Techno-economic analysis of long-distance hydrogen transport (high-voltage cables and pipelines). North Sea case study

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ENERDAY 2024

Date: 12.04.2024, Dresden

Agenda

1. **Introduction**
2. **Background/Motivation**
   - MOHN project
   - OIES paper
3. **Research question**
4. **Methodology**
   - Model framework
5. **Preliminary results**
6. **Conclusion and next steps**

Introduction

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Project MOHN (Masterplan Offshore Hydrogen North Sea) in collaboration with cruh21

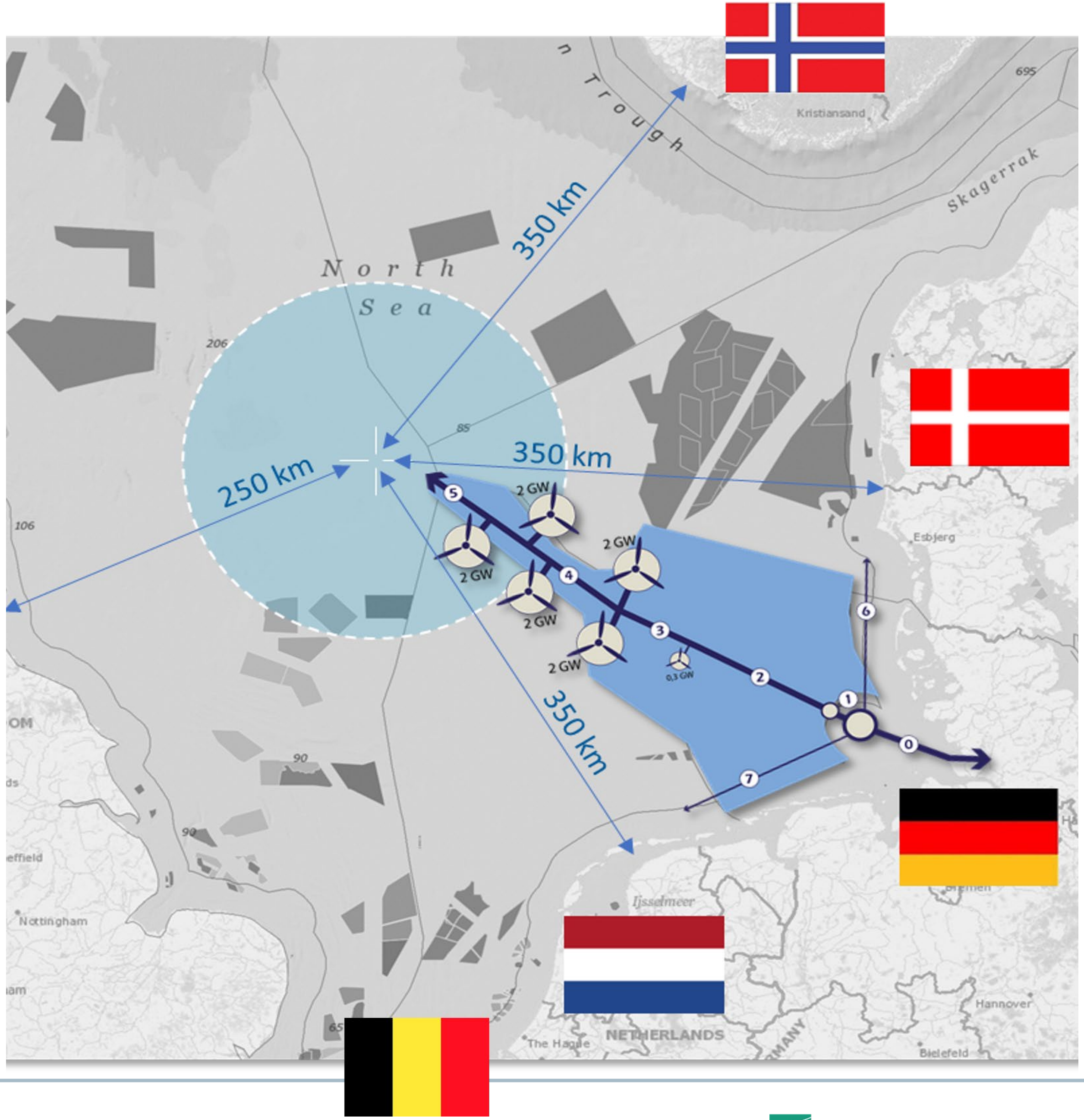
Phase I

Development of a strategy to accelerate the implementation of offshore electrolysis capacity in the German and European North Sea

Sponsored by BMBF

Project time: 01.09.2022-31.05.2025

Budget: 820K€



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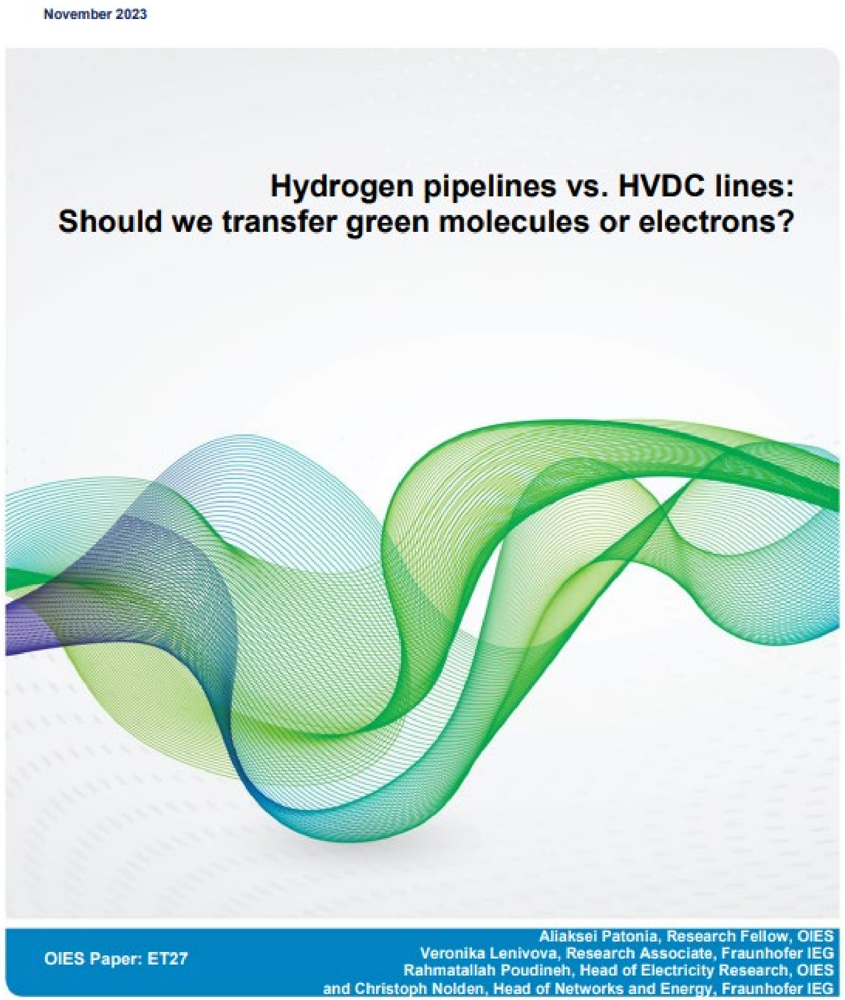
Background/Motivation

HVDC lines vs. hydrogen pipelines: The importance of systems perspective

THE OXFORD INSTITUTE FOR ENERGY STUDIES

Paper main observations:

- HVDC lines and hydrogen pipelines should not be seen as competitors but rather as complementary elements, each offering unique features
- Both options (HVDC lines and H2 pipelines) will likely become integral parts of a complex decarbonised energy system of the future
- While techno-economic features of HVDC lines and H2 pipelines are important, they are not the only factors to consider and focusing solely on each of these technologies in isolation is not productive


November 2023

Hydrogen pipelines vs. HVDC lines:
Should we transfer green molecules or electrons?

OIES Paper: ET27

Aliaksei Patonia, Research Fellow, OIES
Veronika Lenivova, Research Associate, Fraunhofer IEG
Rahmatallah Poudineh, Head of Electricity Research, OIES
and Christoph Nolden, Head of Networks and Energy, Fraunhofer IEG

Source: Patonia et al., 2023

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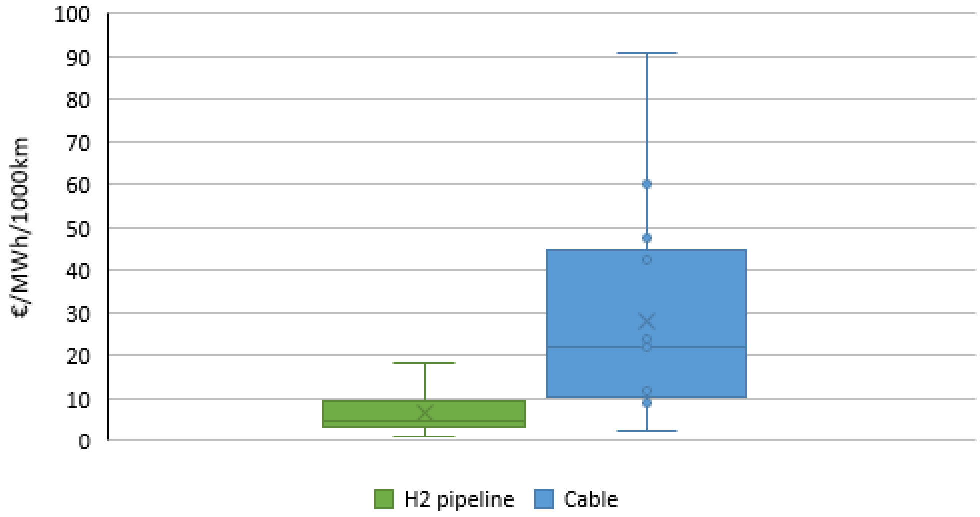
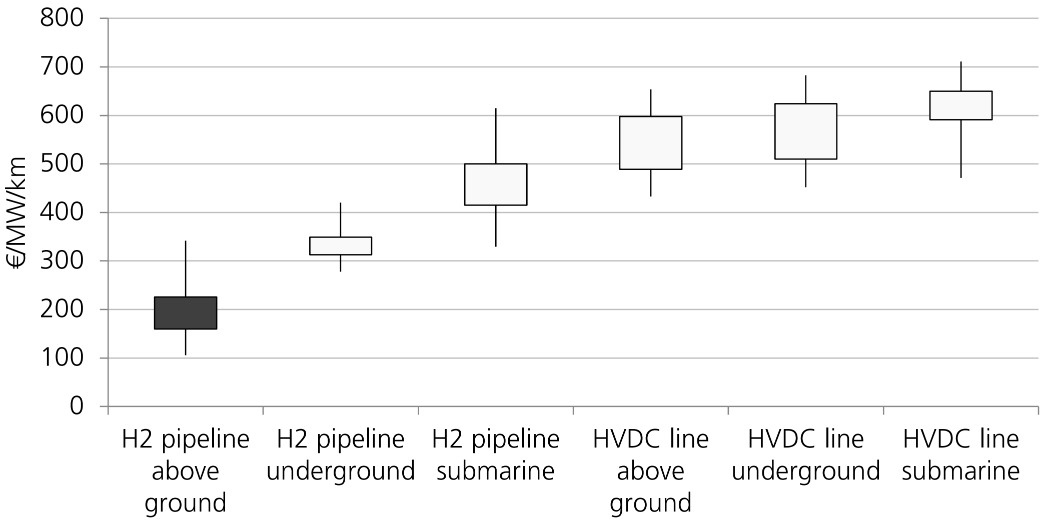
Techno-economic comparison of HVDC lines and H2 pipelines

Result of the literature review

Specific cost ranges for energy transport by HVDC lines and hydrogen pipelines (in EUR/MWh/1,000 km)



Estimated average investment costs for HVDC lines and hydrogen pipelines (in EUR/MW/km)



- The **specific cost ranges** for **hydrogen pipelines** appear to **be more favourable** (between 1.1 and 18.2 EUR/MWh/1,000 km) than **for HVDC projects** (2.3 to 90.1 EUR/MWh/1,000 km).
- The cost drivers that would apply to both hydrogen pipelines and HVDC lines are the scale and length of such projects, materials (for pipelines and cables), regulatory compliance (permitting costs, environmental impact assessments, etc.) and labour costs, as well as environmental considerations such as the need to navigate a challenging system or sensitive infrastructure.
- Hydrogen production costs and availability of storage are not considered in the comparison.

Source: Patonia et al., 2023

Research objective

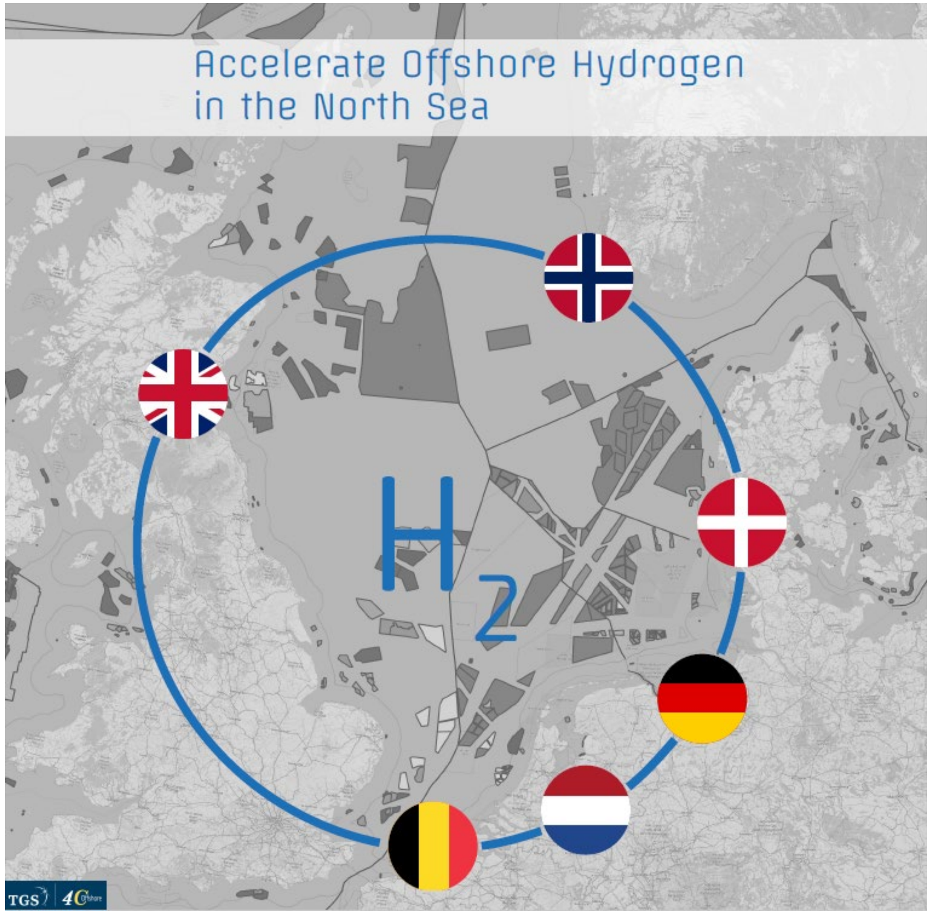
Pipelines vs. HVDC lines from the energy system perspective:

Case study of the North Sea

Case study of the North Sea

When considering offshore wind generation, what is the optimal way of transporting energy over long distance for hydrogen production?

- What is the cost of offshore produced hydrogen?
- How can we compare H_2 pipeline transport and HVDC transport?
- What is the breakeven point for the pipeline and transport: which distance km, which capacity?



Methodology

Scenarios:

Isolated		Cooperation
2030	2040	2050

Countries: DE, DK, GB, NL, NO

Input

- Wind parks max capacity and geolocation from cruh21
- Country-specific offshore hydrogen demand
- Techno-economic input data (CAPEX, OPEX, efficiency, lifetime, WACC
- Weather data for offshore wind generators
- Landuse factor (preservation areas, shipping routes, existing infrastructure, etc.)

Pypsa-Eur Framework v0.8.0*

Preparing network
- **Custom base network**
- **Custom energy carrier: Offshore Hydrogen**
- **build powerplants and renewable profiles**

Simplifying Network
- **Clustering**
- **Aggregation of H2 demand**
- **Countries of interest:**
  - **DE, DK, GB, NL, NO**

Add extra components
- **Electrolysers**
- **Storages**
- **Grid deployment**
  - **H2 Pipelines**
  - **DC lines**

Solving Network
- **Overnight/Myopic**
- **Objective function**
- **LOPF**
- **Additional Constraints, variables**

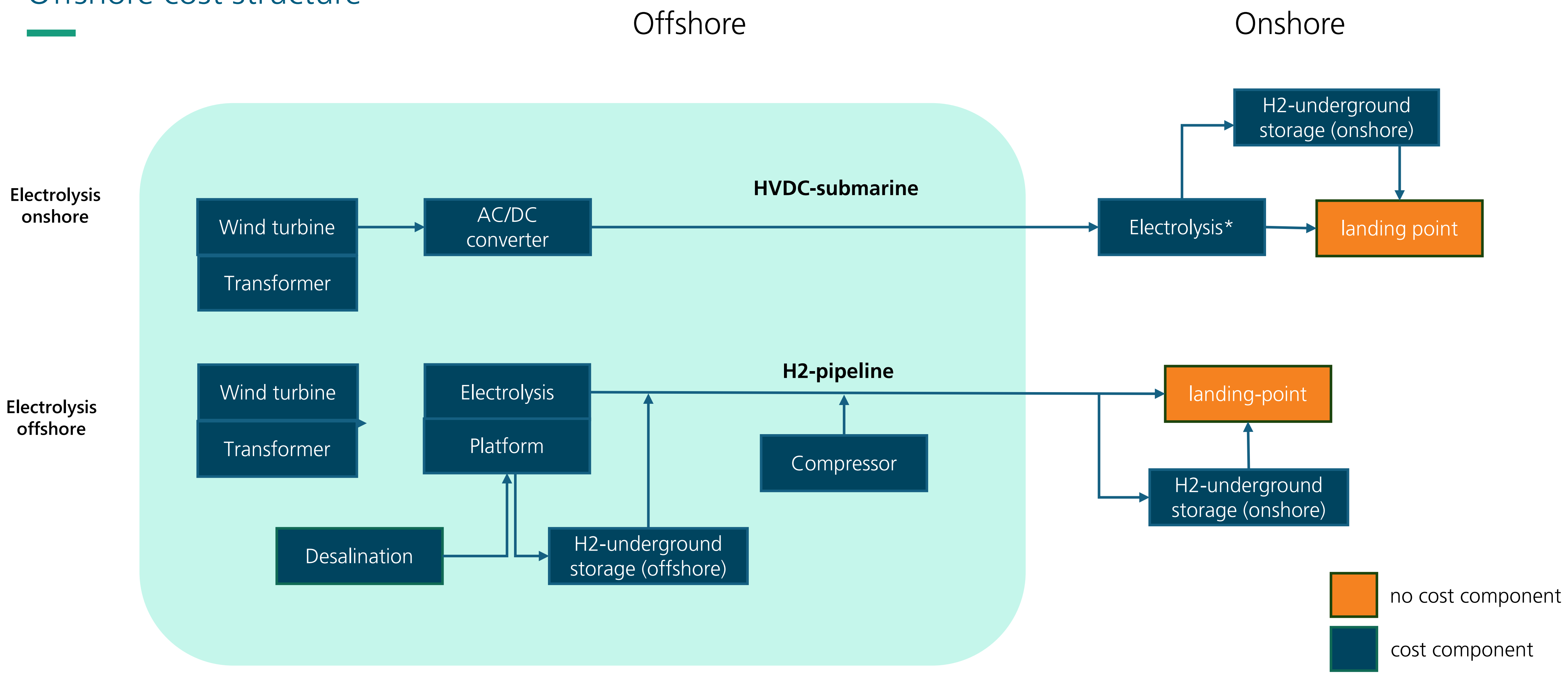
Output

- Cost-Optimised wind and electrolyser capacities at the best locations
- Cost-Optimised Hydrogen pipeline and cable infrastructure
- Locational LCOH
- Marginal price of hydrogen at onshore locations
- Cost-Optimised Hydrogen storages

- ***Based on the model proposed by*** P. Glaum, F. Neumann, T. Brown: *Offshore Wind Integration in the North Sea: The Benefits of an Offshore Grid and Floating Wind.* 2023.

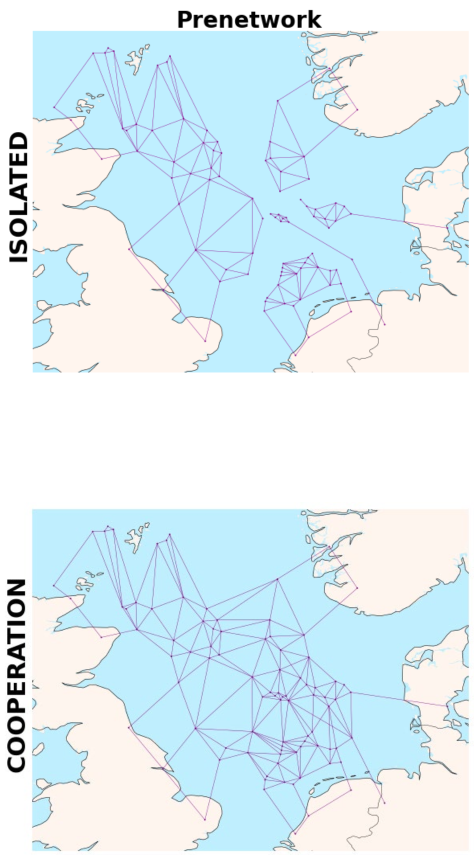
Methodology – Case Study

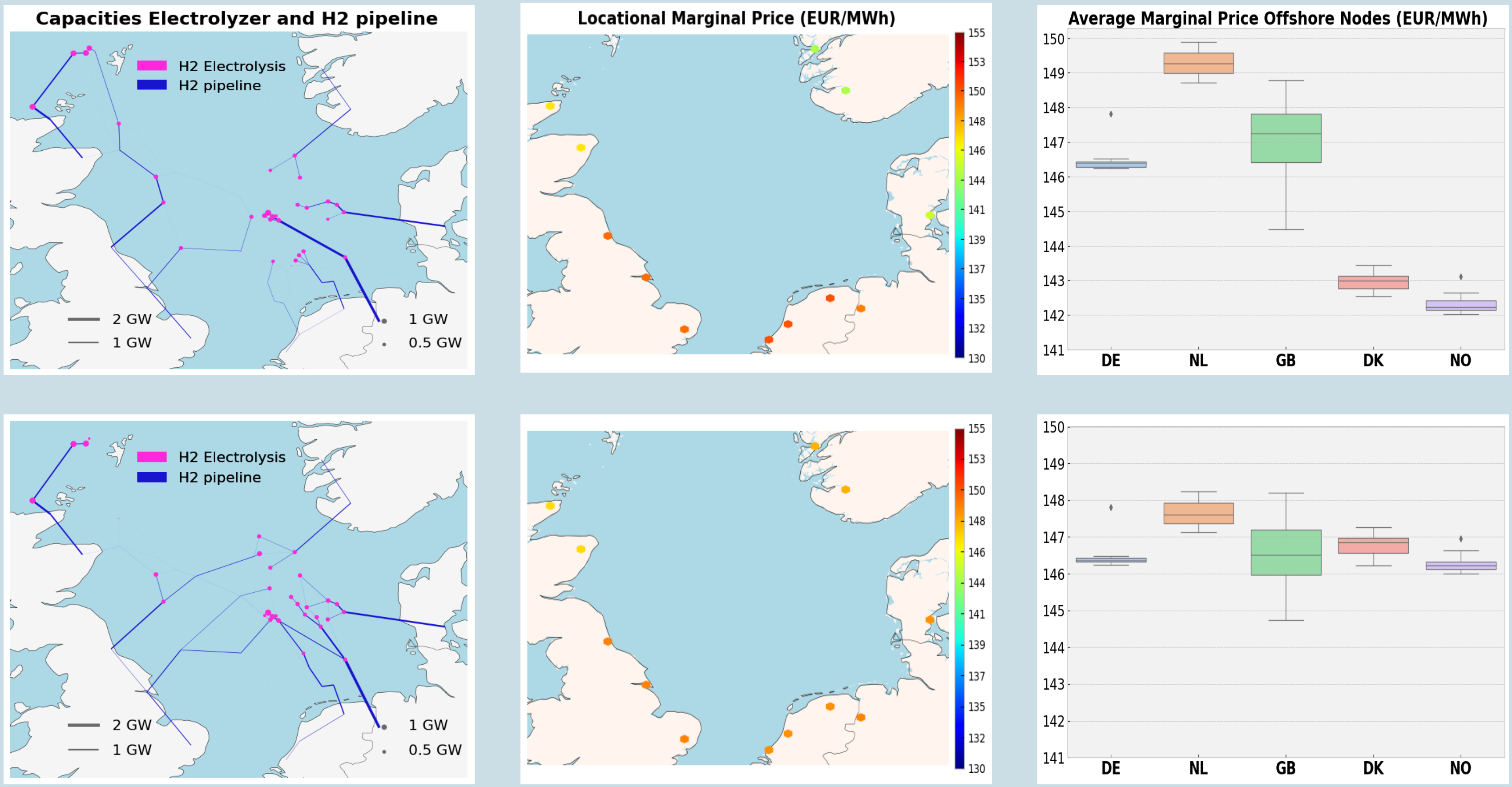
Offshore cost structure



Preliminary results

Isolation vs. Cooperation scenario in 2050





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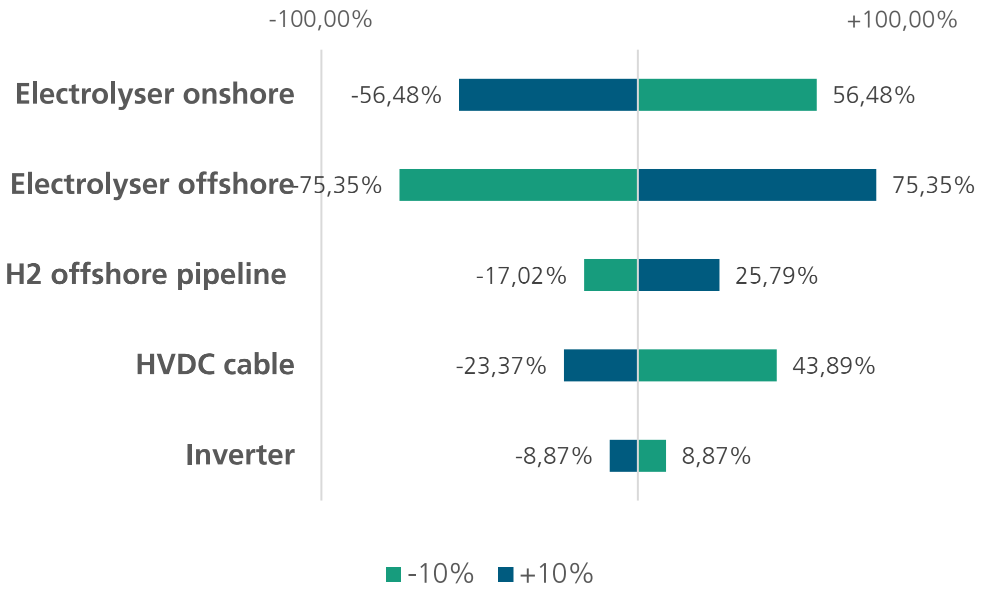
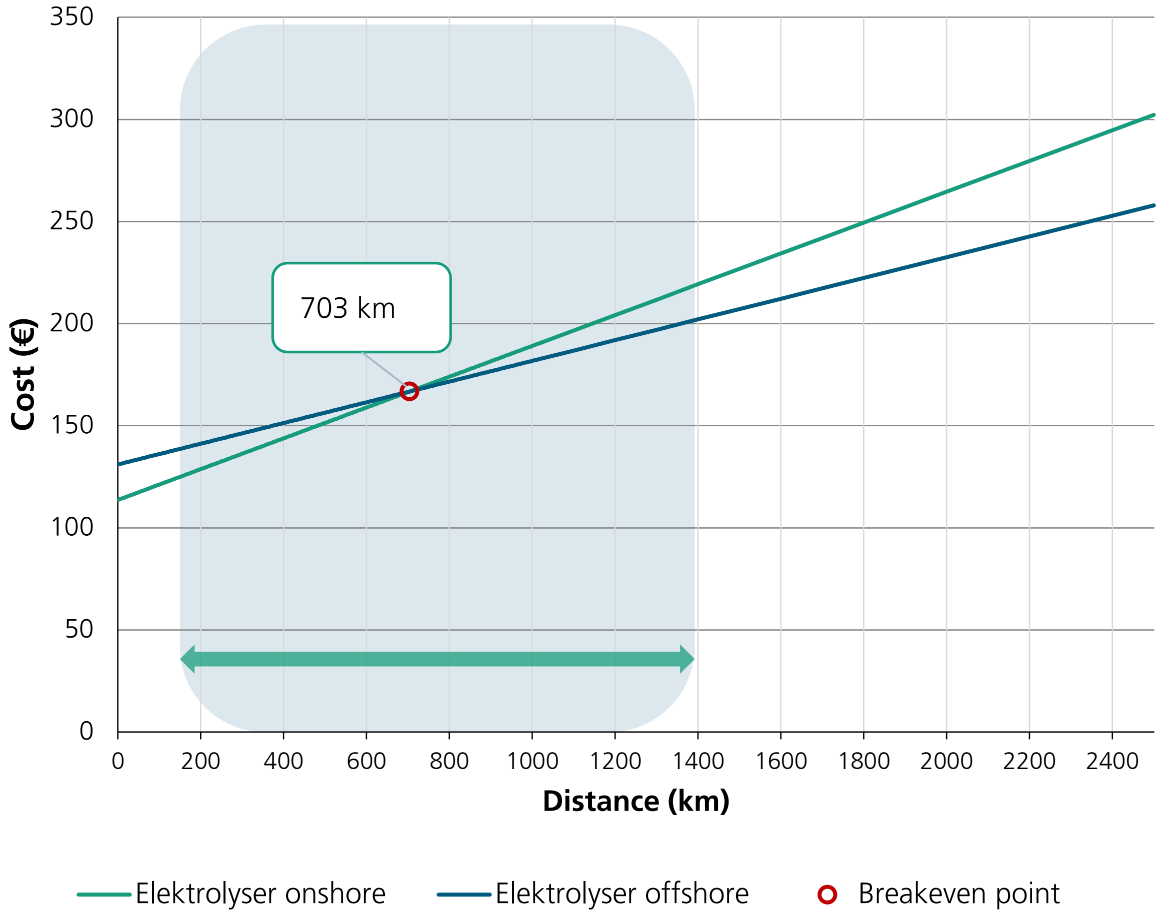
Breakeven point: pipelines and cable

Sensitivity of the cost input parameters to the breakeven point (distance)

Reference:	Unit	Electrolyser onshore	Electrolyser offshore
Electrolyser	€/kW	98	131
Cable	€/kW/km	0,075	0
H2 Pipeline	€/kW/km	0	0,051
HVDC inverter	€/kW	15,43	0





Next steps:

Improvement for the LP optimisation models

Piecewise linear function (PWL)*

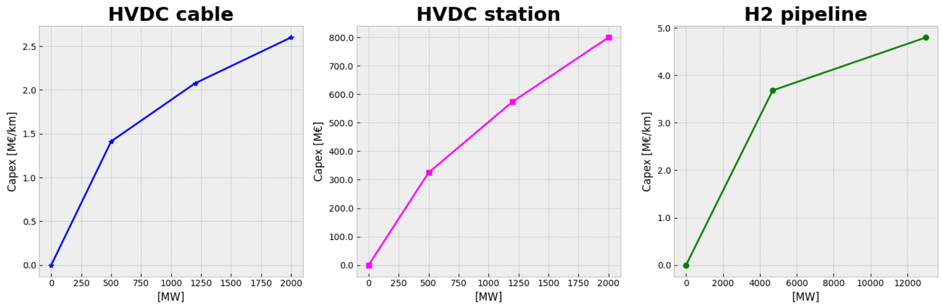
Economy of scale: price per unit decrease for larger capacities

Non-linear estimation of the investment costs:

$$\mathcal{C}_{cable} = \mathcal{A}x^{0.44} \qquad \text{(HVDC cables)}$$

$$\mathcal{C}_{station} = \mathcal{B}x^{0.65} \qquad \text{(HVDC converter station)}$$

$$\mathcal{C}_{pipeline} = \mathcal{H}x^{0.26} \qquad (H_2 \text{ pipeline})$$



Include Binaries

include different types of pipelines and cables in the model (with different technical configurations and costs)

$$0 \leq p_{ij}^{min} \leq p_{ij}^{opt} \leq p_{ij}^{max} \qquad \forall (i,j) \in E, i \neq j$$

$$0 \leq b_{ij}^{k} * p_{ij}^{k_{min}} \leq p_{ij}^{opt} \leq p_{ij}^{k_{ma}} * b_{ij}^{k} \qquad \forall (i,j) \in E, k, i \neq j$$

$$\sum_{k} b_{ij}^{k} \leq 1 \qquad \forall (i,j) \in E, i \neq j$$

$$b_{ij}^{k} \in \{0,1\} \qquad \forall (i,j) \in E, k, i \neq j$$

Here we denote:

- $i, j \in \mathcal{N}$ number of nodes
- $k \in \mathcal{K}$ number of pipeline types
- $p_{ij}^{min}, p_{ij}^{max}$ the minimum and maximum pipeline capacity

* Vloedgraven: System role of energy hubs in the North Sea by an energy system optimisation study (2023), Vloedgraven_MA_ET.pdf

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Conclusion and next steps

From the first sight, **hydrogen infrastructure** seems to have **economic advantage** over the cable infrastructure, mainly due to available offshore hydrogen storages

The techno-economic analysis has shown that **input parameters for hydrogen pipeline and HVDC cable are not as sensitive as other cost compartments** of the supply chain, e.g. electrolyser CAPEX

Locations with better weather conditions for offshore wind turbines provide **better cost saving potential** than efficient build out of infrastructure

Adding economies of scale will have a big impact on the model results

Further integration in the energy system model is needed to assess the investment in infrastructure

Thank you for your attention!

Kontakt

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Back up

PyPSA-Eur

Rules Overview

Preparing networks	Simplifying networks	Simplifying networks	Plotting + Summary
• base_network • build_powerplants • build_renewable profiles • add_electricity	• simplify_network • cluster_network • add_extra_components • prepare_network	• solve_network • solve_operations_network	• Plot_p_nom_max • make_summary

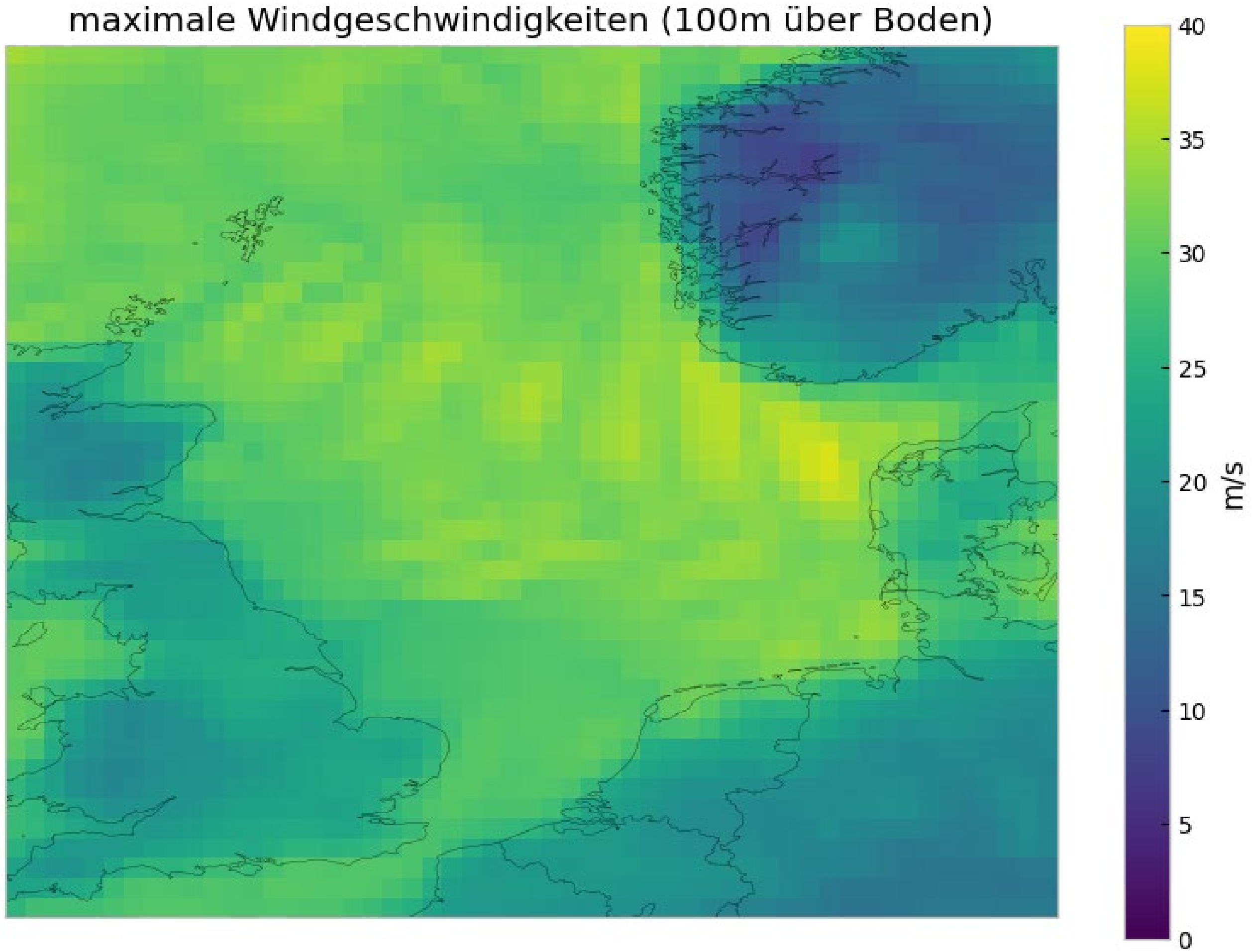
Documentation about the rules, where the relevant **settings**, **inputs** and **outputs** of each one of the rules are listed and explained

⇩

https://pypsa-eur.readthedocs.io/en/latest/preparation.html

https://pypsa-eur.readthedocs.io/en/latest/preparation.html#

Input – Wetterdaten



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Input – offshore H_2 Demands

Maximum Output Wind [TWh]	
DK	33,56
NO	27,13
DE	37,90
NL	58,84
GB	110,01

2030	TWh
DK	6,75
NO	0,27
DE	4,50
NL	3,22
GB	4,05

2040	TWh
DK	13,00
NO	3,62
DE	18,15
NL	7,63
GB	25,65

2050	TWh
DK	16,75
NO	7,96
DE	25,25
NL	10,71
GB	37,2

Offshore H2 Demand

Total demand EHB TWh				
	2030	**2040**	**2050**	Offshore Ratio
DE	90	363	505	0,05
DK	27	52	67	0,25
NO	8	17	24	***
NL	46	109	153	0,07
GB	27	171	248	0,15

Max H2 offshore potential	
	TWh
DE	37,90
DK	33,56
NO	27,13
NL	58,84
GB	110,01

***

NO Ratio:	
2030	0,03
2040	0,21
2050	0,33

Offshore demand TWh			
	2030	**2040**	**2050**
DE	4,5	18,15	25,25
DK	6,75	13	16,75
NO	0,27	3,62	7,96
NL	3,22	7,63	10,71
GB	4,05	25,65	37,2

Source: EHB 2022, WindEurope 2022, DNV 2023

Costs Assumptions

Kostentyp	Parameter	2030	2040	2050	Quellen
Wind (offshore-far)	Investment (€/kW)	1800	1680	1640	Danish Energy Agency, technology_data_for_el_and_dh.xlsx
Wind (offshore-float)	Investment (€/kW)	3000	2700	2400	https://doi.org/10.1016/j.adapen.2021.100067
Wind (offshore-near)	Investment (€/kW)	1380	1240	1190	Danish Energy Agency, technology_data_for_el_and_dh.xlsx
Wind station (far)	Investment (€/kWel)	220	220	220	Fraunhofer IWES 2023
Wind station (float)	Investment (€/kWel)	220	220	220	Fraunhofer IWES 2023
Wind station (near)	Investment (€/kWel)	220	220	220	Fraunhofer IWES 2023
Pipeline (offshore) (0,5 GW – 5 GW)	Investment (€/km/MW)	500	500	500	DNV 2023
HVDC submarine	Investment (€/km/MW)	932,3	932,3	932,3	Härtel et al. (2017): https://doi.org/10.1016/j.epsr.2017.06.008 .
Elektrolyseur (offshore)	Investment (€/kW)	450 (+281,8)	300 (+281,8)	250 (+281,8)	Fraunhofer ISE 2023 , Danish Energy Agency, data_sheets_for_renewable_fuels.xlsx

Plattformkosten -> ~281,8€/kW

Annahmen Plattformkosten: 500MW Elektrolyseur; Gesamtkosten: 140.900.000 €