IEW 2025 — Nara, Japan

The Role of Projects of Common Interest in Reaching Europe’s Energy Policy Targets

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Motivation: 2030 policy targets

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.

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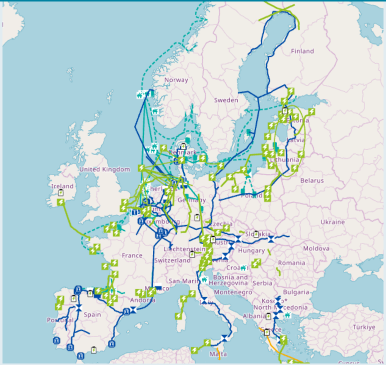
Motivation: PCI-PMI projects

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 What is the long-term value of PCI-PMI projects in supporting the EU’s climate and energy policy targets, and what are the associated costs?

2 What are the costs of adhering to the EU policy targets, even when the implementation of PCI-PMI projects is delayed?

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

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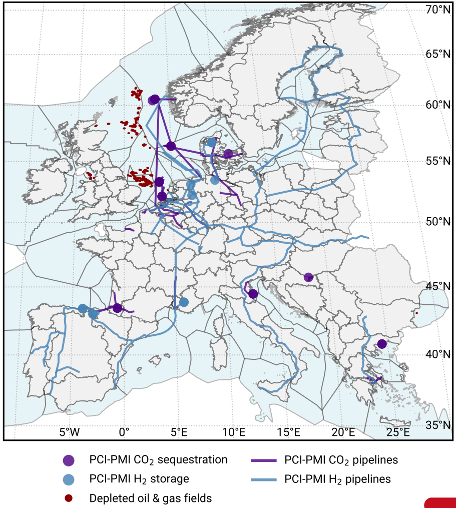
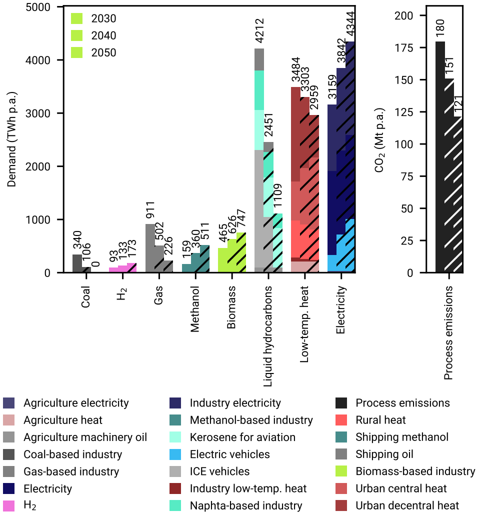
Model setup

- Including sectors **power, heat, transport, industry, feedstock** and **agriculture**
- **Myopic optimisation** for 2030, 2040 and 2050
- **Co-optimising** generation, transmission, storage, and power-to-X conversion
- Resolving 34 countries to **99 regions** (NUTS mix) at **4-hourly** temporal resolution on avg. (using tsam).
- Implementing **PCI-PMI** HVAC, HVDC, hydrogen and carbon infrastructure projects as well as key GHG, H_2 production, electrolyser capacity, and CO_2 sequestration targets (next slide). Additional sequestration potential from **depleted oil and gas fields** [6]
- **Regret analysis** approach based on 5 long-term scenario, 3 short-term scenarios, in total 60 model runs



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

Exogenous demand



- Demand for electricity, heat, gas, biomass, and transport is regionally and temporally resolved
- ICE vehicles in land transport expected to fully phase out in favour of EV by 2050
- Demand for methanol and hydrocarbons, including kerosene primarily driven by shipping, aviation, and industry sector (not spatially resolved)
- Unabatable process emissions from industry sector, e.g. cement, also considered
- CO_2 sequestration cost assumed at €15/tCO_2 (mid-range estimate)

Source: Own illustration.

Long-term scenarios: Implemented targets

Planning horizon	2030	2040	2050
Targets			
GHG emission reduction	−55 %	−90 %	−100 %
CO_2 sequestration	50 Mt p.a.	150 Mt p.a.	250 Mt p.a.
Electrolytic H_2 production	10 Mt p.a.	27.5 Mt p.a.	45 Mt p.a.
H_2 electrolyser capacity	40 GW	110 GW	180 GW

Model targets based on [1–5]

Source: Own illustration.

Long-term scenarios: Definition

Long-term scenarios	DI	PCI	PCI-n	PCI-in	CP
CO_2 sequestration					
Depleted oil & gas fields*	■	■	■	■	■
PCI-PMI seq. sites**	–	■	■	■	■
H_2 storage					
Endogenous build-out	■	■	■	■	■
PCI-PMI storage sites	–	■	■	■	■
CO_2 pipelines					
to depleted oil & gas fields	■	■	■	■	■
to PCI-PMI seq. sites	–	■	■	■	■
CO_2 and H_2 pipelines					
PCI-PMI	–	■	■	■	■
National build-out	–	■	■	■	■
International build-out	–	–	–	■	■
PCI-PMI extendable	–	–	–	–	■

■ enabled – disabled * approx. 286 Mt p.a. ** approx. 114 Mt p.a.

Source: Own illustration.

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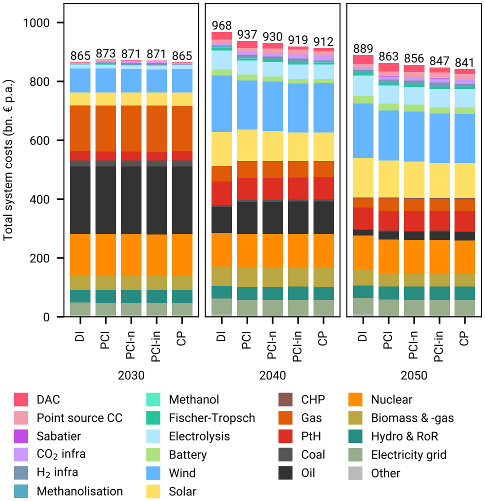
Regret matrix setup

Short-term	Reduced targets	Delayed pipelines	No pipelines
Long-term scenarios			
Decentral Islands (**DI**)	■	–	–
PCI-PMI (**PCI**)	■	■	■
PCI-PMI nat. (**PCI-n**)	■	■	■
PCI-PMI internat. (**PCI-in**)	■	■	■
Central Planning (**CP**)	■	■	■
Targets			
GHG emission reduction	■	■	■
CO_2 sequestration	–	■	■
Electrolytic H_2 production	–	■	■
H_2 electrolysers	–	■	■
CO_2 + H_2 infrastructure			
CO_2 sequestration sites	■	■	■
CO_2 pipelines to seq. site	■	■	■
CO_2 pipelines	■	□	–
H_2 pipelines	■	□	–

■ enabled □ delayed by one period – disabled

Source: Own illustration.

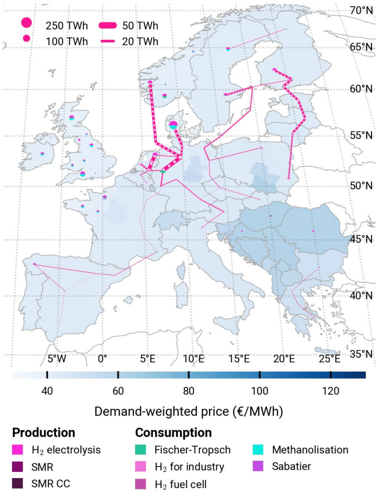
LT — Total system costs

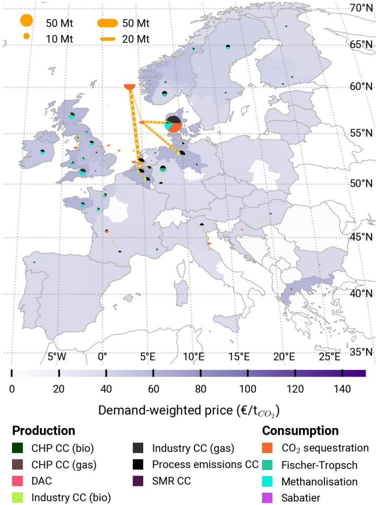


- Highest total annual system costs in 2040: €912-€968 billion per year, driven by sharp decarbonisation pathway
- Adding PCI-PMI projects in 2030 increases costs only marginally
- Strong system cost savings from pipeline investments starting in 2040, around €30-€50 billion per year
- Complete freedom in pipeline expansion unlocks another €7 billion per year in cost savings
- Cost savings stem primarily from reducing reliance into costly DAC technologies and excessive investments into solar and wind

Source: Own illustration.

LT — PCI: 2030 regional H_2, CO_2 balances, transport, and prices





Source: Own illustration.

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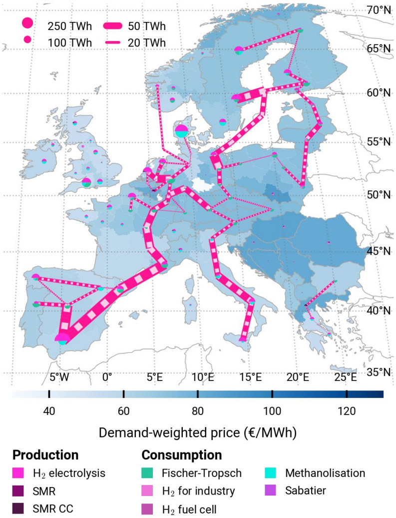
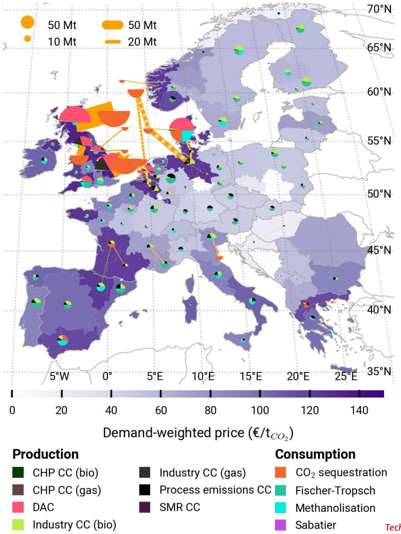
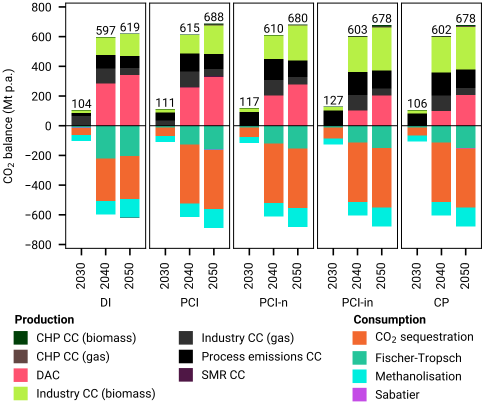
LT — PCI: 2050 regional H_2, CO_2 balances and transport





Source: Own illustration.

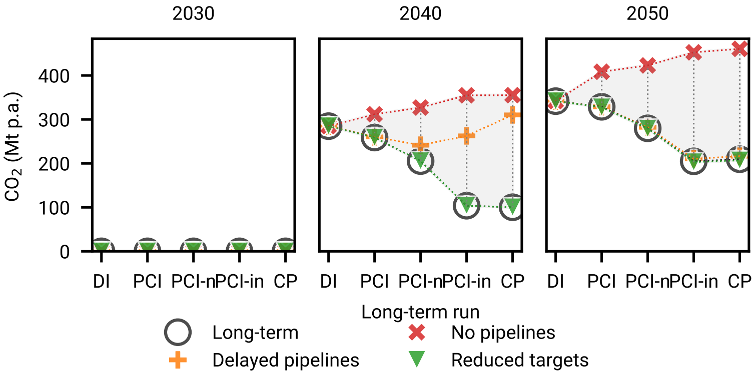
LT — CO_2 balances



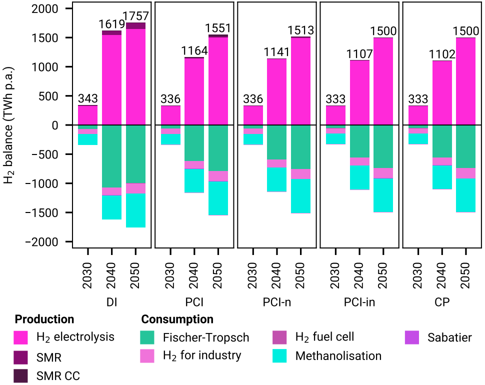
- With increasing pipeline build-out to transport CO_2 from industry and other point sources to sequestration sites, DAA utilisation decreases by almost half (left to right)
- In 2030, 50 Mt p.a. sequestration target is binding, if no pipelines are built. With pipeline build-out, up to 75 Mt p.a. are sequestered
- In 2040 and 2050, all sequestration targets are overachieved, potential of 398 Mt p.a. is fully exploited in all scenarios with PCI-PMI projects.
- Biomass-based industry contributing the largest share of point-source carbon capture
- With lower sequestration potential of 386 Mt p.a. in *DI* scenario, more CO_2 goes into carbon utilisation (Fischer-Tropsch synthesis) instead

Source: Own illustration.

LT — CO_2 balances: Direct Air Capture utilisation



LT — H_2 balances

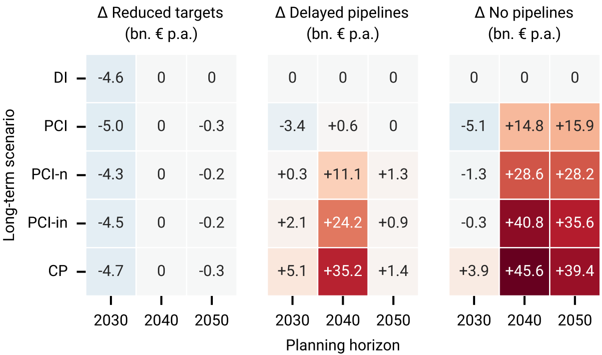


- H_2 production primarily driven by demand for Fischer-Tropsch fuels and methanol
- In 2050, Fischer-Tropsch fuels primarily used to satisfy kerosene in aviation and industrial naphta
- When no pipelines are built, H_2 production is significantly higher, given the need for additional Fischer-Tropsch synthesis to bind CO_2 as an alternative to sequestration
- H_2 71 to 102 TWh p.a. from Steam Methane Reforming without pipelines.

Source: Own illustration.

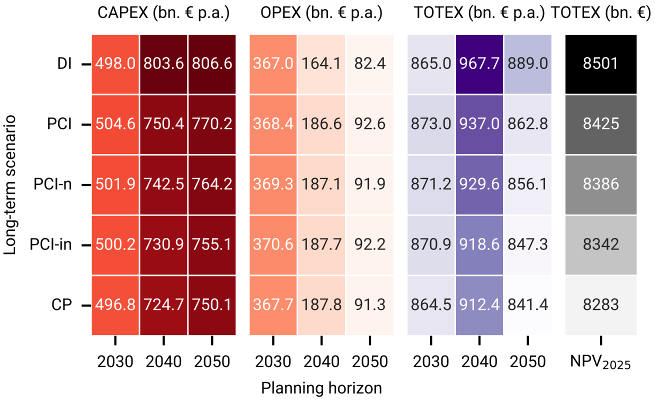
Regret analysis

- Regret is calculated by subtracting annual total system costs of long-term from short-term scenarios
- Regret terms represent additional cost incurred by given short-term incident relative to benchmark scenario
- Positive values indicate higher costs, driven by increased investments into alternative generation, conversion, storage, and CDR technologies, as well as changes in their operation
- Negative values indicate cost savings, which may arise under relaxed policy ambitions



Source: Own illustration.

Value of PCI-PMI projects in the long run



Conclusion

Economic viability & policy targets

- PCI-PMI pipelines bring net system cost reductions, visible in the long-run
- Strategic extensions amplify benefits
- Support EU GHG reduction, H_2, and CO_2 sequestration targets
- Low-regret investment, even when accounting for delays

CCUS & hydrogen utilisation

- Dual purpose: H_2 pipelines link high RES regions to demand centers while CO_2 pipelines connect industry to sequestration sites
- Enable decarbonisation of hard-to-abate sectors and industrial processing including non-abatle process emissions

Tech & risk diversification

- Pipelines boost more efficient use from RES
- Reduce reliance on point source CC and costly, low-TRL CDR technologies, such as DAC

Political support & acceptance

- EU backing ensures funding & fast permitting
- Frequent reporting & transparency builds public trust and acceptance
- Advantage over purely cost-optimal, theoretical plans

References (excerpt)

[1] European Commission. *'Fit for 55': Delivering the EU's 2030 Climate Target on the Way to Climate Neutrality. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2021) 550 Final, Brussels.* 2021. (Visited on 01/26/2025).

[2] European Commission. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Towards an Ambitious Industrial Carbon Management for the EU.* 2024. (Visited on 05/05/2025).

[3] European Commission. *REPowerEU Plan. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2022) 230 Final, Brussels.* 2022. (Visited on 01/26/2025).

[4] European Commission. Directorate General for Energy. and Fraunhofer Institute for Systems and Innovation Research. "METIS 3, Study S5: The Impact of Industry Transition on a CO2 Neutral European Energy System.". In: (2023). DOI: 10.2833/094502. (Visited on 05/05/2025).

[5] European Parliament and Council of the European Union. *Regulation (EU) 2024/1735 of the European Parliament and of the Council of 13 June 2024 on Establishing a Framework of Measures for Strengthening Europe's Net-Zero Technology Manufacturing Ecosystem and Amending Regulation (EU) 2018/1724 (Text with EEA Relevance).* June 2024. (Visited on 01/26/2025).

[6] Fabian Hofmann et al. "H2 and CO2 Network Strategies for the European Energy System". In: *Nature Energy* (Apr. 2025), pp. 1–10. ISSN: 2058-7546. DOI: 10.1038/s41560-025-01752-6. (Visited on 04/16/2025).

Thank you.

↪ github.com/pypsa/pypsa-eur

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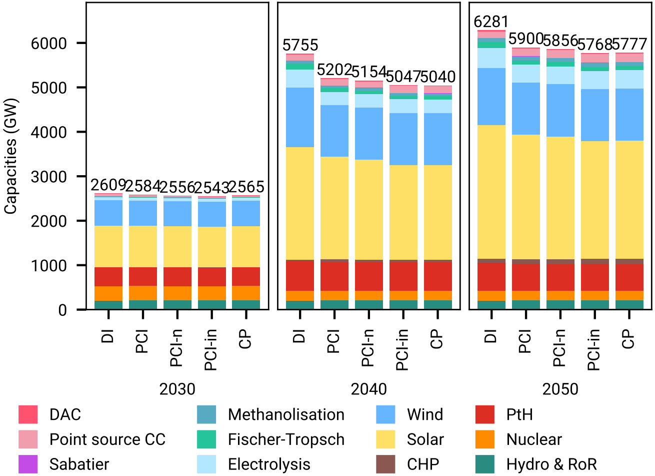
Appendix

Cost assumptions for key technologies

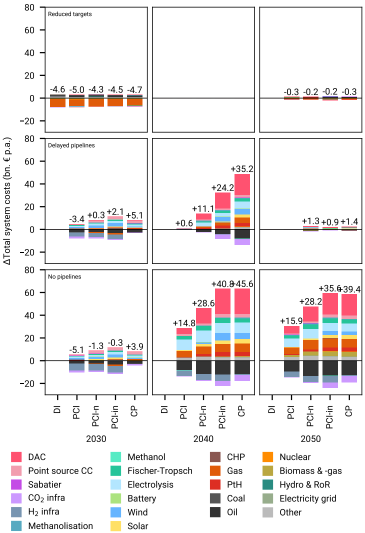
	Unit	CAPEX	FOM
Pipeline infrastructure			
CO_2 onshore pipelines	€/tCO_2/hkm	2116	0.9 %/a
CO_2 offshore pipelines	€/tCO_2/hkm	4233	0.5 %/a
H_2 onshore pipelines	€/MW_{H_2}/km	304	1.5-3.2 %/a
H_2 offshore pipelines	€/MW_{H_2}/km	456	3.0 %/a
Conversion			
Electrolysis	€/kW_e	1000-1500	4.0 %/a
SMR	€/MW_{CH_4}	522 201	5.0 %/a
SMR CC	€/MW_{CH_4}	605 753	5.0 %/a

Source: Own illustration.

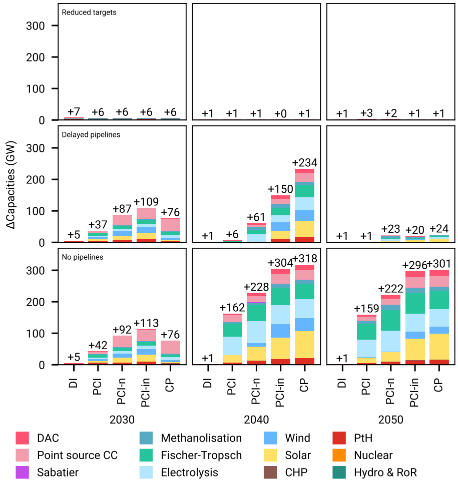
LT — Installed capacities



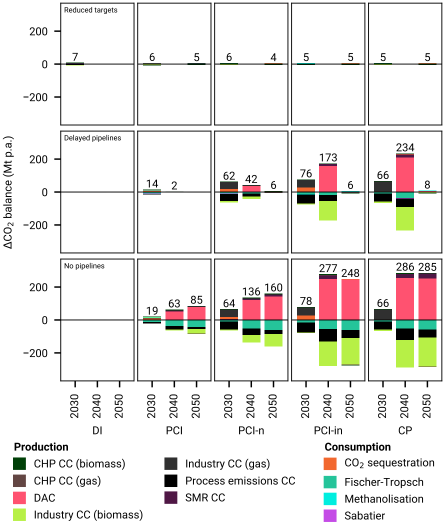
ST — Delta system costs



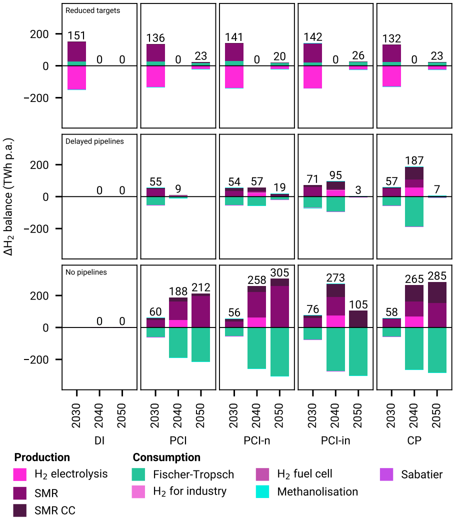
ST – Delta capacities



ST — Delta balances CO_2



ST — Delta balances H_2



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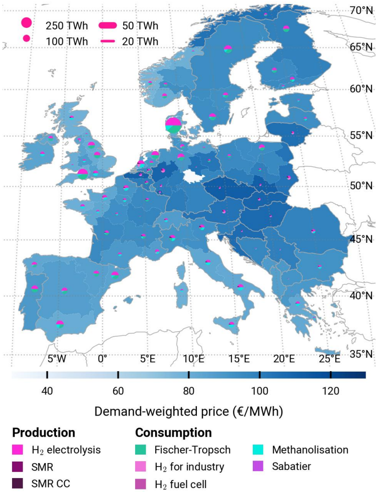
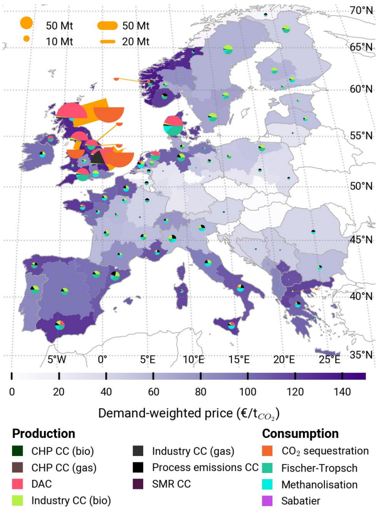
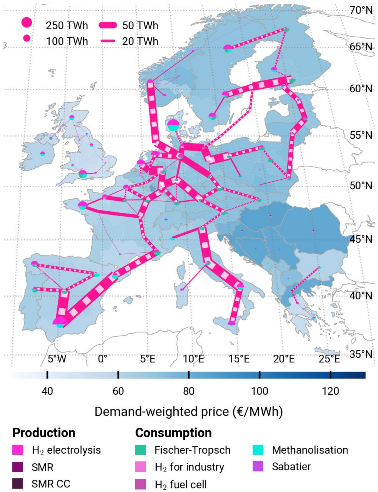
DI — PCI: 2050 regional H_2, CO_2 balances, transport, and prices

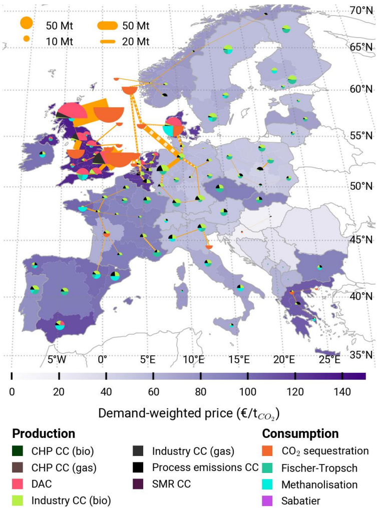




Source: Own illustration.

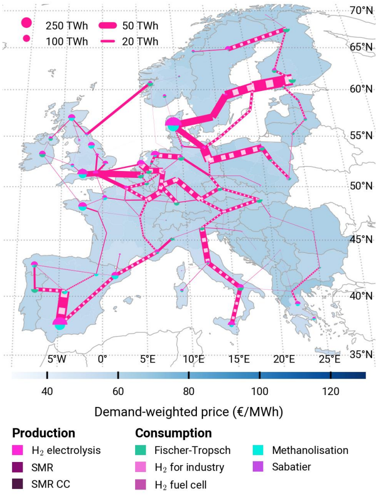
PCI-n — PCI: 2050 regional H_2, CO_2 balances, transport, and prices

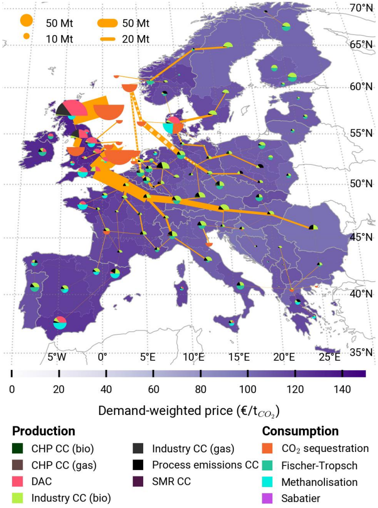




Source: Own illustration.

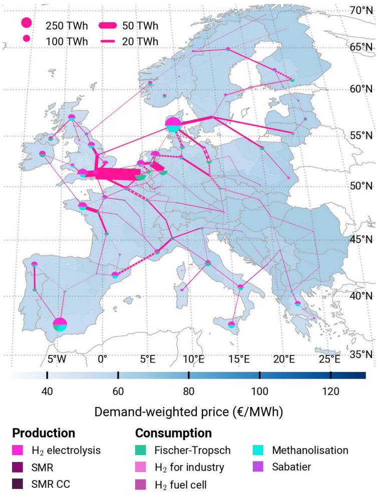
PCI-in — PCI: 2050 regional H_2, CO_2 balances, transport, and prices

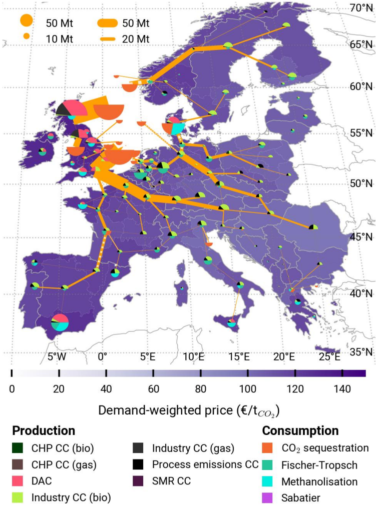




Source: Own illustration.

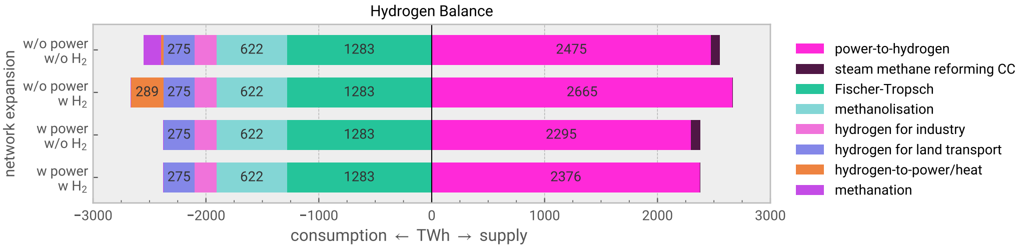
CP — PCI: 2050 regional H_2, CO_2 balances, transport, and prices





Source: Own illustration.

Why H_2? Most H_2 is used for derivative fuels and chemicals!

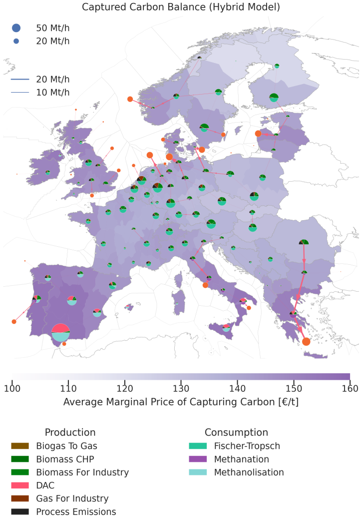


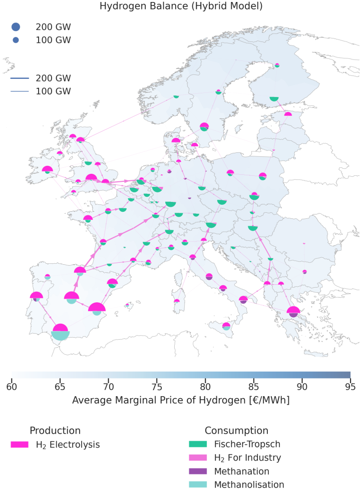
Mostly **green electrolytic hydrogen supply**. **Few direct uses of hydrogen** in the energy system, but it is used to synthesise other fuels and chemicals:

- 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

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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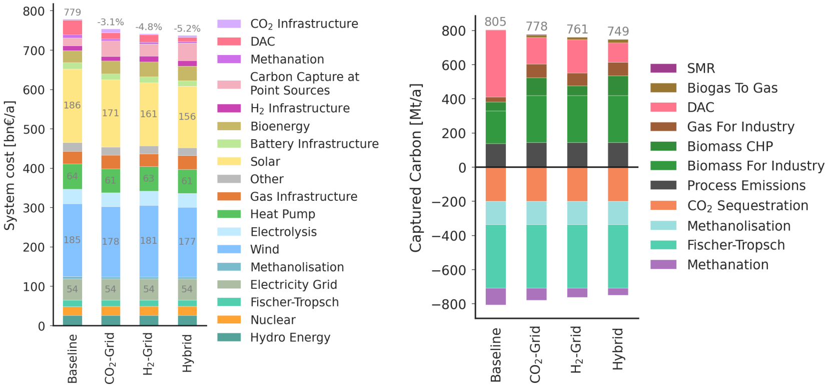
Carbon management: Capture, use, transport and sequestration

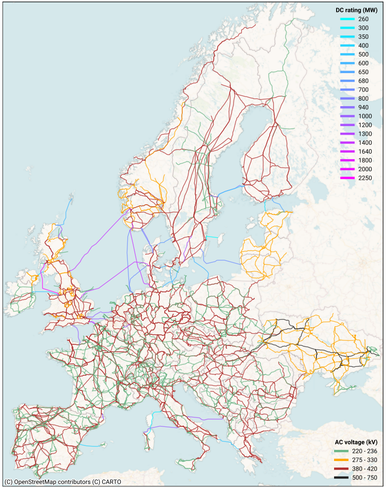


- **CCS** for process emissions (for instance, in cement industry)
- **CCU** for e-synfuels and e-chemicals (in particular, shipping, aviation, plastics)
- **CDR** for unabatable and negative emissions (to offset imperfect capture rates)

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

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

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