DTU

Marie Münster, Professor DTU Management

MIT+CBS+DTU+Cambridge

2024 European Energy Policy Conference

Maritime Ports and Shipping: Gateways for the Energy Transition?

ChatGPT generated image

Ports as gateways for the energy transition

Harbour

- Transport hub for goods, fuels, materials and passengers between land and sea
- Ships for installing and O&M of offshore wind turbines
- Ships for fishing and aquaculture
- Ships for harvesting of algae

Energy hub

- Electricity supply of ships while at shore
- Fuel hub including hydrogen, ammonia and methanol
- Landing zone for electricity from offshore wind turbines
- Energy infrastructure hub for electricity, hydrogen and green fuels
- Producer of renewable energy and alternative fuels
- Industrial hub facilitating use of by-products including heat and oxygen
- Collecting offshore wind turbines

Ports as Energy Transition Hubs (POTENT)

MSCA network (15 PhDs)

The main research objectives of POTENT focus on **how ports can support and accelerate the clean energy transition in Europe**.

Research questions are organized along three work packages (WP):

WP1 ‘Transition Infrastructure’ aims to identify gaps in renewable energy and green fuel infrastructure and develop technologies to address these gaps, especially integration of digital technologies to optimize energy use, improve efficiency, and integrate renewables.

WP2 ‘Socio-Techno-Economic Analysis’ considers the systemic aspects of integrated energy ports, including the implications of integrating ports into electricity grids, and the socioeconomic and regulatory aspects of port development.

WP3 ‘Port Governance and Business Models’ investigates the governance and business model challenges and opportunities that ports face in the energy transition and explores how they can create and capture value, manage stakeholder relationships, and make decisions that align with the energy transition goals.

Our PhD project: De-Risking Green Maritime Fuel Transition with focus on modeling risk and uncertainty - and developing adaptability strategies (2025-2028)

Ports as gateways for the energy transition

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- **Energy infrastructure hub for electricity, hydrogen and green fuels**
- **Producer of renewable energy and alternative fuels**
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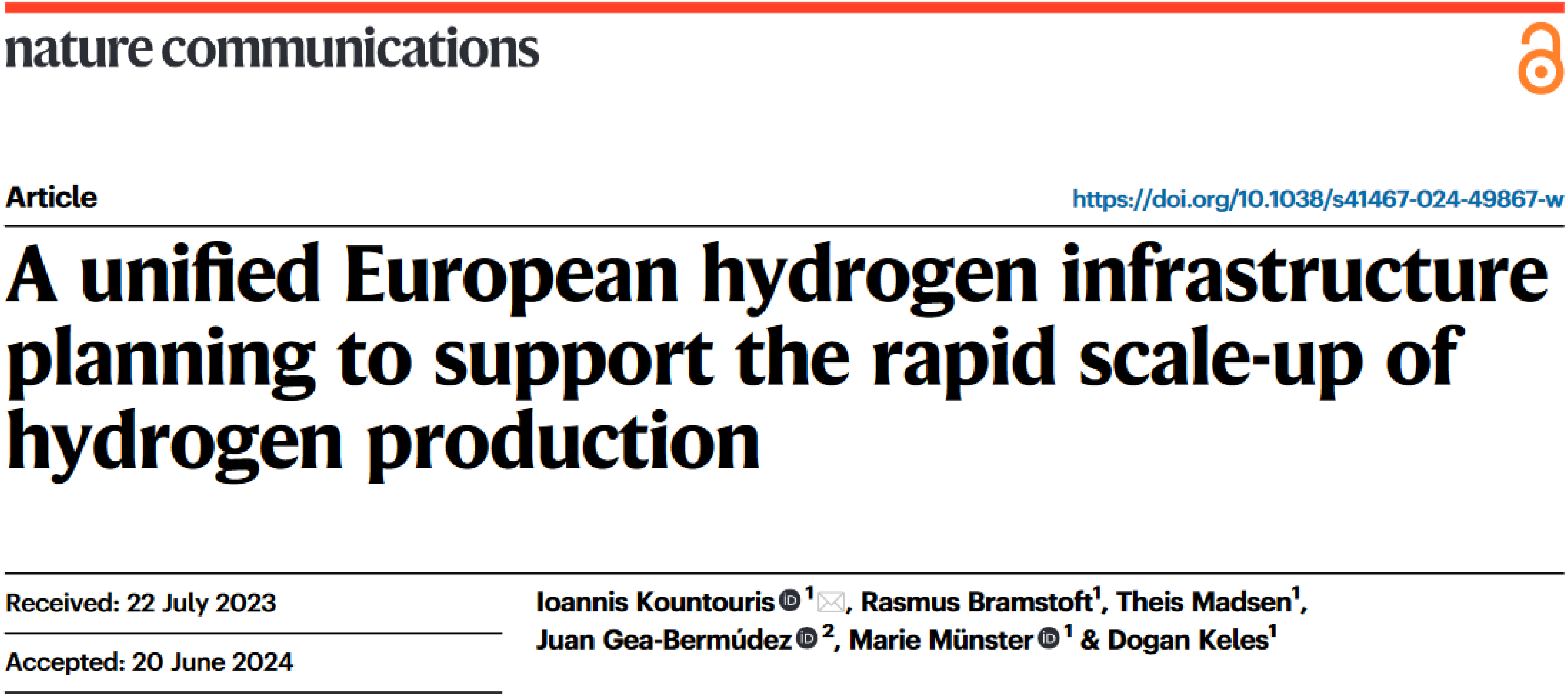


nature communications

Article

https://doi.org/10.1038/s41467-024-49867-w

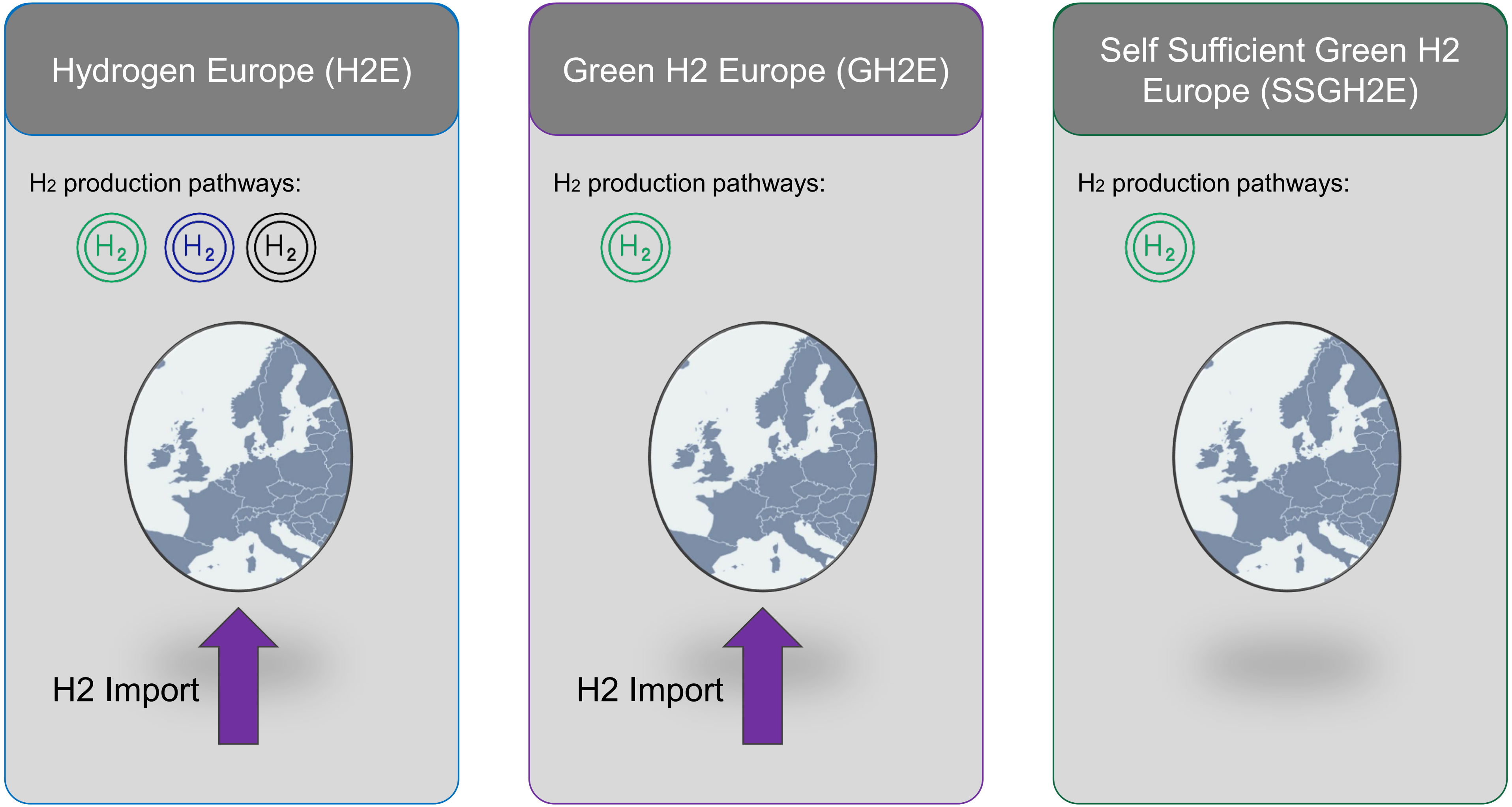
A unified European hydrogen infrastructure planning to support the rapid scale-up of hydrogen production

Received: 22 July 2023

Accepted: 20 June 2024

Ioannis Kountouris[1], Rasmus Bramstoft[1], Theis Madsen[1], Juan Gea-Bermúdez[2], Marie Münster[1] & Dogan Keles[1]

Scenarios



Hydrogen Europe (H2E)

H_2 production pathways:

H_2 H_2 H_2

H2 Import

Green H2 Europe (GH2E)

H_2 production pathways:

H_2

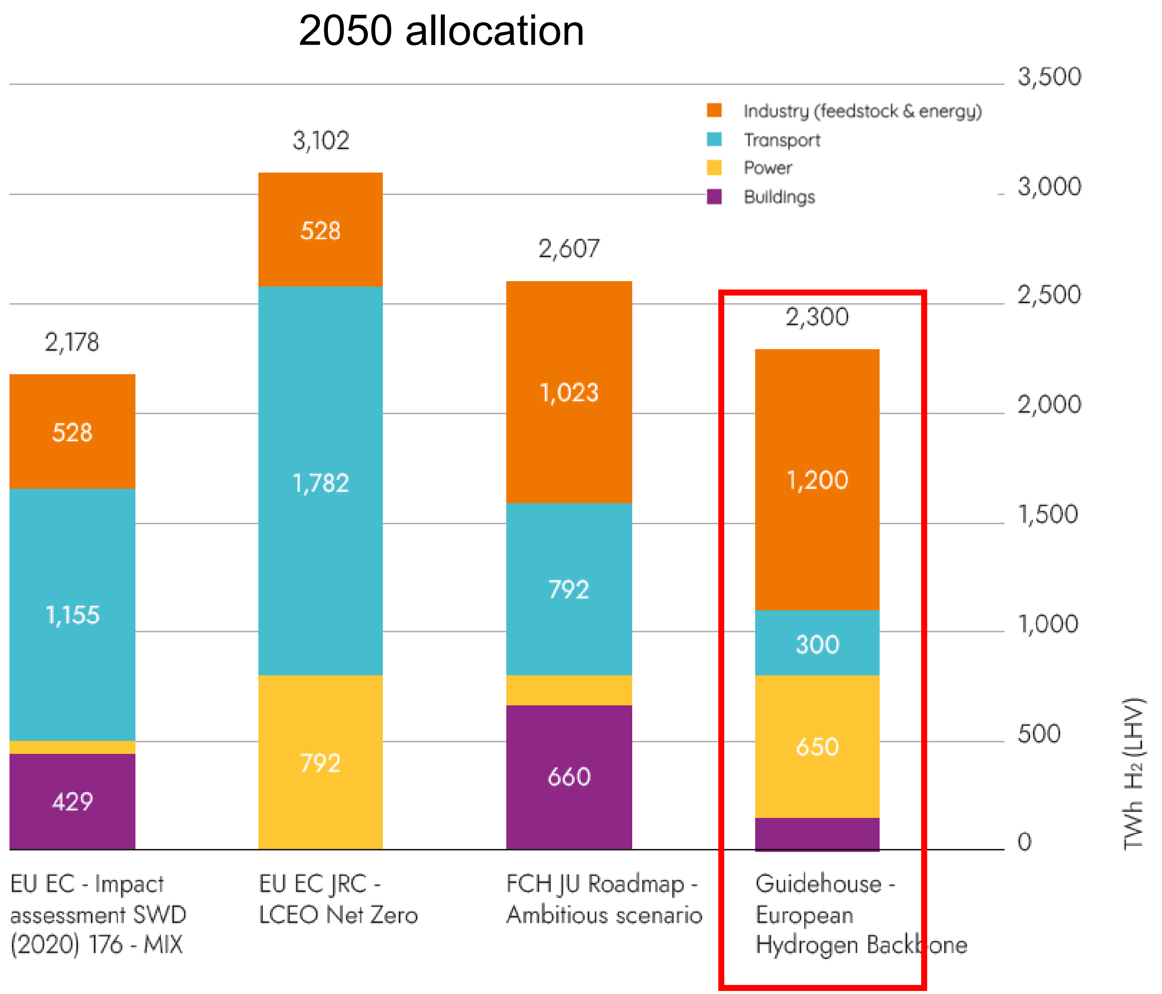
H2 Import

Self Sufficient Green H2 Europe (SSGH2E)

H_2 production pathways:

H_2

DATA: European Hydrogen BackBone (EHB) – 28 Gas TSOs



Source: Analysing future demand, supply, and transport of hydrogen, June 2021

Source: A European Hydrogen infrastructure vision covering 28 countries, April 2022

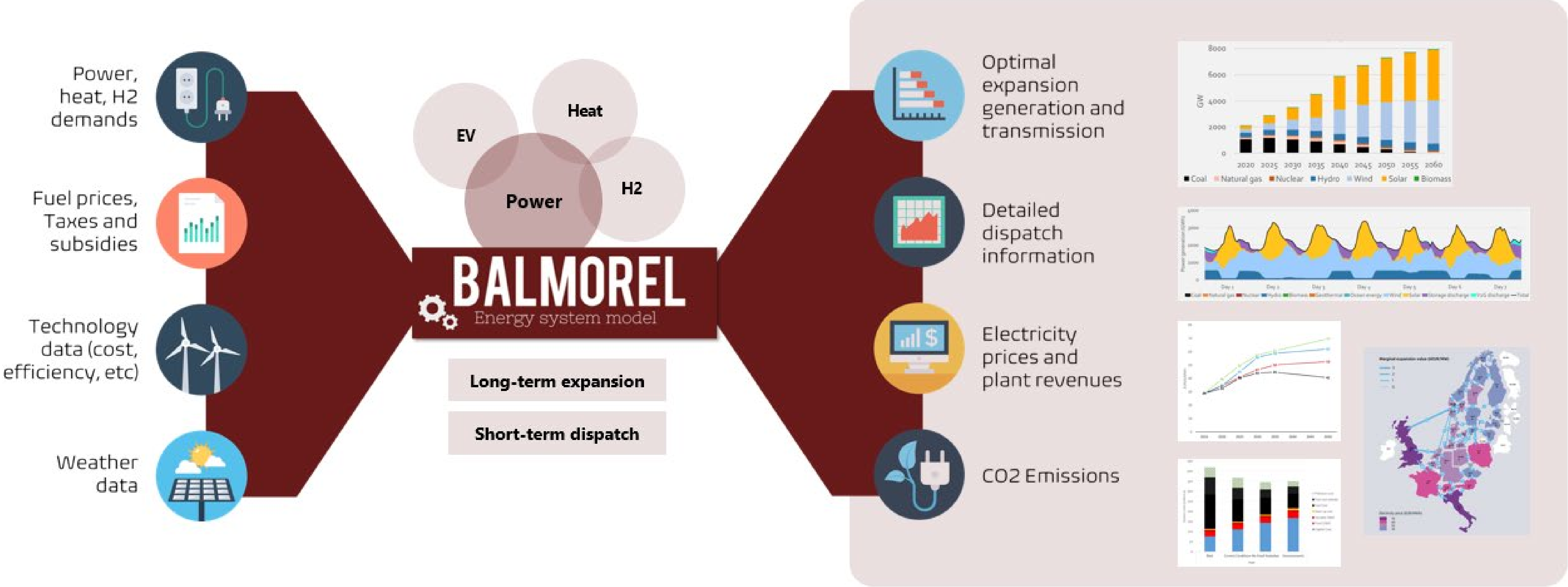
WEO 2022, conventional fuel prices (NZE scenario), high CO2 tax 140 €/ton for 2030, to 250 €/ton for 2050

Sector coupled energy systems analysis - Balmorel

Partial Equilibrium model

Objective Function: Minimize socio-economic cost of operations and investments

Open source (GAMS based) www.balmorel.com



Power, heat, H2 demands

Fuel prices, Taxes and subsidies

Technology data (cost, efficiency, etc)

Weather data

Long-term expansion

Short-term dispatch

Optimal expansion generation and transmission

Detailed dispatch information

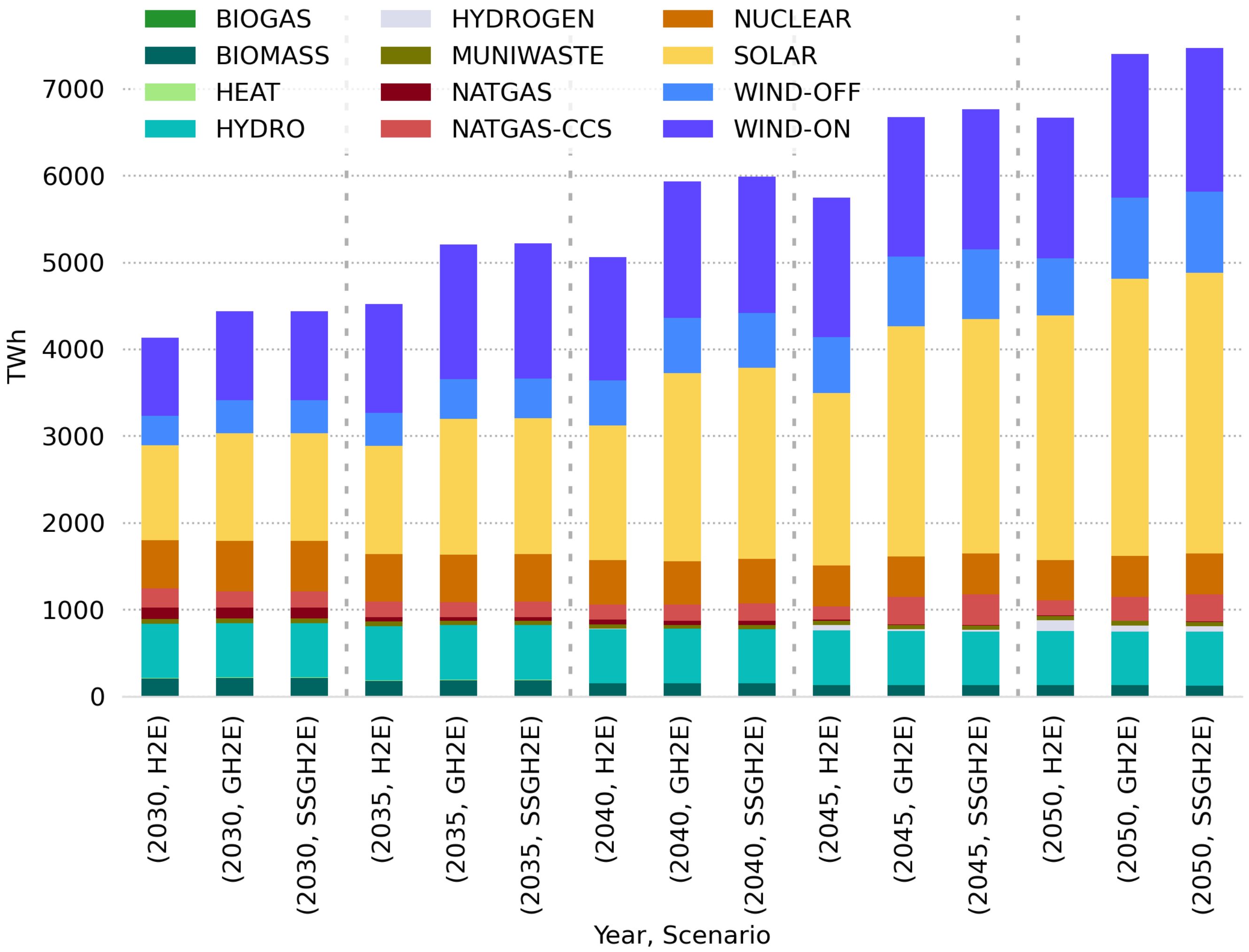
Electricity prices and plant revenues

CO2 Emissions

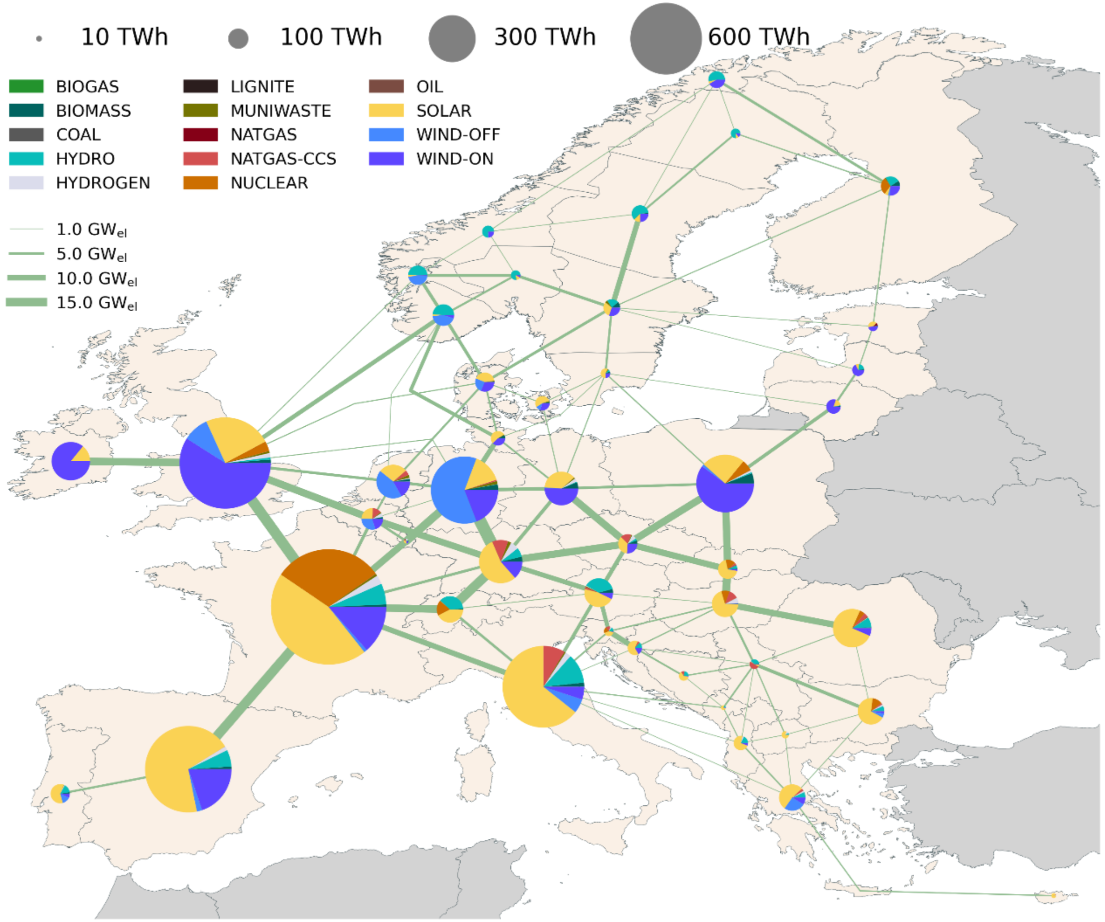
Ea, Energianalyse 2022

Results: Electricity mix (2050)

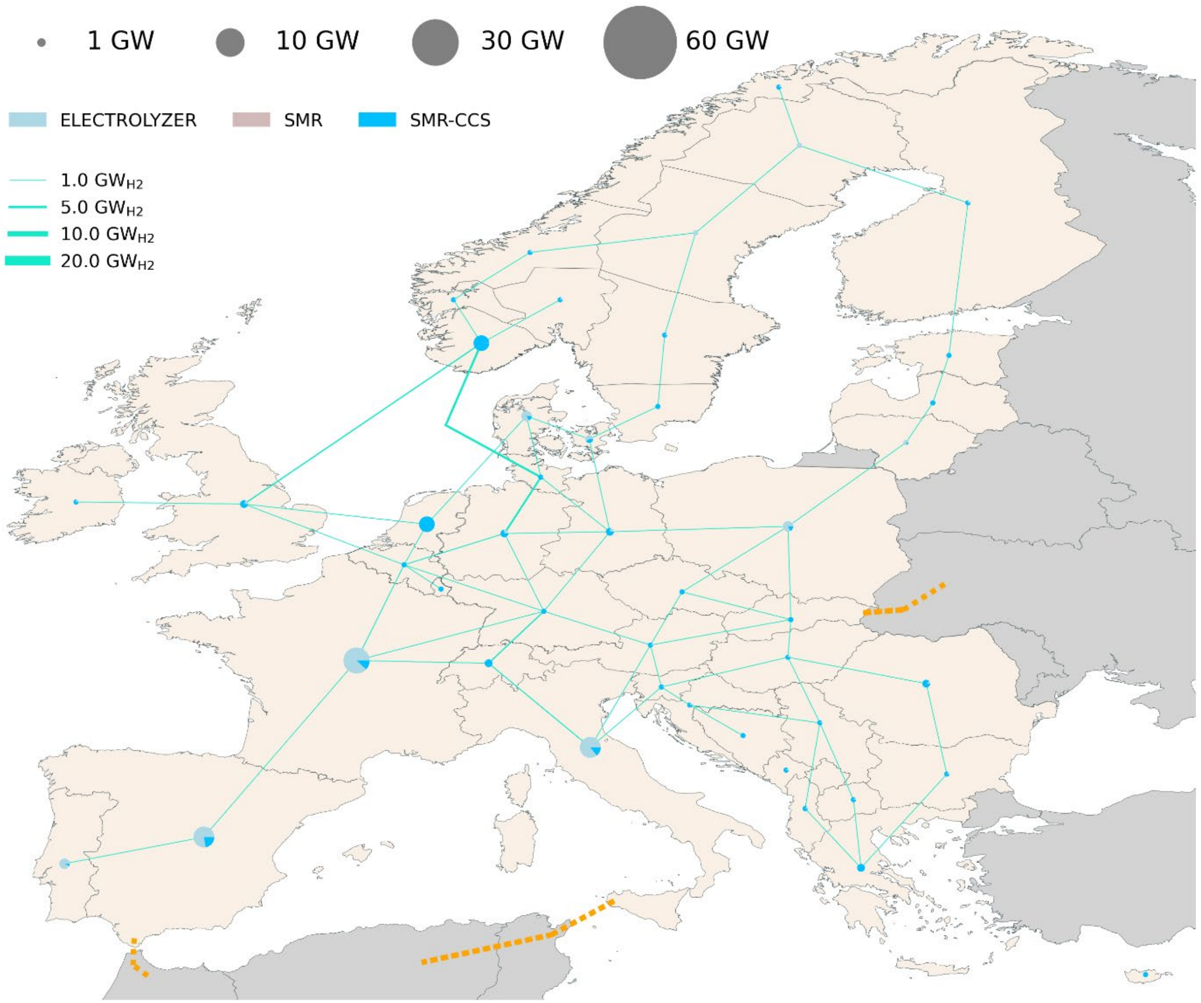
Green: Approximately additional 800 TWh of electricity demand



Scenario: BASE

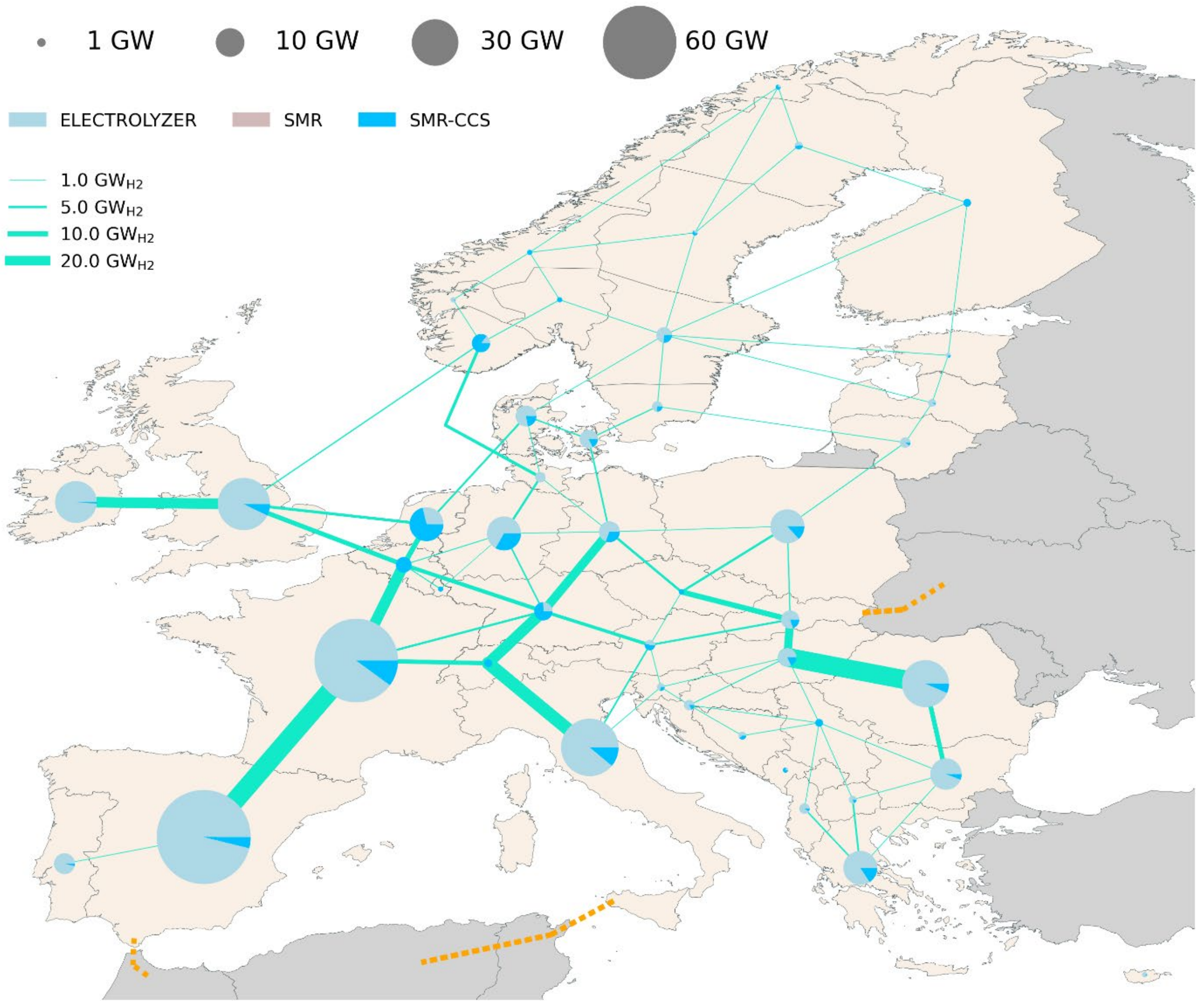


Results: BASE - Where, when and how to produce H2?



2030

H2 Demand: 332 TWh



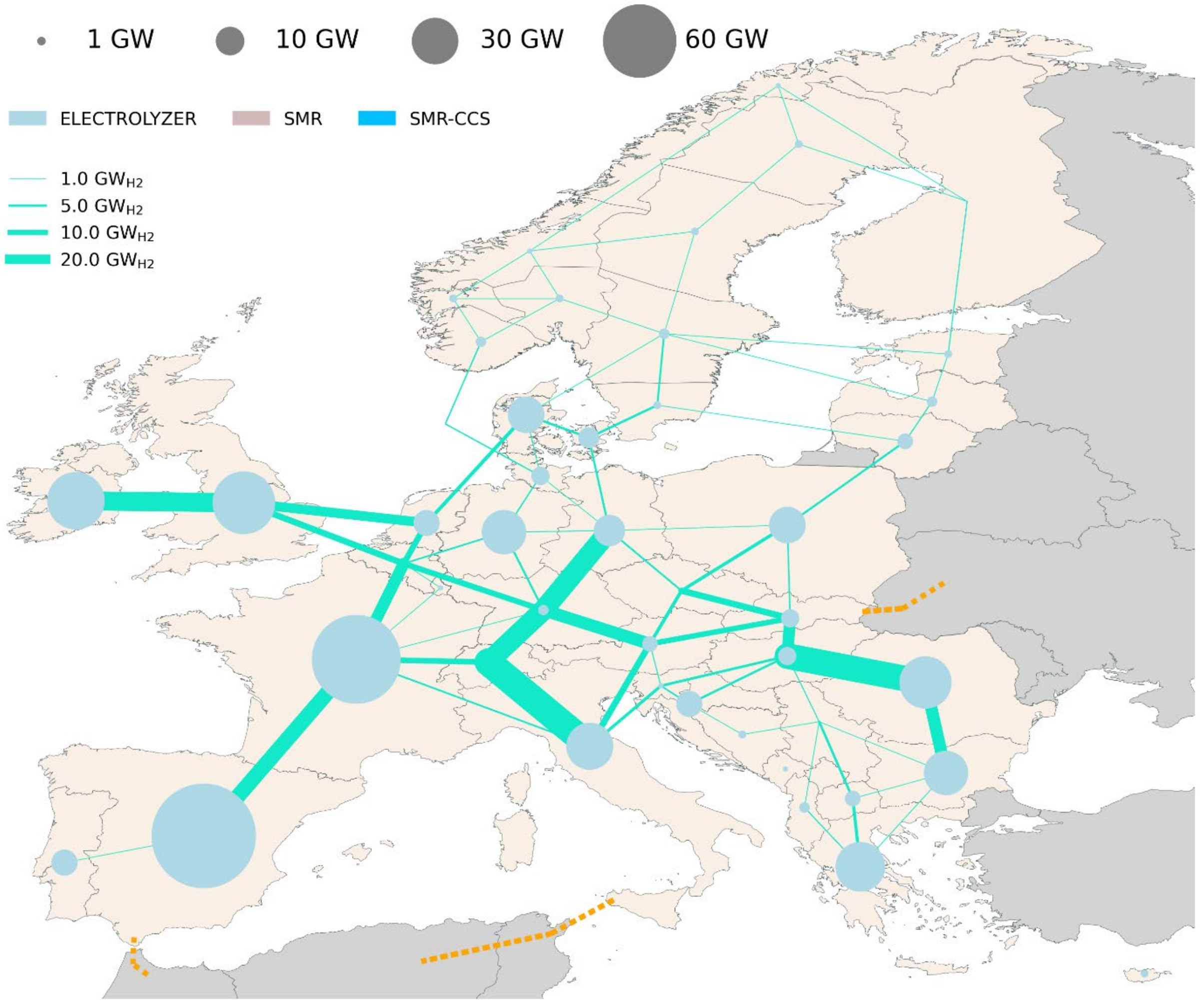
2050

1768 TWh (>x5)

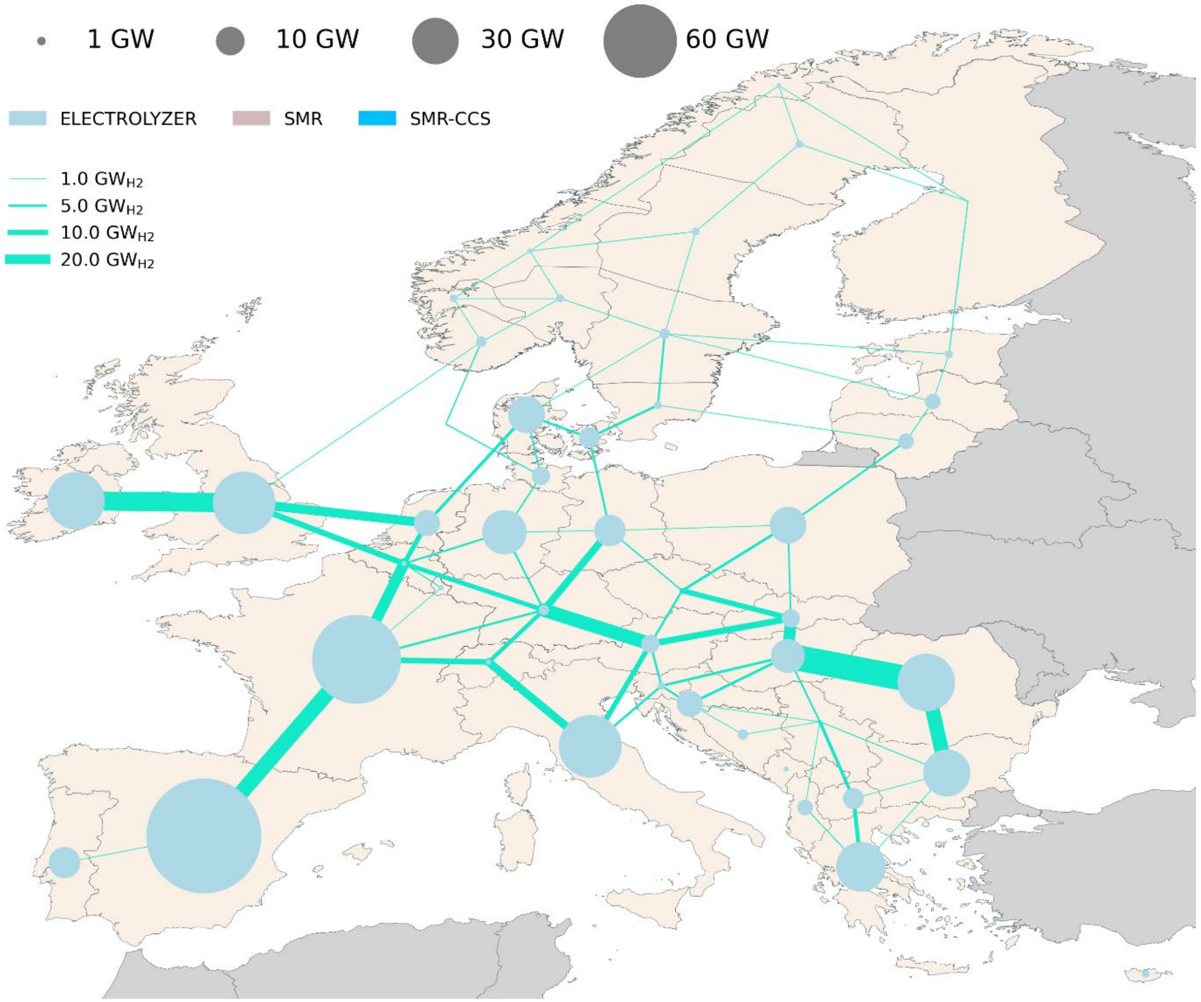
Going green and self-sufficient (2050)

From 450 GW to 505 GW Electrolysis

Scenario: Green H2 Europe

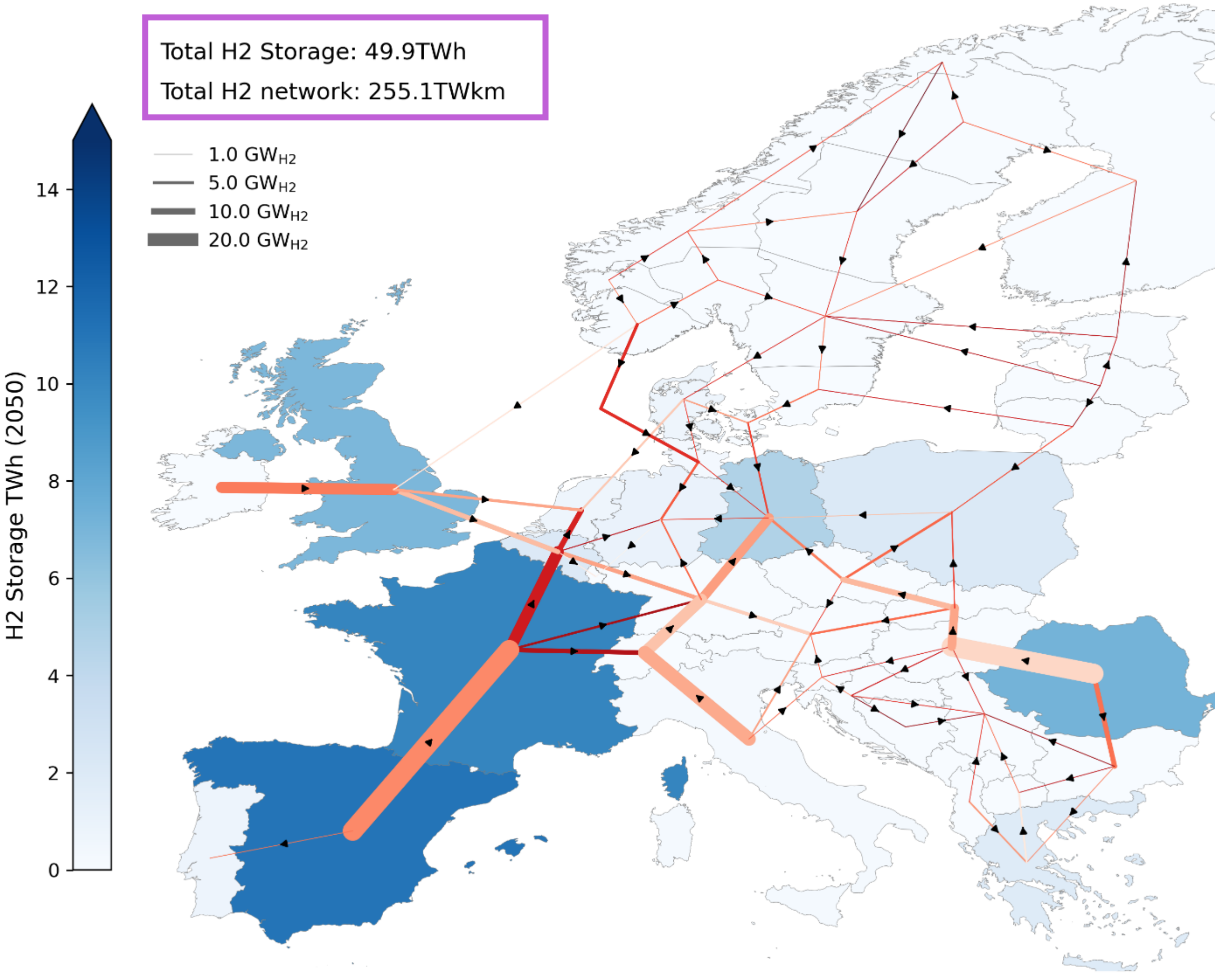


Scenario: Self-sufficient EU



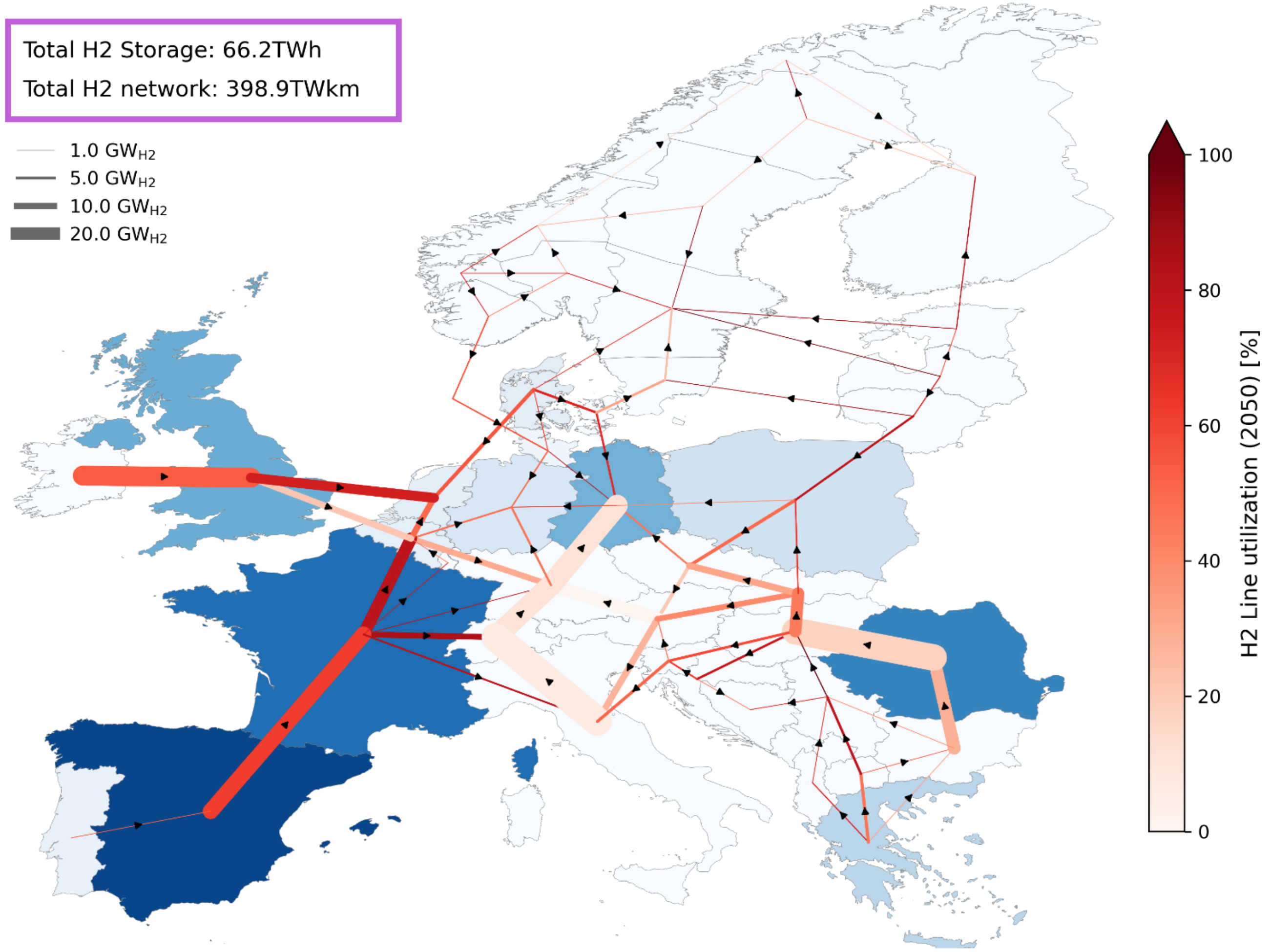
Going green with imports (2050)

Scenario: BASE


Total H2 Storage: 49.9TWh

Total H2 network: 255.1TWkm

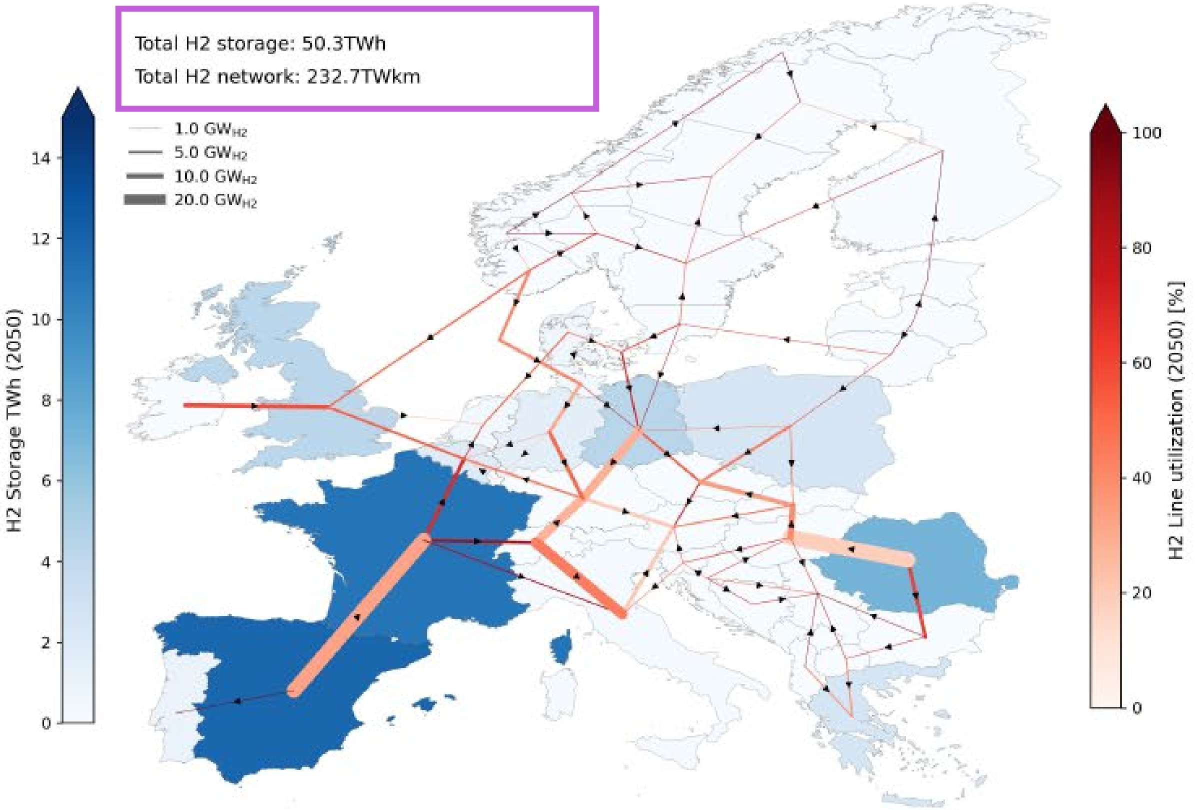
Scenario: Green H2 Europe


Total H2 Storage: 66.2TWh

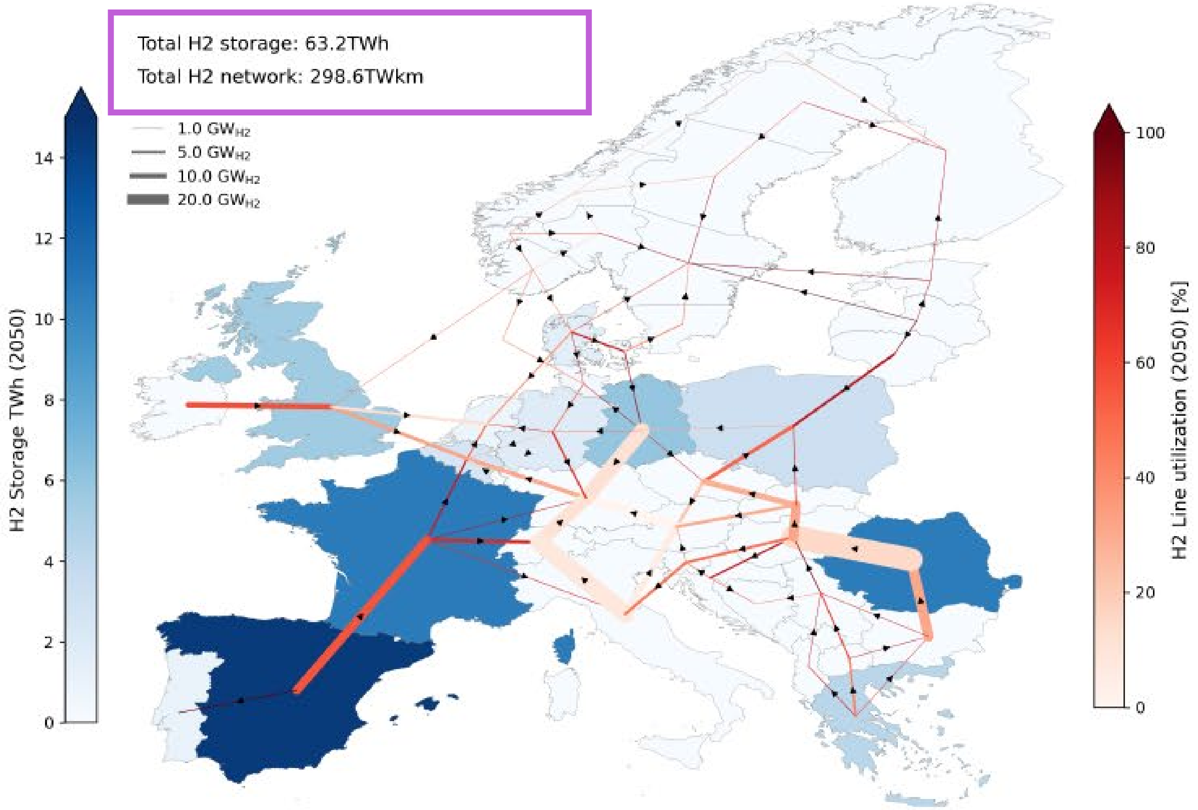
Total H2 network: 398.9TWkm

Co-location of H2 and e-fuel production

Scenario: BASE



Scenario: Green H2 Europe



613 TWh hydrogen derivatives production allowed to reallocate (60%)

~50% reduction in imports of H2 to Central Europe (DE, NL, BE)

18% reduction in network expansion in 2050

Conclusions on hydrogen infrastructure

- Hydrogen production needs to be flexible
- Hydrogen production is located in the periphery (mainly the South) to supply West/ Central Europe.
- Some hydrogen imports to Europe via pipelines from third nations.
- A green hydrogen European economy would require a rapid infrastructure scale-up and additional renewable investments.
- Storage provides flexibility (intra day and seasonal) integration of PV and less need for grids
- Co-location of H2 and derivatives production can reduce H2 imports to Central Europe and hence the network substantially
- Europe can become self-sufficient and utilize green hydrogen by 2050 at relatively small additional system costs

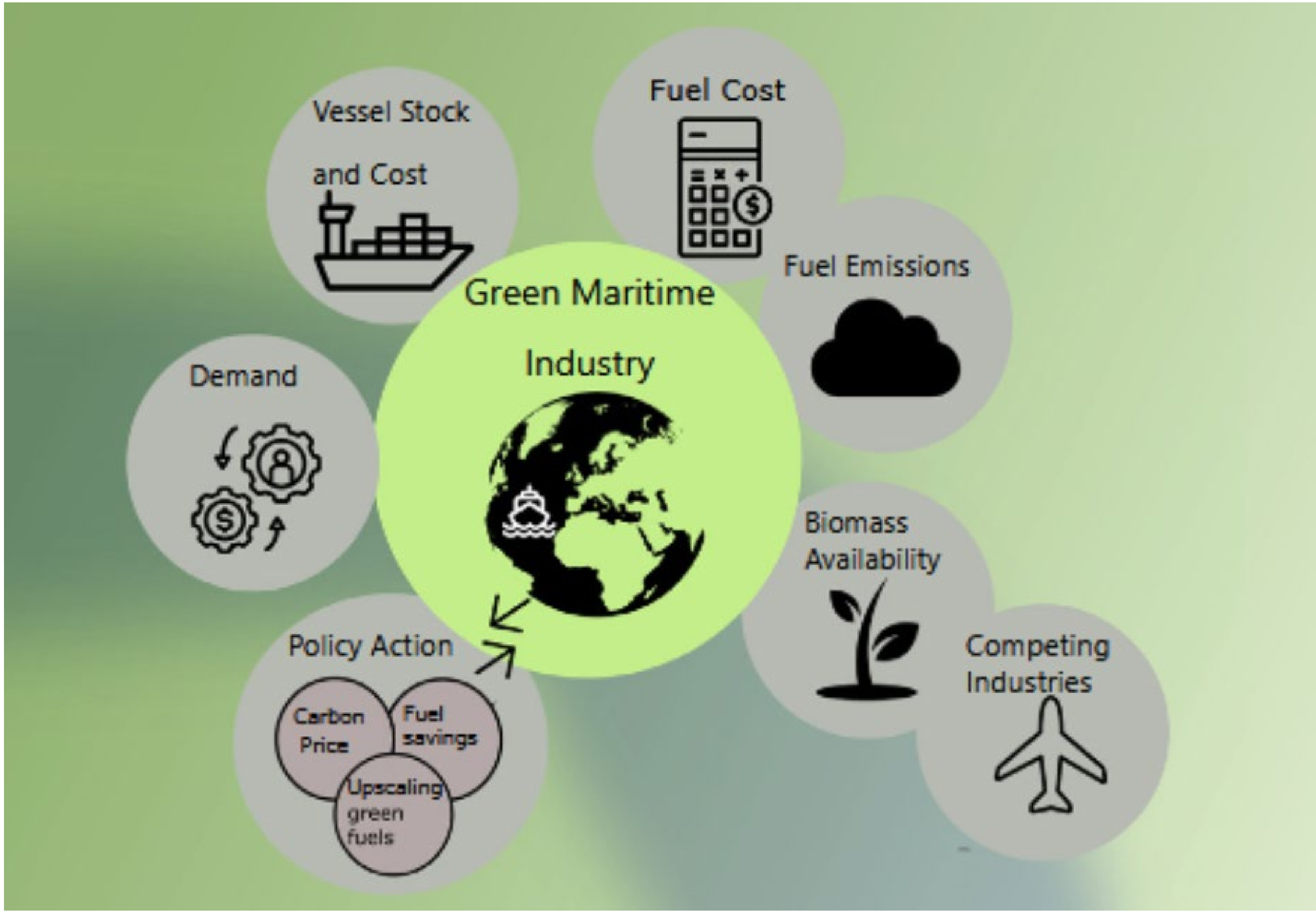
Future, energy efficient, wind assisted shipping, sailing on green fuels

ARTICLE · Volume 25, Issue 12, 105630, December 22, 2022 · ***Open Access***

Requirements for a maritime transition in line with the Paris Agreement

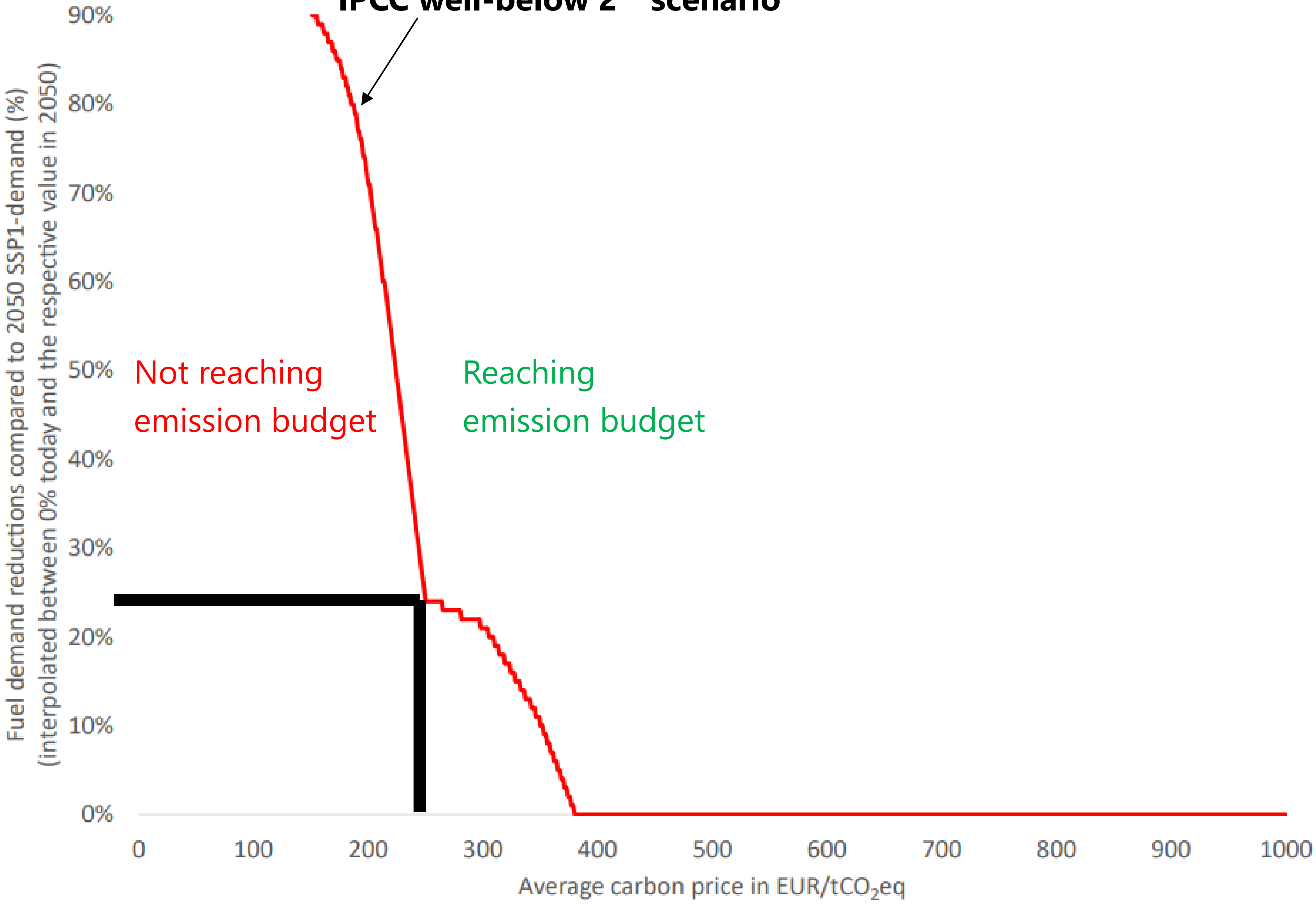
Sebastian Franz 2 · Nicolas Campion · Sara Shapiro-Bengtsen · Rasmus Bramstoft · Dogan Keles · Marie Münster

SEAMAPS model



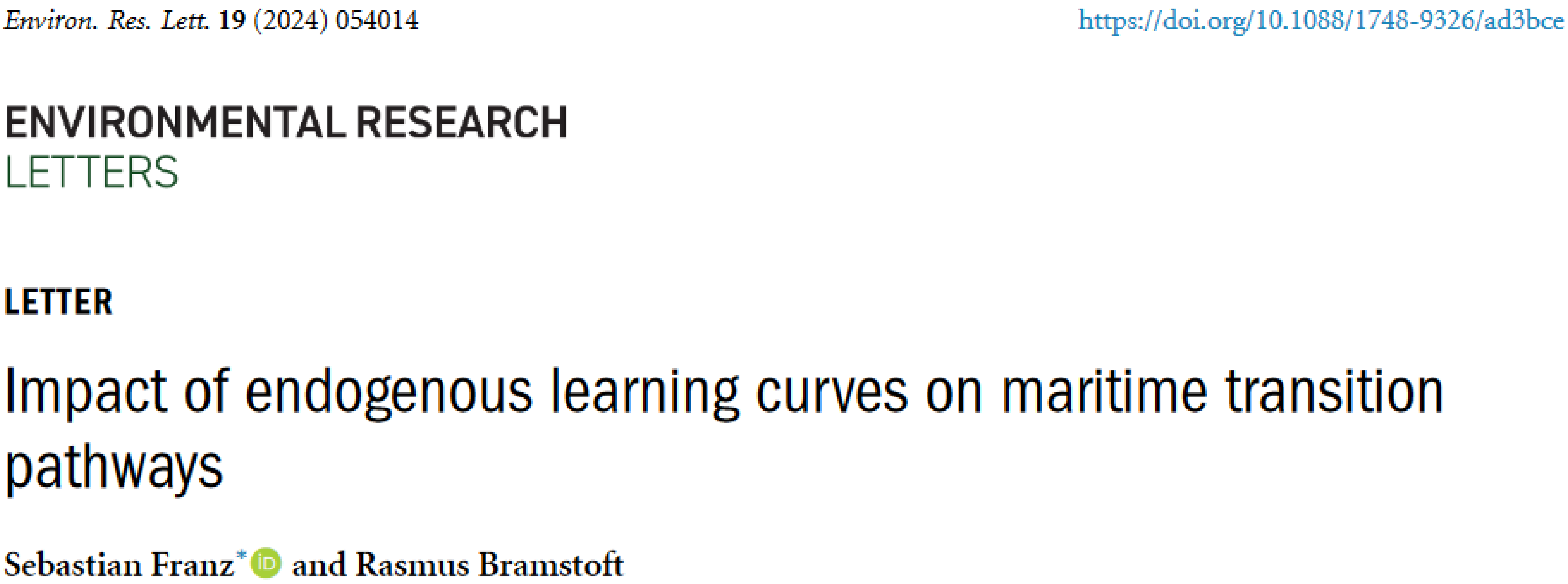
Solution space to reach

IPCC well-below 2° scenario



Conclusion on policies

1. Significantly higher carbon pricing (around 300EUR/tCO_2eq) than currently expected by industry and literature (200EUR/tCO_2eq can be found in existing literature)
2. Fuel efficiency gains reaching around 20-30% lower fuel demand compared to today's projection in 2050
3. Fast upscaling of low-carbon technologies of at least 50% annual capacity growth



Environ. Res. Lett. **19** (2024) 054014 https://doi.org/10.1088/1748-9326/ad3bce

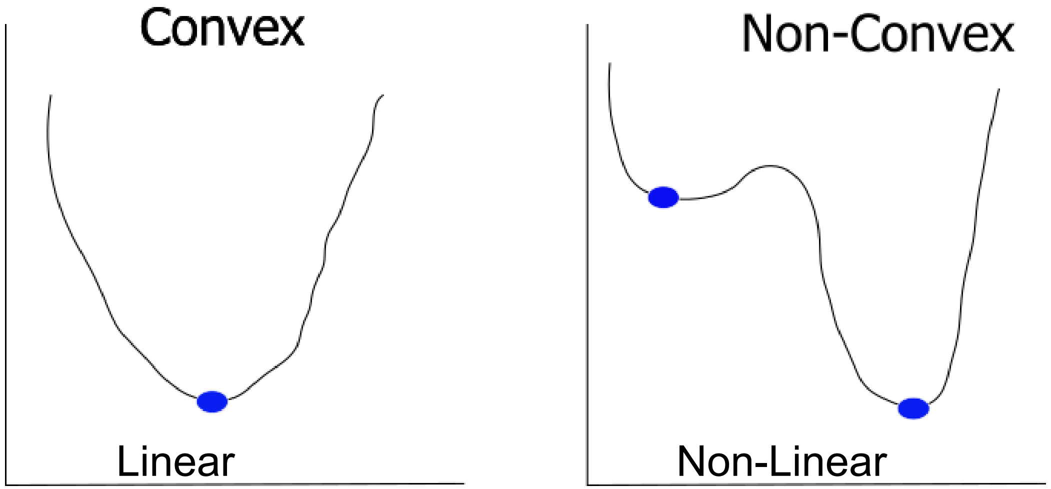
ENVIRONMENTAL RESEARCH
LETTERS

LETTER

Impact of endogenous learning curves on maritime transition pathways

Sebastian Franz* and Rasmus Bramstoft

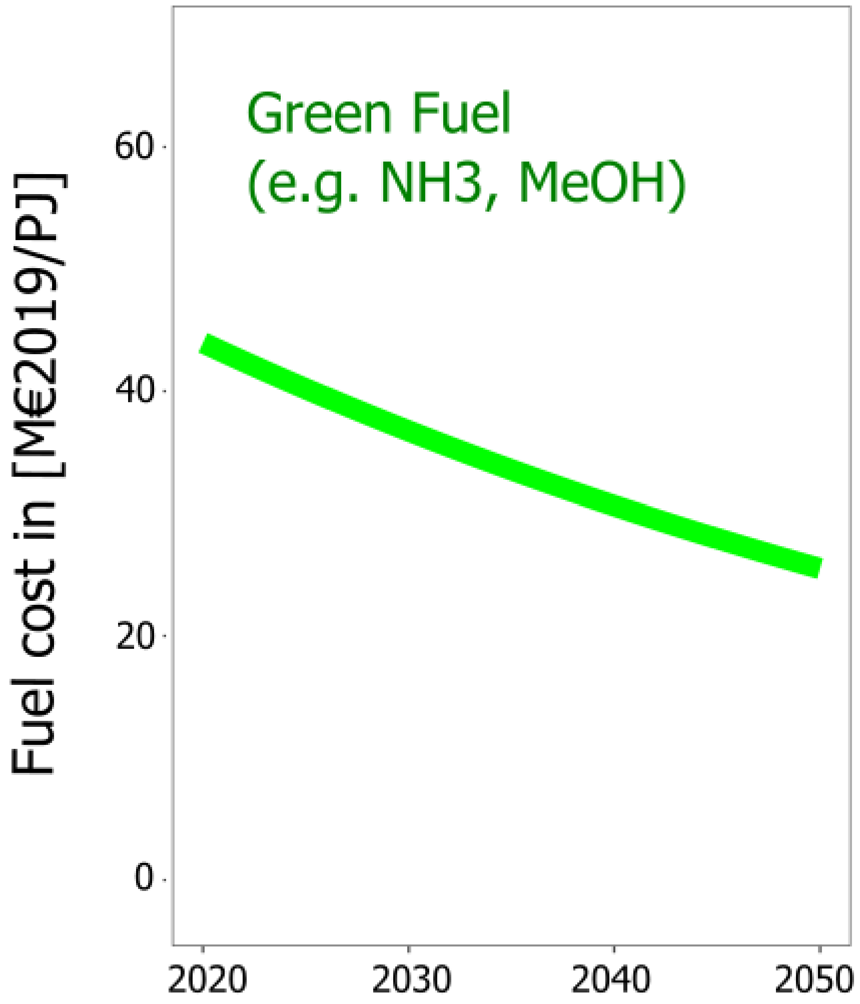
Non-convex Mixed-Integer Quadratically Constrained Programming (MIQCP)



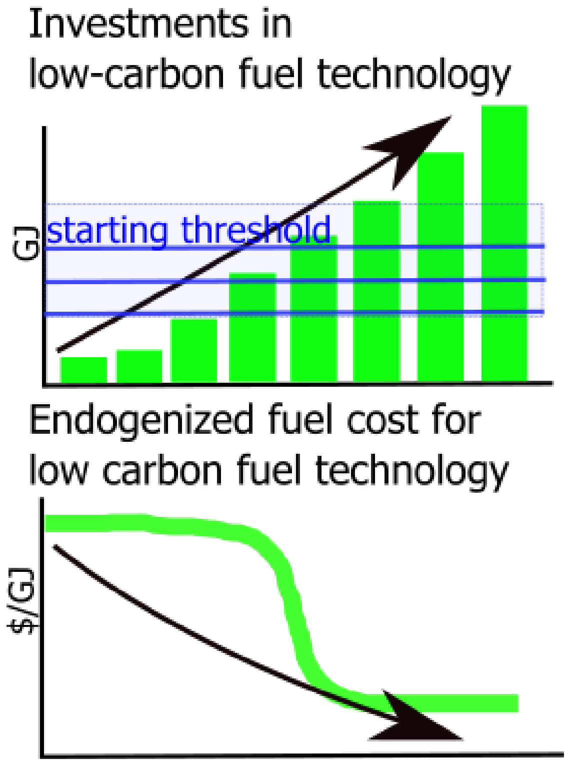
Relaxing optimality gap (MIPGap parameter) else so solutions can be found
→ Only near optimal solutions can be found

Source: https://www.gurobi.com/wp-content/uploads/2020-01-14_Non-Convex-Quadratic-Optimization-in-Gurobi-9.0-Webinar.pdf

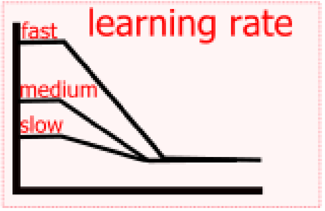
Exogenous cost curve



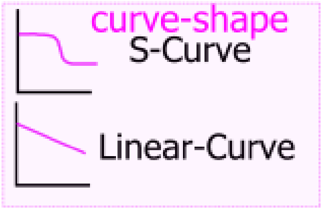
Novel model dynamics as fuel costs become a variable depending on historical investments


Investments in low-carbon fuel technology

Endogenized fuel cost for low carbon fuel technology

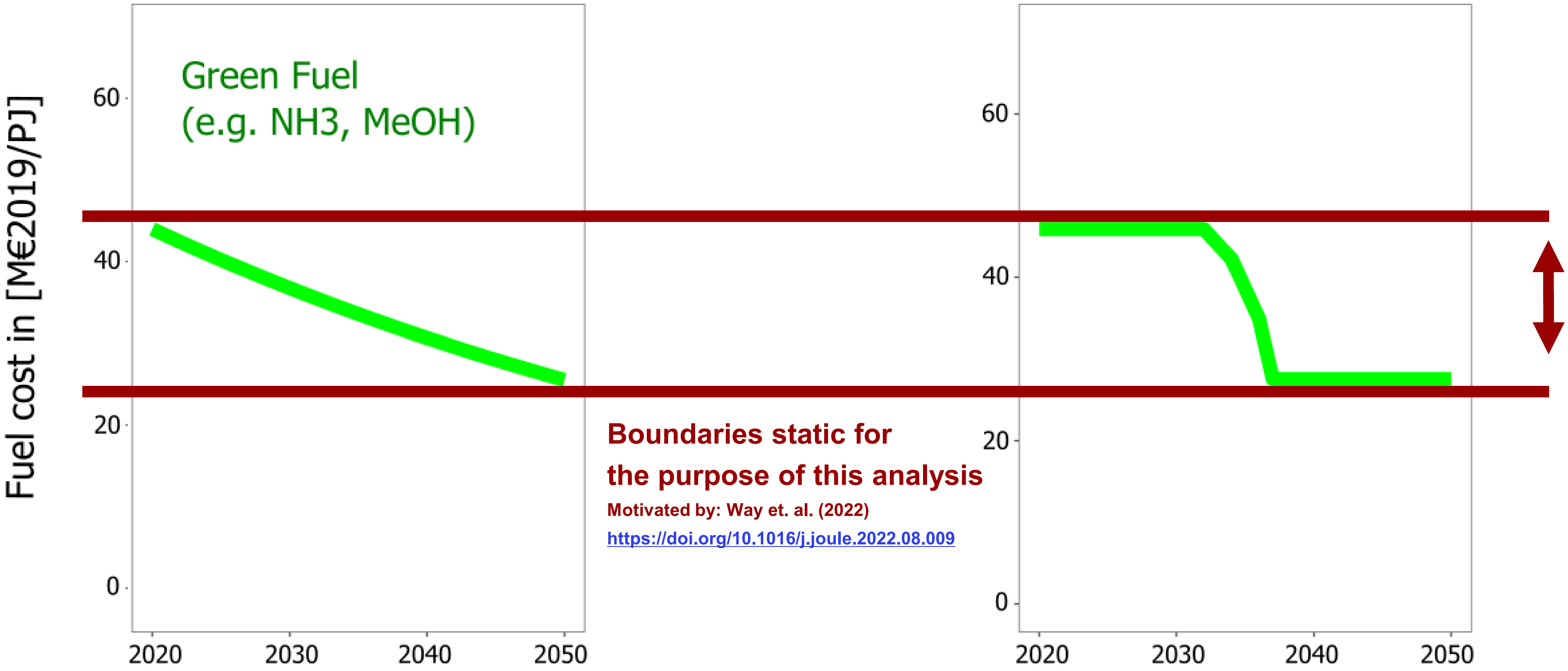


To model experience based learning a starting threshold, a learning rate, and a curve-shape have to be assumed



Input to optimization model
Exogenous cost curve

Output from optimization model
Endogenous cost curve

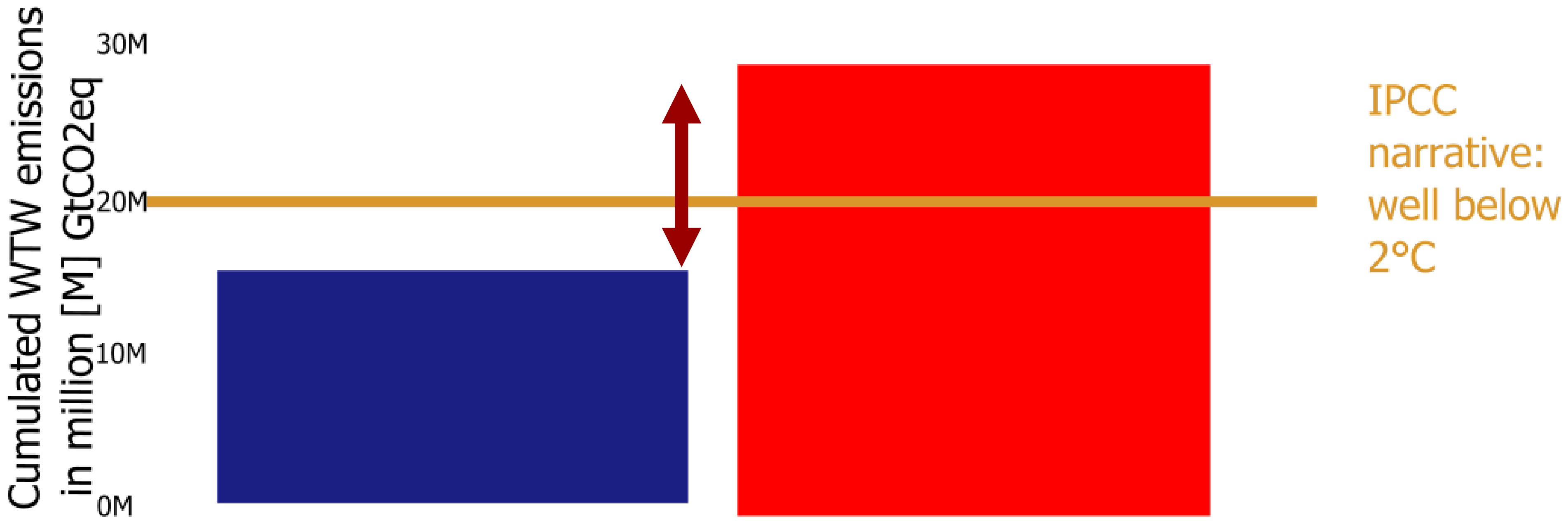


Boundaries static for the purpose of this analysis

Motivated by: Way et. al. (2022)

https://doi.org/10.1016/j.joule.2022.08.009

- Significant difference between both modelling methods
- Difference depends on the underlying assumptions
- In general: With endogenous learning the models does not have to **wait** for cost to decay.



Output from Optimization Model Endogenous learning curve

Output from Optimization Model Exogenous learning curve

Conclusions on endogenous learning curves

1. Significantly lower cumulative emissions (up to 45%) over the modelling horizon
2. The importance of early investments and policy measures to trigger experience-based learning as quickly as possible
3. Cost of climate mitigation is lower. BUT: Subsidies and technology cost may increase (disregarded in this analysis) → Objective here: Show the impact on decarbonization system cost not total cost (including subsidies & technology cost but also climate damage "savings")

Overall conclusion

- Yes!
- Maritime ports and shipping can become important gateways for the energy transition

The end ☺

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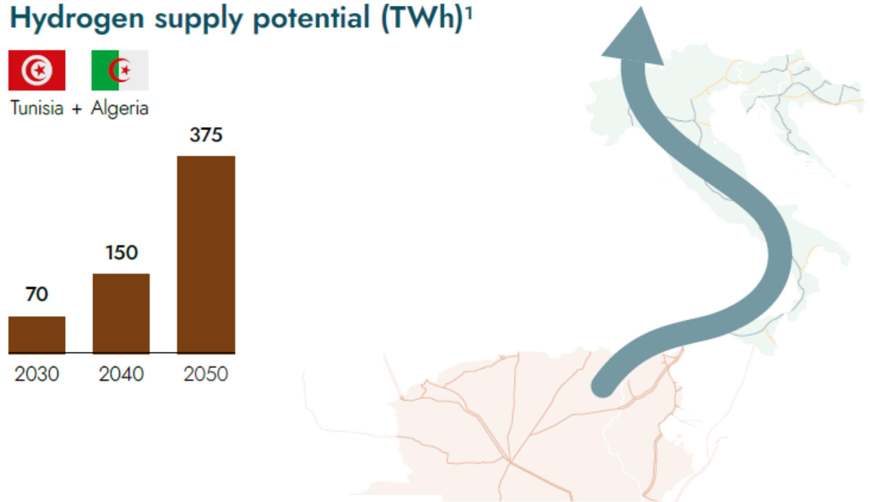
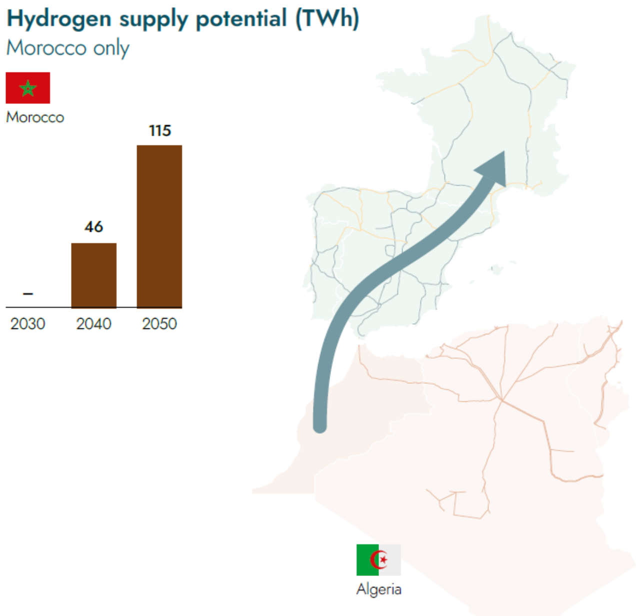
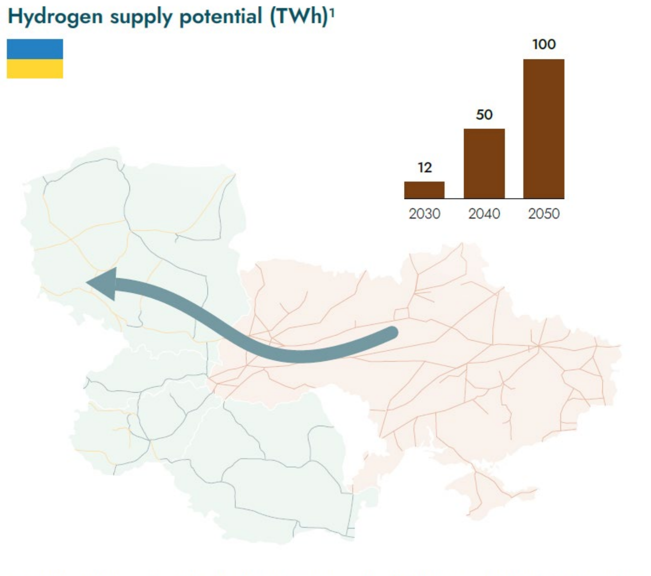
Hydrogen production import - modeling



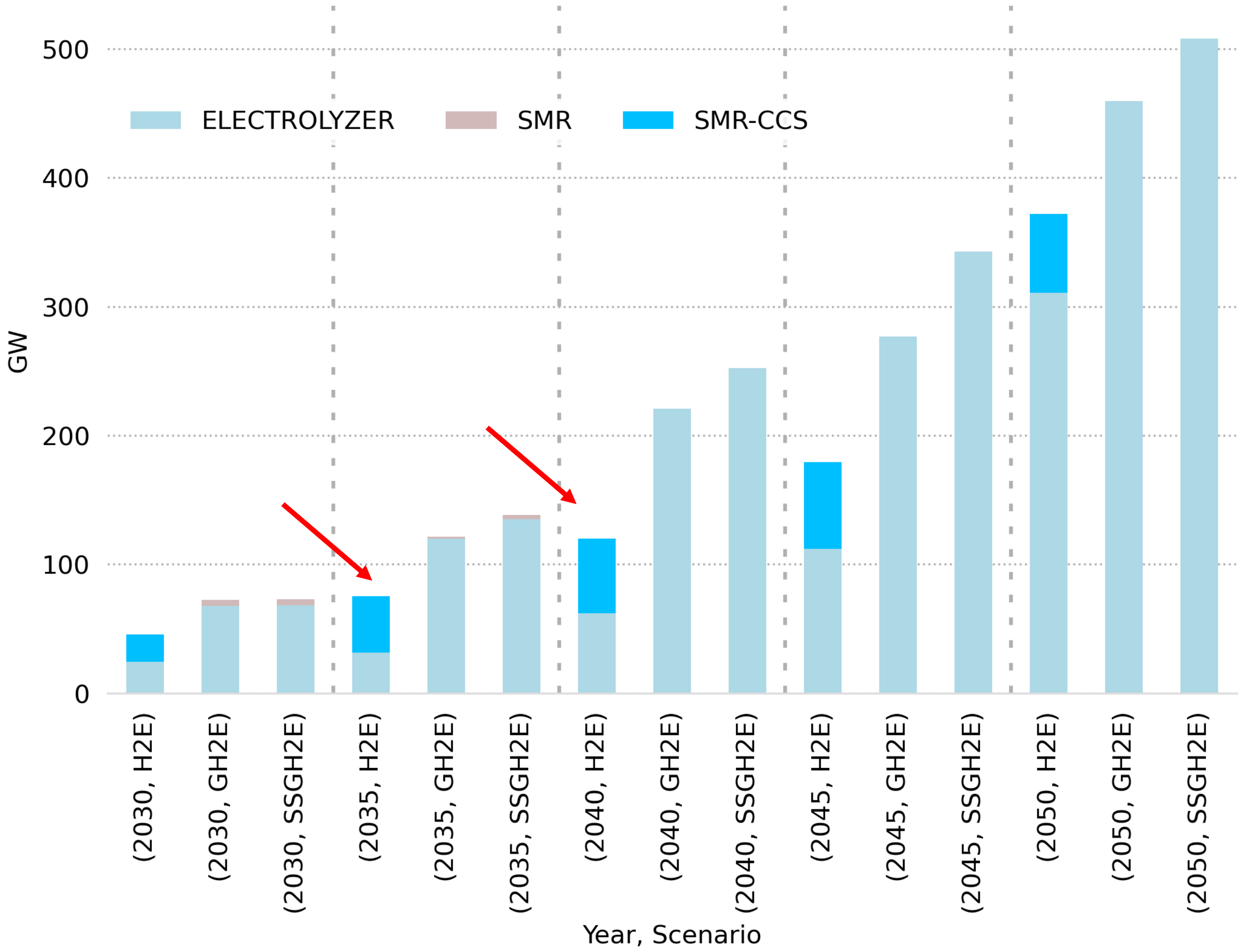




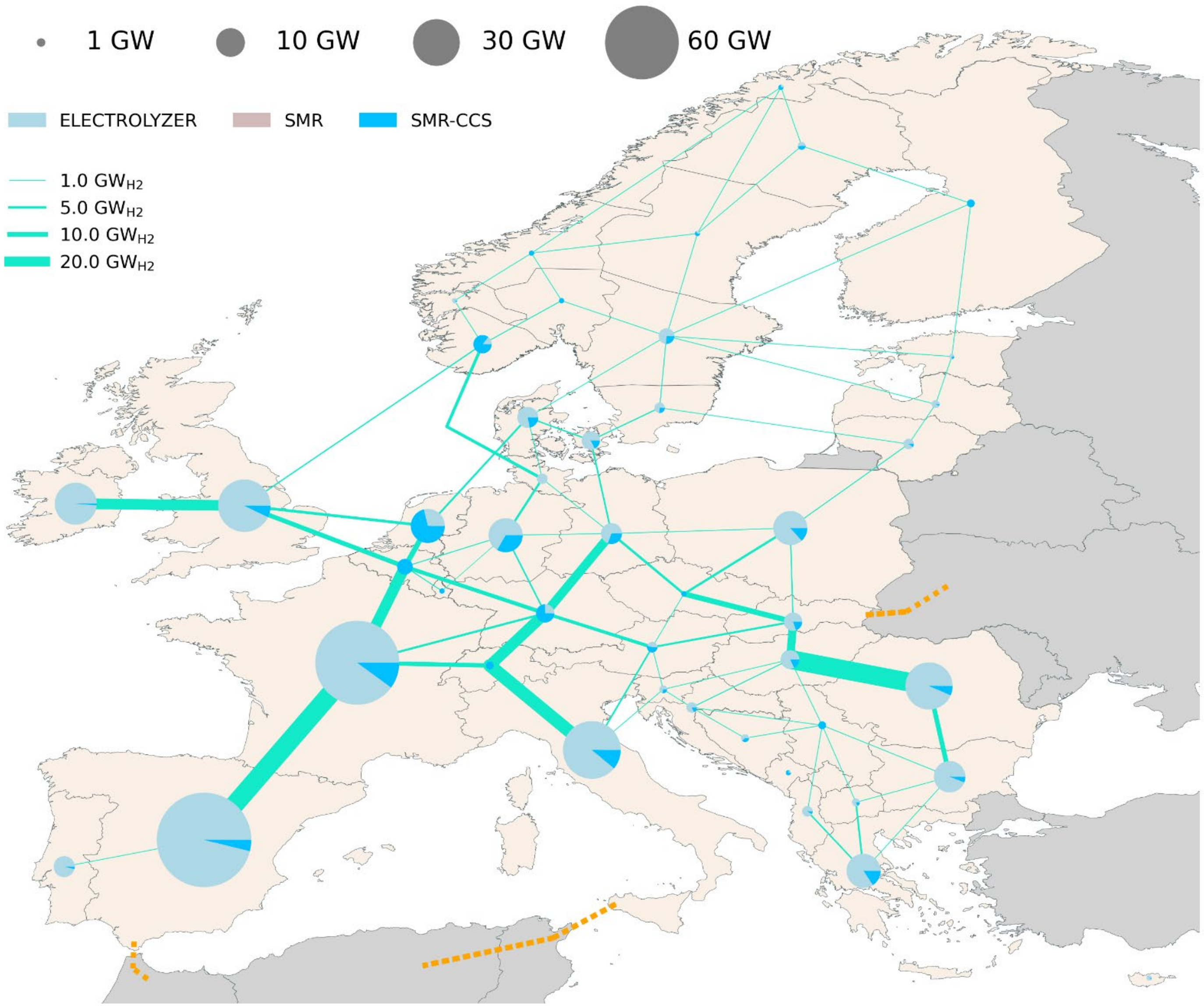
Note: Export projections to Europe from 2030 to 2040-2050 are based on an assumed four-fold increase in exports by 2040 and two-fold increase from 2040 to 2050. These assumptions are informed by scale up projections from other export countries of this study and Hydrogen Europe's 2x40 GW report.

Source: Five hydrogen supply corridors for Europe in 2030, EHB, May 2022

Blue Hydrogen: A possible lock in effect!



Hydrogen Imports from 3rd nations



Scenario: Base

Hydrogen Capacities (2050)

- Electrolysis capacity: $305GW_{h2}$ (3500-5500 FLH)
- SMR-CSS capacity: $61\ GW_{h2}$

Importing H_2 from 3rd nations (2050)

- Marroco: 42/115 (TWh)
- Tunisia: 61/375 (TWh)
- Ukraine: 23/100 (TWh)

System costs (2050)

System cost difference to BASE 2050:

GH2E	~ 3 %
SSGH2E	~ 4 %

Maritime optimization model (SEAMAPS)

$$\min Z = \sum_{s,y} \boldsymbol{INV}_s \cdot \boldsymbol{NB}_{s,y} + \boldsymbol{OEM}_s \cdot \boldsymbol{SS}_{s,y} + \sum_{,f,y} \boldsymbol{F}_{f,s,y} \cdot (\boldsymbol{FC}_{f,y} + \boldsymbol{FT}_{f,y}) \qquad (1)$$

Investment expenditure for a new build average vessel (parameter)

New build ships (variable)

Operation and maintenance cost (parameter)

Ship-stock (variable)

Maritime optimization model (SEAMAPS)

$$\min Z = \sum_{s,y} \boldsymbol{INV}_s \cdot \boldsymbol{NB}_{s,y} + \boldsymbol{OEM}_s \cdot \boldsymbol{SS}_{s,y} + \sum_{s,f,y} \boldsymbol{F}_{f,s,y} \cdot (\boldsymbol{FC}_{f,y} + \boldsymbol{FT}_{f,y}) \quad (1)$$

Type and amount of fuel used

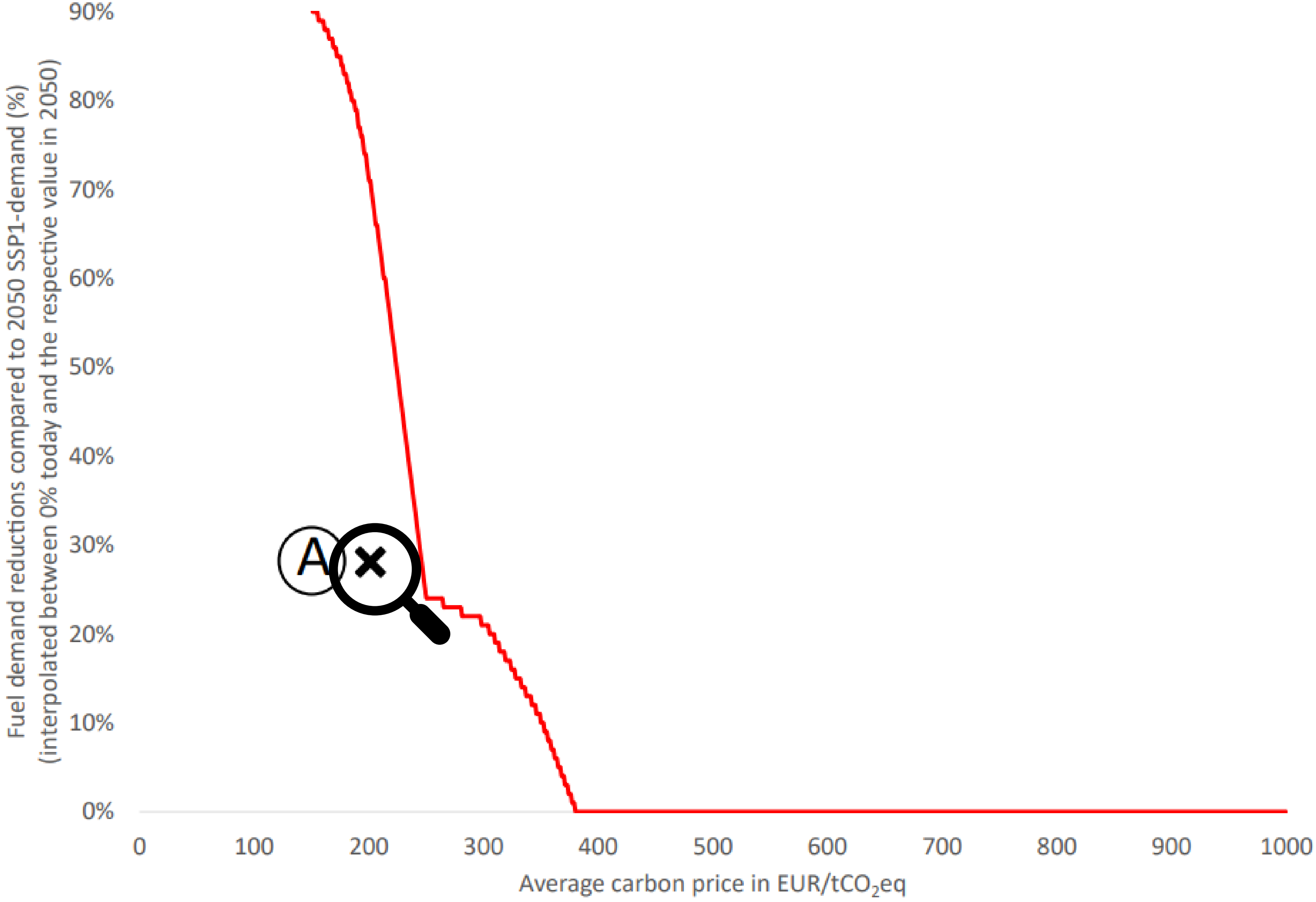
(variable)

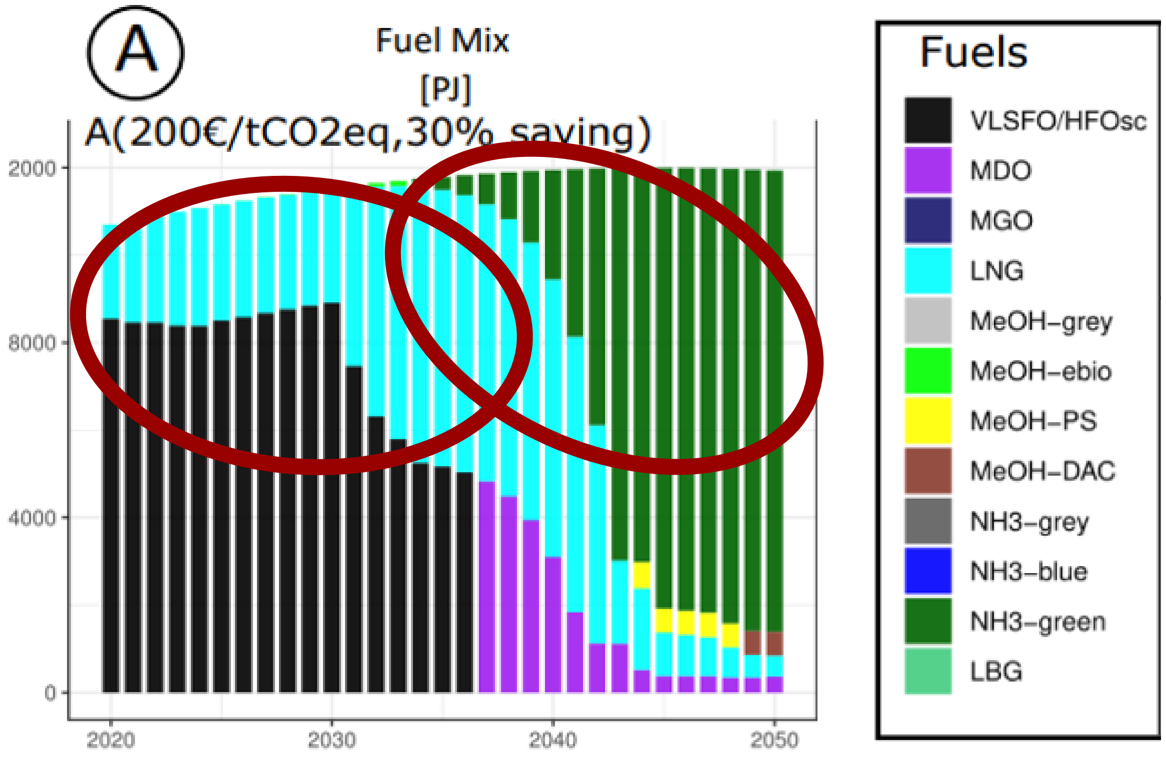
Fuel-cost

(parameter (MIP) or variable (Non-convex MICQP))

Fuel-tax/carbon tax

(parameter)


Fuel demand reductions compared to 2050 SSP1-demand (%)
(interpolated between 0% today and the respective value in 2050)
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
100
200
300
400
500
600
700
800
900
1000
Average carbon price in EUR/tCO$_2$eq
A


A
Fuel Mix
[PJ]
A(200€/tCO2eq,30% saving)
2000
8000
4000
0
2020
2030
2040
2050
Fuels
VLSFO/HFOsc
MDO
MGO
LNG
MeOH–grey
MeOH–ebio
MeOH–PS
MeOH–DAC
NH3–grey
NH3–blue
NH3–green
LBG