European Climate + Energy Modelling Forum (ECEMP 2025)

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

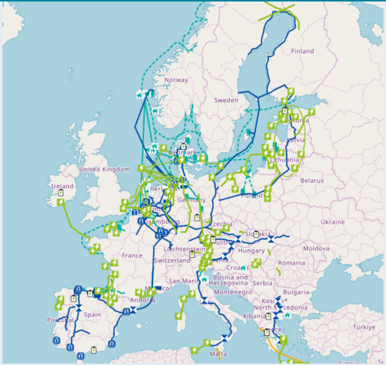
- **Net-Zero Industry Act**
- Essential component in helping industries to reduce their net emissions
- Provides means to capture unavoidable emissions from hard-to-abate sectors like cement, steel, chemicals, etc.

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



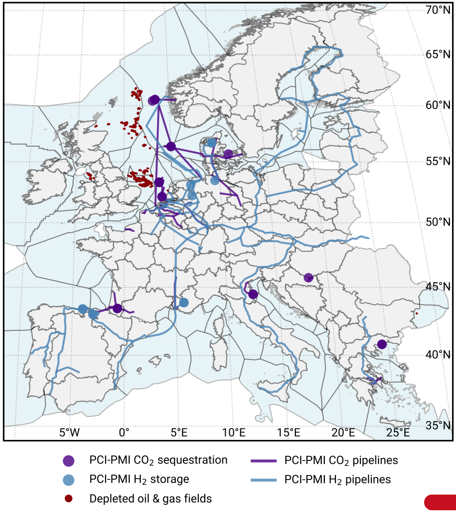
1 What is the long-term value of PCI-PMI projects in supporting the EU’s climate and energy policy targets, and what are the associated costs?

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

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**
- **Regret analysis** approach based on 5 pathways, 3 (short-term) perturbations, in total 60 model runs + 90 sensitivity runs



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

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Model setup: Used terms

Pathway

- **Long-term planning trajectory** including generation, transmission, storage, power-to-X investment and operation decisions
- Assuming policy, climate, and energy **targets are met**

Perturbation

- **Short-term shock** to the anticipated pathway, e.g. project delays, cancellations or changing policy environment
- System **adapts** to the perturbation with limited set of short-term investment options

Regret

- In **decision theory** typically defined as difference in economic value, payoff, or cost between a chosen strategy and the optimal strategy.
- Regret term represents the **additional cost** incurred from not following the cost-optimal strategy.
- Implemented in **two steps**: 1) Implementation of pathways 2) Performance of first-stage investments evaluated under perturbation scenarios.

Pathways: 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

Source: Own illustration.

Pathways: Definition

Pathway	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.

Regret matrix setup

Perturbation	Reduced targets	Delayed pipelines	No pipelines
Pathway			
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.

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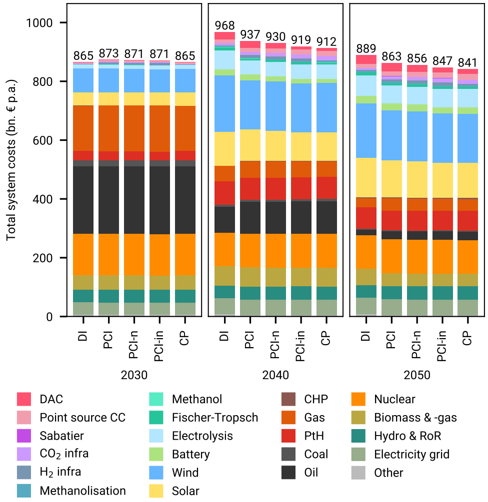
Pathways – Total system costs



- 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.

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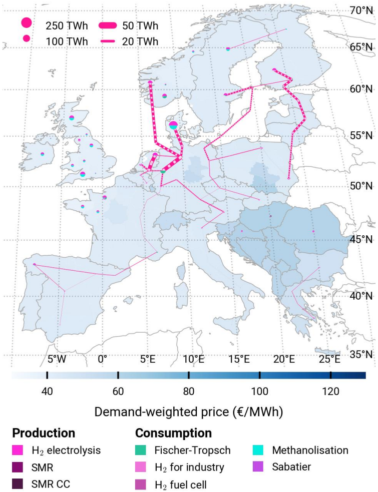
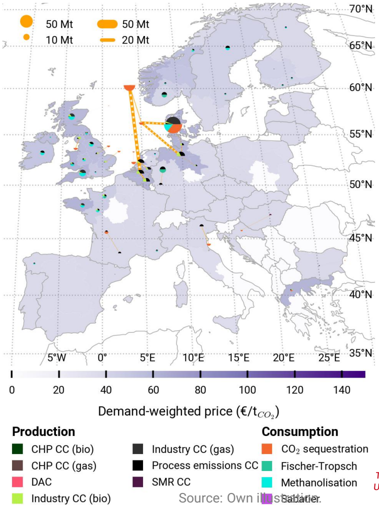
Pathways — PCI: 2030 regional H_2, CO_2 balances, transport, and prices





Source: Own illustration.

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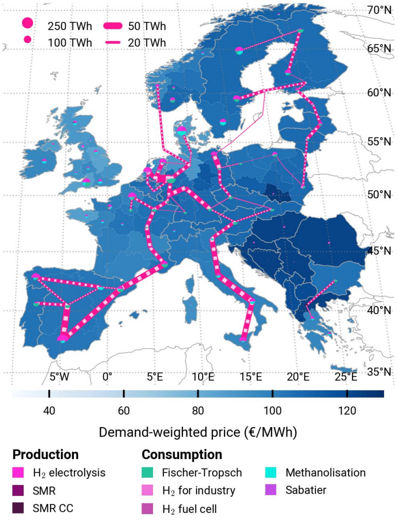
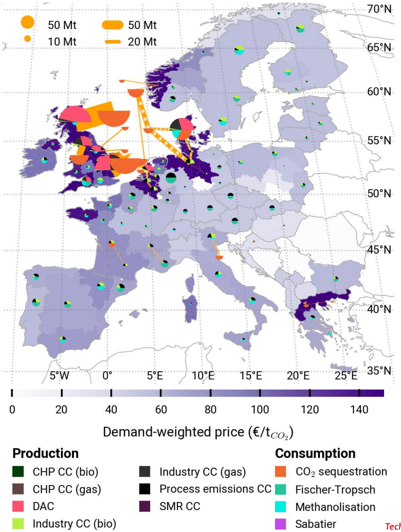
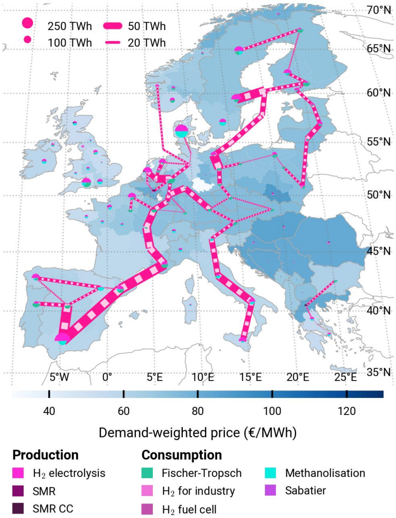
Pathways — PCI: 2040 regional H_2, CO_2 balances and transport

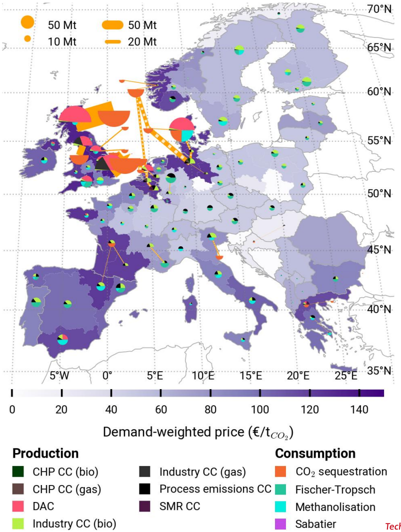




Source: Own illustration.

Pathways – PCI: 2050 regional H_2, CO_2 balances and transport





Source: Own illustration.

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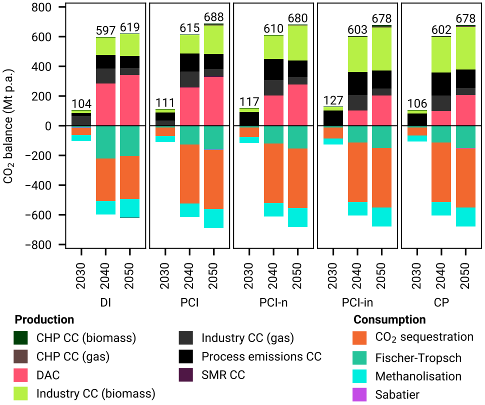
Pathways — CO_2 balances



- 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.

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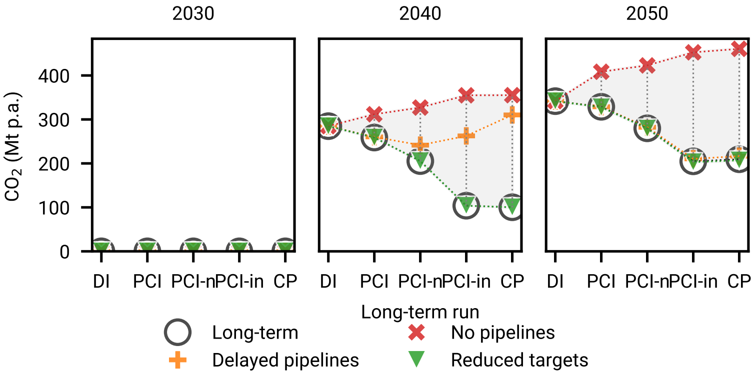
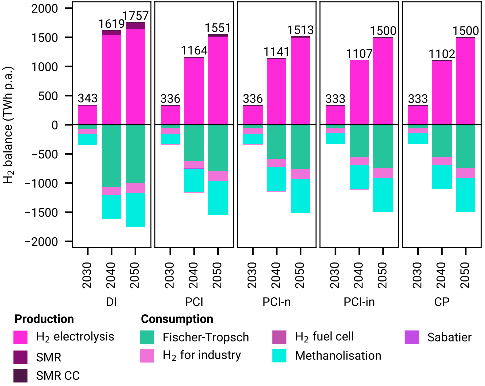
Pathways — CO_2 balances: Direct Air Capture utilisation



Pathways – H_2 balances

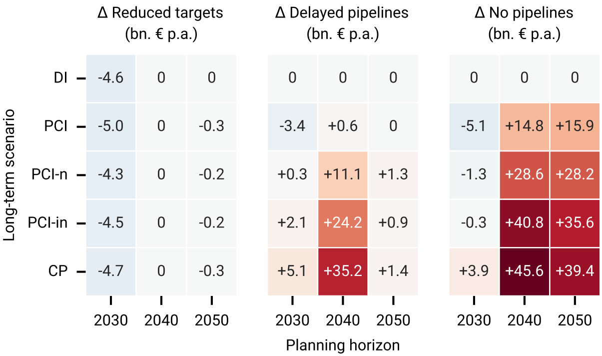


- H_2 production primarily driven by demand for Fischer-Tropsch fuels and methanol
- In 2050, Fischer-Tropsch fuels primarily used to satisfy kerosene in aviation and industrial naphta
- When no pipelines are built, H_2 production is significantly higher, given the need for additional Fischer-Tropsch 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.

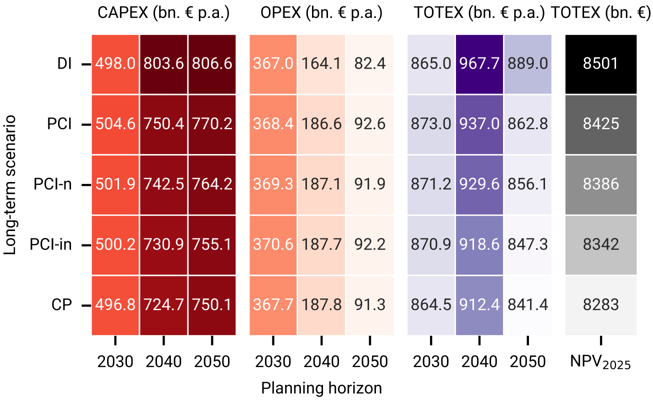
Regret analysis

- Regret is calculated by subtracting annual total system costs of pathway from perturbation scenarios
- Regret terms represent additional cost incurred by given perturbation 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

Thank you.

↪ github.com/pypsa/pypsa-eur

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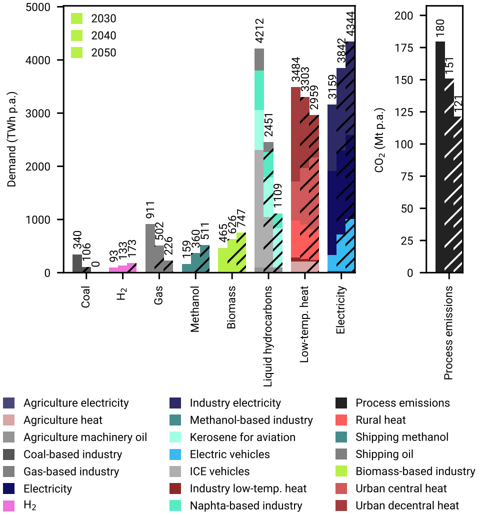
Exogenous demand



- 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)

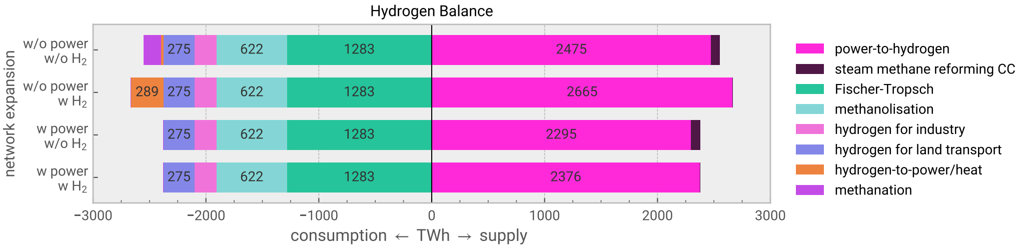
Source: Own illustration.

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.

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



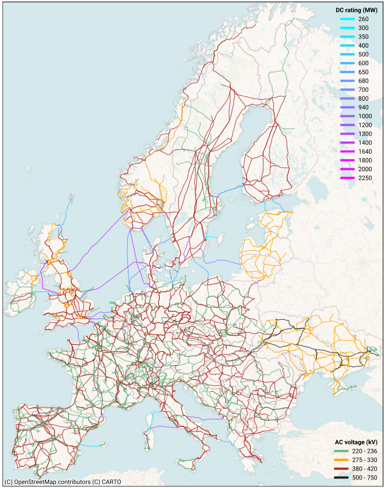
Mostly **green electrolytic hydrogen supply**. **Few direct uses of hydrogen** in the energy system, but it is used to synthesise other fuels and chemicals:

- 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

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