

ISESA

1st International Symposium on Energy System Analysis

**Resilient strategies for the European energy system
A case study on 2030 EU policy targets**

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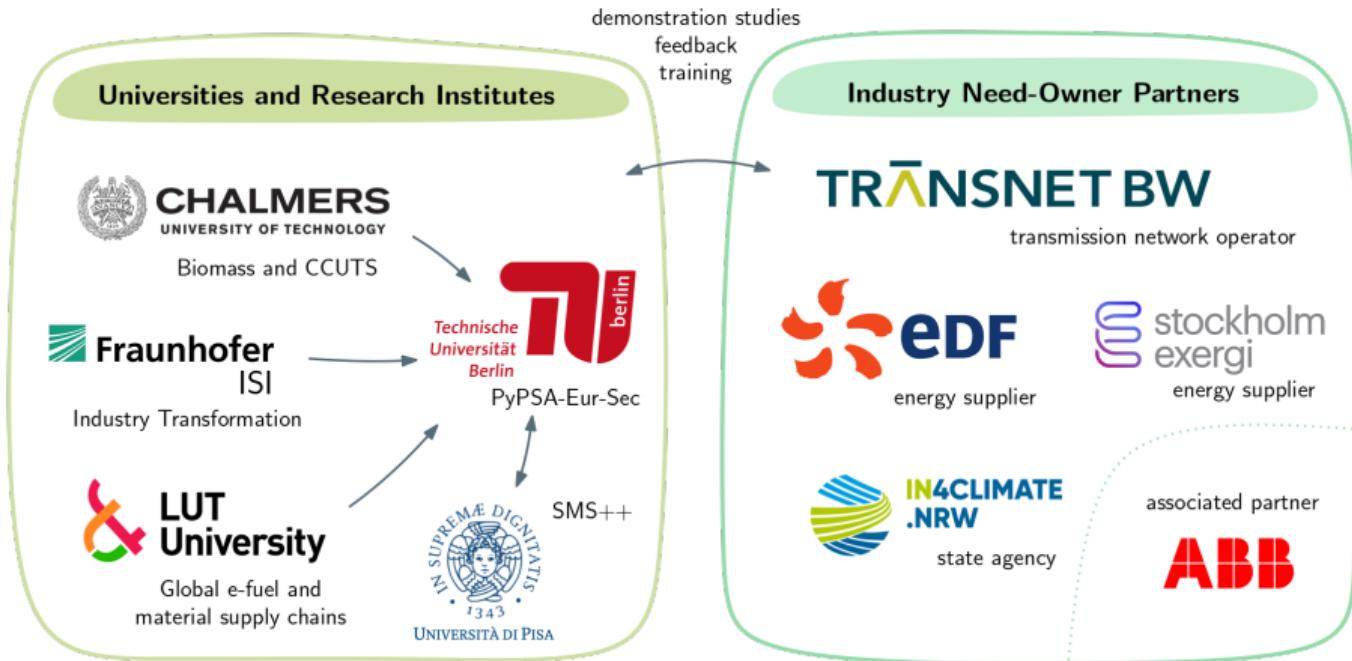


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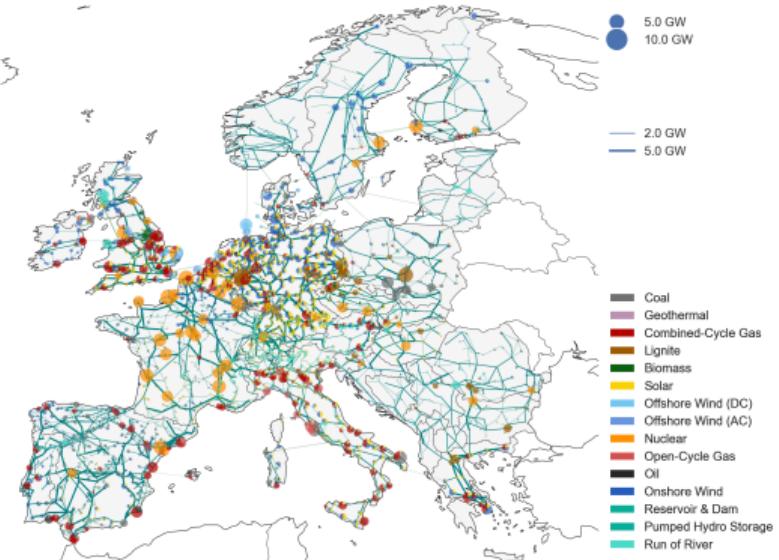
RESILIENT project partners



Funded via **CETPartnership 2022** Call – **BMWK** for all German partners.

PyPSA-Eur: An open-source, sector-coupled model for Europe

- Spatially and temporally highly resolved linear optimisation model that covers the European continent,
- Built on top of the open-source toolbox **PyPSA**,
- Includes **stock** of existing power plants, renewable potentials, availability **time series**,
- Covers the **electricity high-voltage grid** from AC 220 kV to 750 kV (UA) and DC 150 kV upwards, option to include planned transmission projects (TYNDP and German NEP),
- Maintained by the Department of Digital Transformation in Energy Systems at **TU Berlin**.



Source: <https://pypsa-eur.readthedocs.io>

Selection of planned model developments

Computational methods for uncertainties

- decomposition techniques
- large-scale stochastic optimisation
- **test robustness of system**
- using SMS++ framework

Carbon management and biomass usage

- **CO₂ network**
- **CO₂ sequestration potentials**
- circular carbon economy and recycling
- biomass usage options

Industry transformation (FORECAST)

- fuel and process switching
- industry relocation
- carbon sources and feedstocks
- data on stock & investment cycles
- new technologies (oxyfuel cement, etc.)

Global green fuel and material markets

- **imports of green energy and materials**
- **effects on European infrastructure**
- restructuring of value chains
- risks (geopolitical, technological, etc.)

Case study: Motivation and research questions

The EU has set ambitious targets for 2030, including the electricity, hydrogen and CO₂ infrastructure sector.

55 % emission reduction

- Fit for 55
- Translating to an emission allowance of ca. 2 bn. t CO₂ p.a. in 2030
- Covering the electricity, heat, industry, transport, buildings and agriculture sectors

10 Mt p.a. green H₂ production

- REPowerEU
- Accelerating the transition away from fossil fuels (esp. Russian gas), enhancing energy security through renewables
- Aligns with European Green Deal and targets scaling up renewable H₂ in hard-to-electrify-sectors

50 Mt p.a. CO₂ sequestration

- Net-Zero Industry Act
- Essential component in helping industries to reduce their net emissions
- Provides means to capture unavoidable emissions from hard-to-abate sectors like cement, steel, chemicals, etc.

Case study: Motivation and research questions

What are PCI-PMI projects?

- Projects of Common Interest (PCIs) are key **cross-border infrastructure projects** that link the energy systems of EU countries
- Projects of Mutual Interest (PMIs) include cooperations with countries outside the EU
- Intend “to help the EU achieve its **energy policy and climate objectives**: affordable, secure and sustainable energy for all citizens and the long-term decarbonisation of the economy in accordance with the **Paris Agreement**”
- “Potential overall benefits of the project must outweigh its costs”
- Given their **lighthouse character**, these projects are highly likely to be implemented.
- Large infrastructure projects (incl. PCI-PMI) are however commonly facing delays due to permitting, procurement bottlenecks, etc.

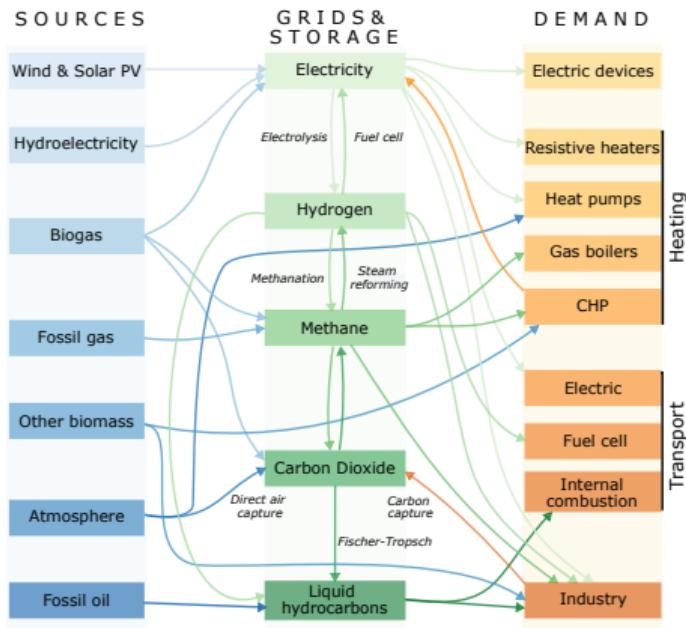
Project map



- 1 At **what cost** do we stick to the targets? How does a **delay of PCI-PMI projects** affect the system?
- 2 What is the **impact** of **missing** the EU 2030 policy targets for **CO₂ sequestration** and **H₂ production**?

Case study: Model setup

- Including sectors **power, heat, transport, industry, feedstock** and **agriculture**
- Minimising **total system costs** (investment and operation) for the target year **2030**
- **Co-optimising** generation, transmission, storage, and power-to-X conversion
- Resolving 34 countries to **90 regions** at **3-hourly** temporal resolution
- Implementing **PCI-PMI** HVAC, HVDC, hydrogen and carbon infrastructure projects as well as key **policy targets**:
 - 55 % emission reduction (**Fit for 55**)
 - 10 Mt p.a. production of hydrogen (**REPowerEU**)
 - 50 Mt p.a. of CO₂ sequestration (**Net-Zero Industry Act**)



Source: <https://pypsa-eur.readthedocs.io>

Case study: Scenario setup

Base (All targets)

- Including PCI-PMI HVAC, HVDC, H₂ and CO₂ infrastructure projects with a planned commissioning date by 2030
- Including exogenous CO₂ sequestration and H₂ storage sites
- Endogeneous expansion of CO₂ pipelines and national H₂ pipelines
- Endogeneous expansion of H₂ storage sites
- 55 % emission reduction target
- 10 Mt p.a. H₂ production target
- 50 Mt p.a. CO₂ sequestration target

Scenario A. PCI-PMI delay (All targets)

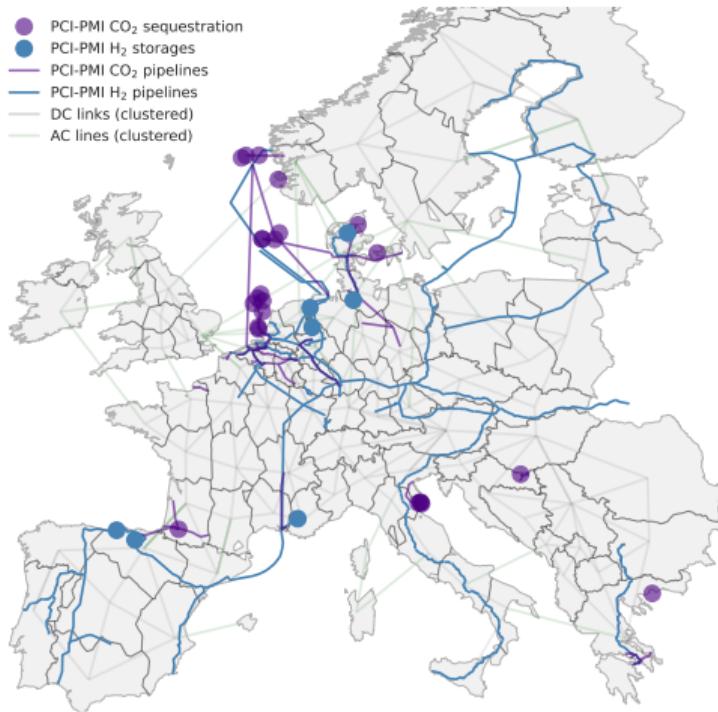
- Delay of all PCI-PMI projects, no H₂ and CO₂ pipelines will be ready by 2030
- Endogeneous expansion of H₂ storage sites and CO₂ sequestration sites – according to technical sequestration potential (Hofmann et al., 2024)
- 55 % emission reduction target
- 10 Mt p.a. H₂ production target
- 50 Mt p.a. CO₂ sequestration target

Scenario B. PCI-PMI delay (Emission target only)

- Delay of all PCI-PMI projects, no H₂ and CO₂ pipelines will be ready by 2030
- Dropping H₂ production and CO₂ sequestration targets
- Endogeneous expansion of H₂ storage sites and CO₂ sequestration sites – according to technical sequestration potential (Hofmann et al., 2024)
- 55 % emission reduction target

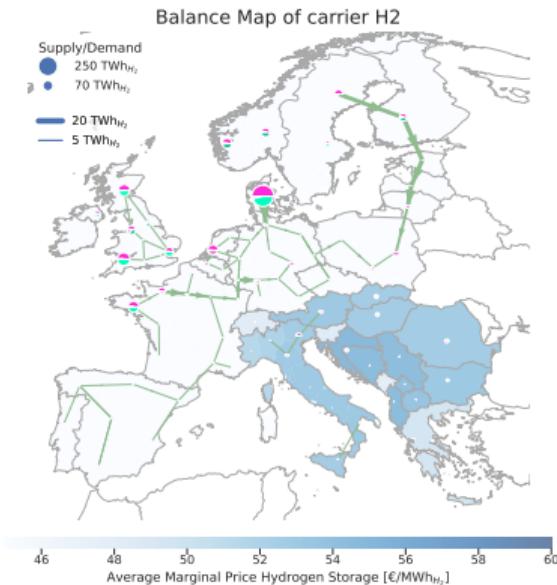
Case study: Base – Modelled PCI-PMI H₂ and CO₂ infrastructure

- Base scenario incorporates PCI-PMI projects for H₂ and CO₂ infrastructure, including pipelines, storages (H₂) and sequestration sites (CO₂), as well as new/upgraded high-voltage AC and high-voltage DC lines commissioned by 2030
- Total CO₂ sequestration capacity sums up to 75 Mt p.a., mostly located in the North Sea
- Total H₂ storage capacity sums up to 977 GWh_{H₂}

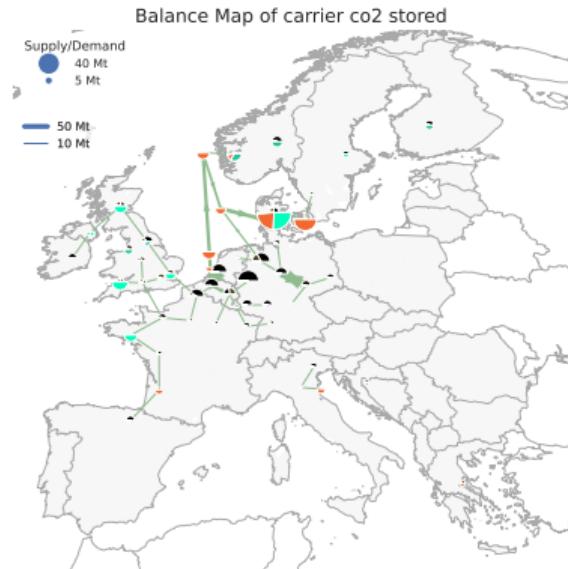


Source: Own illustration based on data extracted from
https://ec.europa.eu/energy/infrastructure/transparency_platform/map-viewer

First results: Base (All targets)



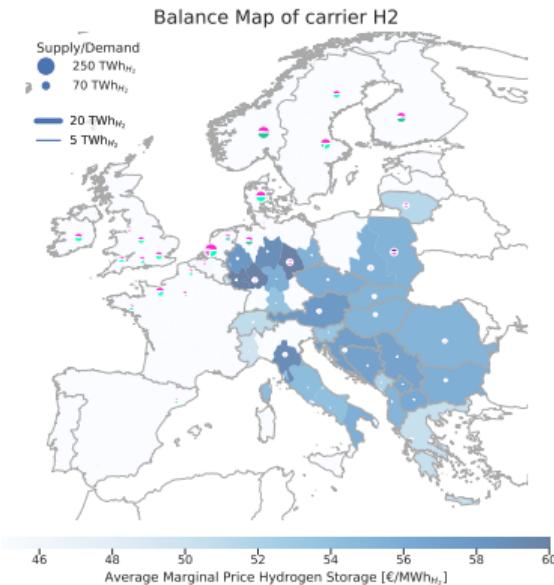
- | | |
|-------------------|--------------------|
| Production | Consumption |
| H2 Electrolysis | Fischer-Tropsch |
| H2 for industry | H2 Fuel Cell |
| SMR | Sabatier |
| SMR CC | methanolisation |



- | | |
|------------------------------------|--------------------|
| Production | Consumption |
| DAC | Fischer-Tropsch |
| SMR CC | Sabatier |
| gas for industry CC | co2 sequestered |
| process emissions CC | methanolisation |
| solid biomass for industry CC | |
| urban central gas CHP CC | |
| urban central solid biomass CHP CC | |

Source: Own illustration.

First results: Scenario A. PCI-PMI delay (All targets)

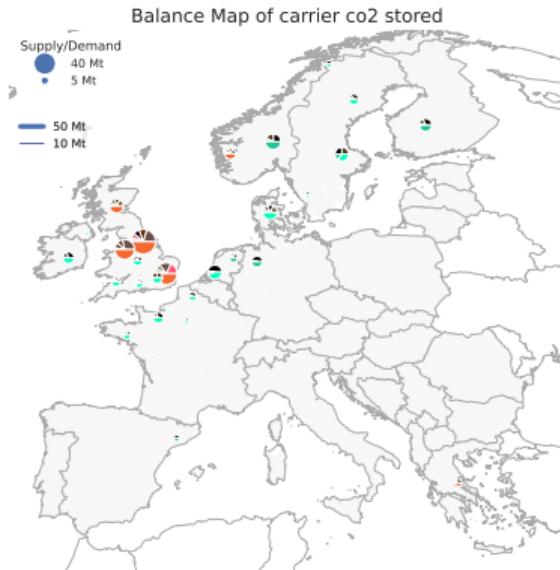


Production

- H₂ Electrolysis
- H₂ for industry
- SMR
- SMR CC

Consumption

- Fischer-Tropsch
- H₂ Fuel Cell
- Sabatier
- methanolisation



Production

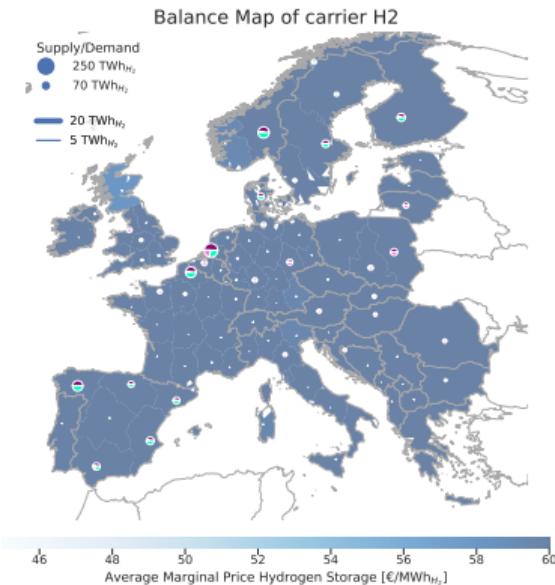
- DAC
- SMR CC
- gas for industry CC
- process emissions CC
- solid biomass for industry CC
- urban central gas CHP CC
- urban central solid biomass CHP CC

Consumption

- Fischer-Tropsch
- Sabatier
- co₂ sequestered
- methanolisation

Source: Own illustration.

First results: Scenario B. PCI-PMI delay (Emission target only)

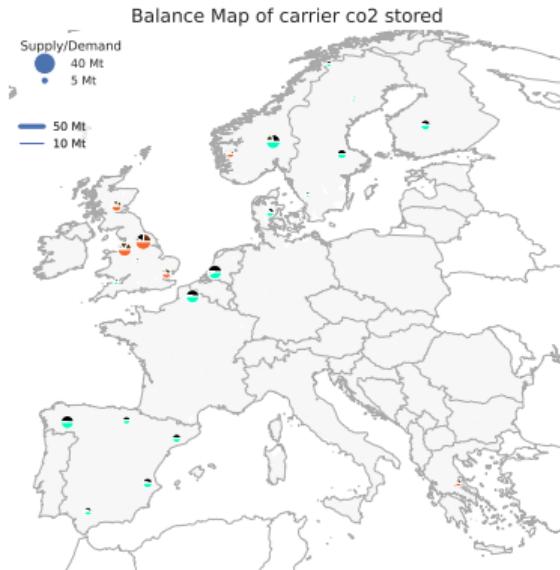


Production

- H₂ Electrolysis
- H₂ for industry
- SMR
- SMR CC

Consumption

- Fischer-Tropsch
- H₂ Fuel Cell
- Sabatier
- methanolisation



Production

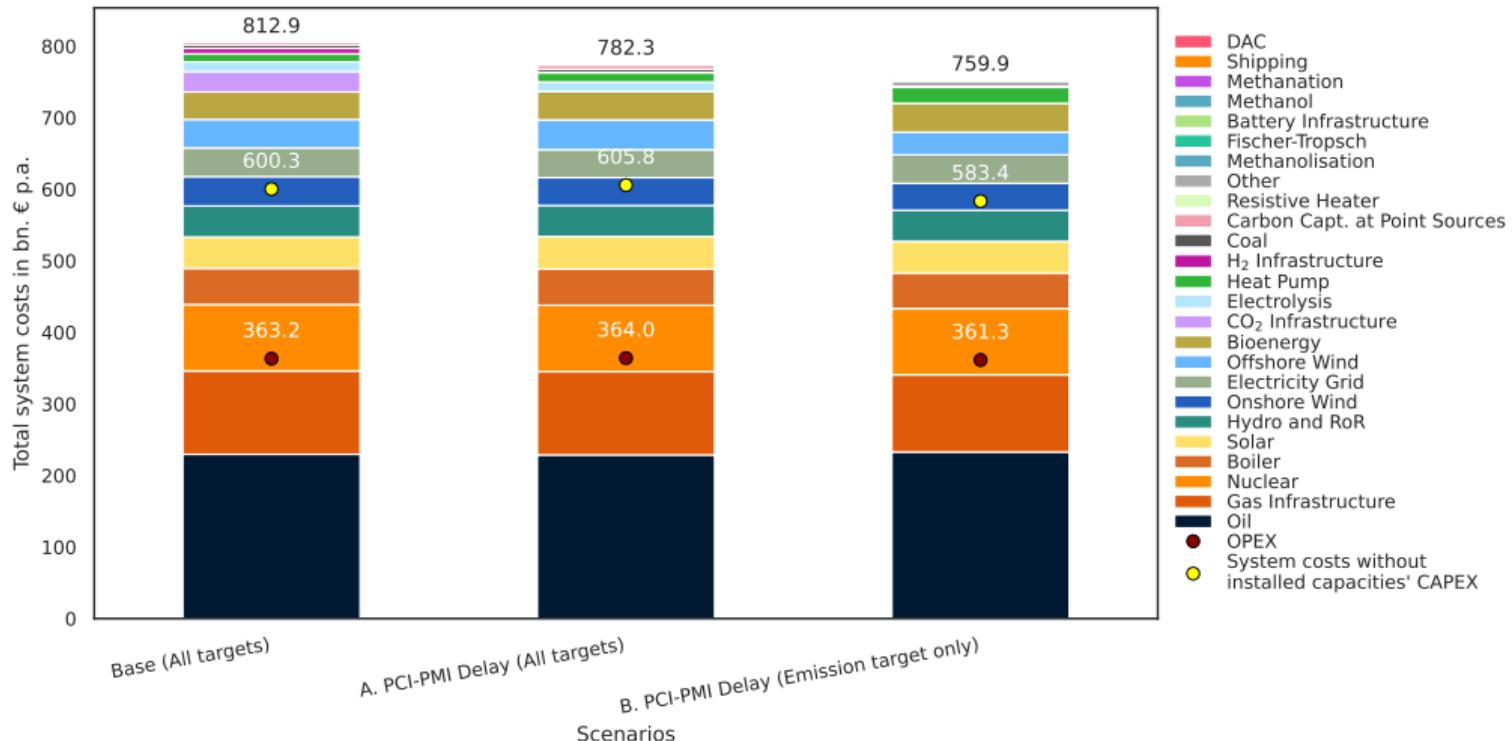
- DAC
- SMR CC
- gas for industry CC
- process emissions CC
- solid biomass for industry CC
- urban central gas CHP CC
- urban central solid biomass CHP CC

Consumption

- Fischer-Tropsch
- Sabatier
- co₂ sequestered
- methanolisation

Source: Own illustration.

First results: Total system costs



Case study: First takeaways for modelling year 2030

- 1 Reaching the EU's 2030 H₂ production and CO₂ sequestration targets translates into around **20 bn. € p.a. in total system costs** for all included sectors, with or without PCI-PMI H₂ and CO₂ infrastructure projects.
- 2 By omitting a H₂ target, almost no electrolyzers are installed. **Around 8 Mt of H₂** are still produced to cover industrial H₂ and methanol (primarily shipping) demand. Instead of through electrolysis, this demand is met by decentral steam methane reforming (SMR).
- 3 Setting a policy target may however be essential to **kick-start the H₂ economy**. H₂ is then primarily created through electrolysis and used as a **precursor** for methanolisation and to meet industrial demand.
- 4 Without specifying a CO₂ sequestration target, the system still captures and sequesters **around 21 Mt of CO₂ p.a.** (primarily from process emissions).
- 5 While all three **EU policy targets for 2030 can still be achieved** without PCI-PMI infrastructure, they bring additional benefits:
 - PCI-PMI H₂ pipelines help distribute more **affordable green H₂** from northern and south-western Europe to high-demand regions central Europe
 - PCI-PMI CO₂ pipelines connect **industrial sites** and their process emissions to **major offshore sequestration sites in the North Sea** (DK, NO, NL).

Outlook

- Including **all relevant PCI-PMI projects**, i.e. hybrid offshore interconnectors (energy islands), electricity storages, CO₂ shipping routes
- Looking at the **long-term value of PCI-PMI projects** in a sector-coupled European energy system through modelling pathways towards 2040 and 2050
- Incorporating technology-specific **build-out rate limits** for earlier target years, e.g. for electrolysis
- Assessing the impact of **sector-specific** PCI-PMI project delays

Thank you.

↪ github.com/pypsa/pypsa-eur

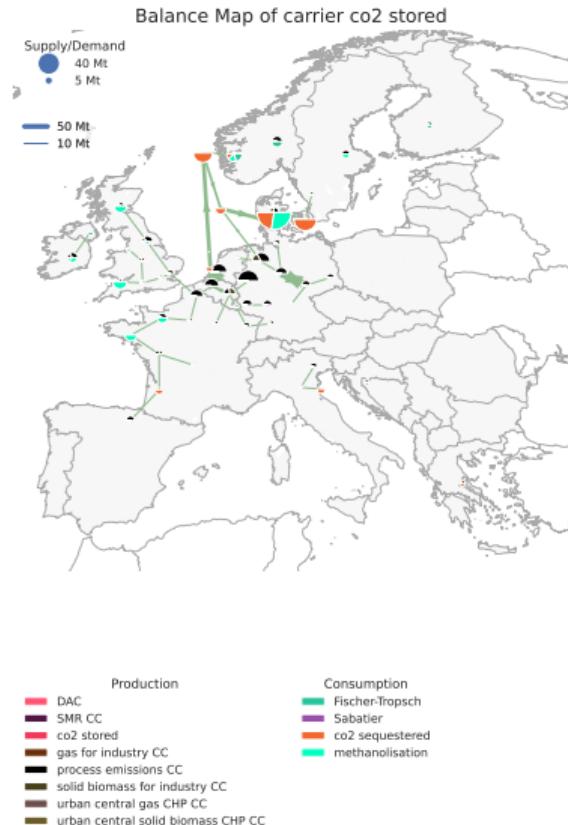
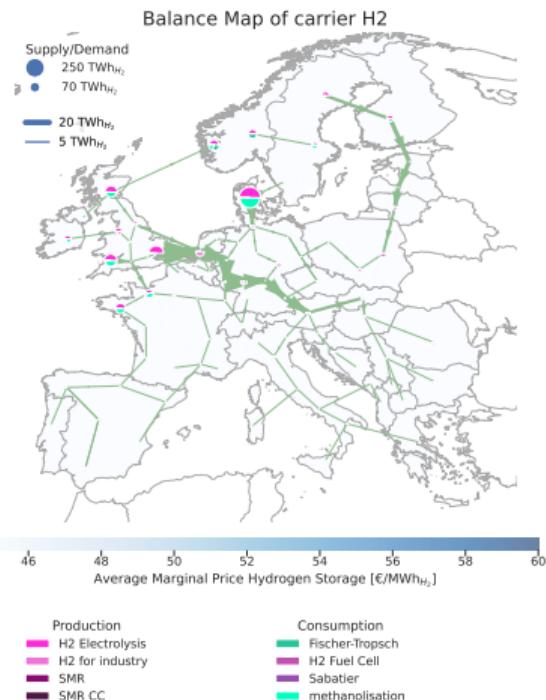
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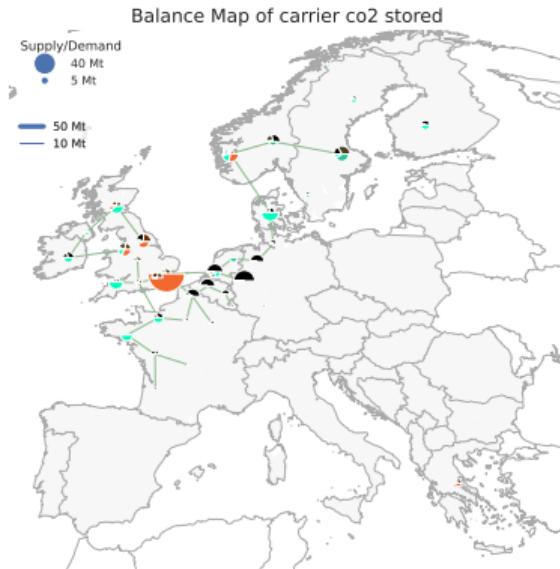
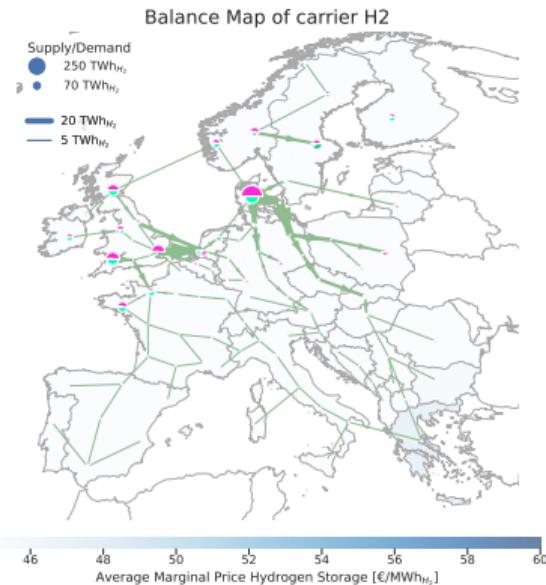
Appendix

Case study: Sensitivity – Base ext. (All targets)



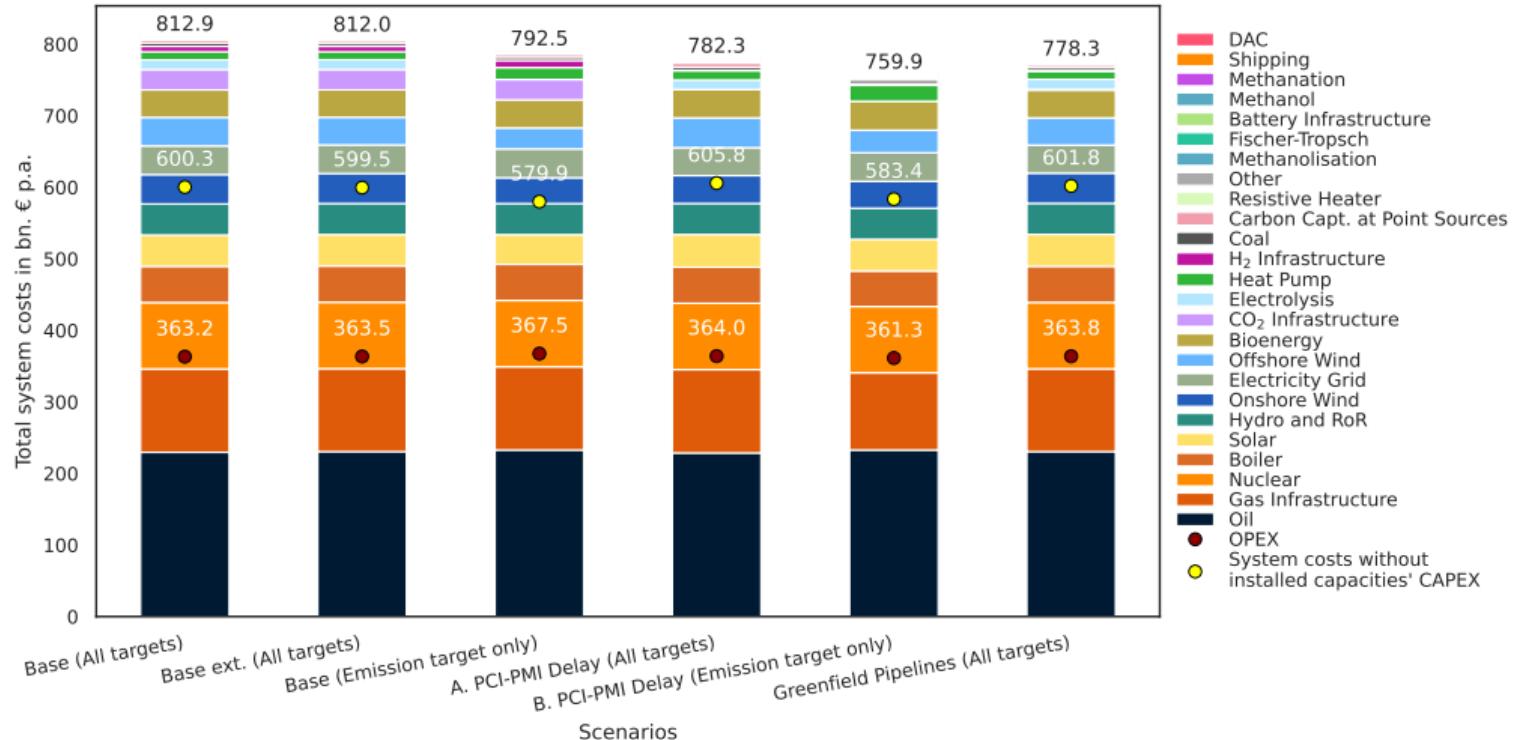
Source: Own illustration.

Case study: Sensitivity – Greenfield Pipelines (All targets)



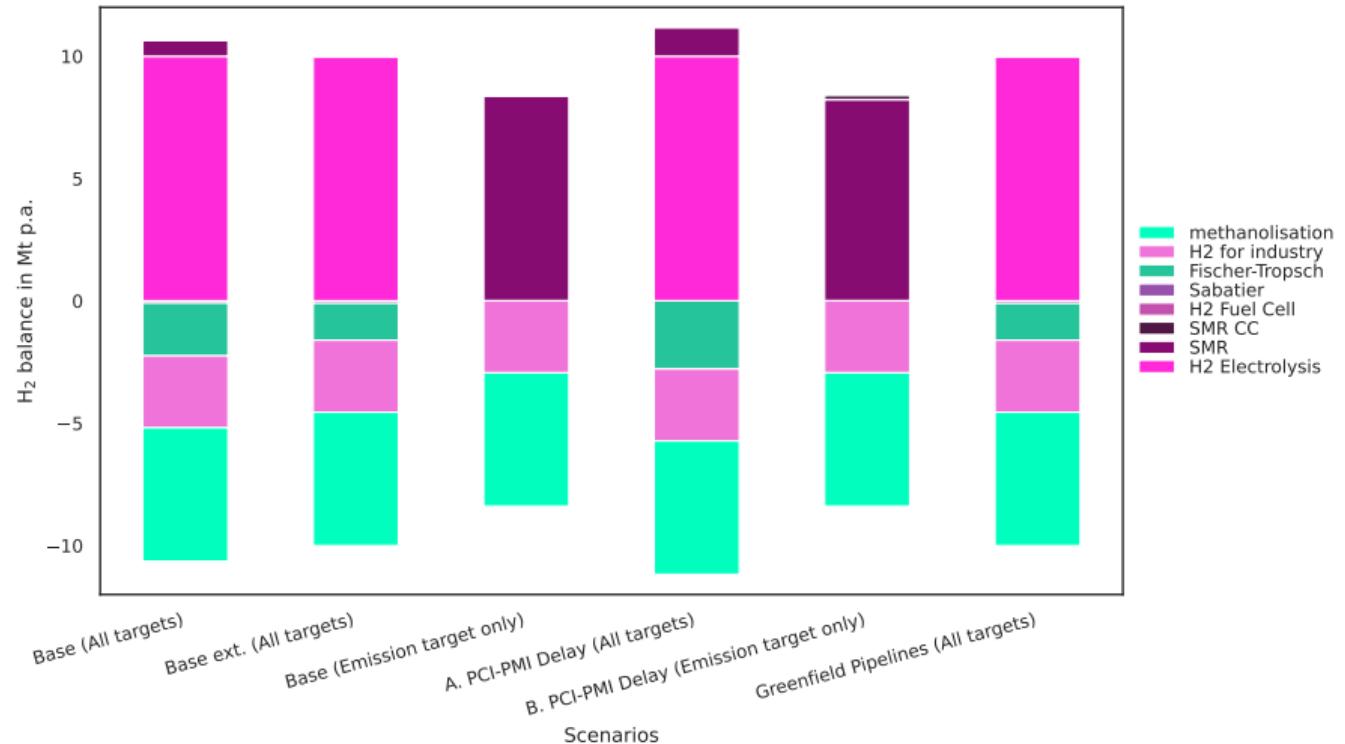
Source: Own illustration.

First results: Total system costs



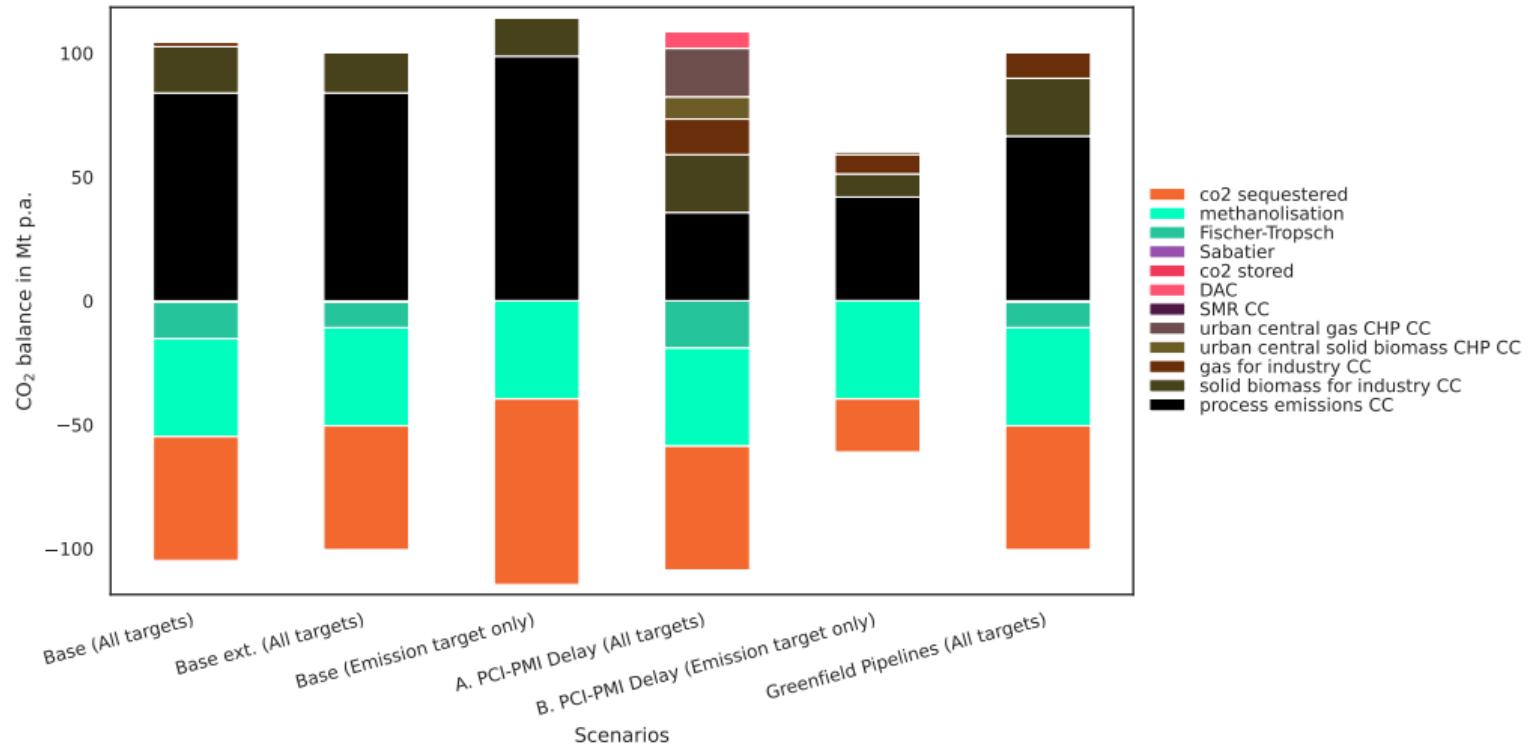
Source: Own illustration.

First results: Hydrogen balance



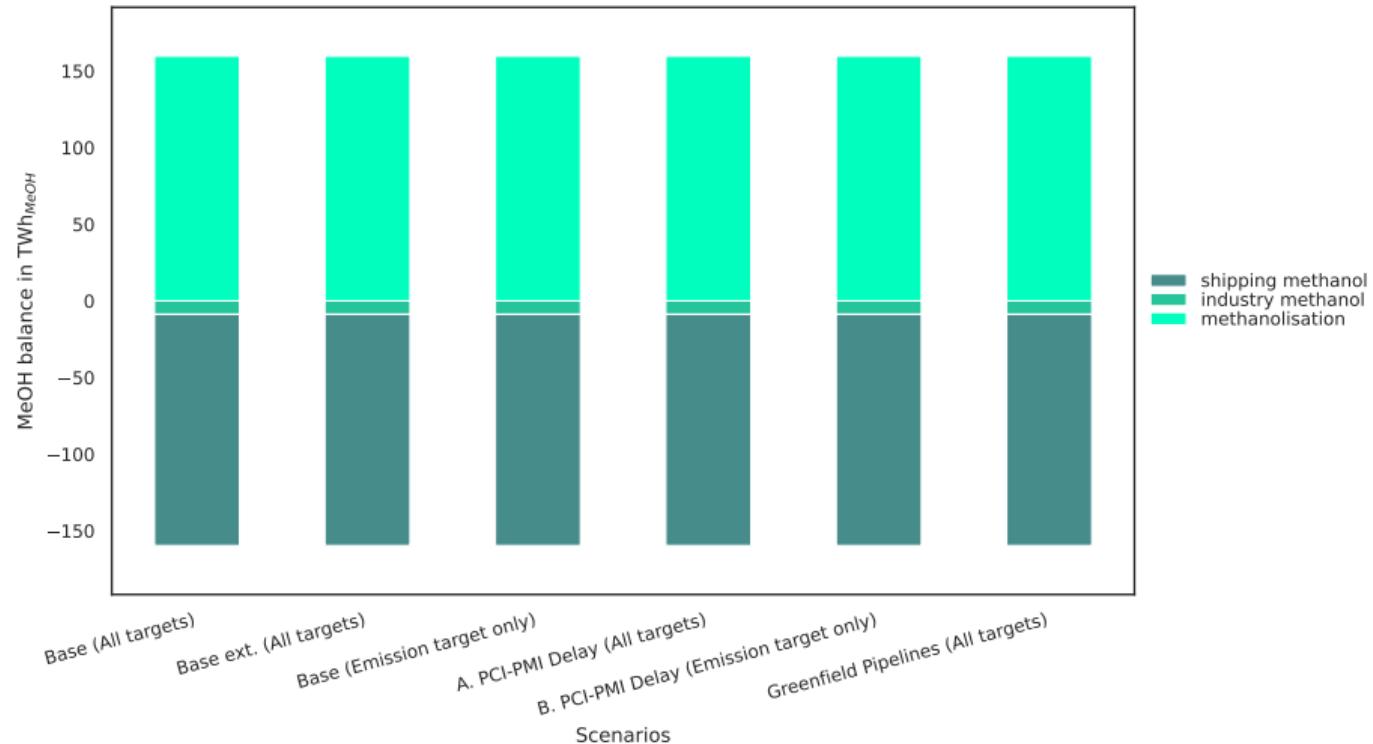
Source: Own illustration.

First results: Carbon balance



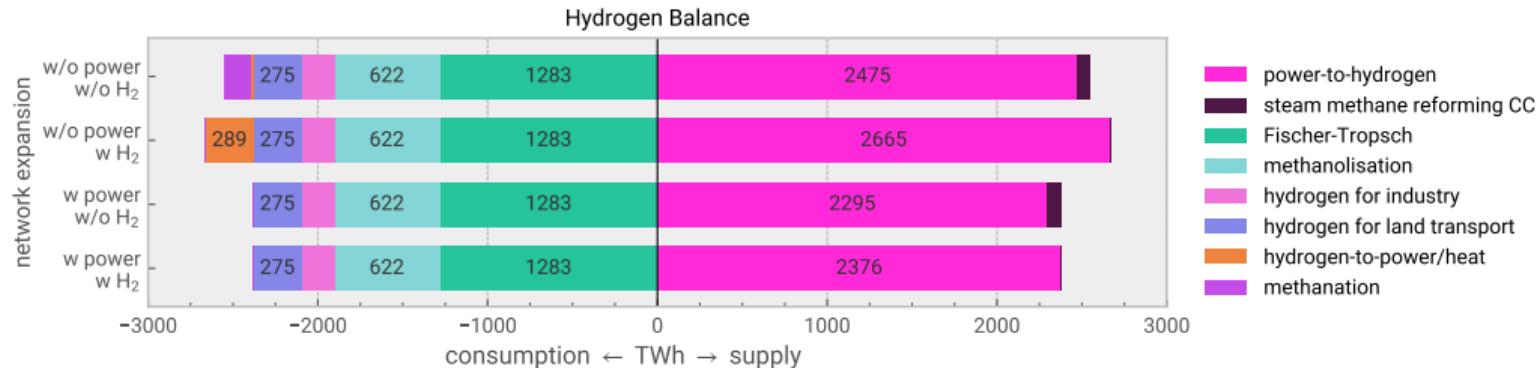
Source: Own illustration.

First results: Methanol balance



Source: Own illustration.

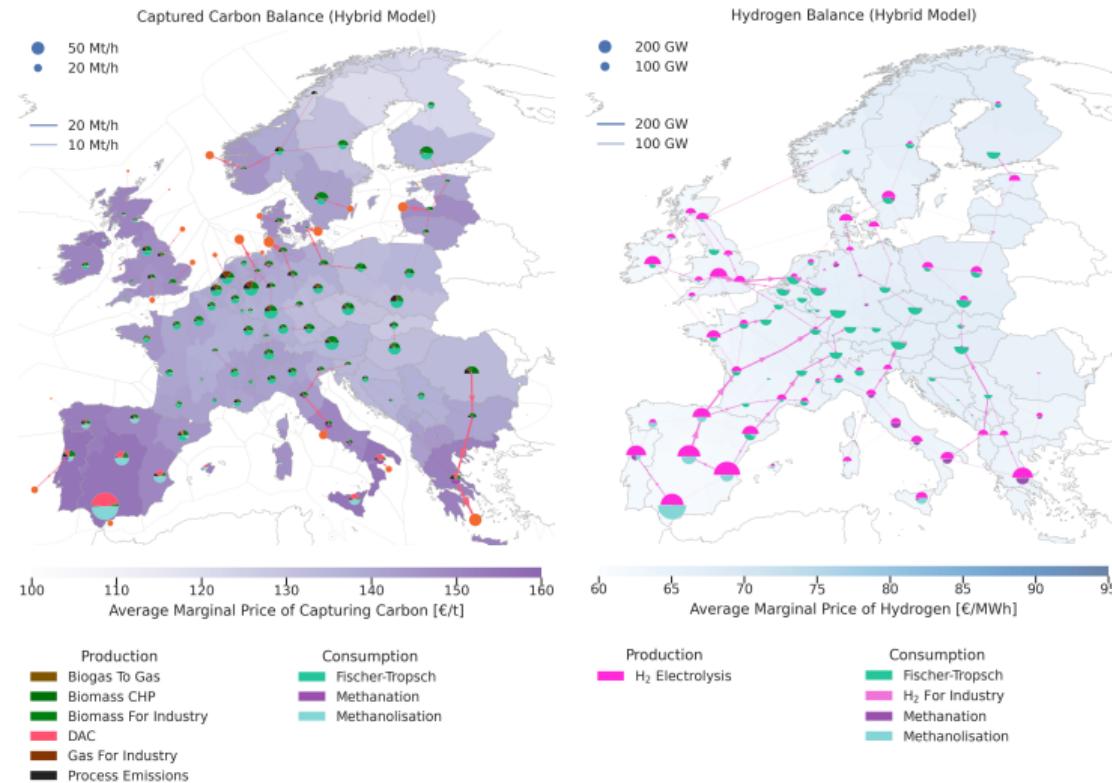
Why H₂? Most H₂ is used for derivative fuels and chemicals!



Mostly **green electrolytic hydrogen supply**. Few direct uses of hydrogen in the energy system, but it is used to synthesise other fuels and chemicals:

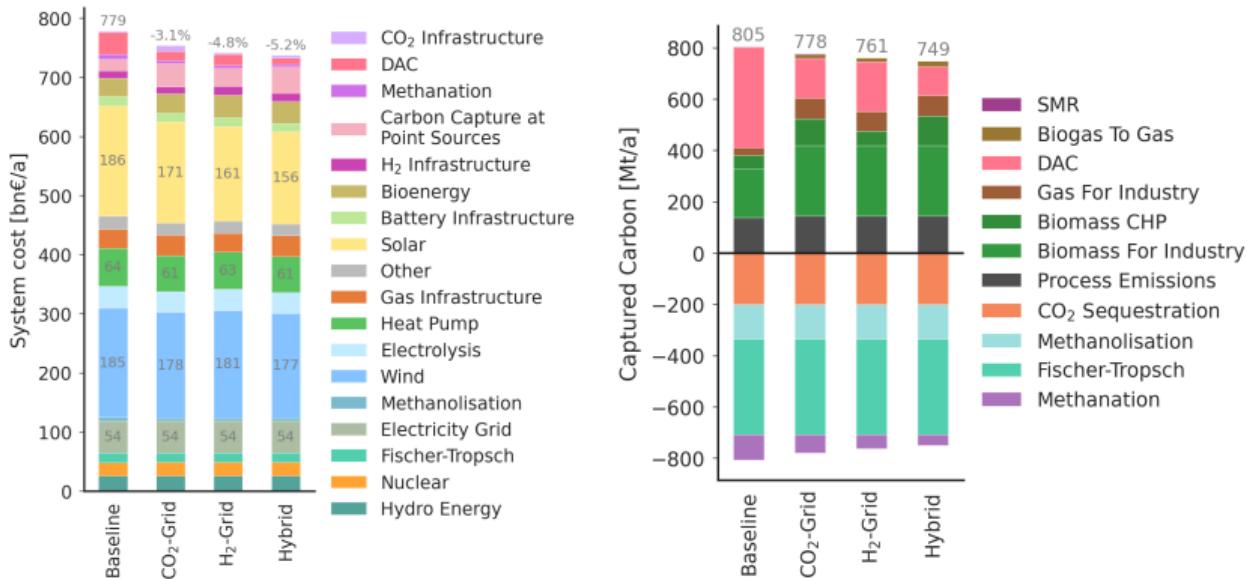
- ammonia for fertilizers
- direct reduced iron for steelmaking
- shipping and aviation fuels
- precursor to high-value chemicals
- backup heat and power supply
- some heavy duty land transport

Transporting CO₂ to H₂ or transporting H₂ to CO₂?



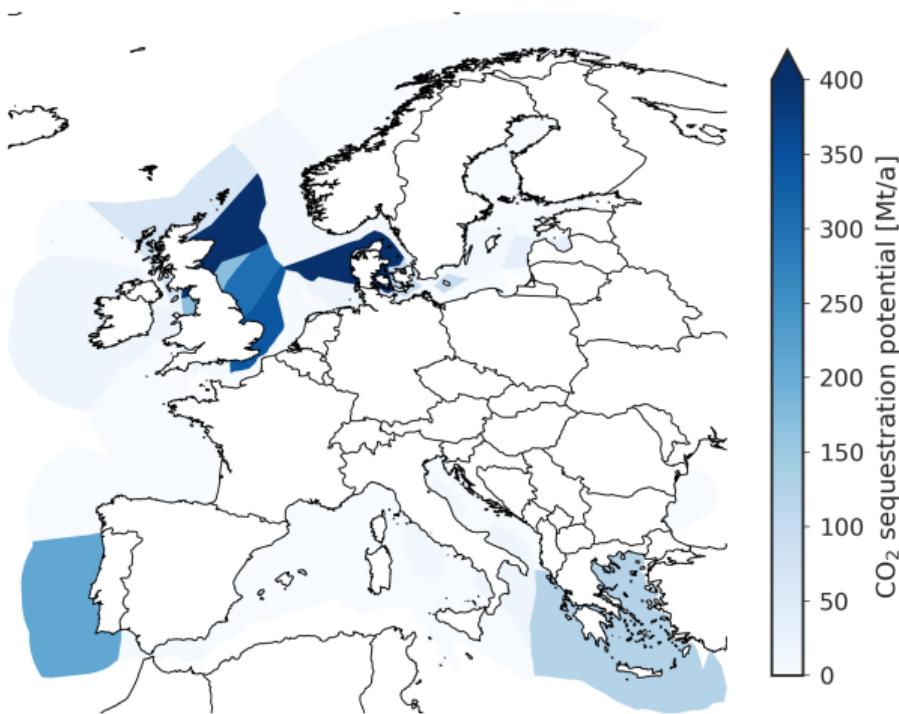
Source: Hofmann, Tries, Neumann, Zeyen, Brown, 2024
<https://arxiv.org/abs/2402.19042>

Carbon management: Capture, use, transport and sequestration



- CCS for process emissions (for instance, in cement industry)
- CCU for e-synfuels and e-chemicals (in particular, shipping, aviation, plastics)
- CDR for unabatable and negative emissions (to offset imperfect capture rates)

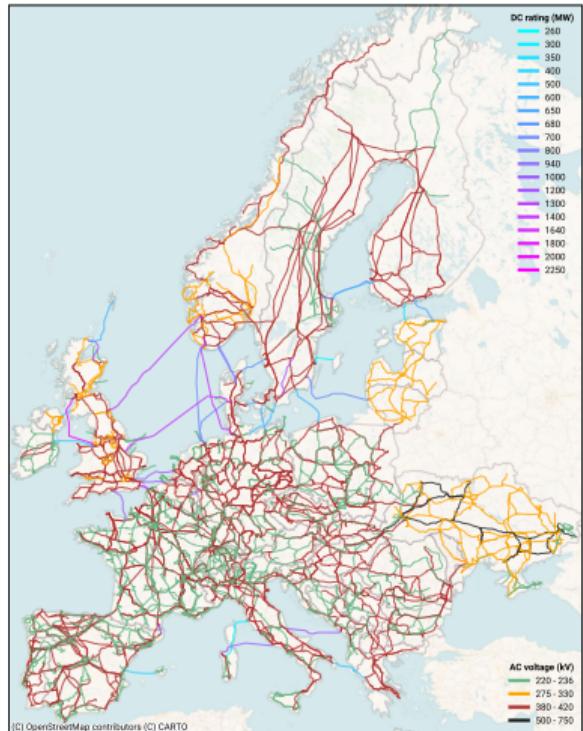
Maximum sequestration potential



Source: Hofmann, Tries, Neumann, Zeyen, Brown, 2024
<https://arxiv.org/abs/2402.19042>

Electricity high-voltage grid based on OpenStreetMap (OSM)

- Dataset contains a topologically connected representation of the European high-voltage grid (220 kV to 750 kV) constructed using OpenStreetMap data
- Heuristic cleaning process was used to for lines and links where electrical parameters are incomplete, missing, or ambiguous
- Close substations within a radius of 500 m are aggregated to single buses
- Unique transformers are added for each voltage pair in a substation
- AC lines mapped using pandapower's standard line type library. In default version, nominal capacity is set to 70 % of the technical capacity to account for n-1 security approximation
- Includes all 38 European HVDC connections with their nominal rating that are commissioned as of 2024



Source: Own illustration based on data extracted using Overpass Turbo API
<https://openstreetmap.org>