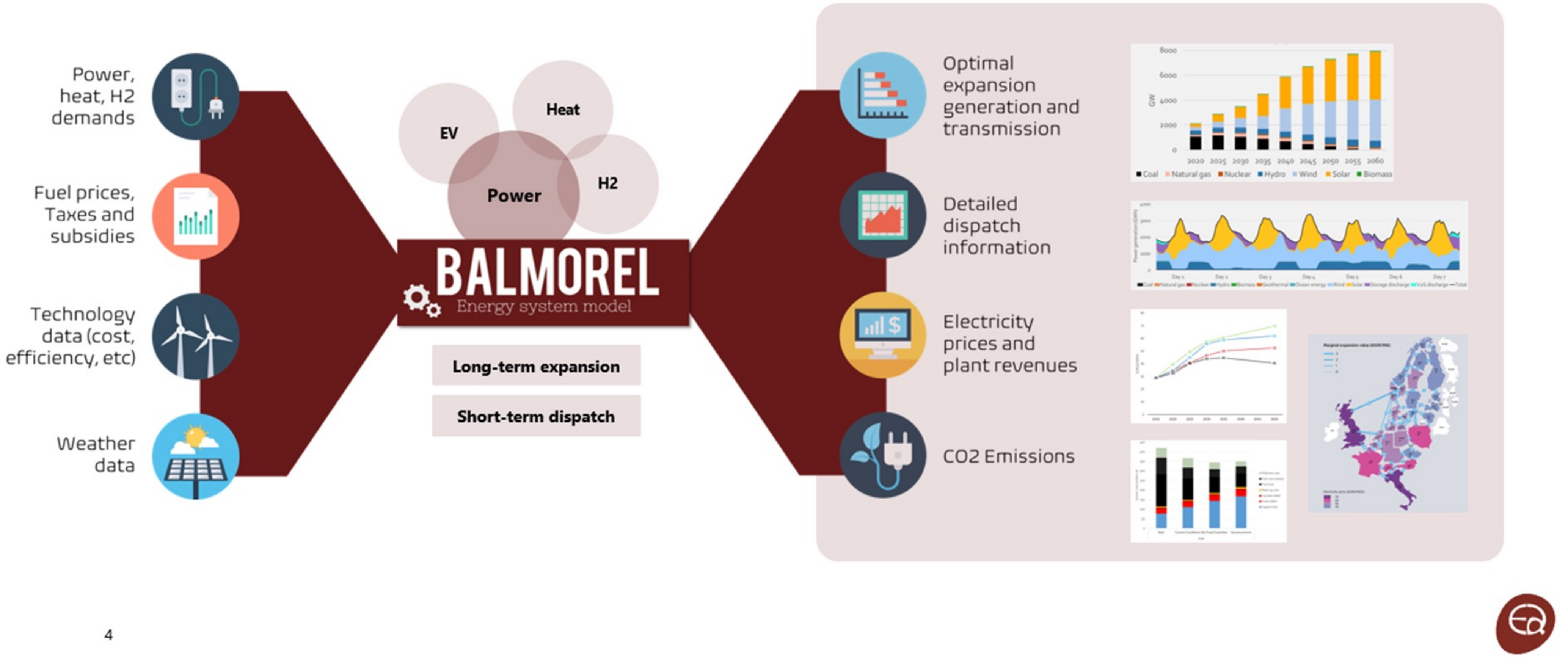
- Circular energy hubs are analysed
  - **2, 12, and 24 GW for the North Sea**
  - **2, 4, and 6 GW for the Baltic Sea**
  - Capacity density of 7 MW/km2
- In steps in the Balmorel optimisation; e.g., for the North Sea:
  - 2 GW
  - 12 GW (= 2 + 10)
  - 24 GW (= 2 + 10 + 12)



Layouts for 2GW, 12GW and 24GW hubs. Each sub-farm is shown in different color.

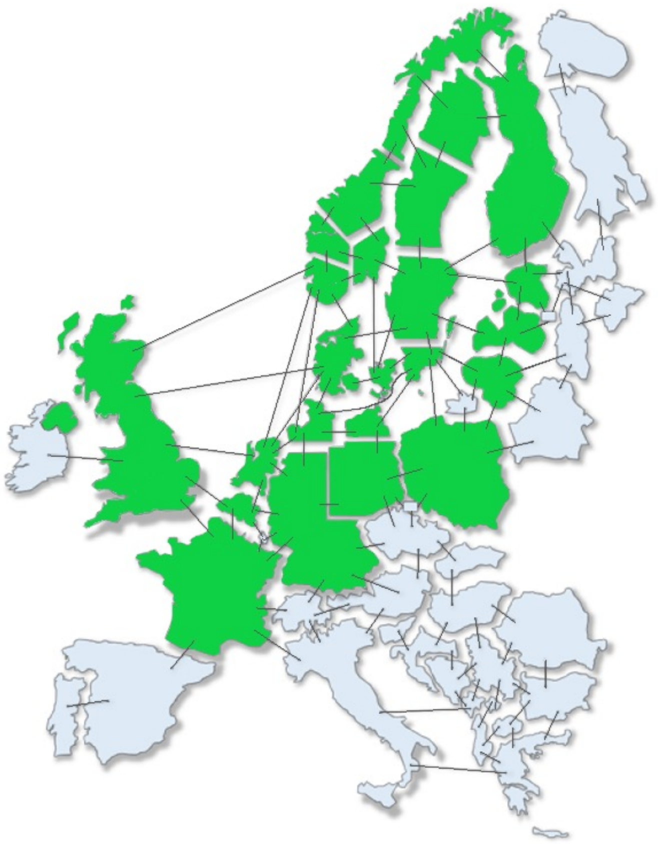
- 18 MW turbines with 340 W/m2 specific power
- Hub height of 150 m

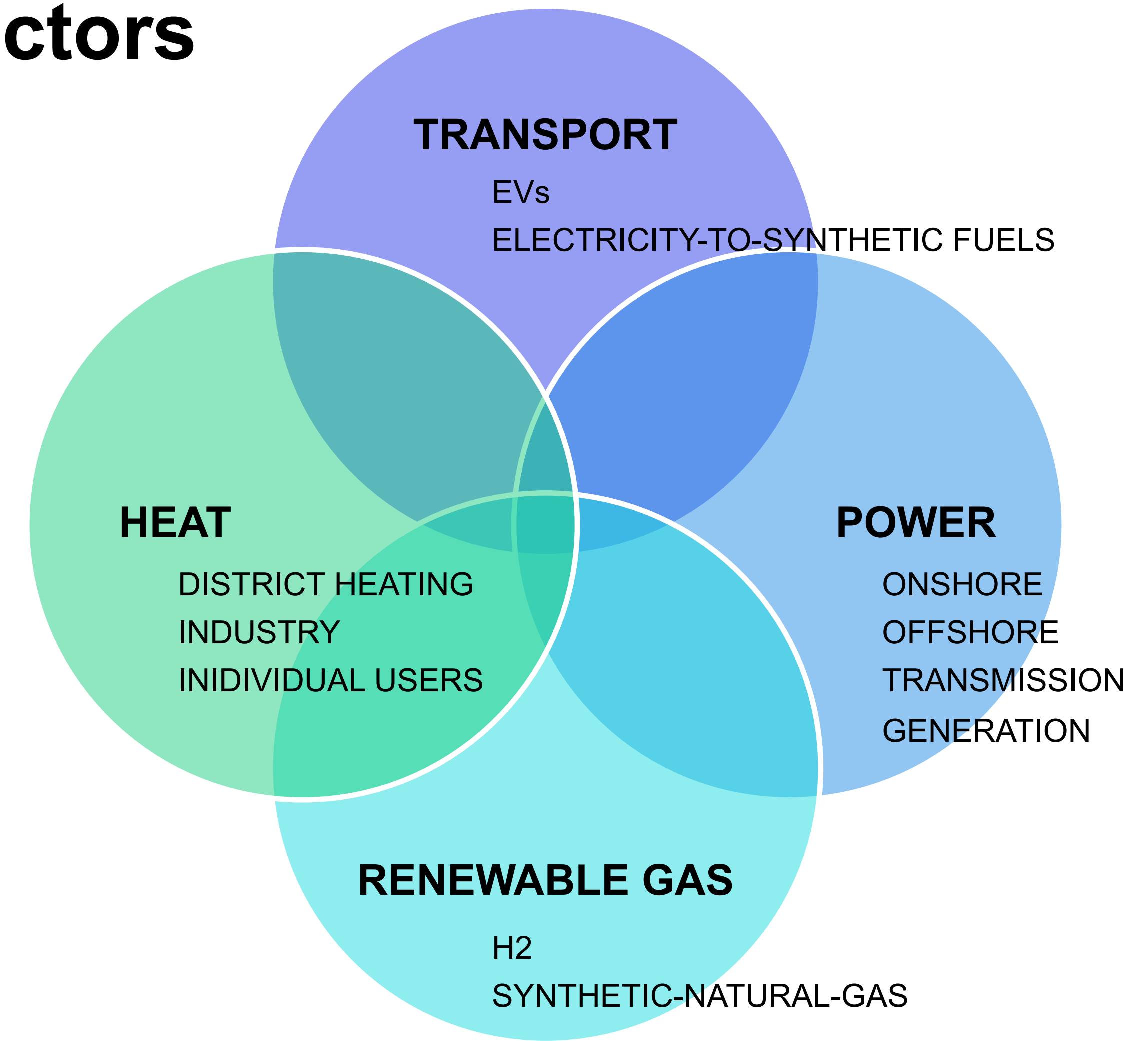
Balmorel energy system model



Source: Ea Energianalyse

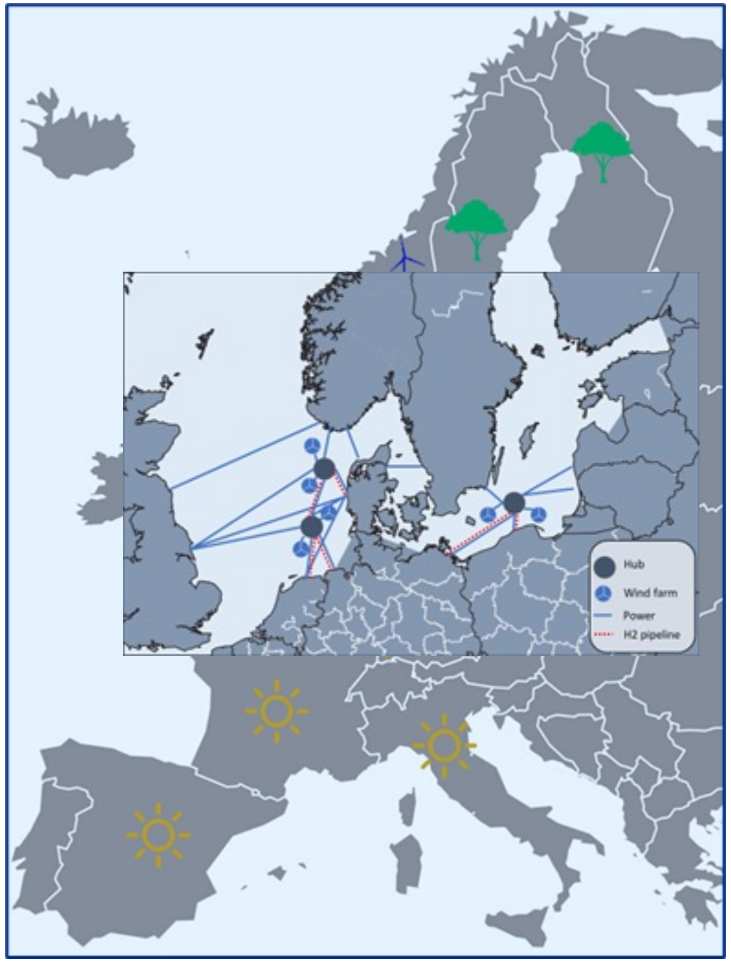
Balmorel:
Geographic scope & sectors





J. Gea-Bermúdez, et al., "The role of sector coupling in the green transition: A least-cost energy system development in Northern-central Europe towards 2050", *Applied Energy*, 2021 (https://doi.org/10.1016/j.apenergy.2021.116685)

Balmorel:
Focus on offshore wind

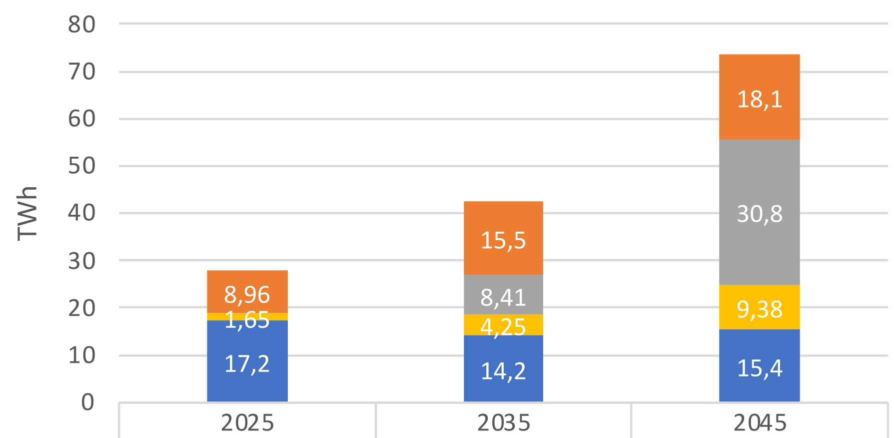


Balmorel in BaltHub

- Transferring offshore grid modelling from the North Sea to the Baltic Sea
- Optimise generation from offshore wind, its locations, as well as it connection to shore (radial vs hub, i.e. connection to more countries)

Focus on the Baltic States:
Renewable generation share and flexibility needs

- The most electrified scenario is used in the analysis as this scenario is likely considering Baltic States goals described in National Strategies.
- Total energy consumption (demand) forecasts in Baltic states consists of 4 main parts: heat, hydrogen, electric vehicles, and exogenous part.
- Energy demand is expected to almost triple from 2025 to 2045 due to electrification, especially, in hydrogen sector.
- In the span of 20 years hydrogen will add to the total demand 30.8 TWh and the total demand will reach 73.68 TWh.
- Such increase in the demand also requires investments in renewable energy sources to meet the obligations to EU.

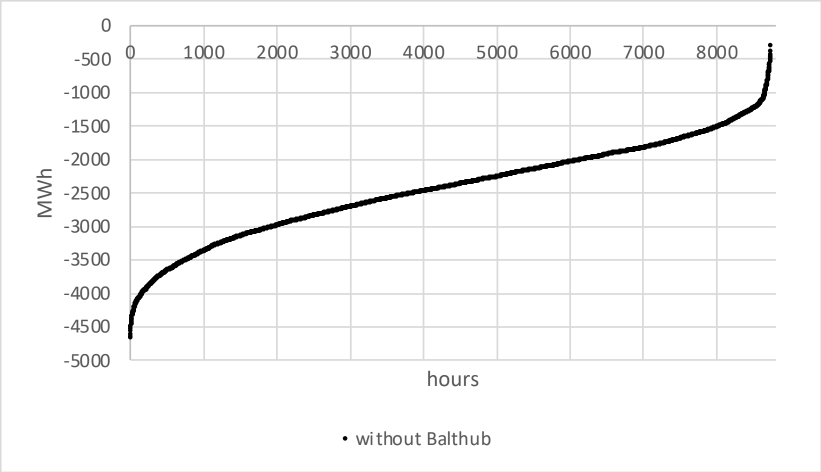


	2025	2035	2045
Heat	8,96	15,5	18,1
Hydrogen	0	8,41	30,8
Electric Vehicles	1,65	4,25	9,38
Exogenous	17,2	14,2	15,4

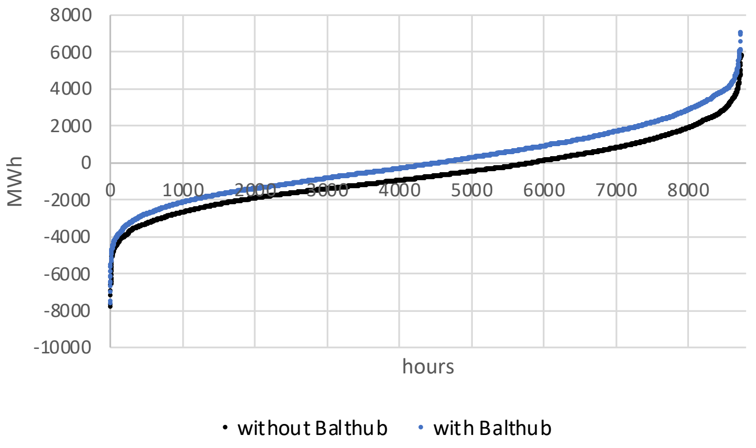
Focus on the Baltic States: Renewable generation share and flexibility needs

$$balance_i = generation_i - demand_i$$

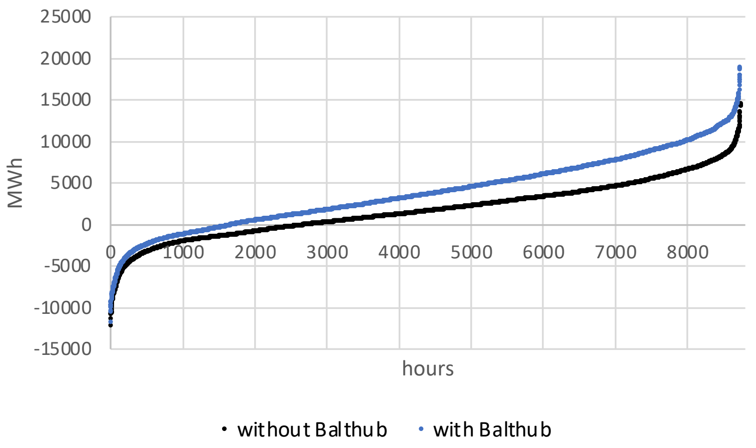
2025



2035



2045



With BaltHub = including the offshore energy hubs and the related grid in the calculations