CBS DEPARTMENT OF ECONOMICS COPENHAGEN SCHOOL OF ENERGY INFRASTRUCTURE

The Nordic Hydrogen Valleys Conference

nordhub2

FUELING THE FUTURE

Insights into locations for green fuel production on the example of green methanol

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EQUIS ACCREDITED AACSB ACCREDITED ASSOCIATION OF MBAS ACCREDITED CEMS PIM

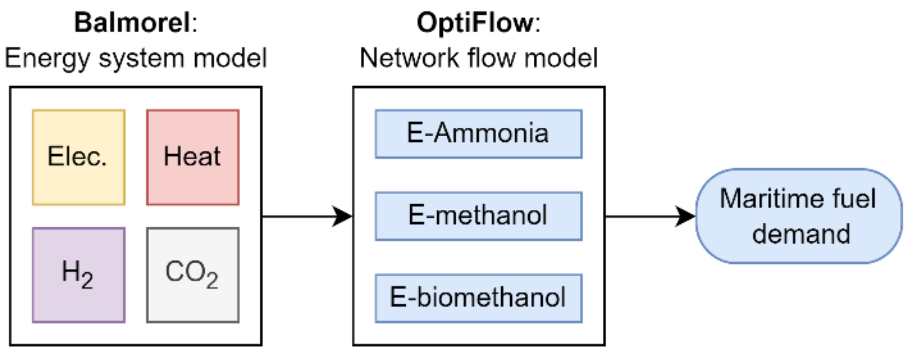
System Perspective (DTU)

Maritime fuel production in the Nordics (DK/FI/NO/SE)

- **What is the role of the Nordic region in renewable fuel production?**
  - Where to produce which maritime fuels?
  - What is the impact of the Nordic import/export balance for electricity, hydrogen, and fuels?

- In progress
  - CO_2 transport
  - Centralized/decentralized production
  - Port level maritime fuel demands (NTNU)
  - Global fuel trading prices (LUT)

- **Model**
  - Balmorel-Optiflow model
  - 2050 (net zero)
  - Elec, heat, H2, MarFuel demands
  - Elec, H2, MarFuel transmission
- **Scenarios**
  - Free transmission balance (FREE)
  - Net-neutral Nordics (NN_hr)



Nordic Energy Research

Nordic Hydrogen Valleys as Energy Hubs

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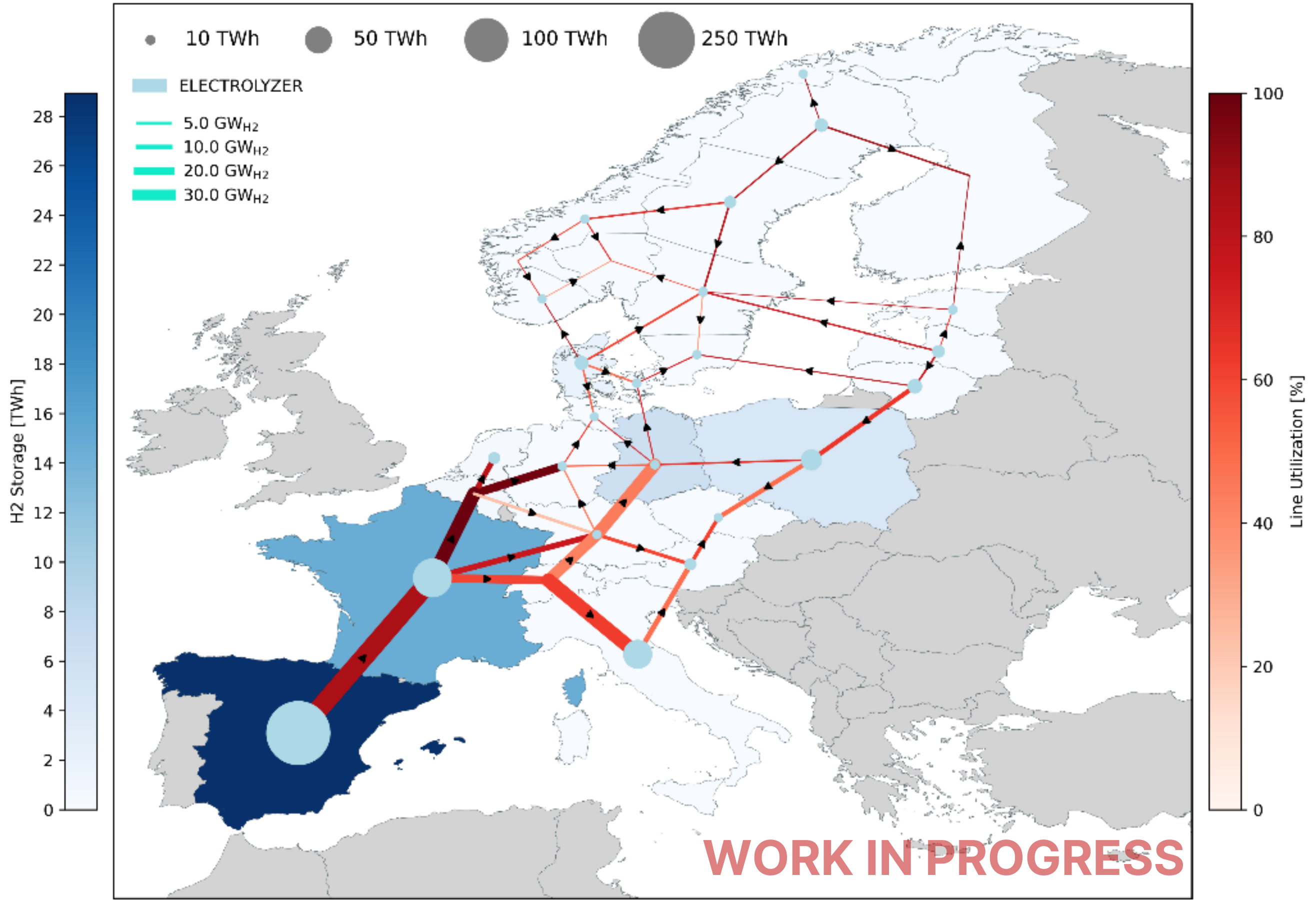
System Perspective (DTU)

Impact of import/export balance on H2 infrastructures

- **H_2 infrastructures in Europe** (FREE)
  - North-South competition
- **FREE**
  - 10 TWh H_2 export: DK → DE
  - 30 TWh H_2 import: Baltics → FI/SE
- **NN_hr**
  - Increased export: DK → DE
  - Reduced import: Baltics → SE
  - 10 TWh increased Nordic H_2 production

Hydrogen infrastructure in the FREE scenario



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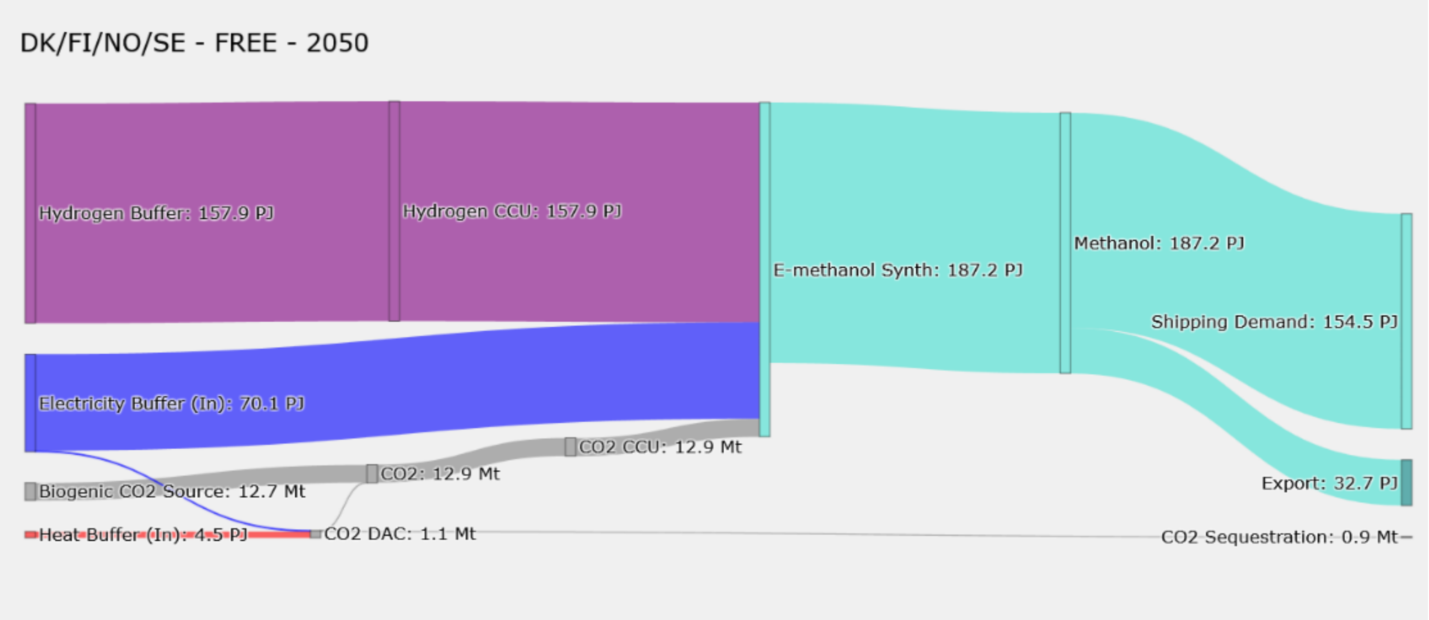
System Perspective (DTU)

Energy flows in the Nordic fuel system

- **FREE**
  - Methanol production only
  - Net Nordic export
- **NN_hr**
  - 10% switch to ammonia

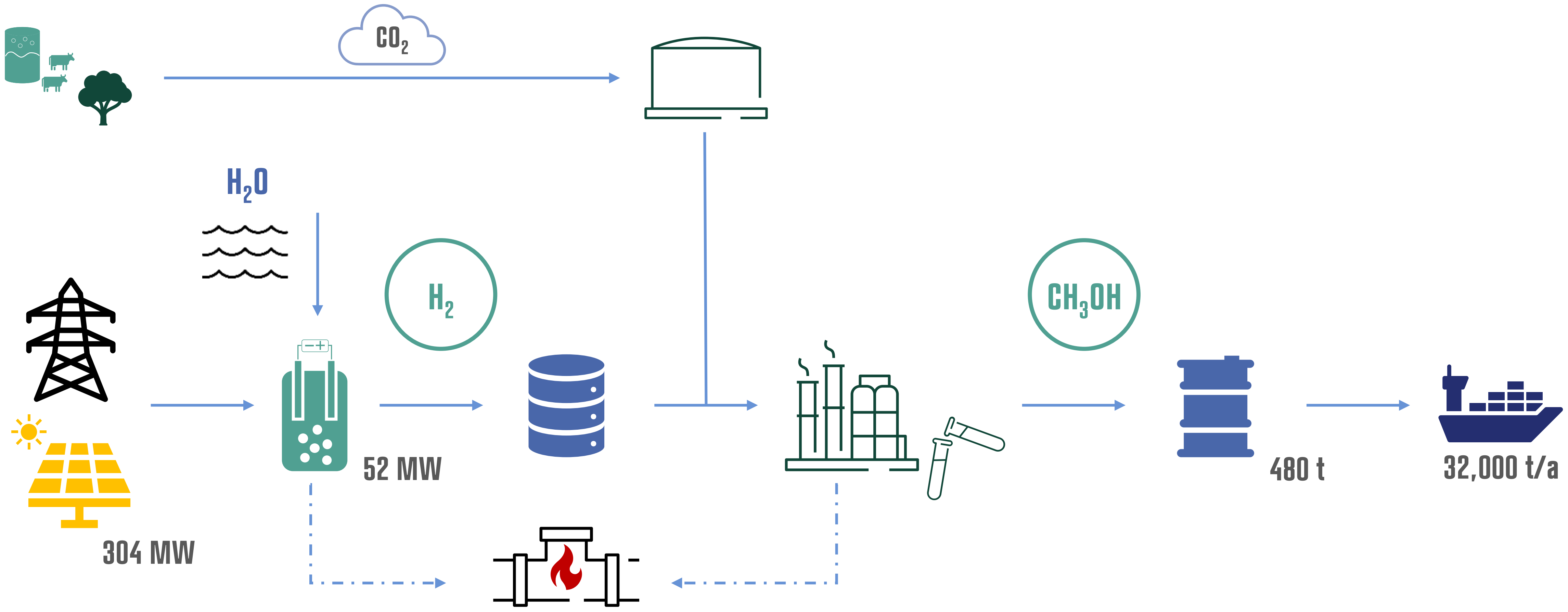
- Rosendal et al. (2024) & Lester et al. (2020)
  - Substantial ammonia share
  - More transport sectors
  - Competition for biomass/CO_2

WORK IN PROGRESS



CSEIs Energy Hub Model

Case study of the Kassø Power-to-Methanol



https://mst.dk/media/0bfe4tuh/20220223-ideoplaeg_kassoe-ptx.pdf

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Nordic Hydrogen Valleys as Energy Hubs

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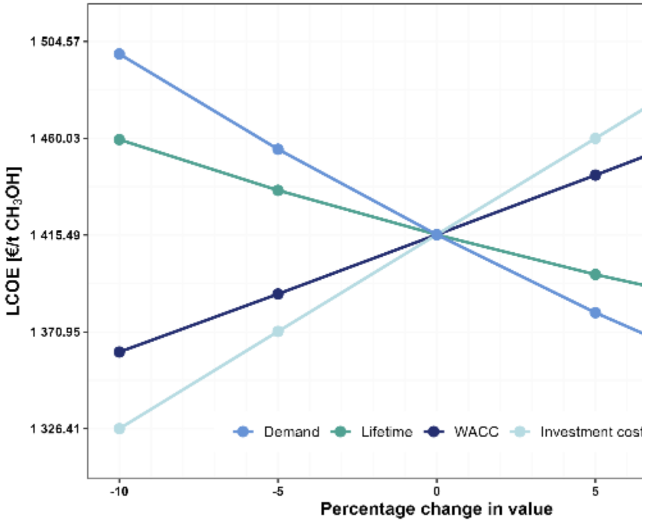
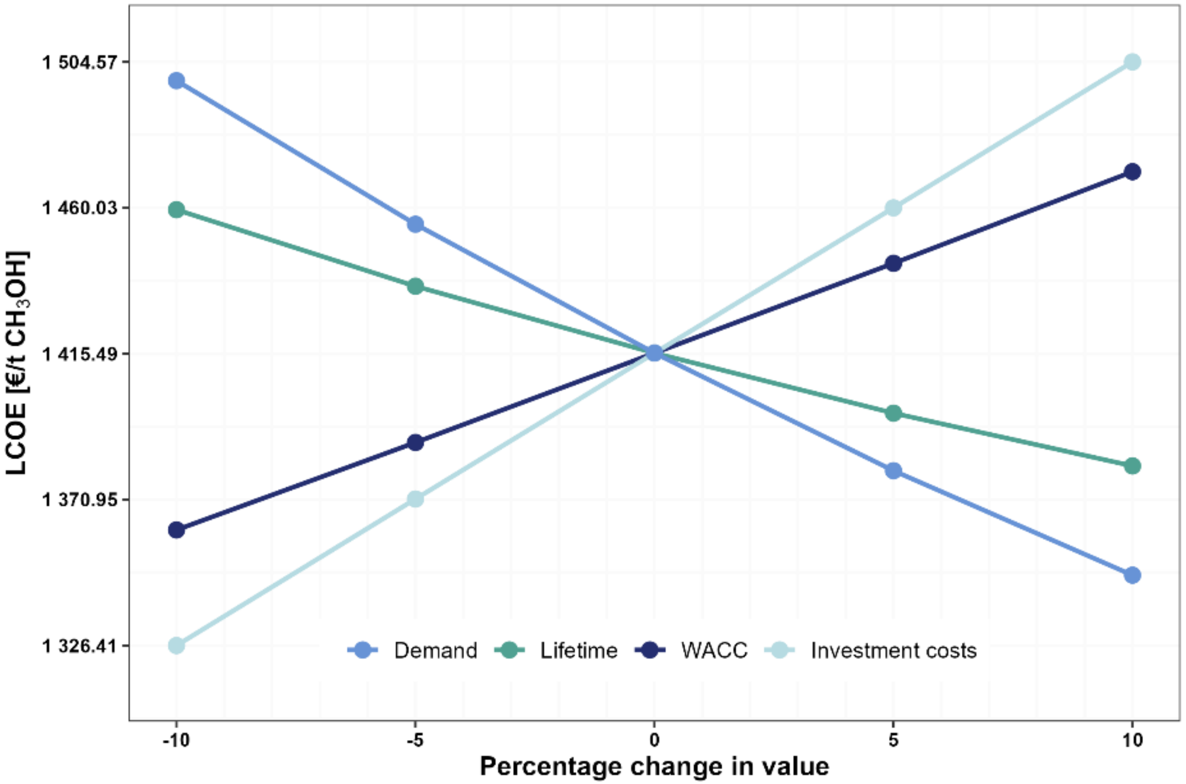
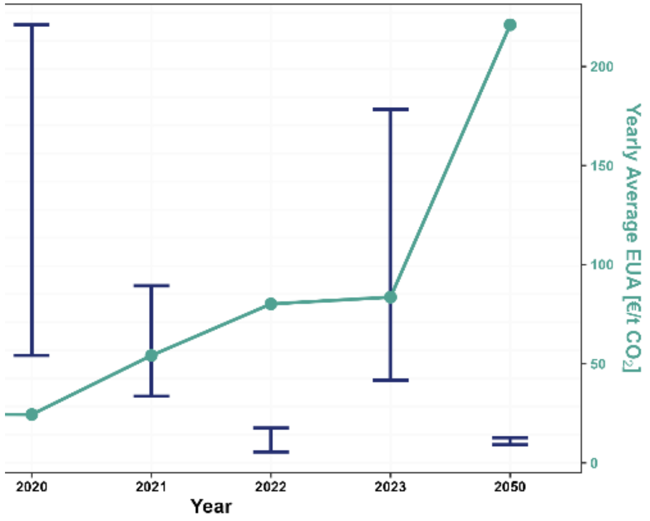
Results

Levelized Cost of Energy are not competitive but require more than financial support schemes

- **Methanol production is currently not profitable**
- **Conflict between variable RES and high full-load hours**







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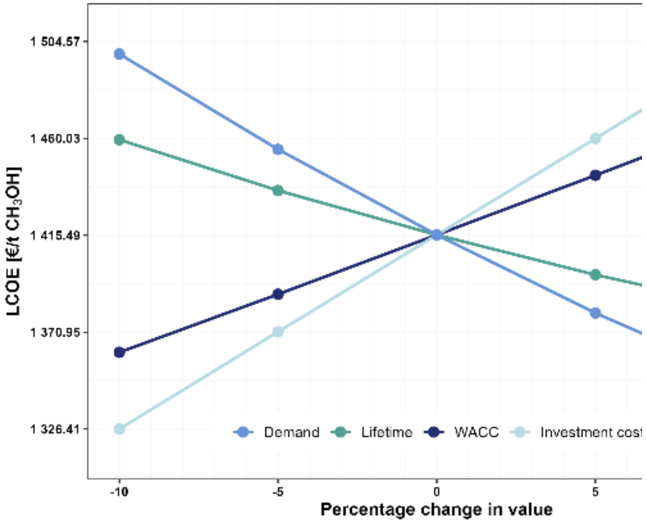

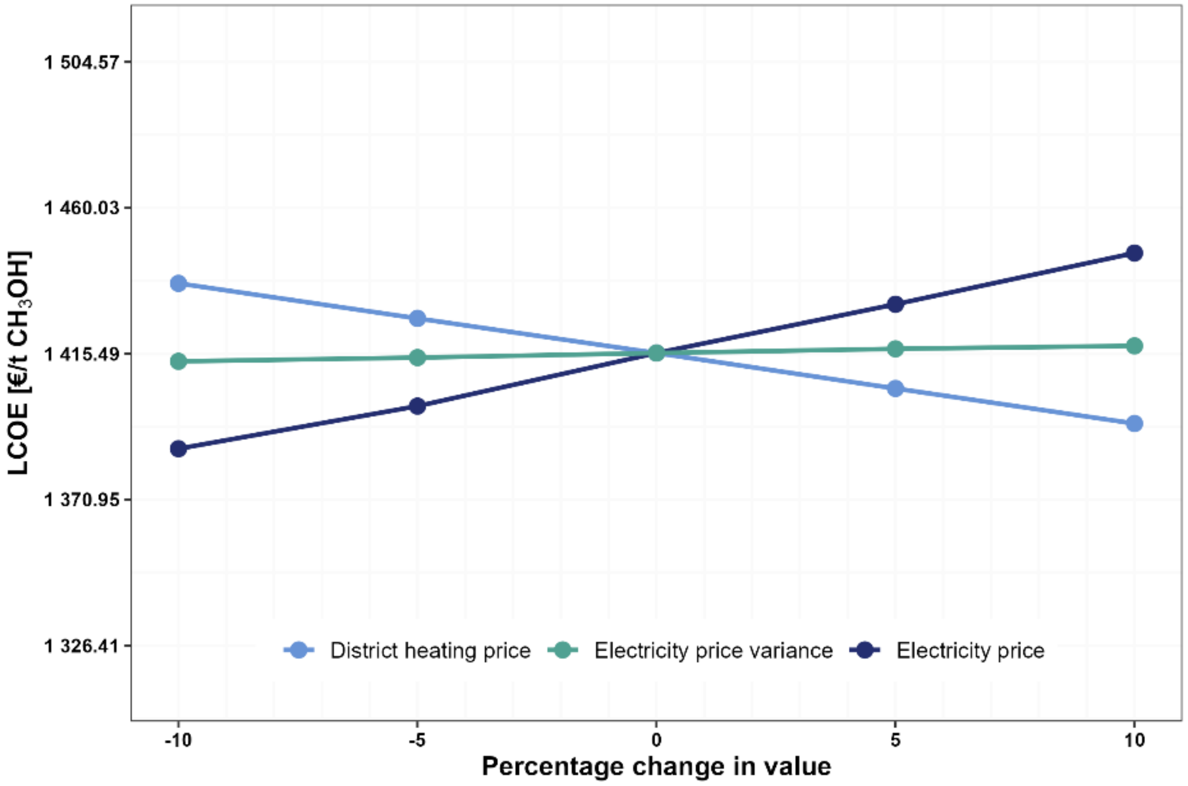

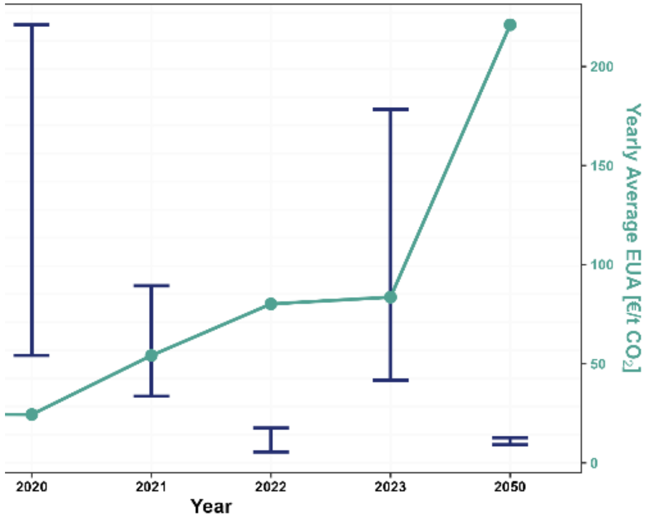

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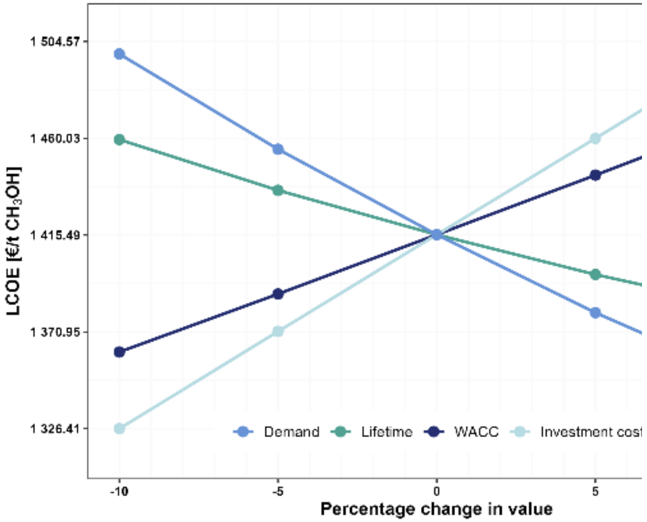
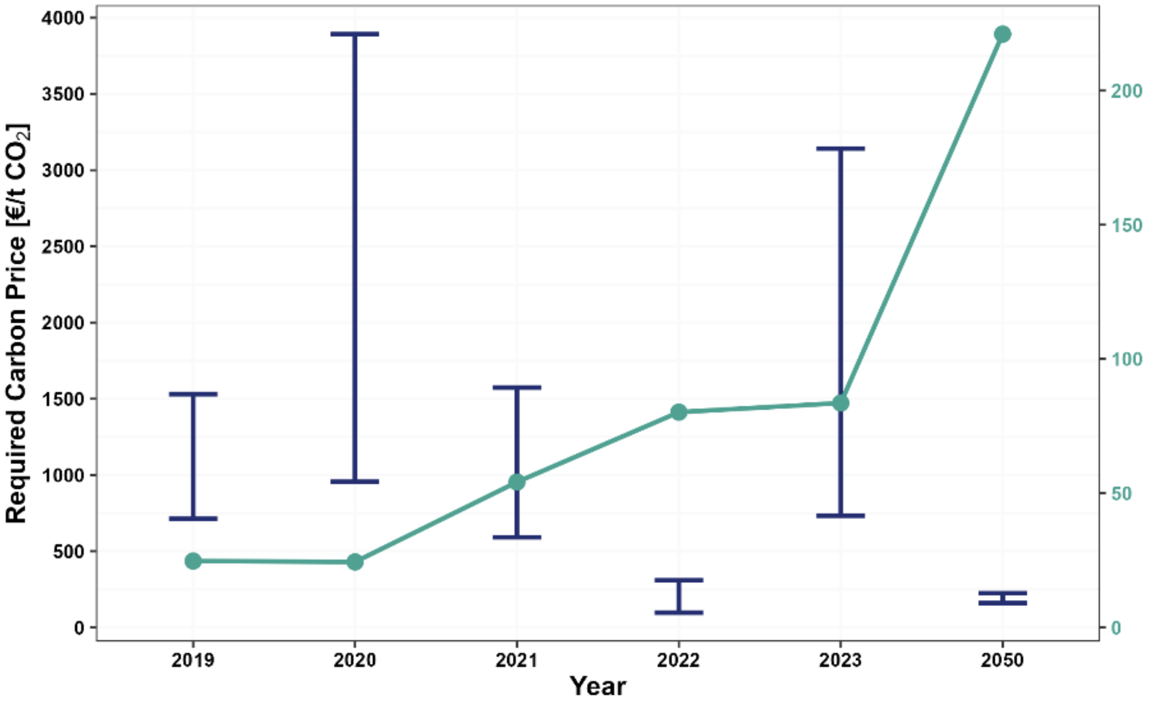
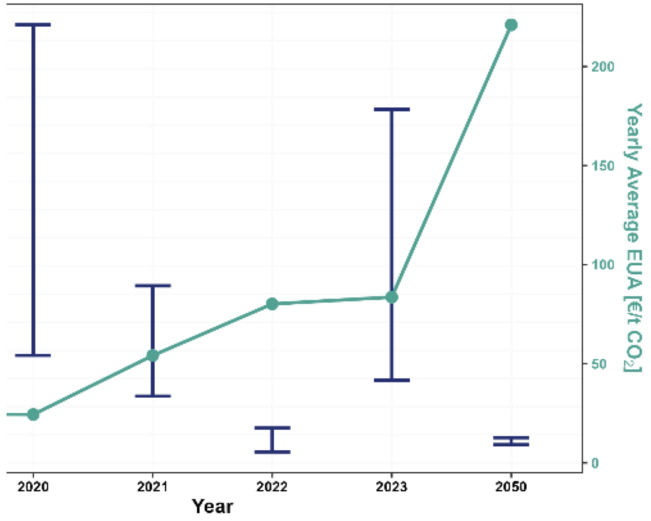




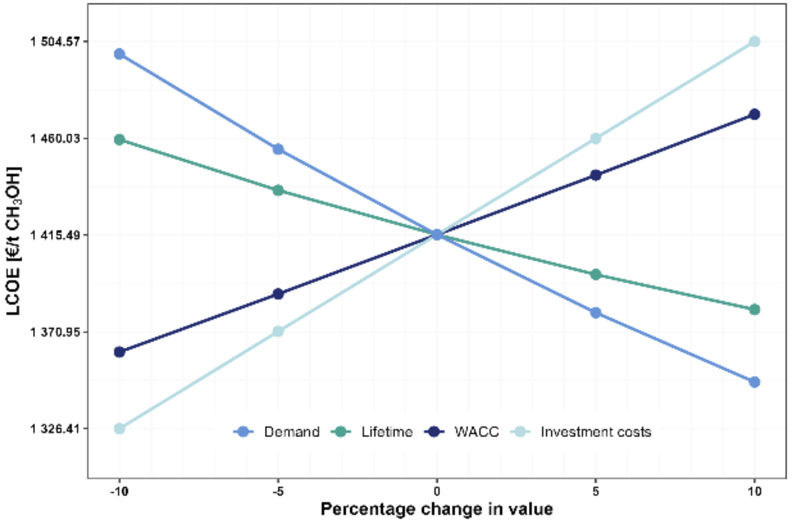


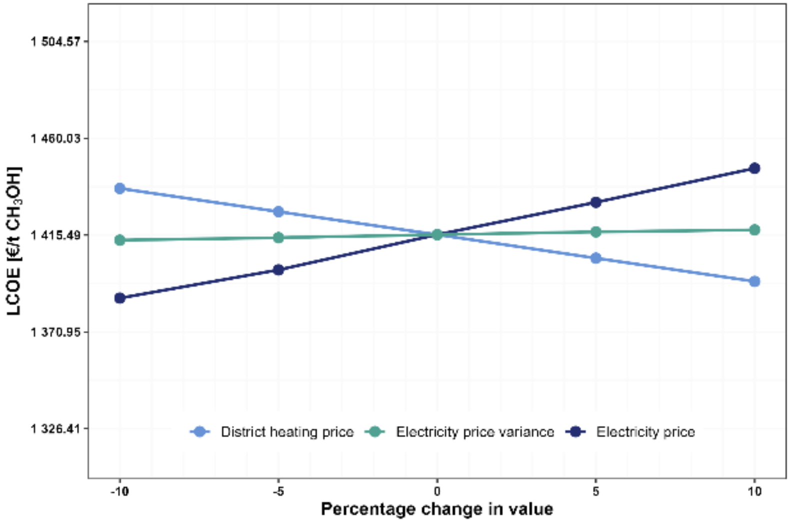
Giehl et al. (2024): The energy hub model.
https://github.com/CSEI-EU/Nord_H2ub/

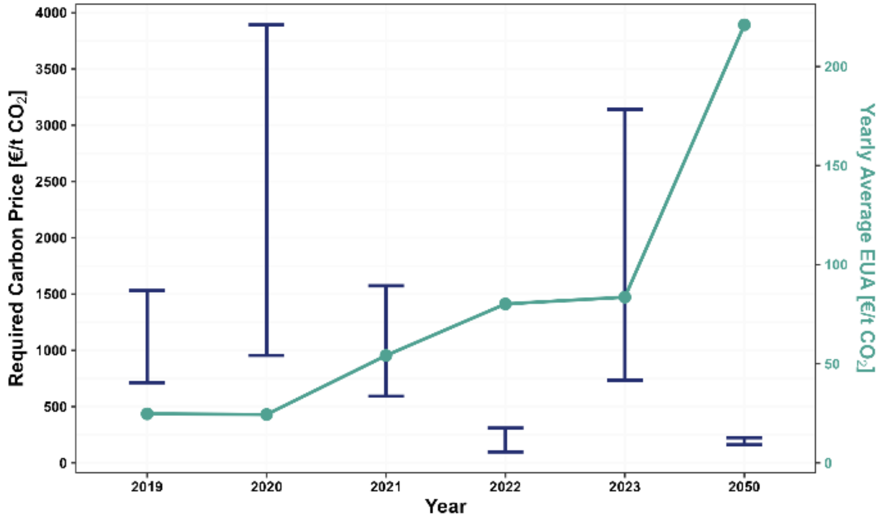
Results

Levelized Cost of Energy are not competitive but require more than financial support schemes

- **Methanol production is currently not profitable**
  - High CAPEX and Power Prices
  - Low demand for green fuels
- **Conflict between variable RES and high full-load hours**
  - Current power mix results in low emission reduction
  - High CO_2-prices necessary short term
  - Additional incentives for green fuel use







Giehl et al. (2024): The energy hub model. https://github.com/CSEI-EU/Nord_H2ub/

Challenges and Limitations

- **Representing the interactions** with the power market
  - Ancillary services
  - Grid fees and tariff structure

- **Modeling side products**
  - Waste heat price and demand
  - CO_2-price difference for carbon source and fossil emissions

- **Further infrastructure** of the hub not covered
  - Cost for on-site pipelines not included
  - buildings, roads, etc.

- **Focus on the application sectors to support leaning curves**
  - E.g., Fuel EU Maritime to reduce greenhouse gas intensity

Outlook

Defining Pathways, Standards, and Partnerships for a Sustainable Future

Provide and Develop a clear pathway towards carbon-neutral fuels
Certification, limits and goals

Maximize green energy supply in transport
Direct electrification, renewable fuels, balancing biomass and CO2 use

Transforming the Fuel Supply Chain
Align planning to support infrastructure development
Establish partnerships to develop value chains

Impact of carbon regulation and certification
Guarantee of Origin, Book and Claim, CO2-pricing
Standards and carbon contracts for difference

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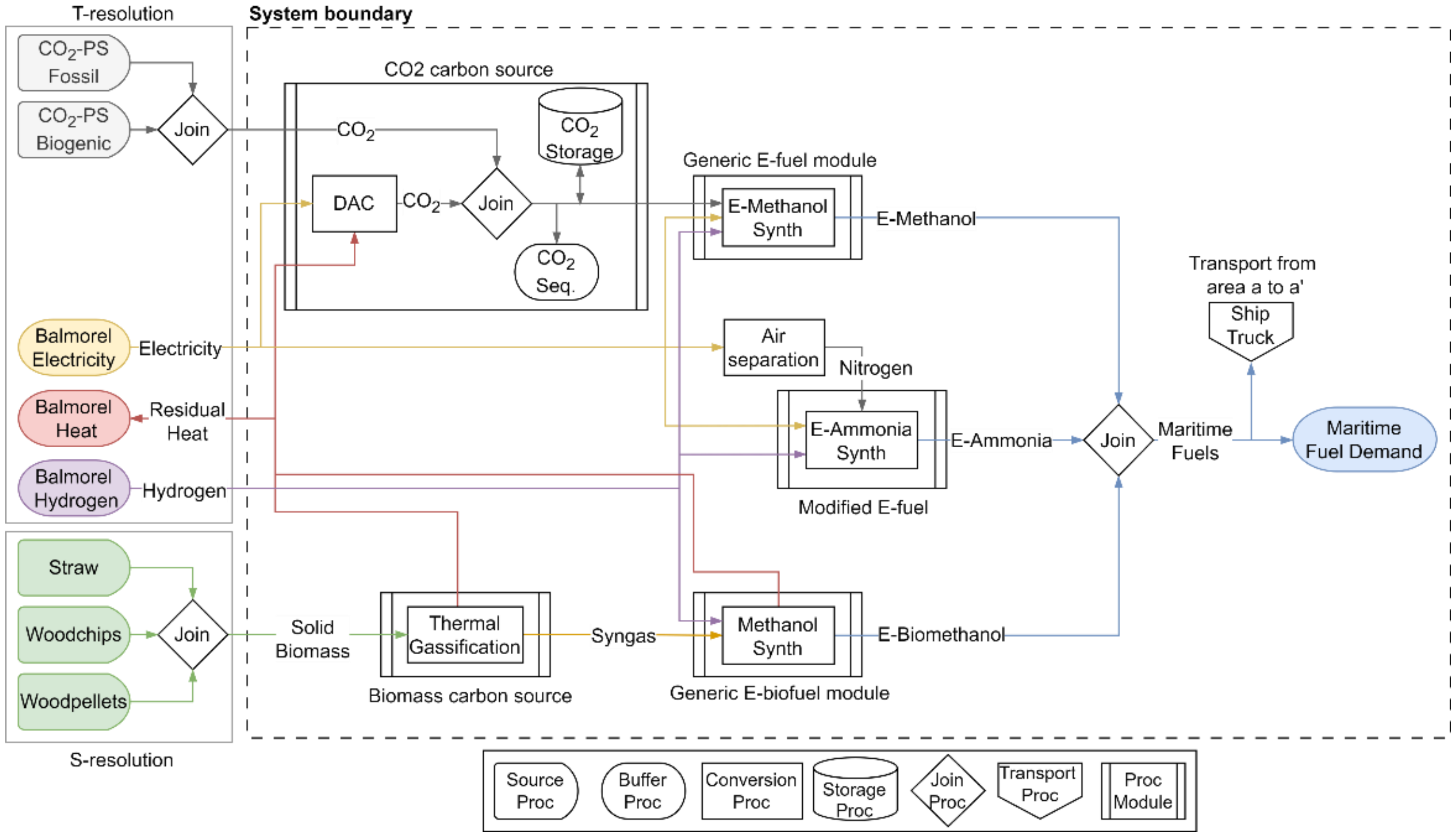
System Perspective

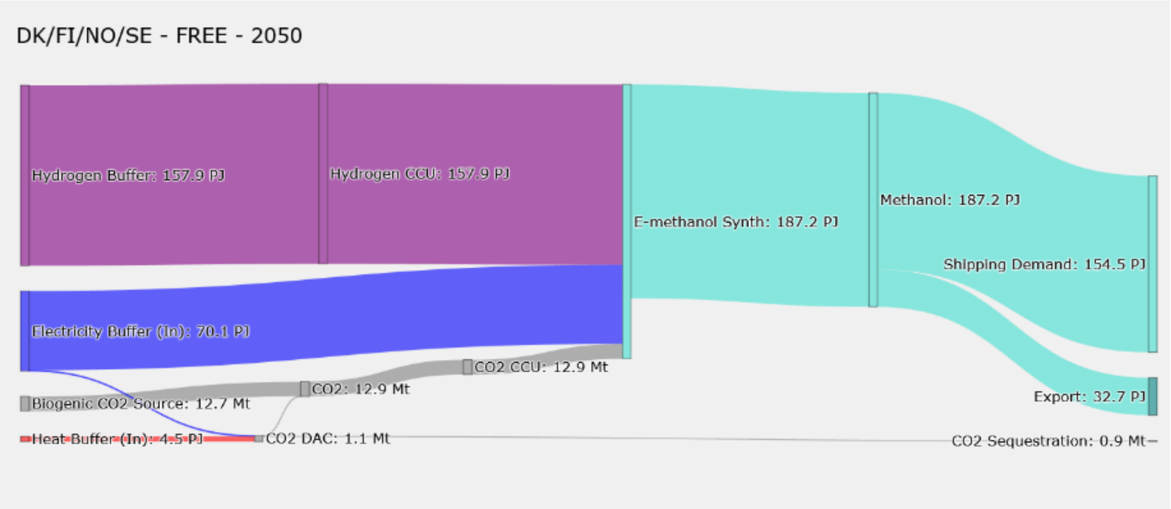
Extra: Flow chart of Balmorel-OptiFlow hardlink

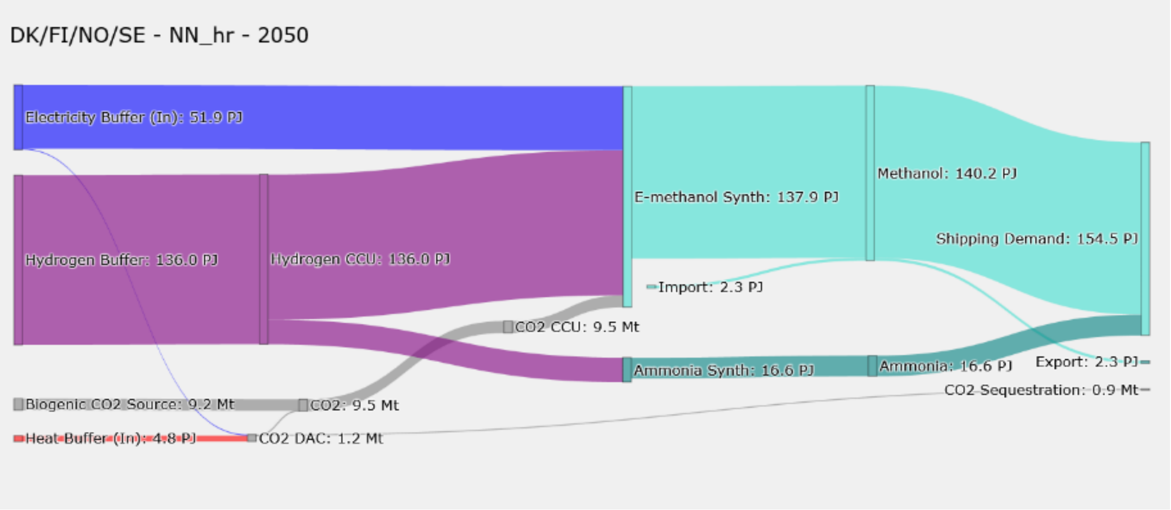


System Perspective

Energy flows in the Nordic fuel system

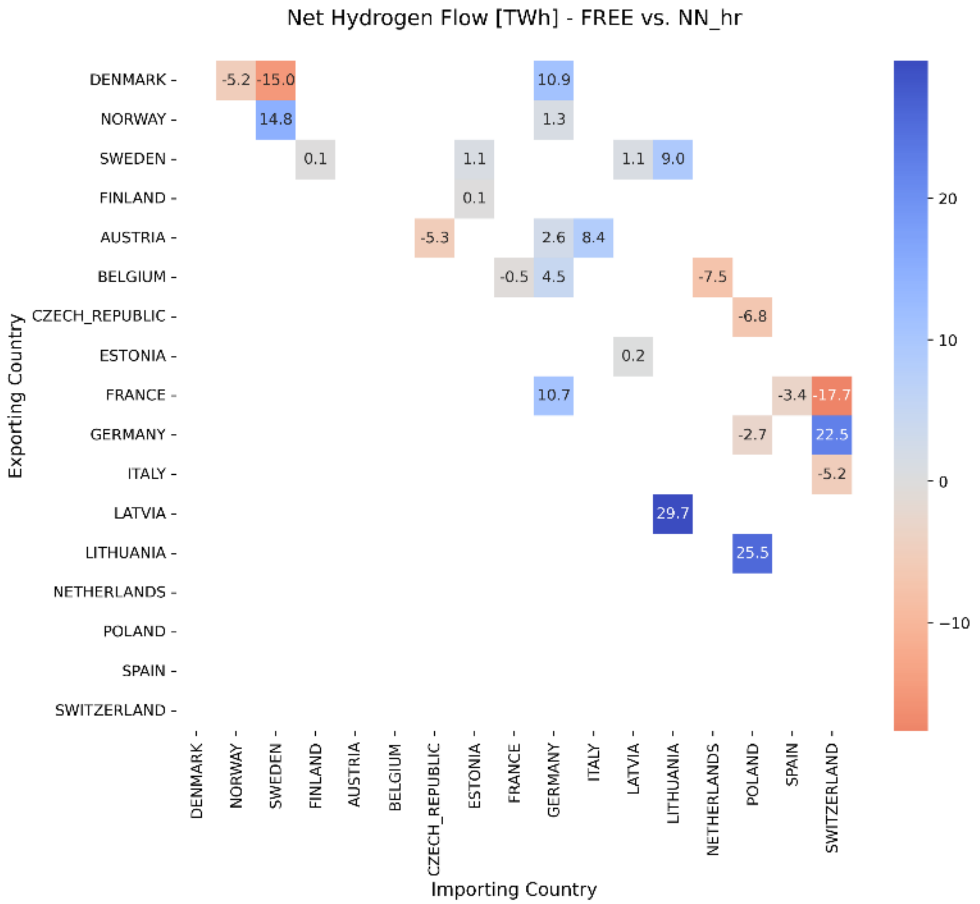
DK/FI/NO/SE	FREE	NN_hr
Avg. EL price	29.2	30.1
Avg. H_2 price [$€_{2015}$/MWh]	37.6	39.8

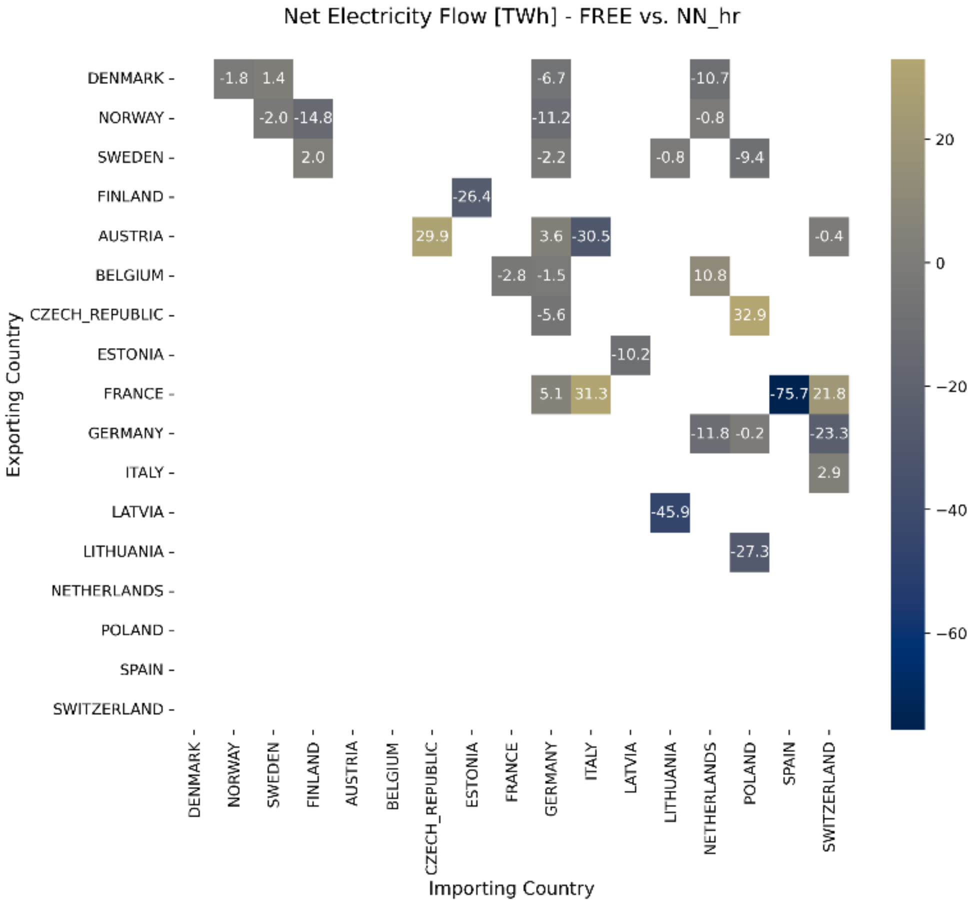




System Perspective

Impact of hydrogen/electricity neutrality





Data Energy Hub Model

Input and Results

Technology	Max Capacity [MW(h)]	Investment Cost [€/MW(h)] Status Quo	Investment Cost [€/MW(h)] 2050	FOM cost [€/MW(h)]	Mean Efficiency [%]	Source
Solar PV	304*	560,000	290,000	11,300	1	[39]
Electrolysis	52	1,900,000	500,000	38,000	0.75	[40]
Methanol Reactor	52	**	**	**	0.96	[40, 7]
Distillation Tower	52	1,350,000	870,000	39,000	0.795	[40, 7]
Steam Unit	100	150,000	130,000	1,070	0.99	[39]
CO_2-Vaporizer	100	500,000***	500,000***	0	0.99	[41]
Hydrogen Storage	5,479	121,000	46,000	638	losses/hour 0.0433 round trip 0.88	[38]
Methanol Storage	2,640	139.58	139.58	2.78	losses/hour 0.0 round trip 0.9997	[42, 43, 44]

* The PV capacity is already installed and not up to the optimization.
** The costs are regarding the output capacity of synthetic methanol. The model splits the process into two steps, and the costs are linked to the final conversion step.
*** Assumption based on offers on online platforms.

Scenario	LCOE [€/t] with PV Revenue	LCOE [€/t] without PV Revenue	Methanol Production [t/a]	Electrolysis Capacity [MW]
Base Variable Efficiency	1121.11	1415.70	32,000	43.06
Constant Efficiency	1112.63	1409.39	32,000	42.28
Only PV Supply	3619.02	3619.02	15,334	52
2050 Prices	755.99	962.54	32,000	52