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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 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.

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.

- 1 Do PCI-PMI projects contribute to achieving the EU's energy policy targets and a net-zero transition in the long run?
- 2 What are the costs associated with adhering to the EU policy targets, even if PCI-PMI projects are delayed?

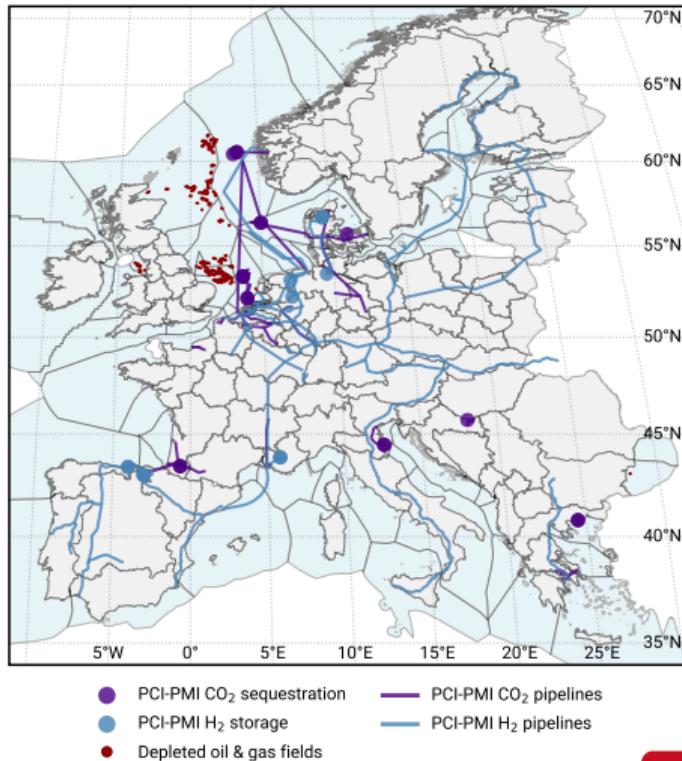
Project map



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

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, H₂ production, electrolyser capacity, and CO₂ 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



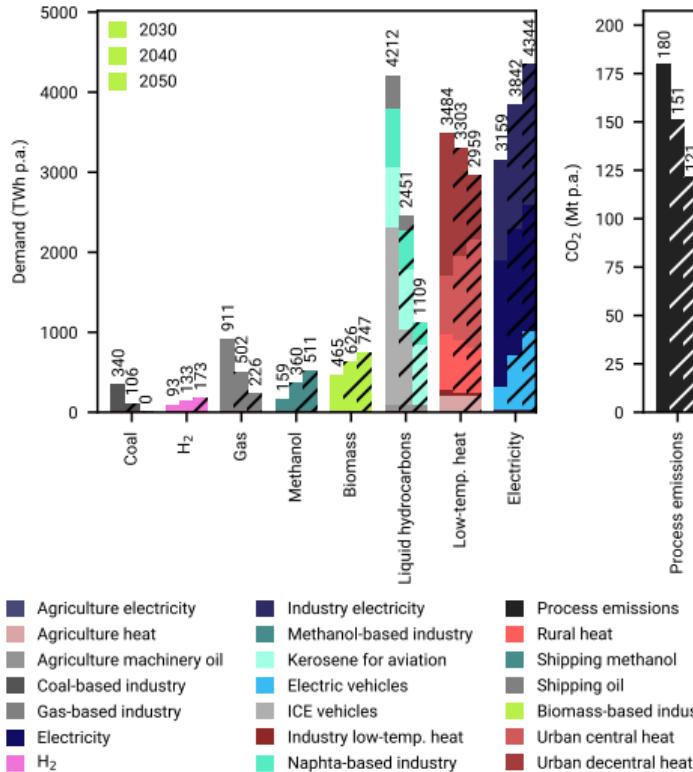
Source: Own illustration based on data extracted from
https://ec.europa.eu/energy/infrastructure/transparency_platform/map-viewer

Pathway for implemented long-term (LT) 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]

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
- CO₂ sequestration cost assumed at €15/tCO₂ (mid-range estimate)

Long-term scenarios

| Long-term scenarios | DI | PCI | PCI-n | PCI-in | CP |
|---|----|-----|-------|--------|----|
| CO₂ sequestration | | | | | |
| Depleted oil & gas fields* | ■ | ■ | ■ | ■ | ■ |
| PCI-PMI seq. sites** | - | ■ | ■ | ■ | ■ |
| H₂ storage | | | | | |
| Endogenous build-out | ■ | ■ | ■ | ■ | ■ |
| PCI-PMI storage sites | - | ■ | ■ | ■ | ■ |
| CO₂ pipelines | | | | | |
| to depleted oil & gas fields | ■ | ■ | ■ | ■ | ■ |
| to PCI-PMI seq. sites | - | ■ | ■ | ■ | ■ |
| CO₂ and H₂ pipelines | | | | | |
| PCI-PMI | - | ■ | ■ | ■ | ■ |
| National build-out | - | ■ | ■ | ■ | ■ |
| International build-out | - | - | - | ■ | ■ |
| PCI-PMI extendable | - | - | - | - | ■ |

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

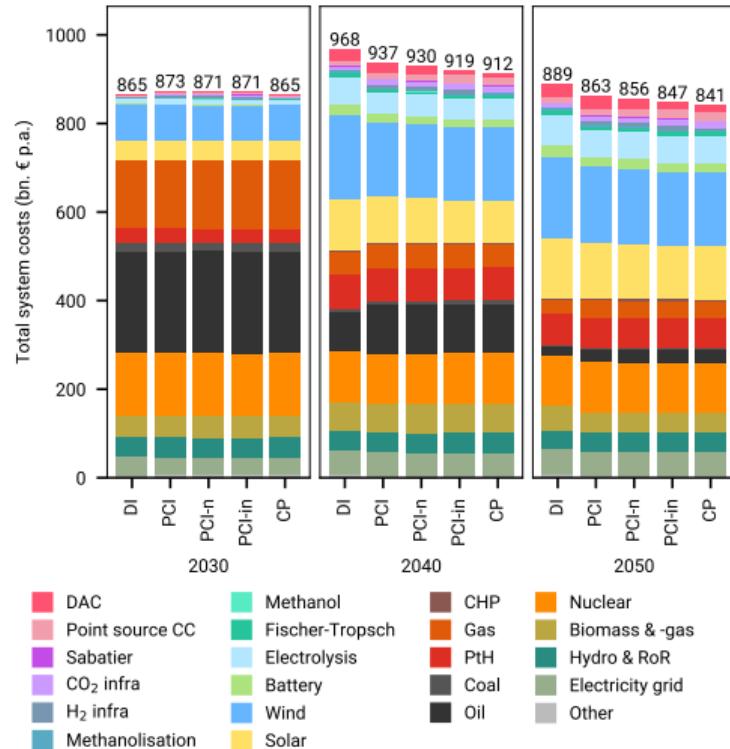
Regret-matrix setup

| | 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 electrolyzers | - | ■ | ■ | ■ |
| CO₂ + H₂ 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.

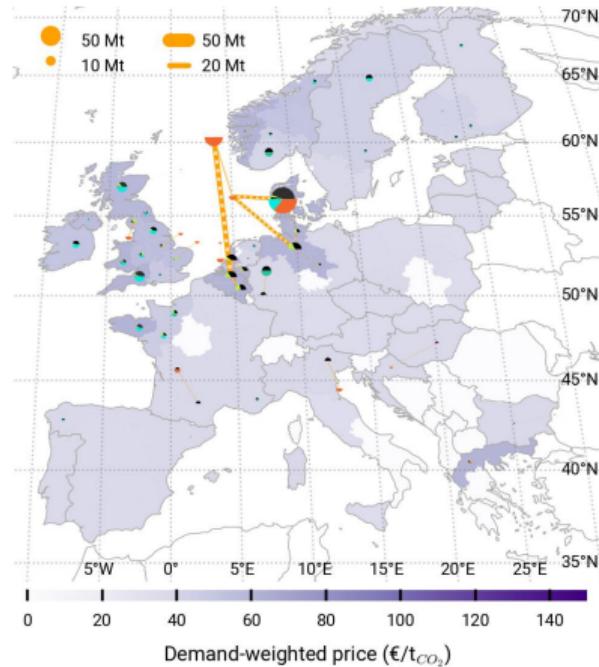
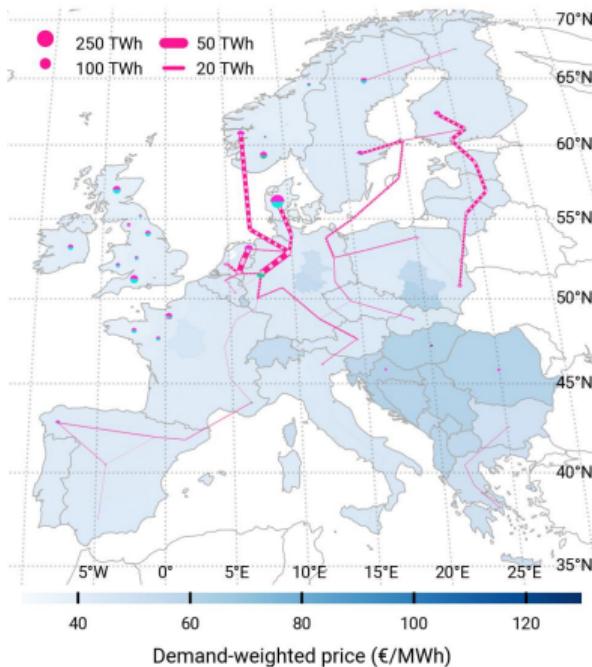
LT – Total system costs



- 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

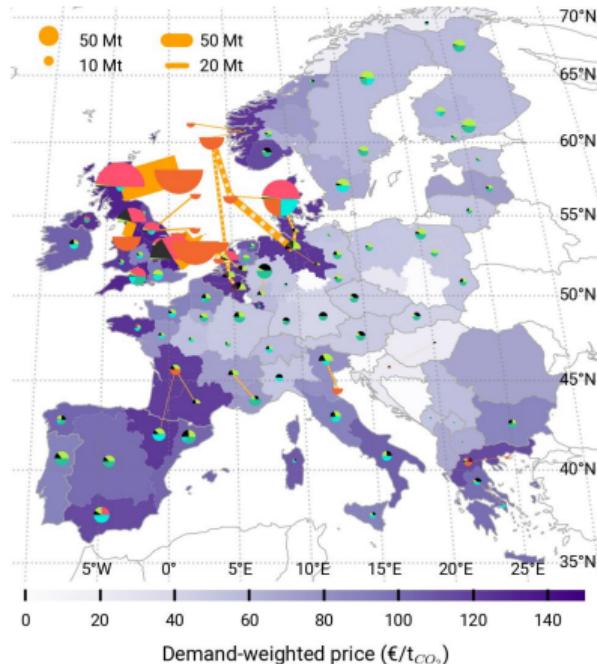
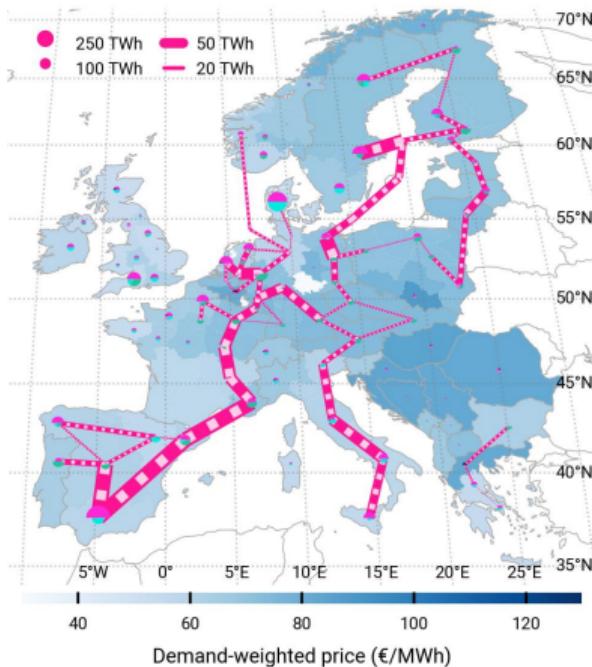
Source: Own illustration.

LT – PCI: 2030 regional H₂, CO₂ balances and transport



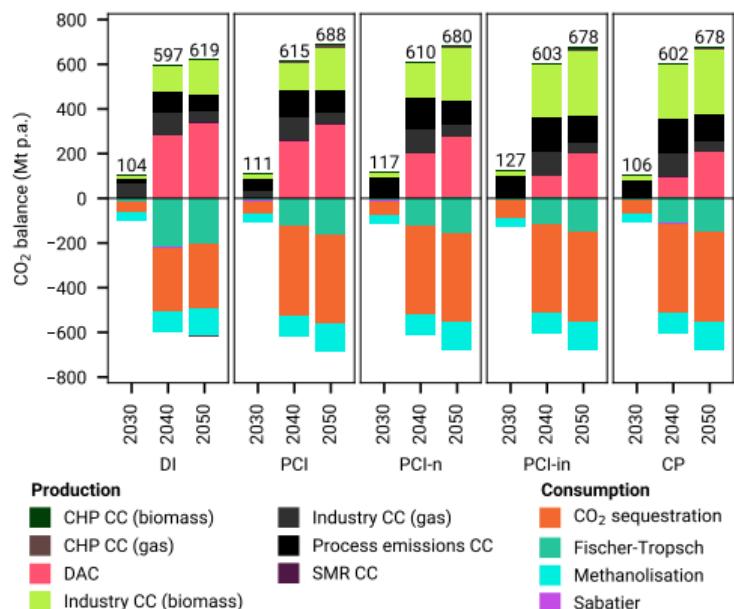
Source: Own illustration.

LT – PCI: 2050 regional H₂, CO₂ balances and transport



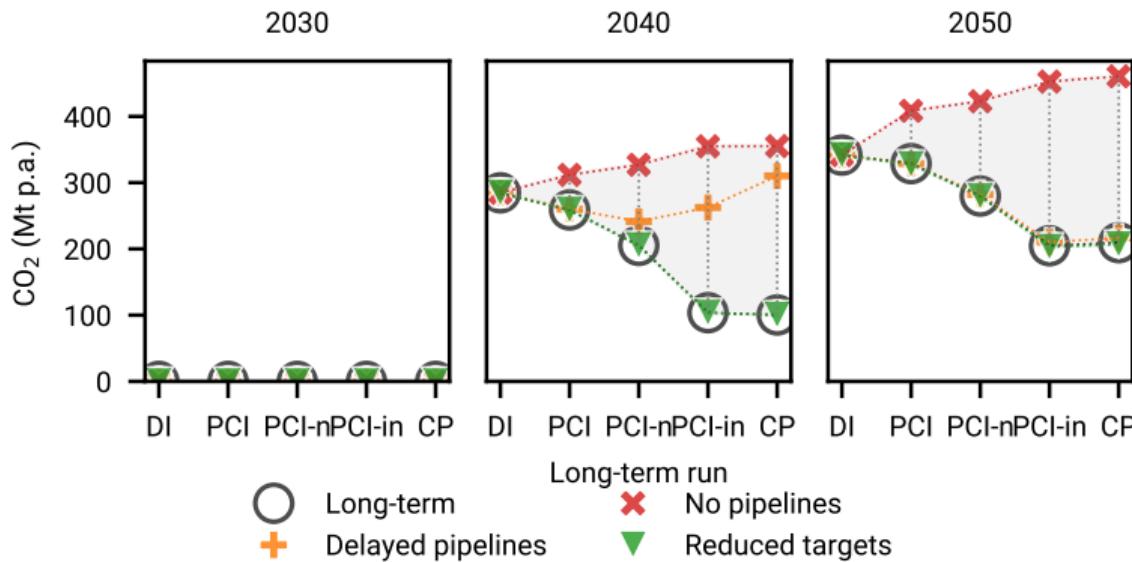
Source: Own illustration.

LT – CO₂ balances

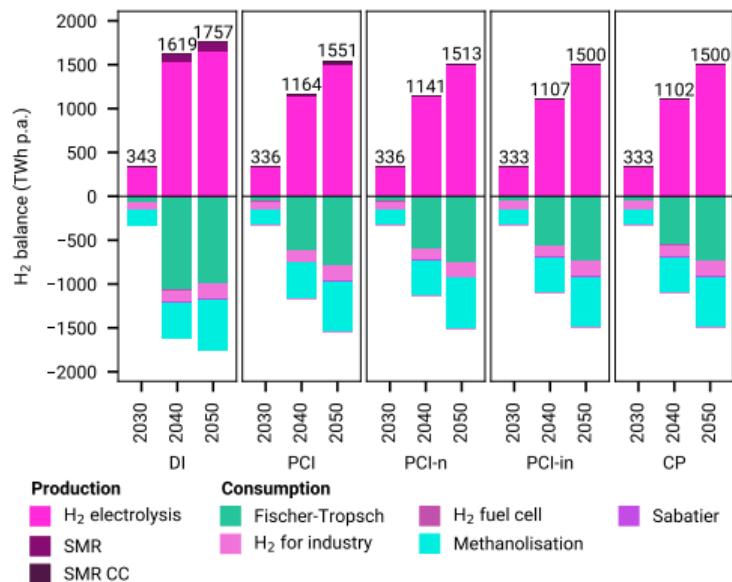


- With increasing pipeline build-out to transport CO₂ from industry and other point sources to sequestration sites, DAA utilisation decreases by almost half (left to right)
- In 2030, 50 Mt p.a. sequestration target is binding, if no pipelines are built. With pipeline build-out, up to 75 Mt p.a. are sequestered
- In 2040 and 2050, all sequestration targets are overachieved, potential of 398 Mt p.a. is 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 CO₂ goes into carbon utilisation (Fischer-Tropsch synthesis) instead

LT – CO₂ balances: Direct Air Capture utilisation



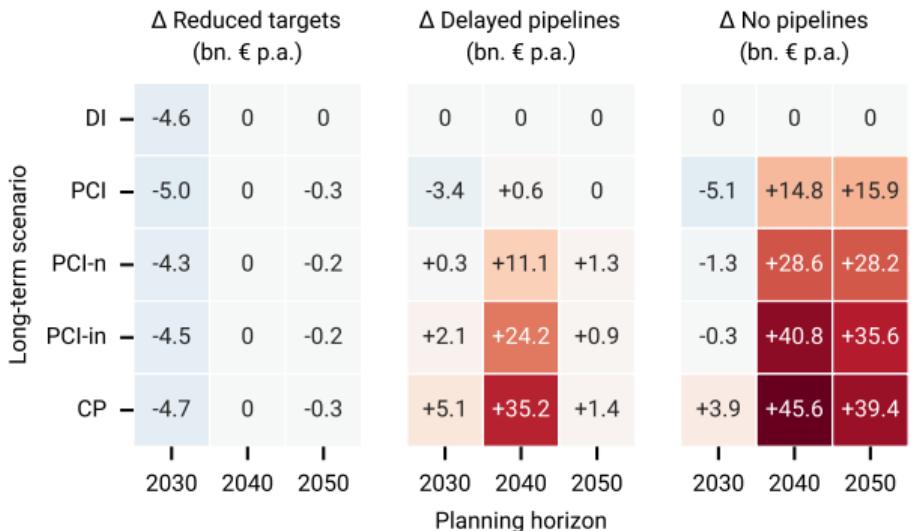
LT – H₂ balances



- H₂ 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, H₂ production is significantly higher, given the need for additional Fischer-Tropsch synthesis to bind CO₂ as an alternative to sequestration
- H₂ from Steam Methane Reforming (71 to 102 TWh p.a.) without pipelines.

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

| | CAPEX (bn. € p.a.) | | | OPEX (bn. € p.a.) | | | TOTEX (bn. € p.a.) | | | TOTEX (bn. €) | |
|--------------------|--------------------|-------|-------|-------------------|-------|-------|--------------------|-------|-------|---------------------|------|
| Long-term scenario | 2030 | 2040 | 2050 | 2030 | 2040 | 2050 | 2030 | 2040 | 2050 | NPV ₂₀₂₅ | |
| | DI | 498.0 | 803.6 | 806.6 | 367.0 | 164.1 | 82.4 | 865.0 | 967.7 | 889.0 | 8501 |
| PCI | 504.6 | 750.4 | 770.2 | 368.4 | 186.6 | 92.6 | 873.0 | 937.0 | 862.8 | 8425 | |
| PCI-n | 501.9 | 742.5 | 764.2 | 369.3 | 187.1 | 91.9 | 871.2 | 929.6 | 856.1 | 8386 | |
| PCI-in | 500.2 | 730.9 | 755.1 | 370.6 | 187.7 | 92.2 | 870.9 | 918.6 | 847.3 | 8342 | |
| CP | 496.8 | 724.7 | 750.1 | 367.7 | 187.8 | 91.3 | 864.5 | 912.4 | 841.4 | 8283 | |

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, H₂, and CO₂ sequestration targets
- Low-regret investment, even when accounting for delays

CCUS & hydrogen utilisation

- Dual purpose: H₂ pipelines link high RES regions to demand centers while CO₂ pipelines connect industry to sequestration sites
- Enable decarbonisation of hard-to-abate sectors and industrial processing including non-abatible 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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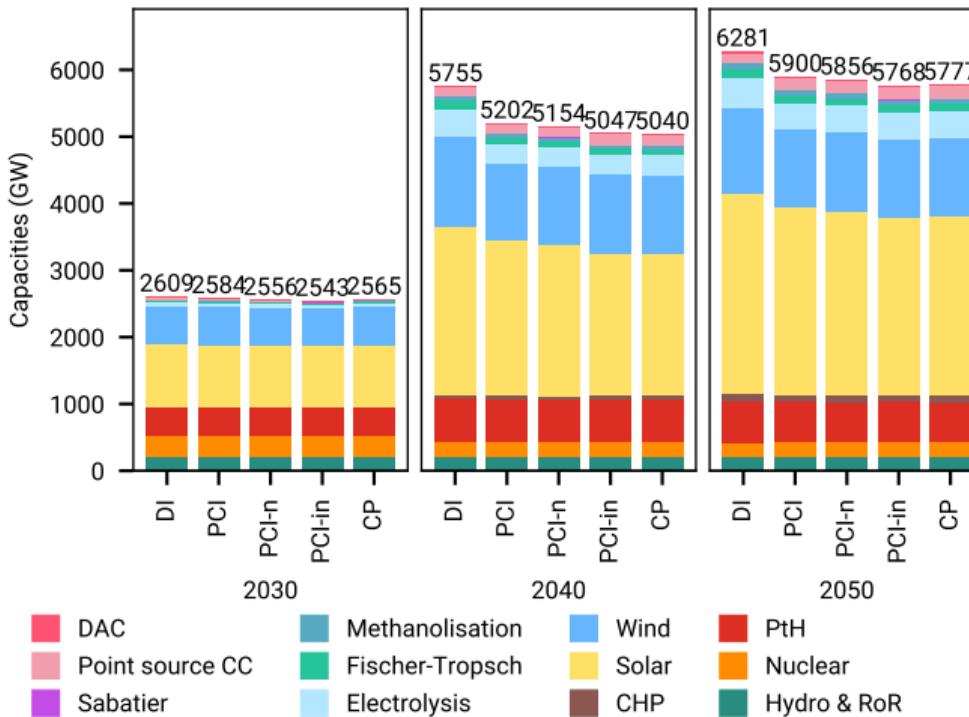
↪ xiong@tu-berlin.de
↪ github.com/bobbyxng

Appendix

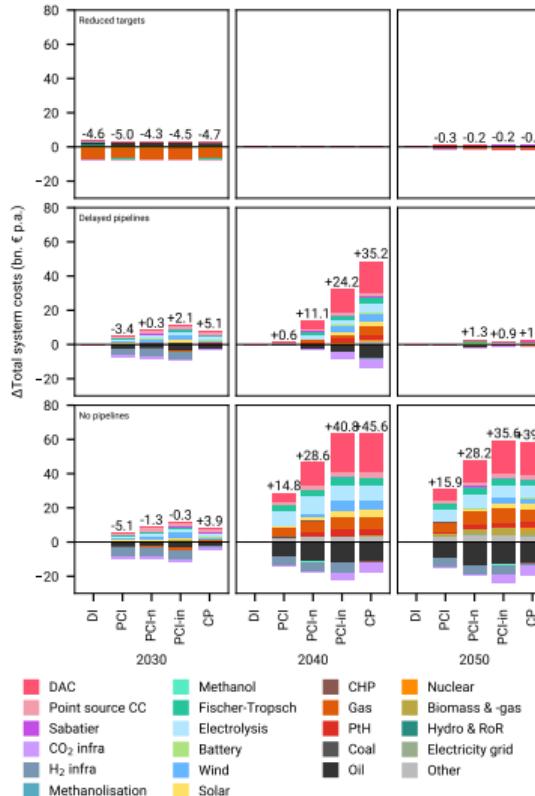
Cost assumptions for key technologies

| | 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 _{H₂} /km | 304 | 1.5-3.2 %/a |
| H ₂ offshore pipelines | €/MW _{H₂} /km | 456 | 3.0 %/a |
| Conversion | | | |
| Electrolysis | €/kW _e | 1000-1500 | 4.0 %/a |
| SMR | €/MW _{CH₄} | 522 201 | 5.0 %/a |
| SMR CC | €/MW _{CH₄} | 605 753 | 5.0 %/a |

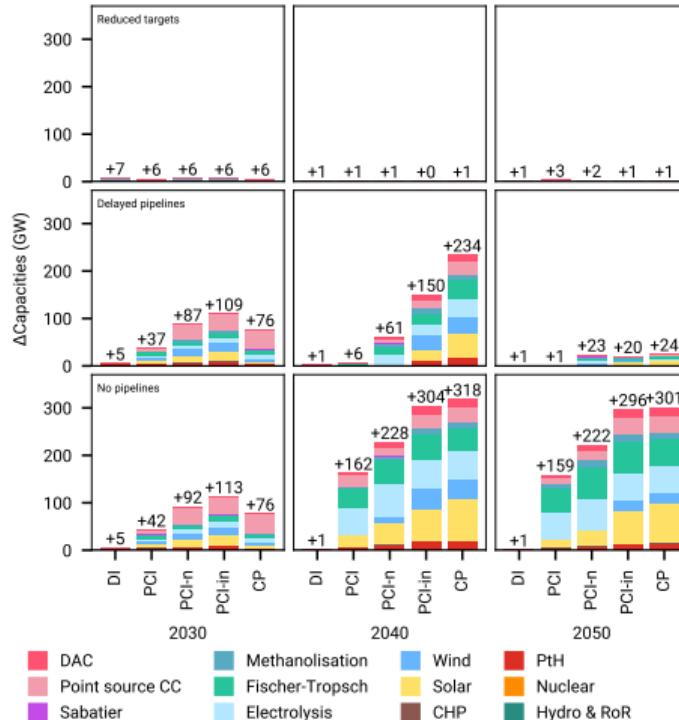
LT – Installed capacities



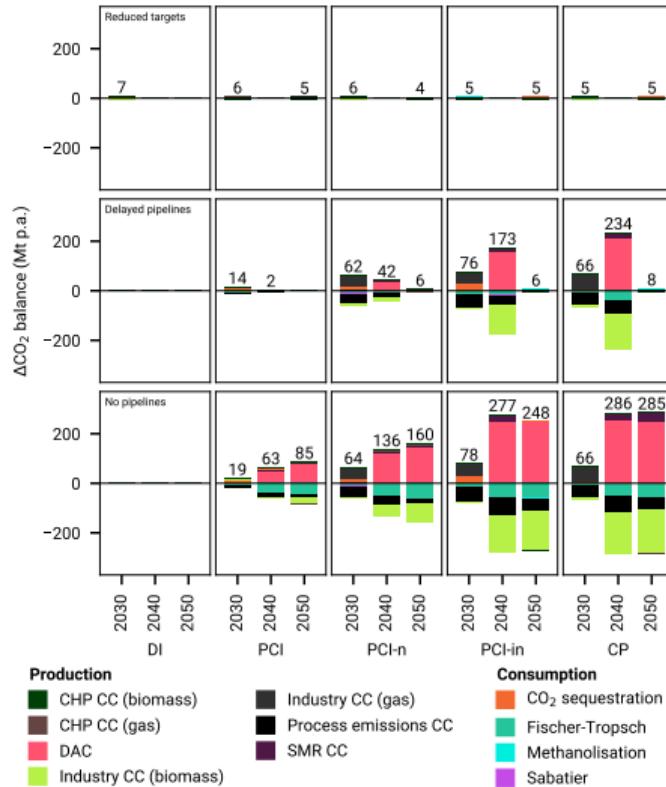
ST – Delta system costs



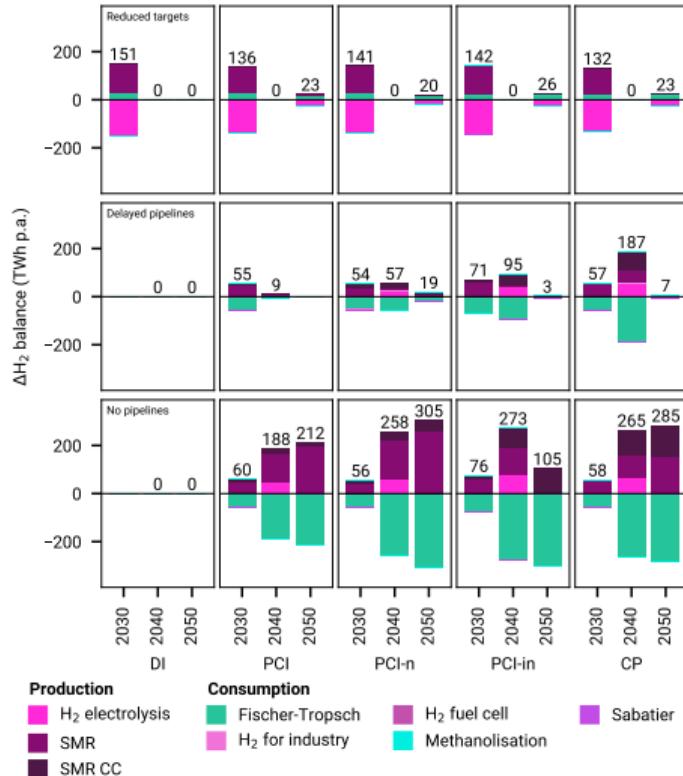
ST – Delta capacities



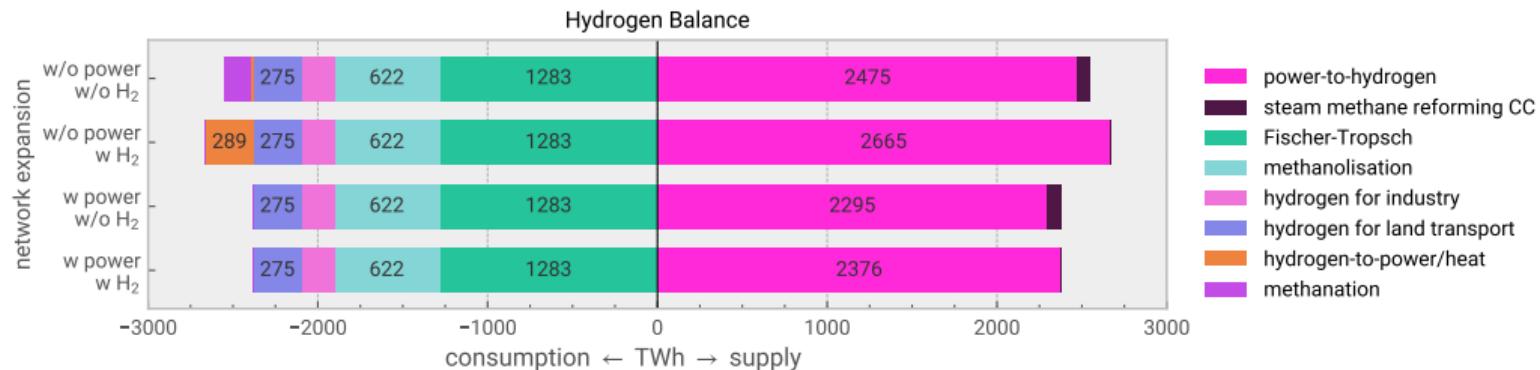
ST – Delta balances CO₂



ST – Delta balances H₂



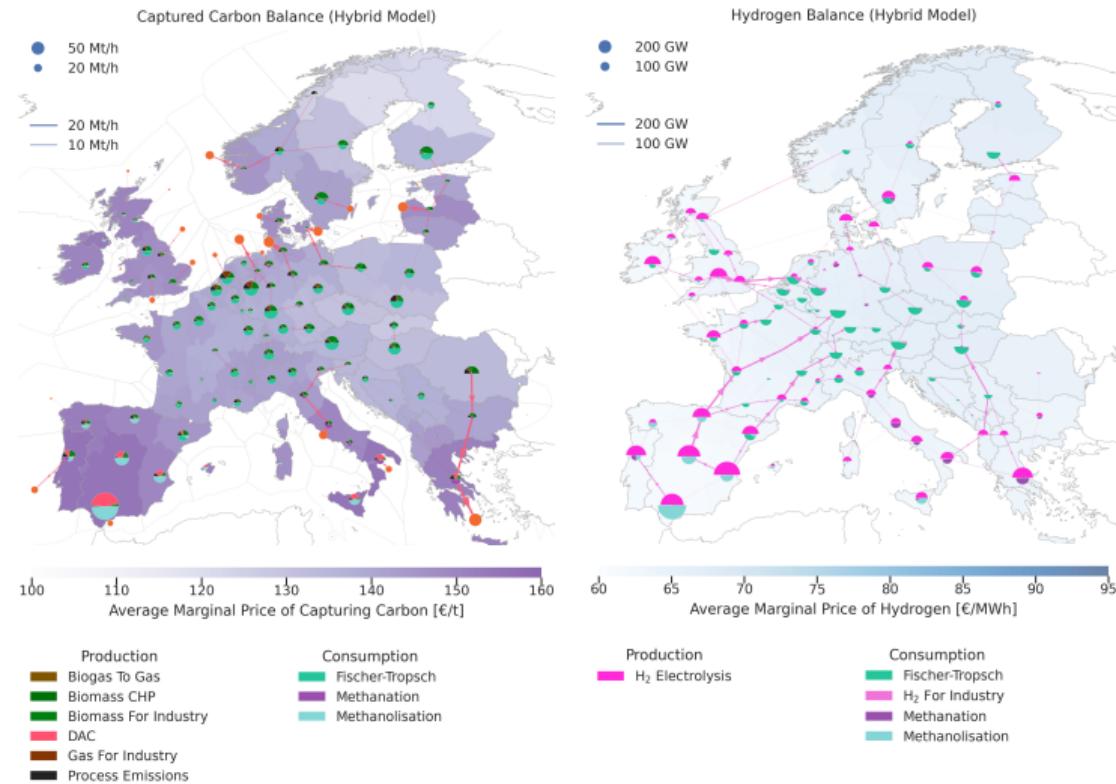
Why H₂? Most H₂ is used for derivative fuels and chemicals!



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

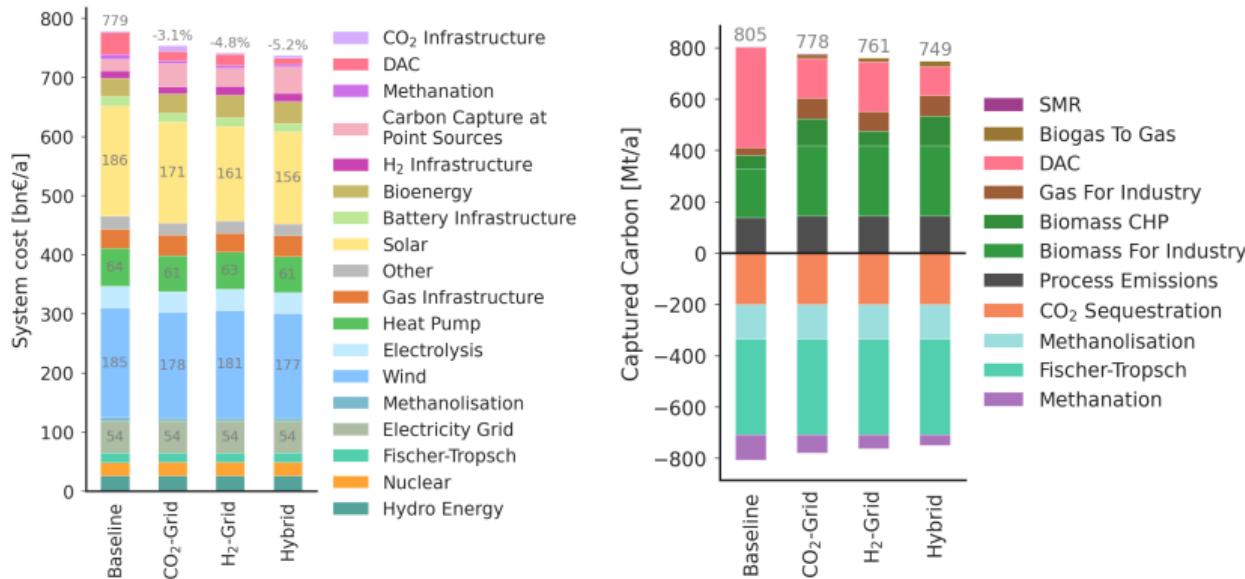
- ammonia for fertilizers
- direct reduced iron for steelmaking
- shipping and aviation fuels
- precursor to high-value chemicals
- backup heat and power supply
- some heavy duty land transport

Transporting CO₂ to H₂ or transporting H₂ to CO₂?



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

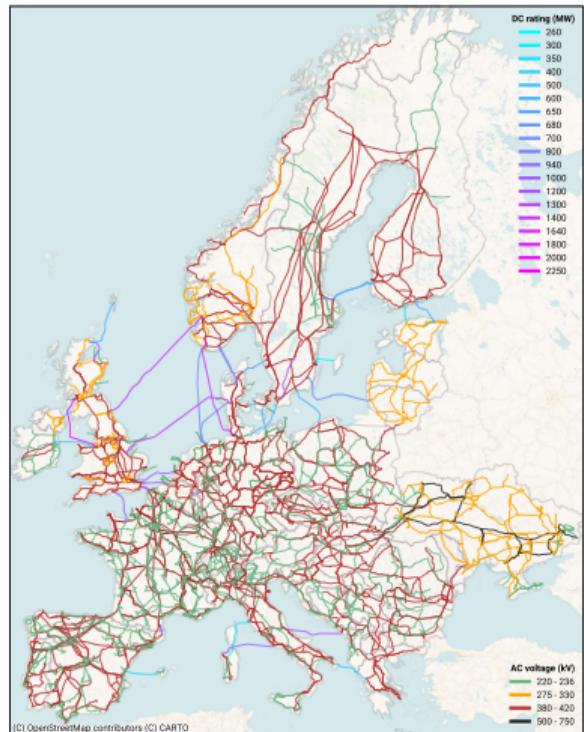
Carbon management: Capture, use, transport and sequestration



- 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)

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>