Going offshore or not: Where to generate hydrogen?

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Turning the Tide: Optimising Europe’s Offshore Energy Future with Holistic Planning and Engagement, April 2024

DTU

Agenda

- Overview of the studied scenarios towards 2050
- Results from the two studies
- Pros and cons for building H_2 infrastructure onshore vs. offshore

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Going offshore or not: Where to generate hydrogen in future integrated energy systems?

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Offshore energy hubs: Cost-effectiveness in the Baltic Sea energy system towards 2050

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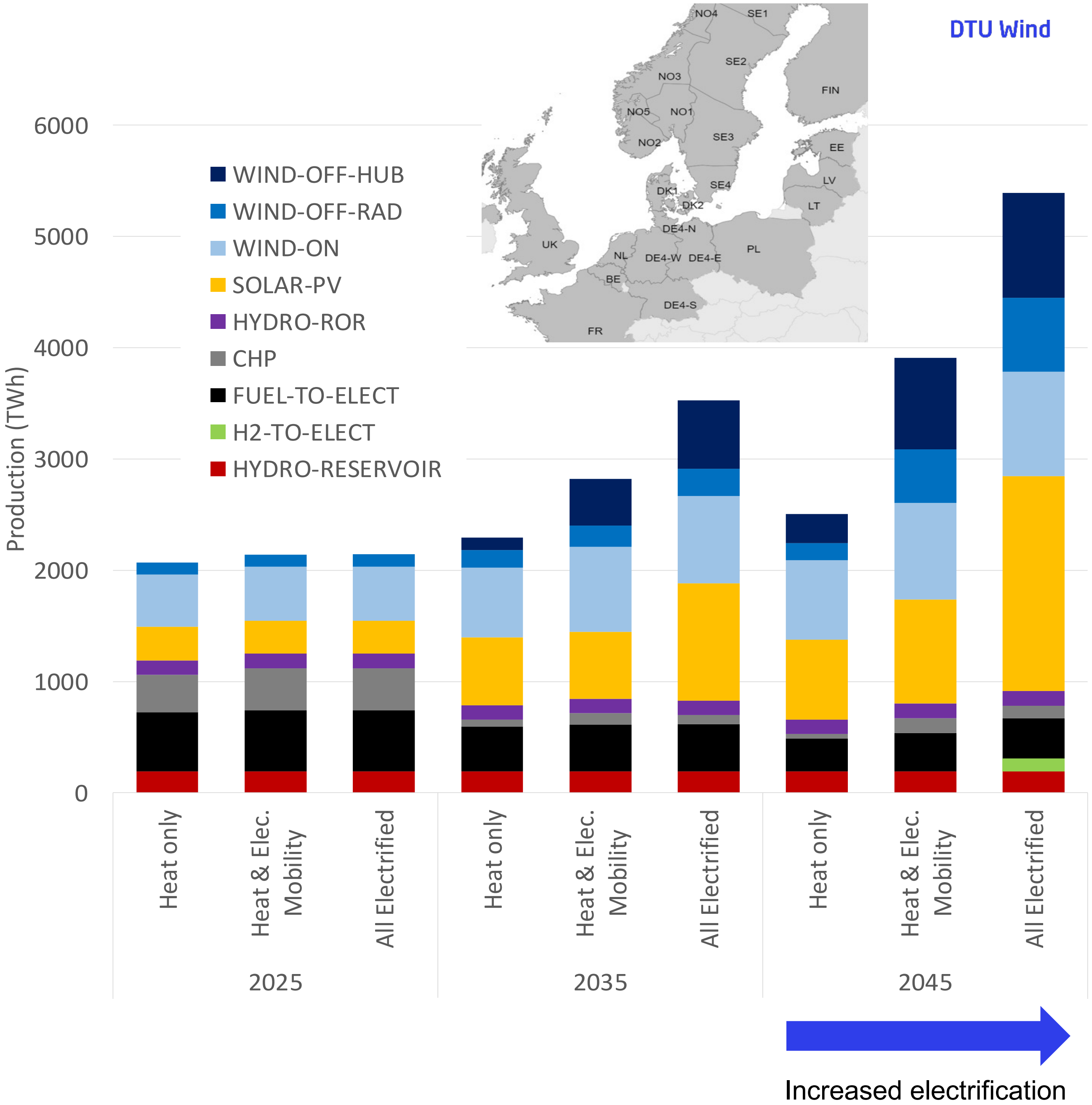
21st Wind & Solar Integration Workshop, 2022

https://orbit.dtu.dk/en/publications/offshore-energy-hubs-cost-effectiveness-in-the-baltic-sea-energy-

Scenarios towards 2050

- **We see potential of offshore energy hubs from the 2030s onwards**
  - Highly dependent on the level of electrification
  - As is all offshore wind in our results
- **Should the hubs be connected to onshore via transmission lines or H_2 pipelines?**

- Note: H_2 demand is assumed exogenously



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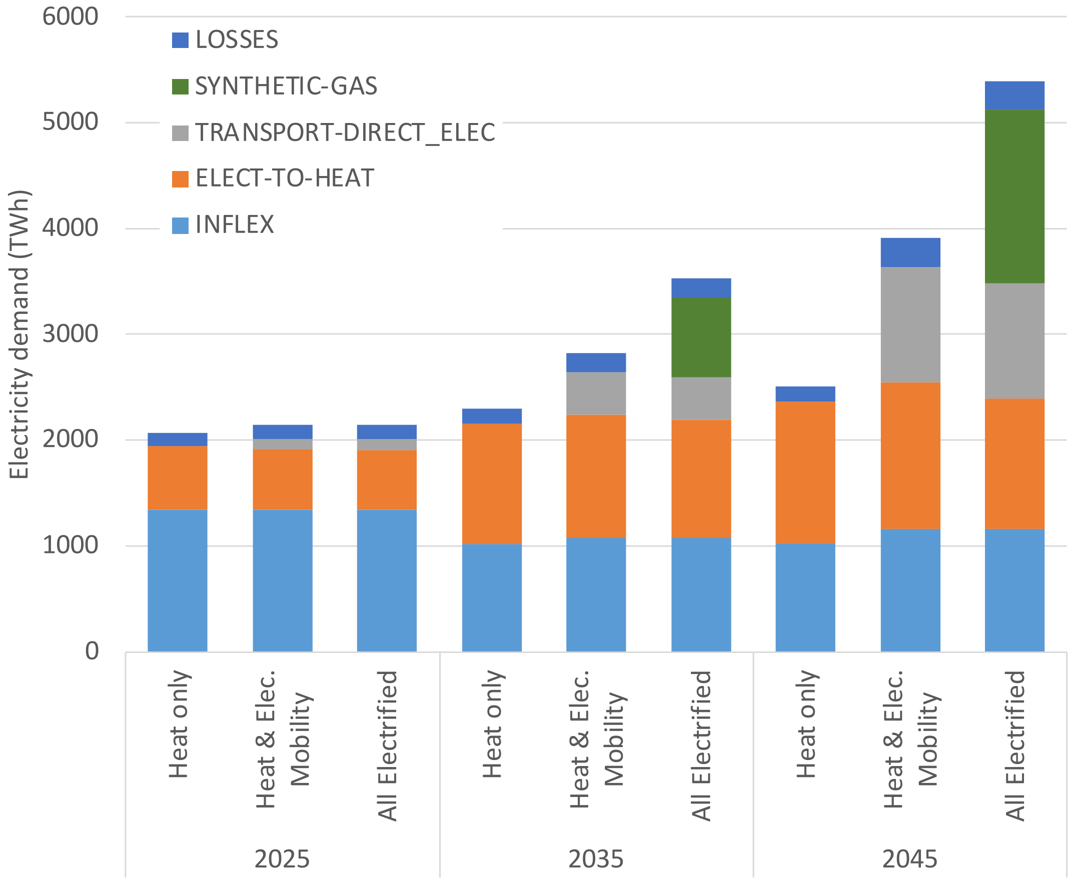
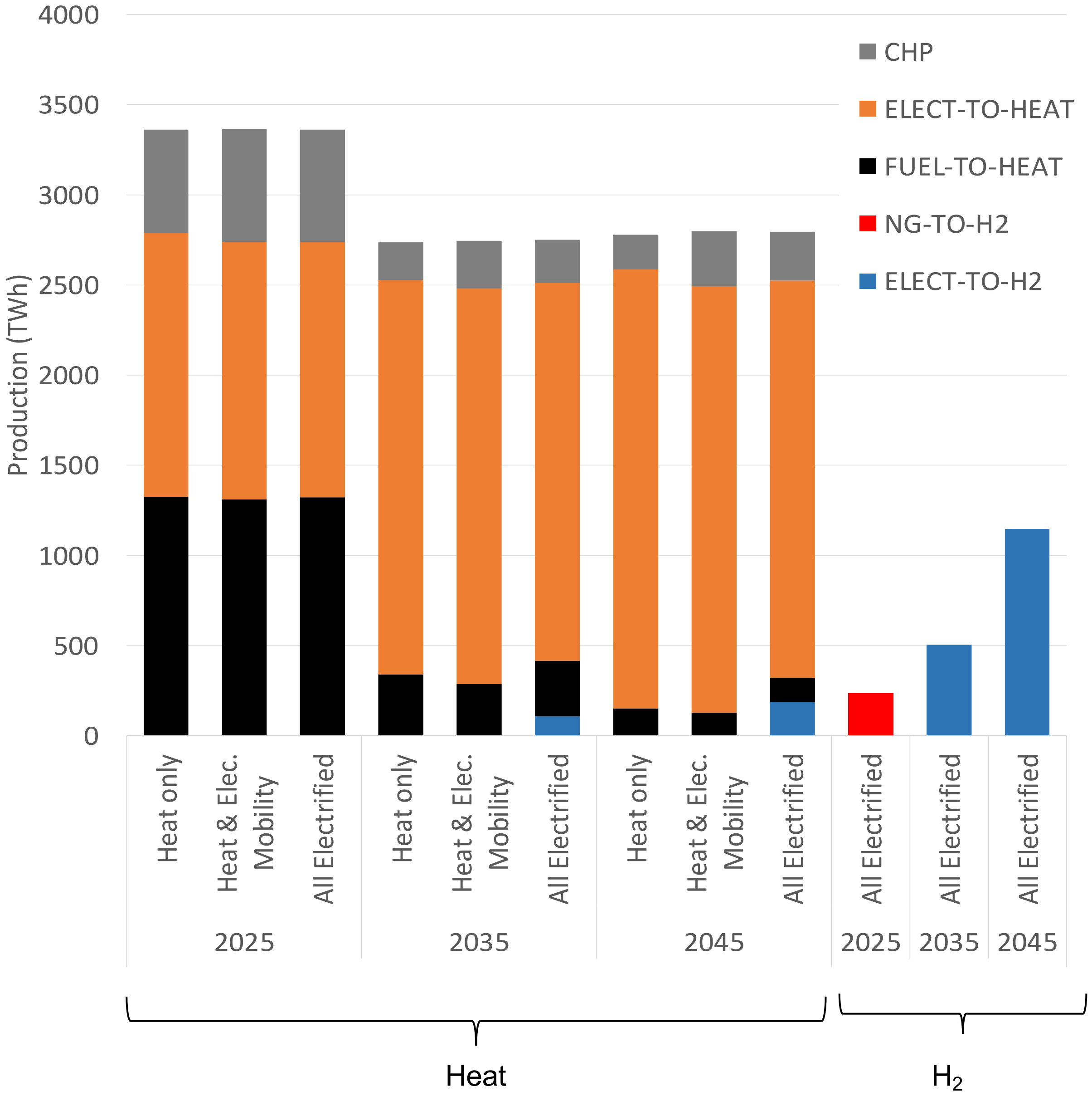
Scenarios towards 2050





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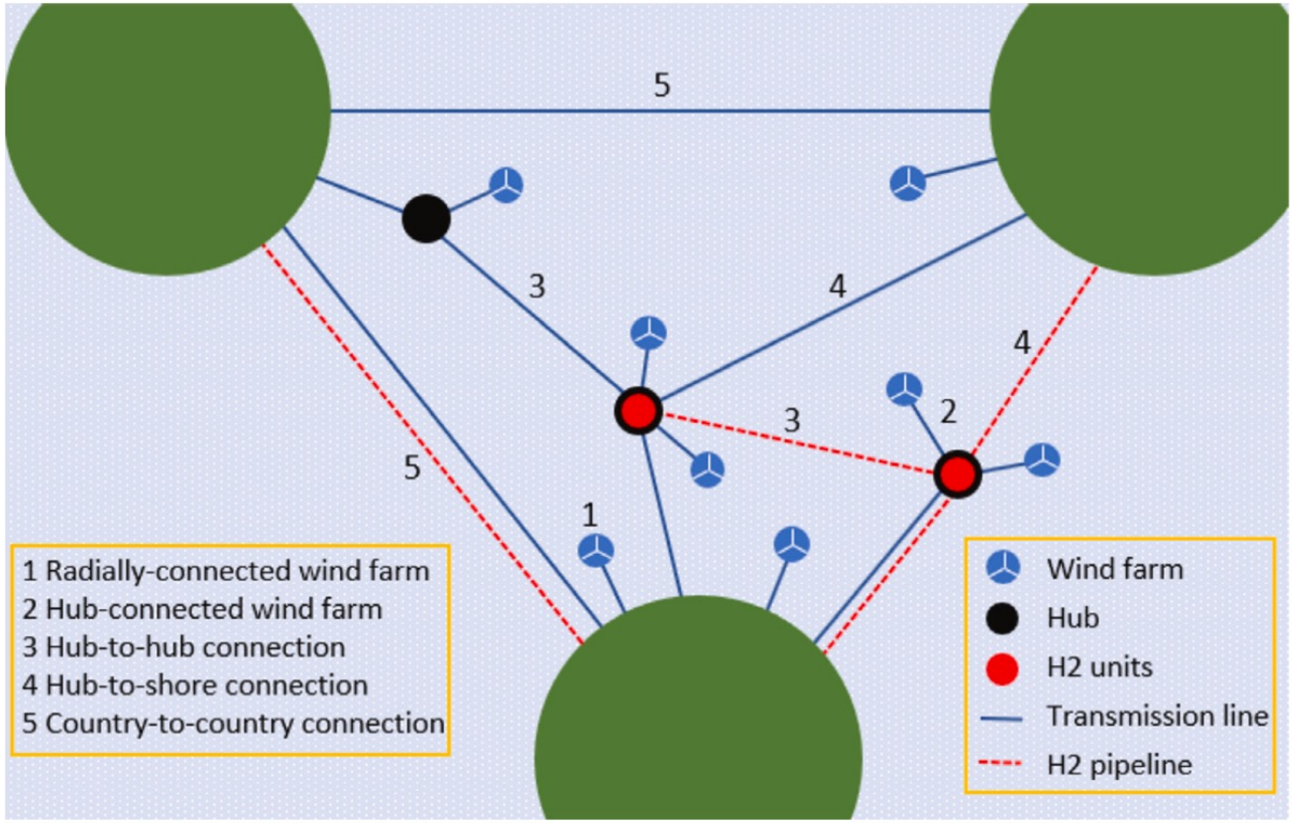
Different offshore infrastructure options in the energy system optimisation



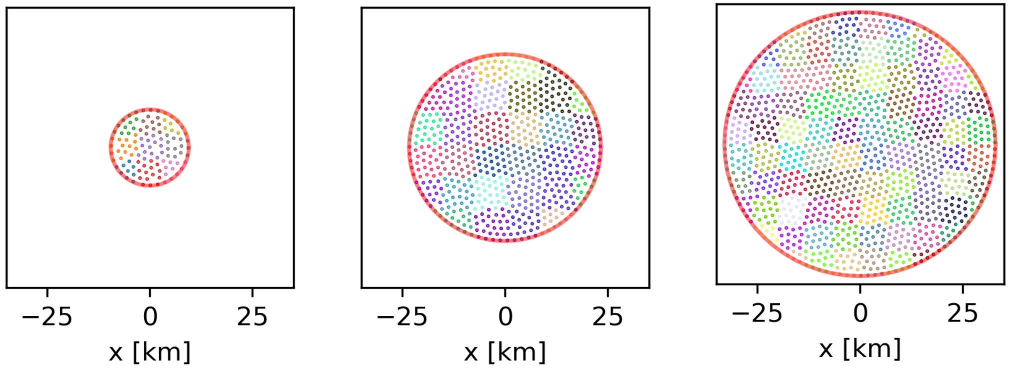
Also hydrogen storage at the hubs

J. Gea-Bermúdez, et al., “Going offshore or not: Where to generate hydrogen in future integrated energy systems?”, *Energy Policy*, 2023

Note about modelling: Large-scale wake losses important to consider

- 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]



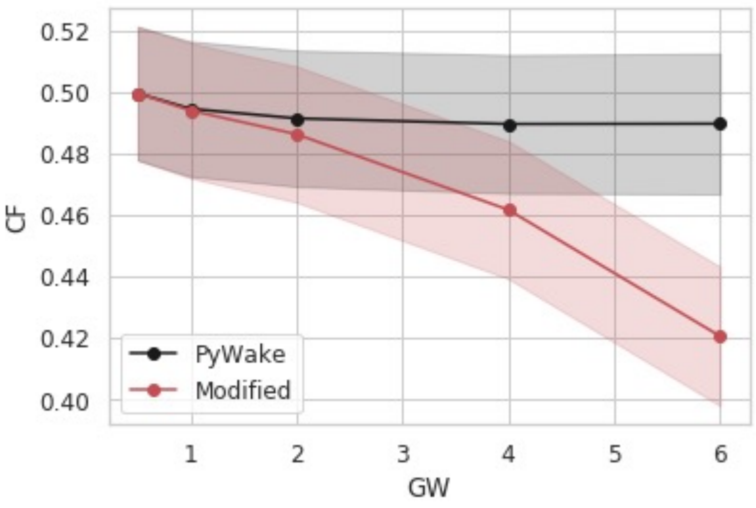
Layouts for 2GW, 12GW and 24GW hubs. Each sub-farm is shown in different color.

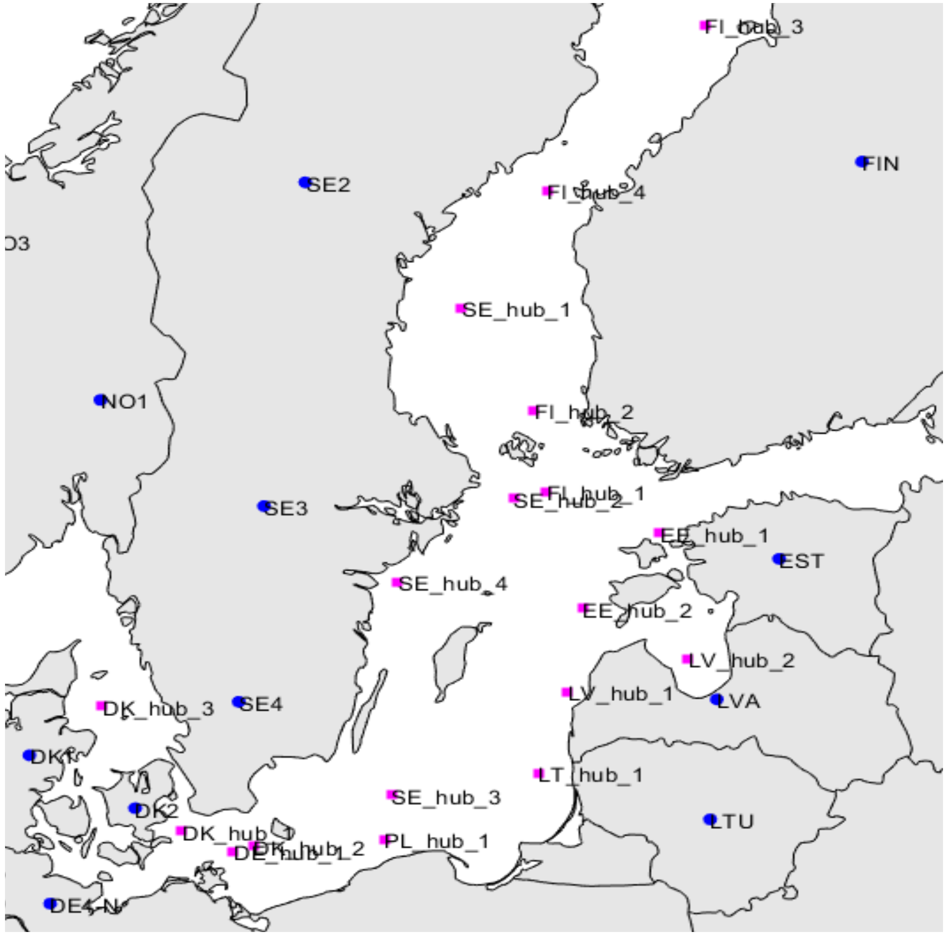
[1] J. Gea-Bermúdez, et al., "Optimal generation and transmission development of the North Sea region: impact of grid architecture and planning horizon", *Energy*, 2020 (https://doi.org/10.1016/j.energy.2019.116512)

[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)

Note about modelling: Large-scale wake losses important to consider





- **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
- **The large-scale wake losses are not considered in most energy system studies**

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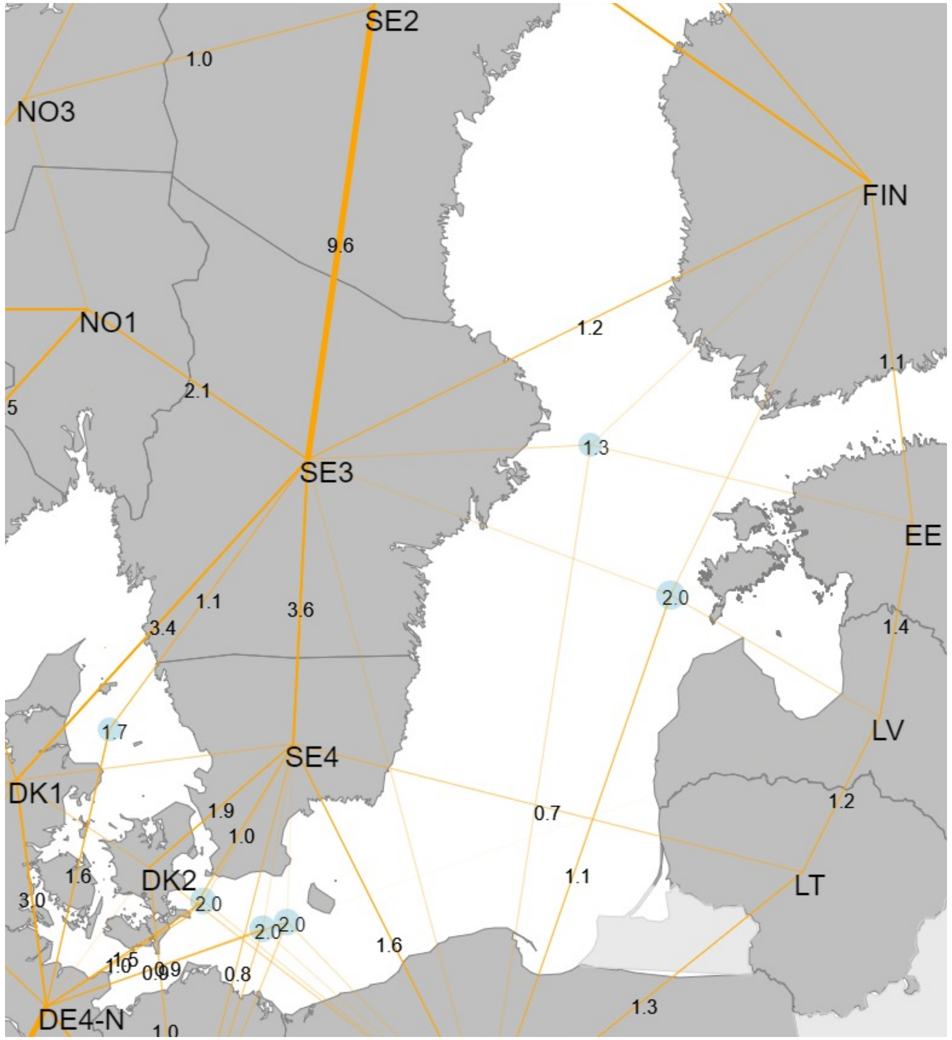
Hubs and transmission lines in the Baltic Sea: Heat only



Low electrification scenario

Installed offshore wind:

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

Some of the hubs seem 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

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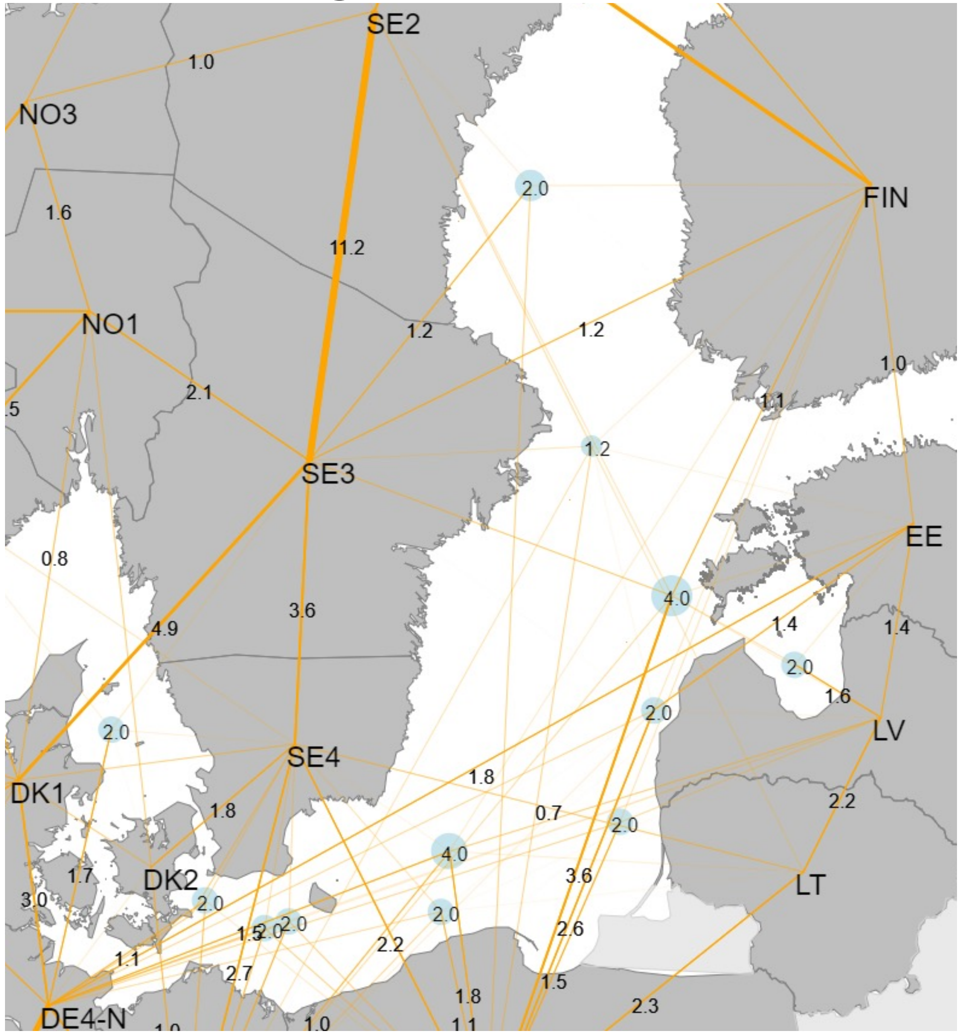
Hubs and transmission lines in the Baltic Sea: Heat & Elec. Mobility



Medium electrification scenario

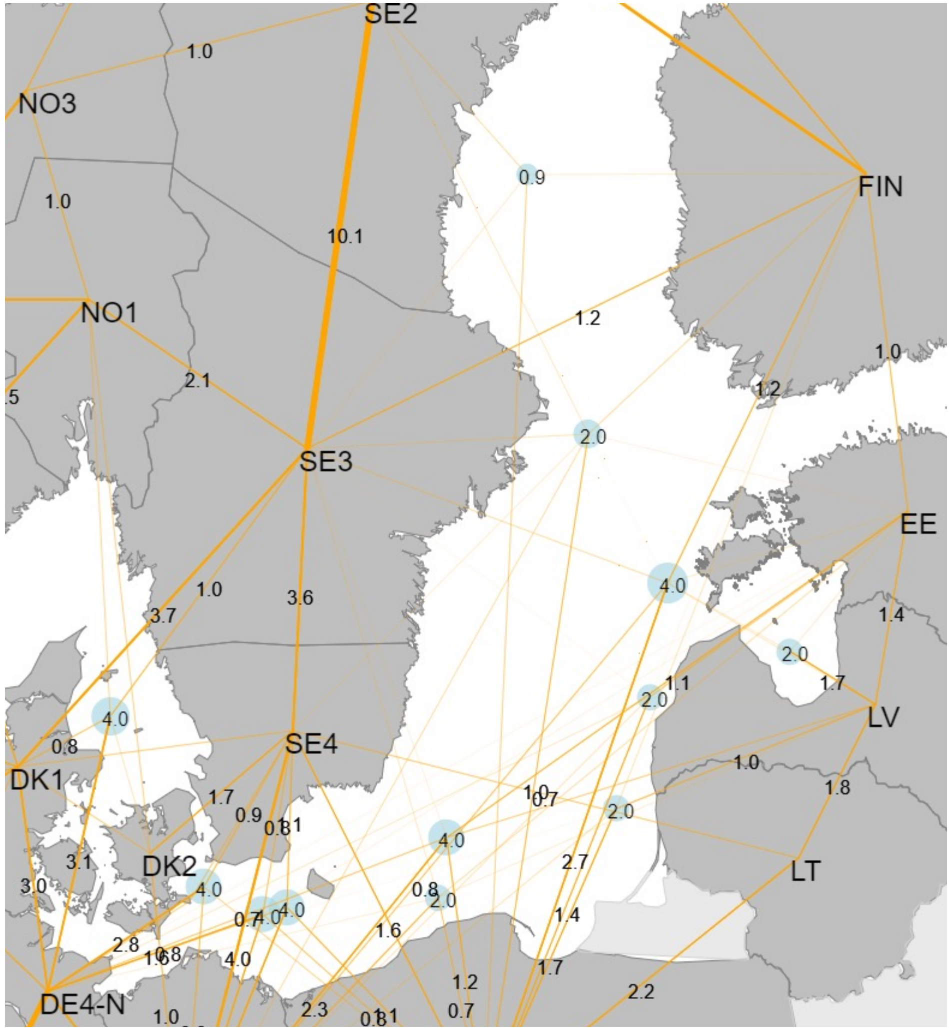
Installed offshore wind:

	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

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

Hubs and transmission lines in the Baltic Sea: 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

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Electrolysers and H_2 pipelines in the Baltic Sea: All Electrified

Very high electrification scenario

Installed electrolysers:

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

Electrolysers are mostly installed onshore

- 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

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More sub-scenarios analysed for the North Sea: All under a highly sector coupled overall scenario

- BASE
- BASE-H2REDIS
- OFFH2
- OFFH2-HUB4H2
- NOEXCESSHEAT
- OFFCAVERN
- ELYZERCOST
- ALL
- ALL-H2REDIS

OFFH2, OFFH2-HUB4H2: Force the model to build electrolysers only at the offshore hubs. In OFFH2-HUB4H2, only H_2 pipelines from hubs to shore

NOEXCESSHEAT: Excess heat from onshore electrolysers cannot be used

OFFCAVERN: Offshore caverns enable cheaper H_2 storage offshore

ELYZERCOST: Different electrolyser cost development assumption

ALL: **The assumptions NOEXCESSHEAT, OFFCAVERN, and ELYZERCOST combined (= pro-offshore H_2 scenario)**

H2REDIS = allow for redistribution of the hydrogen demand for synthetic fuels (aviation and shipping), even at offshore hubs

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Results (all analysed countries): Electricity demand and hub-connected wind

Scenario	Electricity: Total demand (TWh_e) 2035	Total demand (TWh_e) 2045	Hub-connected wind capacity (GW_e) 2035	Hub-connected wind capacity (GW_e) 2045
BASE	3259	5220	82	180
BASE-H2REDIS	3258	5209	77	173
OFFH2	3277	5171	147	338
OFFH2-HUB4H2	3251	5254	111	288
NOEXCESSHEAT	3307	5294	89	180
OFFCAVERN	3295	5256	77	174
ELYZERCOST	3250	5140	85	183
ALL	3346	5246	84	197
ALL-H2REDIS	3342	5257	82	186

Electricity demand quite similar in all scenarios

If we force the model to produce H_2 offshore, we get more offshore wind.

Otherwise, the sub-scenarios see quite similar overall offshore wind buildout (although the “ALL” scenarios see slightly elevated level's)

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Results (all analysed countries): H_2 production from offshore

Scenario	Hub-connected electrolyser generation (TWh_{th})		Share of hub-connected electrolyser generation in total demand	
	2035	2045	2035	2045
BASE	0	21	0%	2%
BASE-H2REDIS	0	9	0%	1%
OFFH2	336	918	100%	100%
OFFH2-HUB4H2	338	962	100%	100%
NOEXCESSHEAT	49	109	15%	10%
OFFCAVERN	7	105	2%	10%
ELYZERCOST	0	25	0%	3%
ALL	51	257	15%	26%
ALL-H2REDIS	65	228	20%	23%

If we force the model to produce H_2 offshore, it produces H_2 offshore

In the "pro-offshore H_2" scenarios, around 20 % of H2 is produced offshore.

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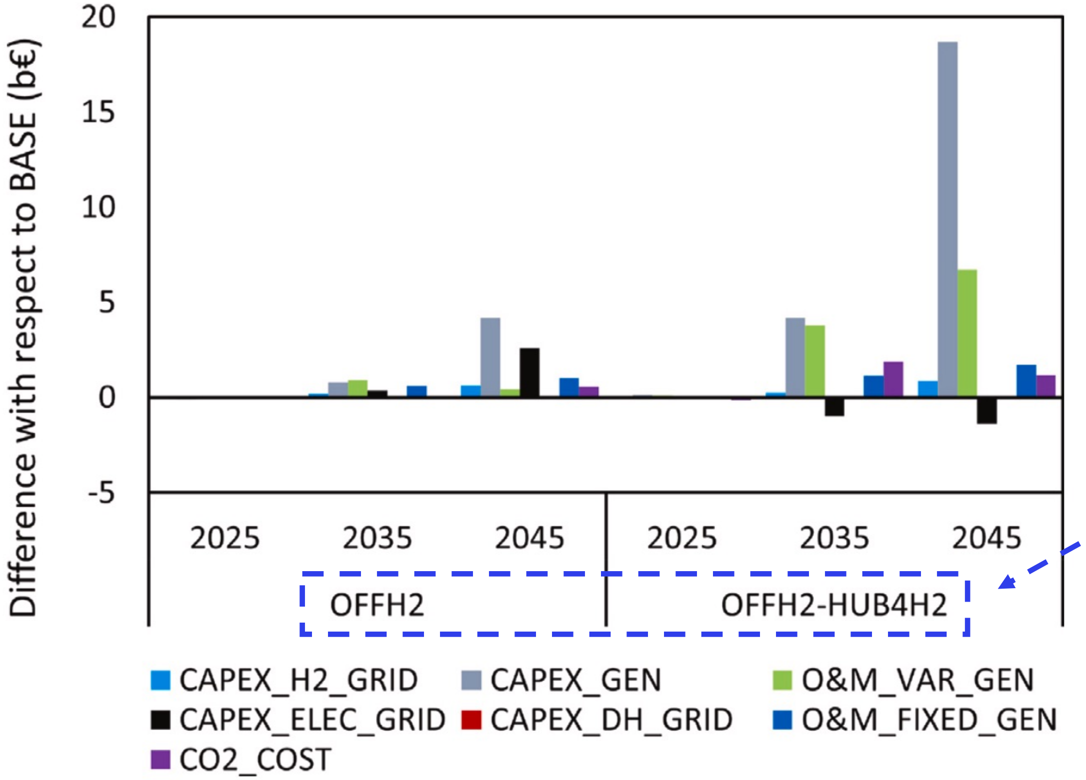
System costs are higher if we only consider H_2 production offshore



These sub-scenarios force the model to build electrolysers only at the offshore hubs.

In OFFH2-HUB4H2, only H_2 pipelines from hubs to shore

- **Thus, at least an extreme scenario with all H_2 offshore and all transmission via pipelines does not seem optimal (from a system perspective)**

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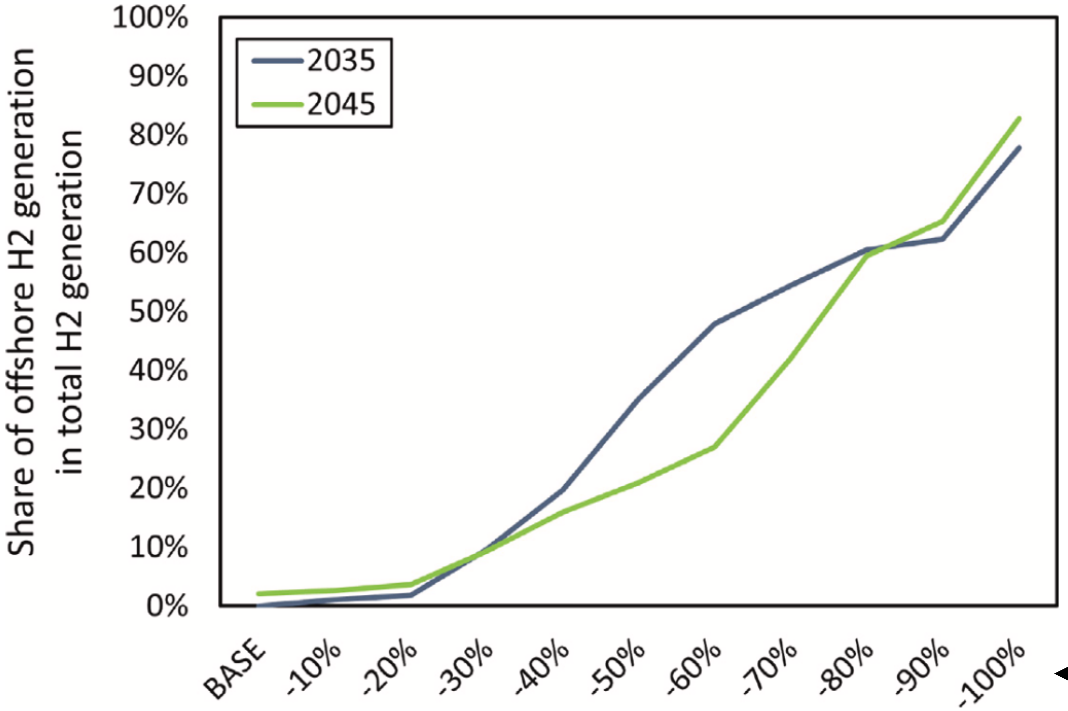
What about if offshore wind is much cheaper?



The BASE level CAPEX values are based on the Danish Energy Agency's technology catalogue: https://ens.dk/en/our-services/projections-and-models/technology-data/technology-data-generation-electricity-and (as it was available in 2021)

← Offshore wind turbine CAPEX reduction

- **Offshore H_2 production significantly increases if offshore wind turbine CAPEX decreases by more than 30% (in the BASE sub-scenario)**

J. Gea-Bermúdez, et al., "Going offshore or not: Where to generate hydrogen in future integrated energy systems?", *Energy Policy*, 2023

Conclusions

- **Both presented studies favour H_2 production onshore (versus offshore)**
  - However, note that the studies share key assumptions and the modelling framework
- **Why onshore H_2 production?**
  - Onshore electrolysers have lower CAPEX as offshore platform is not needed
  - Demand of H_2 is onshore, so closer to demand
  - In our modelling, (onshore) solar PV is a key source of electricity for H_2 production
  - Excess heat can be used in district heating (assuming that this is feasible)
- **Availability of offshore caverns can favour offshore H_2 production**
  - However, in even the most "pro-offshore H_2" scenarios, only around 20 % of H_2 production is projected to be offshore (higher shares are seen if offshore wind CAPEX reduces significantly)
- **Note: as there are many uncertainties related to H_2 infrastructure, it is perfectly feasible to get very different results compared to what is presented here**
  - And it may be that having H_2 production offshore has other benefits not considered in the presented studies