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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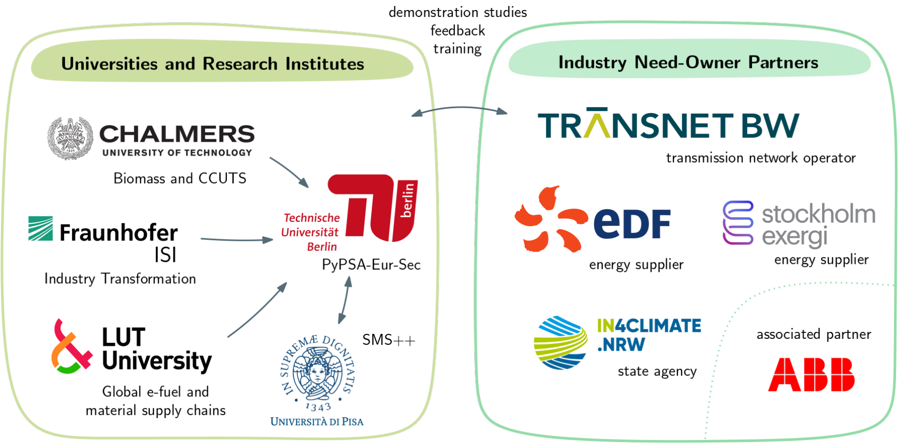
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

RESILIENT project partners

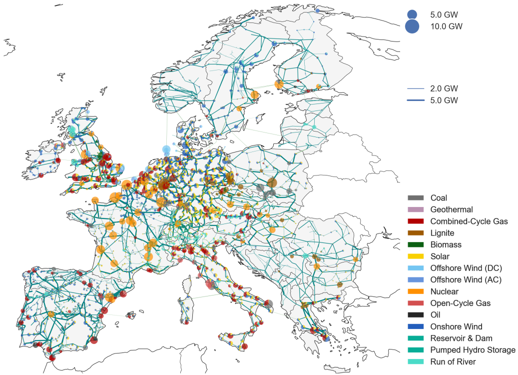


Funded via **CETPartnership 2022** Call — **BMWK** for all German partners.

Source: https://resilient-project.github.io/

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

- **CO_2 network**
- **CO_2 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 CO_2 infrastructure sector.

55 % emission reduction

- **Fit for 55**
- Translating to an emission allowance of ca. 2 bn. t CO_2 p.a. in 2030
- Covering the electricity, heat, industry, transport, buildings and agriculture sectors

10 Mt p.a. green H_2 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 H_2 in hard-to-electrify-sectors

50 Mt p.a. CO_2 sequestration

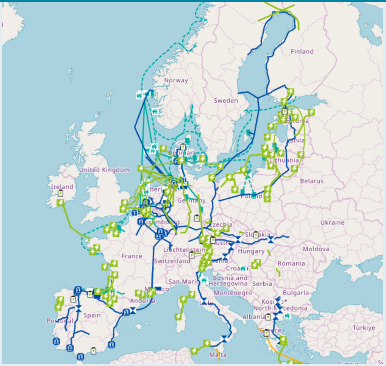
- **Net-Zero Industry Act**
- Essential component in helping industries to reduce their net emissions
- Provides means to capture unavoidable emissions from hard-to-abate sectors like cement, steel, chemicals, etc.

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 **CO_2 sequestration** and **H_2 production**?

Source: https://energy.ec.europa.eu/topics/infrastructure_en and https://ec.europa.eu/energy/infrastructure/transparency_platform/map-viewer

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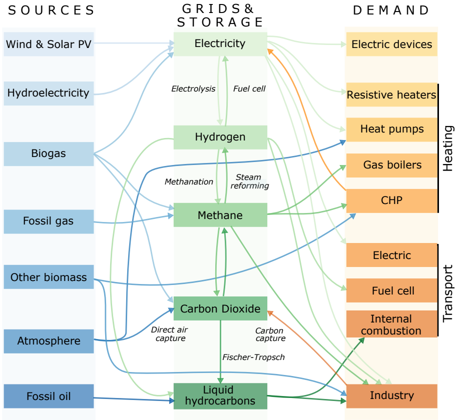
Case study: Model setup

- 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 CO_2 sequestration (**Net-Zero Industry Act**)



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

Case study: Scenario setup

Base (All targets)

- **Including PCI-PMI** HVAC, HVDC, H_2 and CO_2 infrastructure projects with a planned commissioning date by 2030
- Including exogenous CO_2 sequestration and H_2 storage sites
- Endogeneous expansion of CO_2 pipelines and national H_2 pipelines
- Endogeneous expansion of H_2 storage sites
- 55 % emission reduction target
- 10 Mt p.a. H_2 production target
- 50 Mt p.a. CO_2 sequestration target

Scenario A. PCI-PMI delay (All targets)

- **Delay of all PCI-PMI projects**, no H_2 and CO_2 pipelines will be ready by 2030
- **Endogeneous expansion of H_2 storage sites and CO_2 sequestration sites** – according to technical sequestration potential (Hofmann et al., 2024)
- 55 % emission reduction target
- 10 Mt p.a. H_2 production target
- 50 Mt p.a. CO_2 sequestration target

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

- **Delay of all PCI-PMI projects, no H_2 and CO_2 pipelines will be ready by 2030**
- **Dropping H_2 production and CO_2 sequestration targets**
- **Endogeneous expansion of H_2 storage sites and CO_2 sequestration sites** – according to technical sequestration potential (Hofmann et al., 2024)
- 55 % emission reduction target

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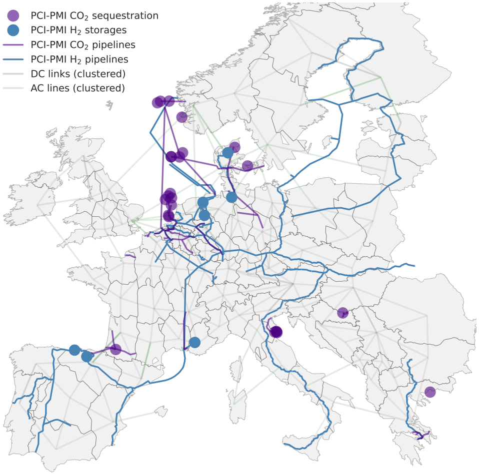
Case study: Base — Modelled PCI-PMI H_2 and CO_2 infrastructure

- **Base** scenario incorporates **PCI-PMI** projects for **H_2** and **CO_2** infrastructure, including pipelines, storages (H_2) and sequestration sites (CO_2), as well as new/upgraded **high-voltage AC** and **high-voltage DC** lines **commissioned by 2030**
- Total CO_2 sequestration capacity sums up to **75 Mt p.a.**, mostly located in the North Sea
- Total H_2 storage capacity sums up to **977 GWh_{H_2}**



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

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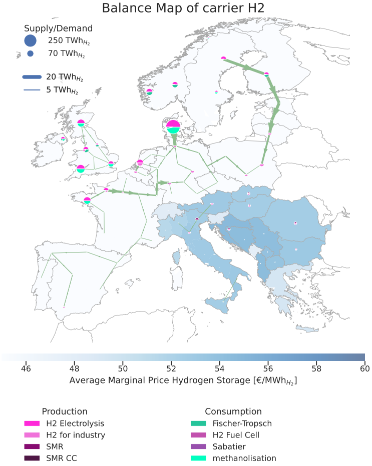
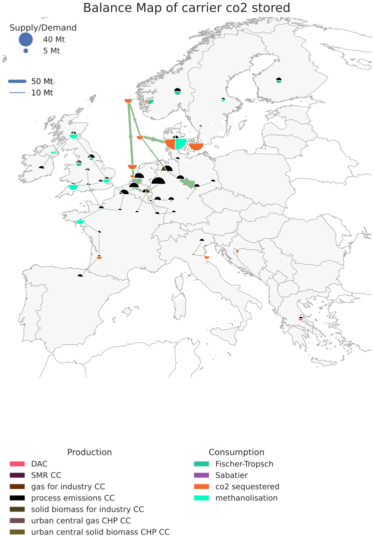
First results: Base (All targets)





Source: Own illustration.

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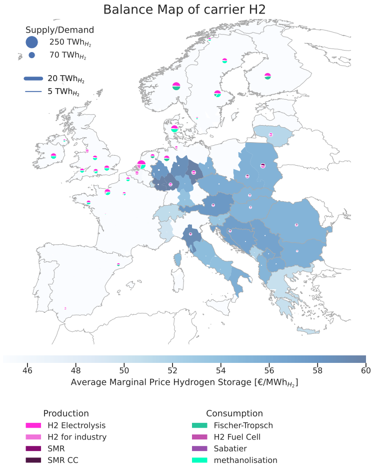
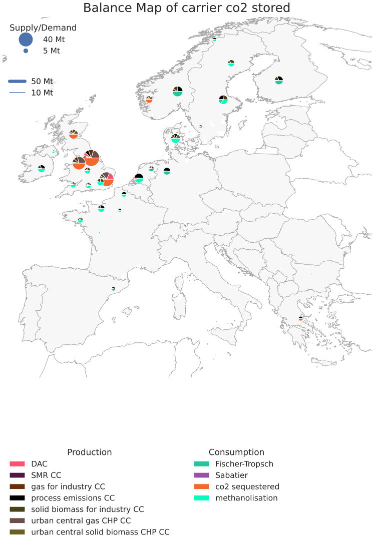
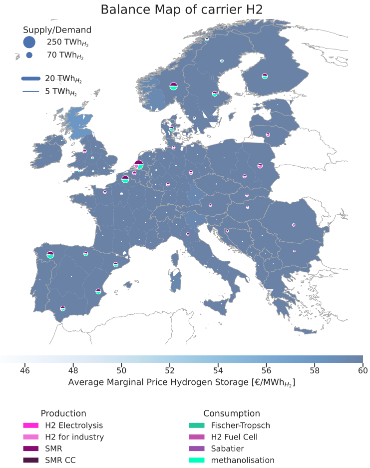
First results: Scenario A. PCI-PMI delay (All targets)

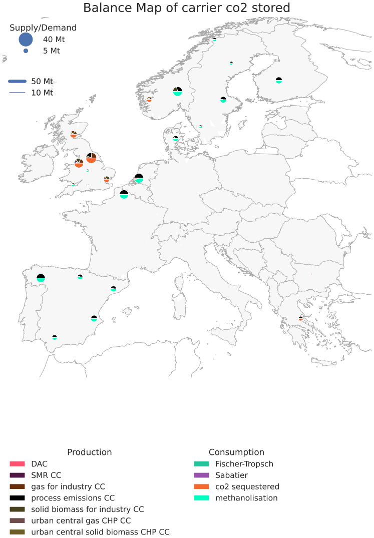




Source: Own illustration.

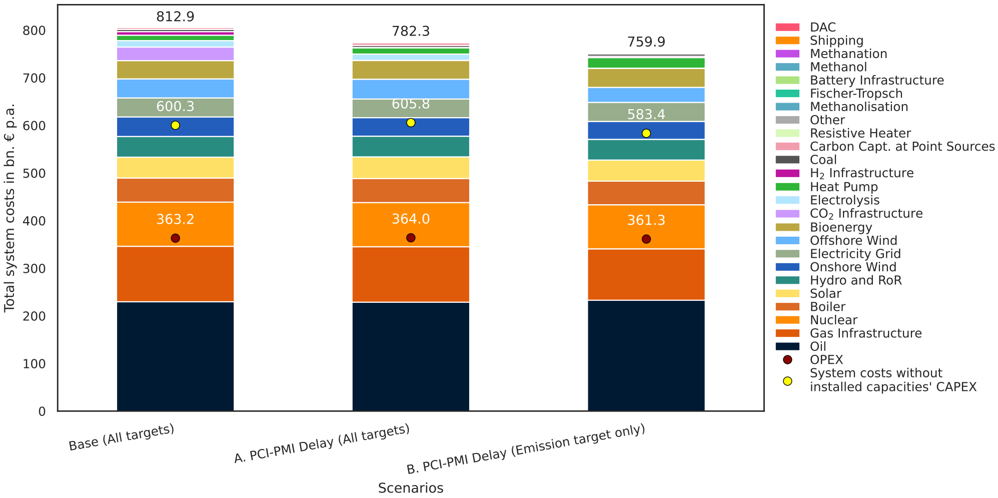
First results: Scenario B. PCI-PMI delay (Emission target only)





Source: Own illustration.

First results: Total system costs



Source: Own illustration.

Case study: First takeaways for modelling year 2030

1. Reaching the EU's 2030 H_2 production and CO_2 sequestration targets translates into around **20 bn. € p.a. in total system costs** for all included sectors, with or without PCI-PMI H_2 and CO_2 infrastructure projects.
2. By omitting a H_2 target, almost no electrolysers are installed. **Around 8 Mt of H_2** are still produced to cover industrial H_2 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 H_2 economy**. H_2 is then primarily created through electrolysis and used as a **precursor** for methanolisation and to meet industrial demand.
4. Without specifying a CO_2 sequestration target, the system still captures and sequesters **around 21 Mt of CO_2 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 H_2 pipelines help distribute more **affordable green H_2** from northern and south-western Europe to high-demand regions central Europe
   - PCI-PMI CO_2 pipelines connect **industrial sites** and their process emissions to **major offshore sequestration sites in the North Sea** (DK, NO, NL).

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Outlook

- Including **all relevant PCI-PMI projects**, i.e. hybrid offshore interconnectors (energy islands), electricity storages, CO_2 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

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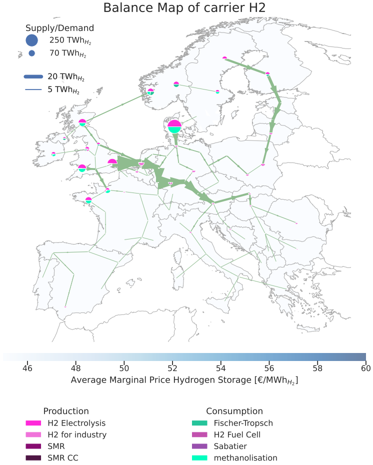
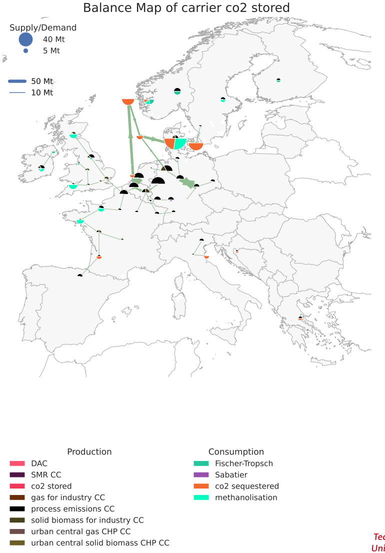
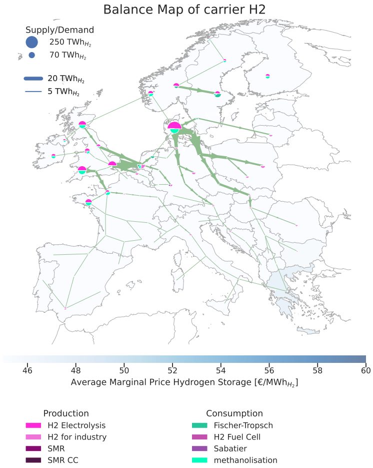
Case study: Sensitivity – Base ext. (All targets)

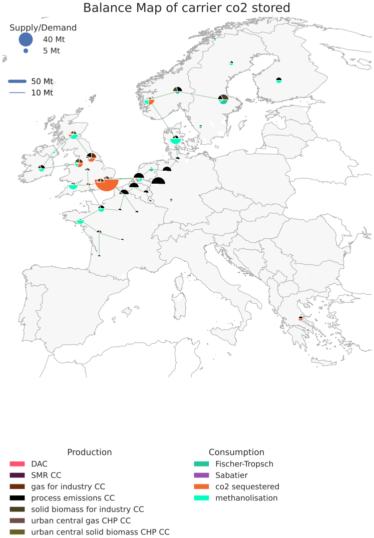




Source: Own illustration.

Case study: Sensitivity – Greenfield Pipelines (All targets)





Source: Own illustration.

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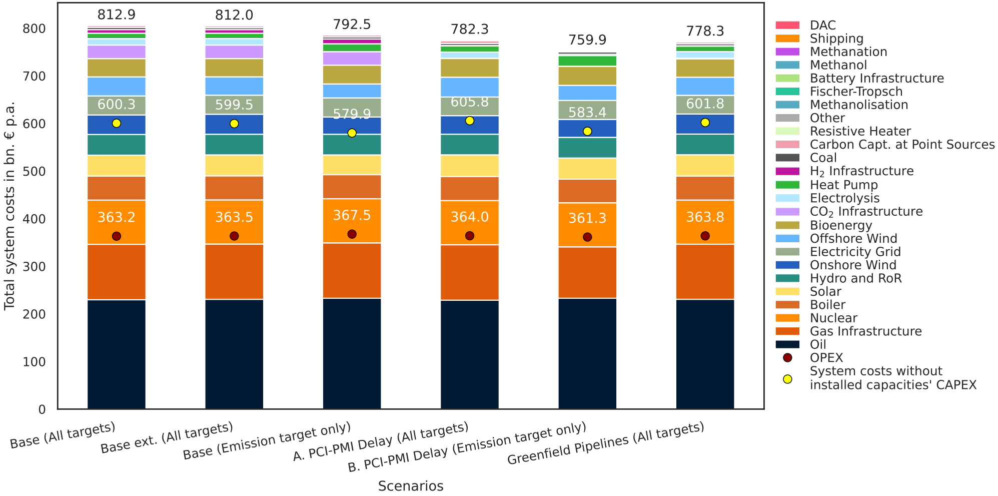
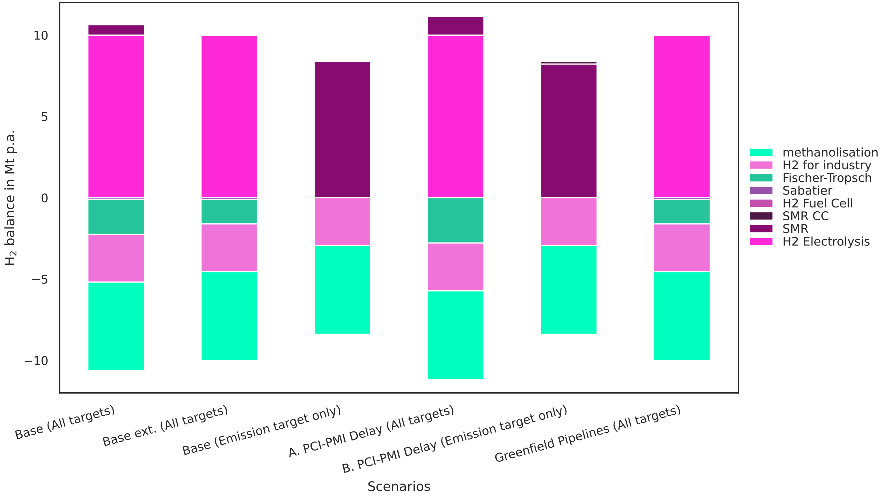
First results: Total system costs



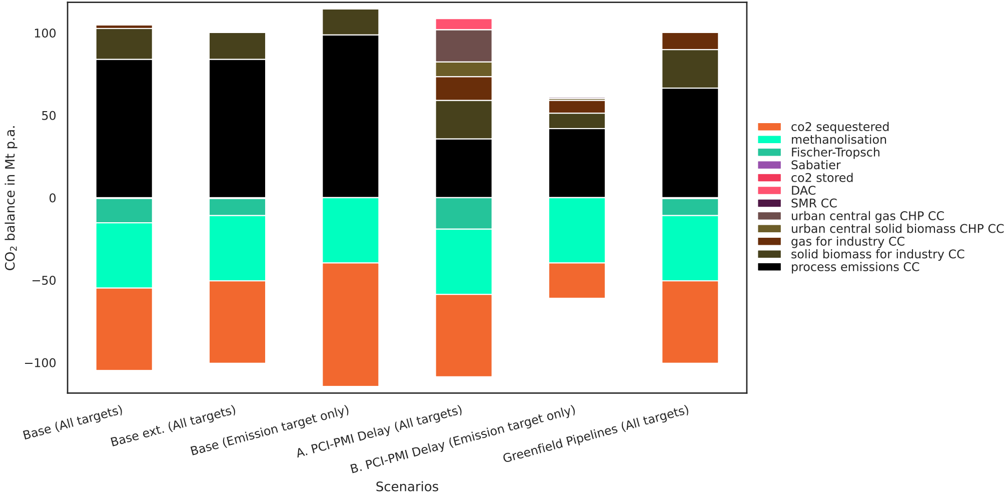
Source: Own illustration.

First results: Hydrogen balance



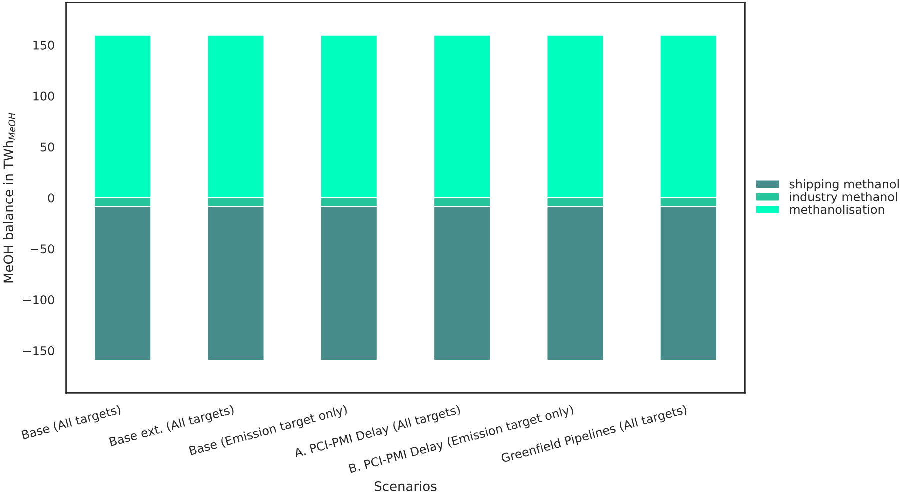
Source: Own illustration.

First results: Carbon balance



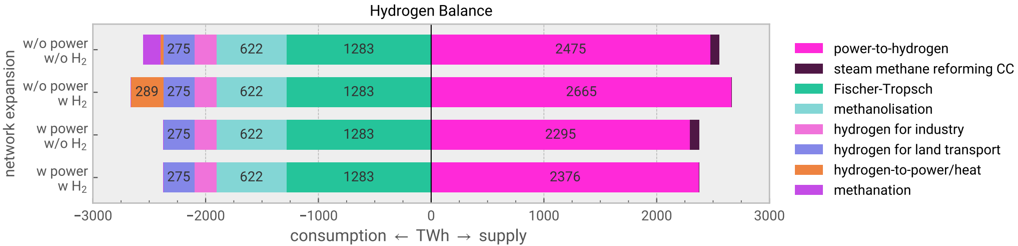
Source: Own illustration.

First results: Methanol balance



Source: Own illustration.

Why H_2? Most H_2 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

Source: Neumann, Zeyen, Victoria, Brown, 2023
https://doi.org/10.1016/j.joule.2023.06.016

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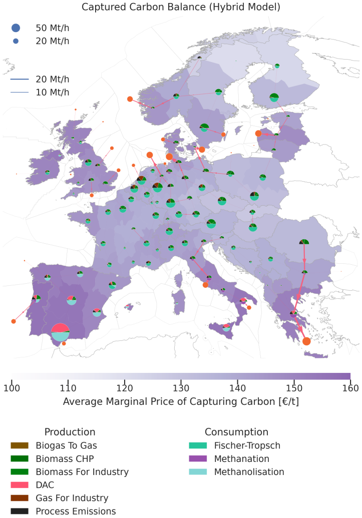
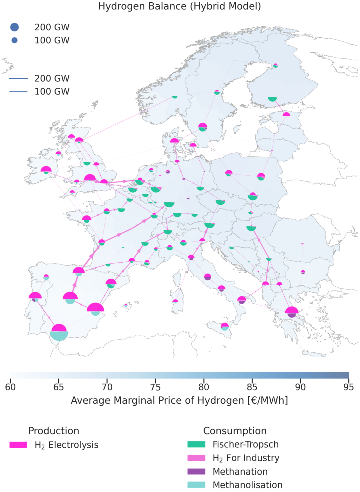
Transporting CO_2 to H_2 or transporting H_2 to CO_2?





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

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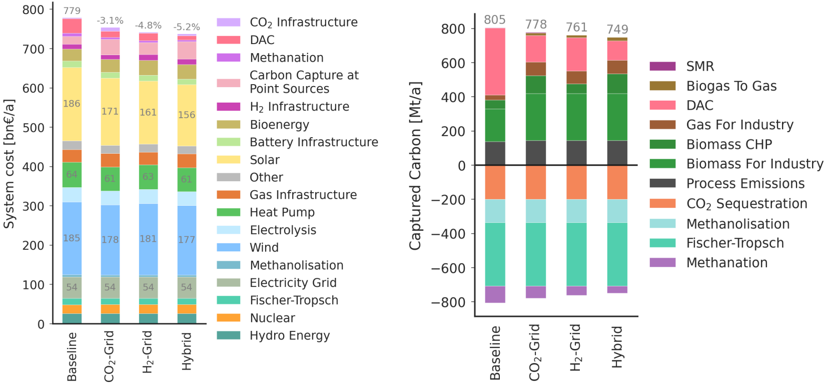
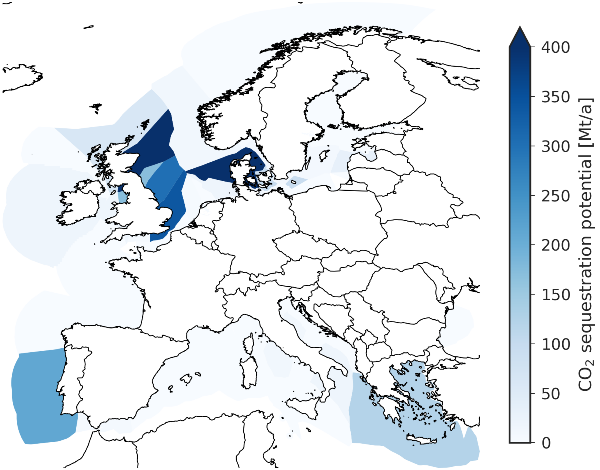
Carbon management: Capture, use, transport and sequestration



- **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)

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

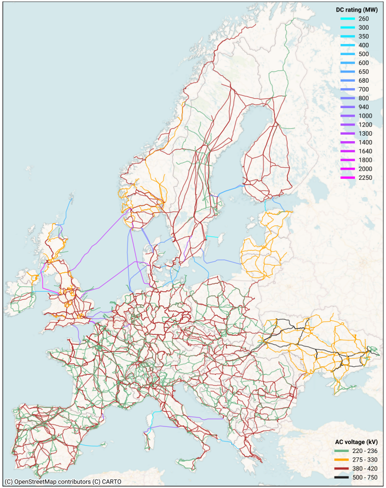
Maximum sequestration potential



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 from https://ec.europa.eu/energy/infrastructure/transparency_platform/map-viewer