Open Energy Infrastructure Planning for Net-Zero Carbon Emissions: Recent Research with PyPSA-Eur

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EN SYS

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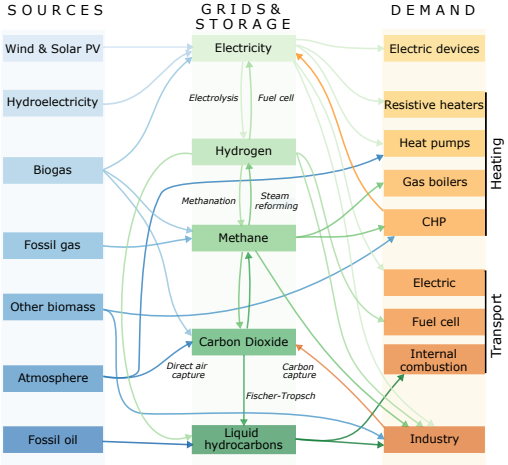
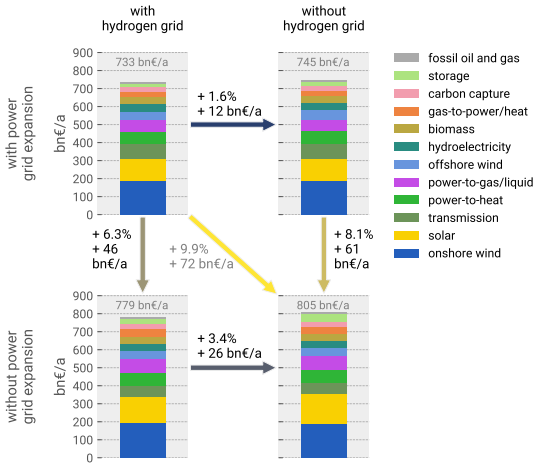
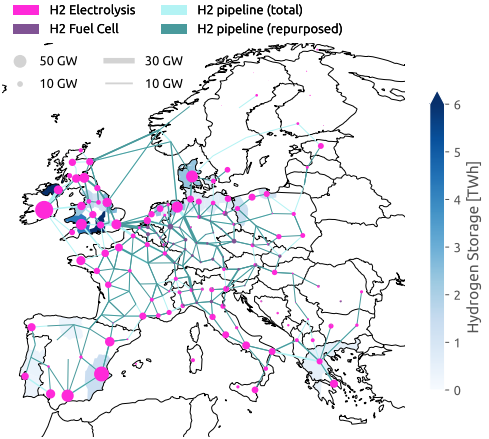
A typical setup for open-source modelling with PyPSA-Eur

- Couple **all energy sectors** (power, heat, transport, industry, feedstocks, agriculture)
- **Co-optimise** generation, transmission, storage, and power-to-X conversion with future **cost projections**
- Resolve **100-200 regions** in Europe
- **2-3 hourly** segmented time series
- Reduce net CO_2 emissions **to zero**
- Minimise system cost in **LP** on **HPC**
- Run a large number of **scenarios**



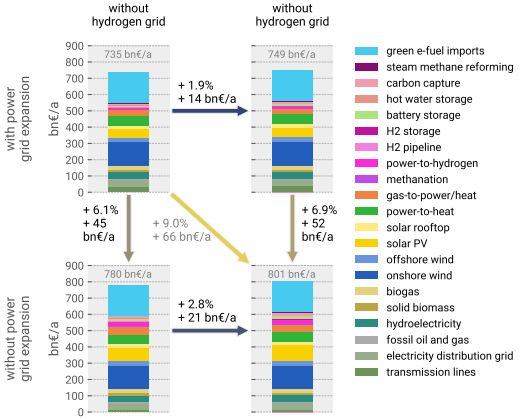
Joule Paper: Comparison of power and hydrogen network benefits

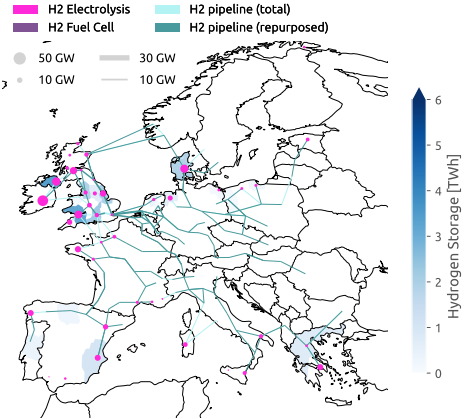




Source: https://doi.org/10.1016/j.joule.2023.06.016, main body

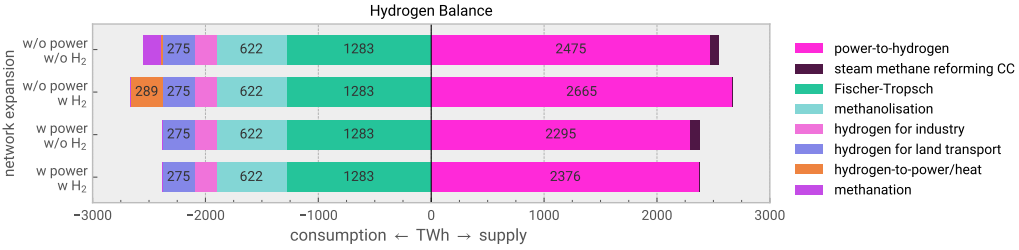
Review: What changes with synthetic fuel imports from abroad?





Source: https://doi.org/10.1016/j.joule.2023.06.016, supplementary material

Why? Most hydrogen 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:

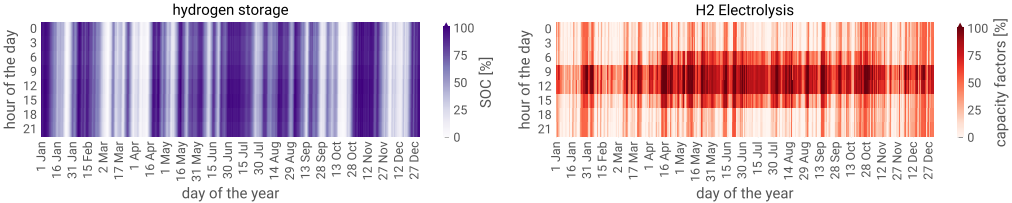
- ammonia for fertilizers
- direct reduced iron for steelmaking
- shipping and aviation fuels
- precursor to high-value chemicals
- backup heat and power supply
- some heavy duty land transport

Source: https://doi.org/10.1016/j.joule.2023.06.016

Two remarks on operational patterns of hydrogen technologies

Hydrogen acts mainly as **intermediary buffer** between
variable electricity feed-in and other more stable PtX processes.

Flexible electrolyser operation important,
but requires local and dynamic price signals to become reality.



Source: https://doi.org/10.1016/j.joule.2023.06.016, supplementary material

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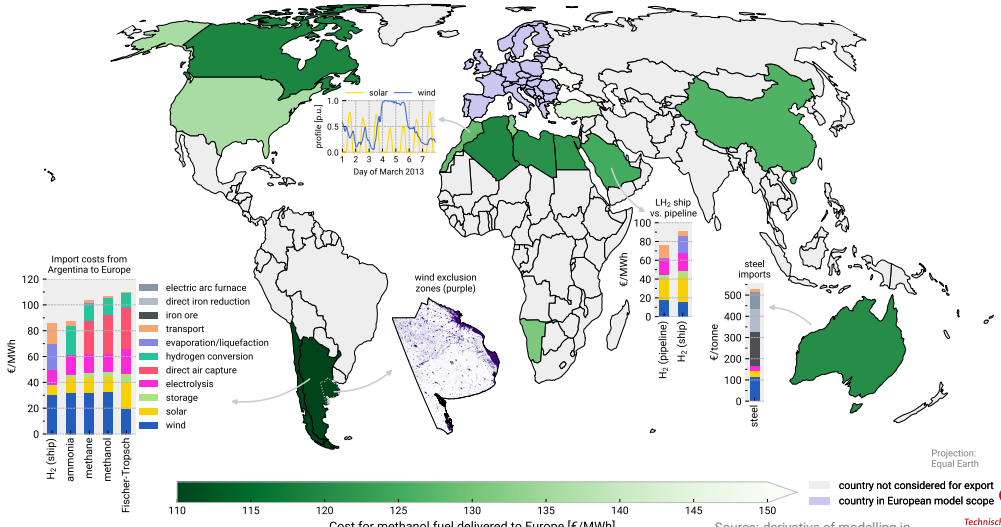
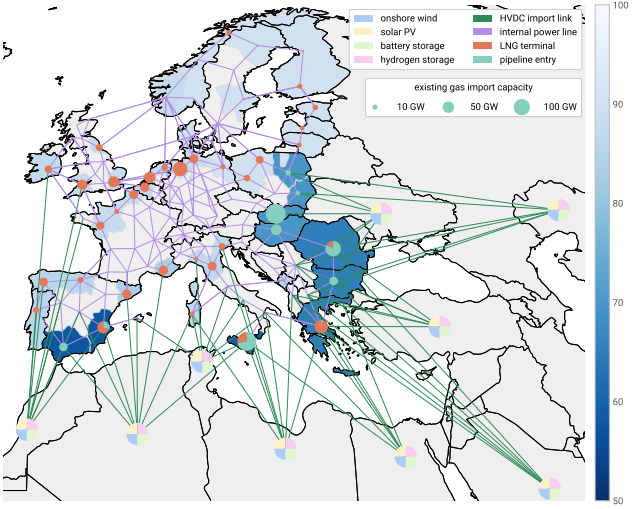
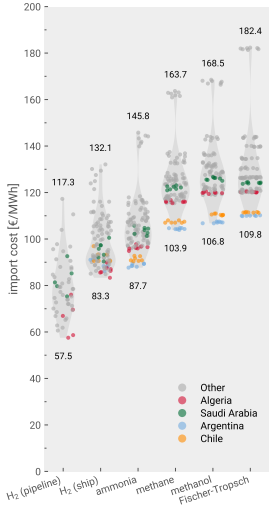
More detail: Green energy & material import supply chains…



Source: derivative of modelling in https://doi.org/10.1371/journal.pone.0281380

. . . put into European energy system model as supply options





Source: Neumann, Hampp, Brown, 2024 *Energy Imports and Infrastructure in a Carbon-Neutral European Energy System*

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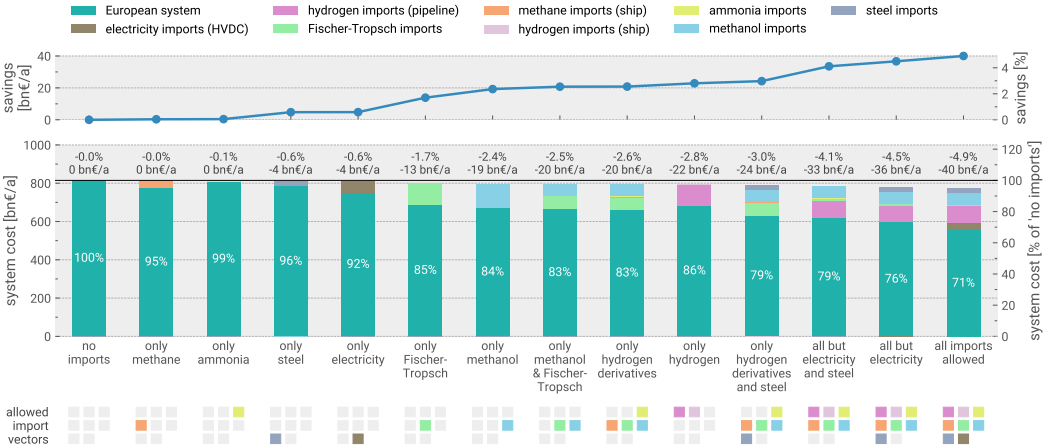
Attainable cost reductions depend on **import vectors** used.



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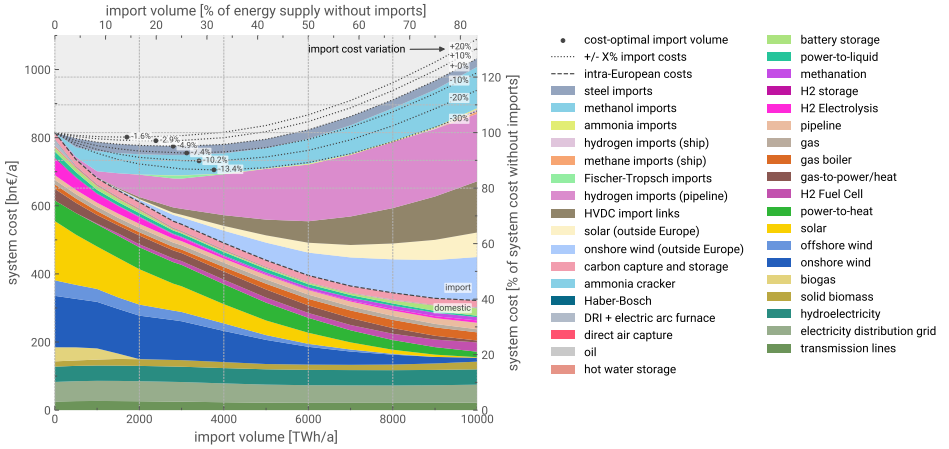
Diminishing return of imports with increasing import volumes.



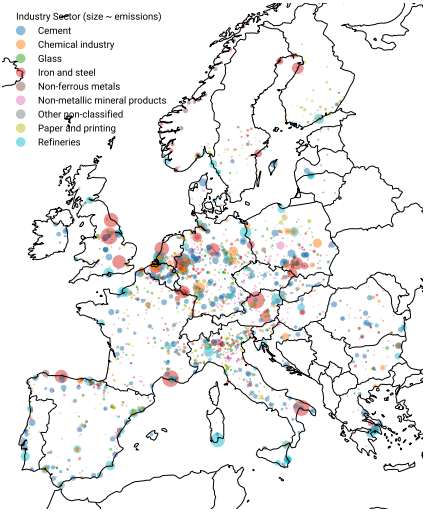
→ 70% of the **5%** cost-benefit can be achieved with imports below **1000 TWh**

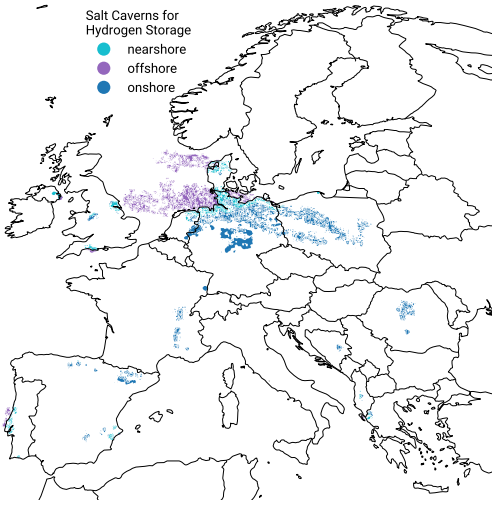
Source: Neumann, Hampp, Brown, 2024 *Energy Imports and Infrastructure in a Carbon-Neutral European Energy System*

5 Takeaway Messages

1. Imports of green energy could reduce cost of European net-zero system **by 1-14%**.
2. **Diminishing returns** for larger import volumes; **preference** for steel, MeOH and H_2.
3. Some **domestic power-to-X** production to integrate variable renewables, utilise waste heat from fuel synthesis and leverage local sustainable CO_2 sources
4. European infrastructure policy requires **coordination** with import strategy.
5. Maneuvering space to accommodate non-cost factors: **geopolitics**, **reuse** of infrastructure, **resilience** of supply chains, diversification, and reduced land usage.

Data: Industrial sites, salt caverns, transmission networks





Source: Hotmaps Industrial Sites Database; Caglayan, 2019; SciGRID_gas

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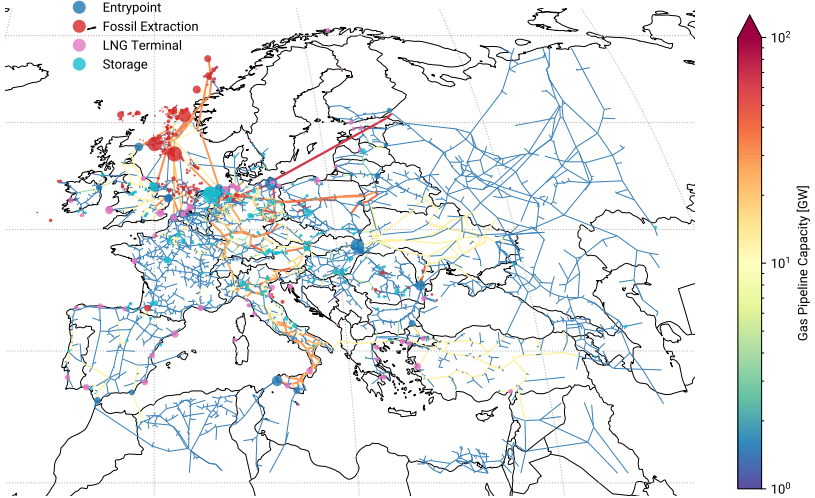

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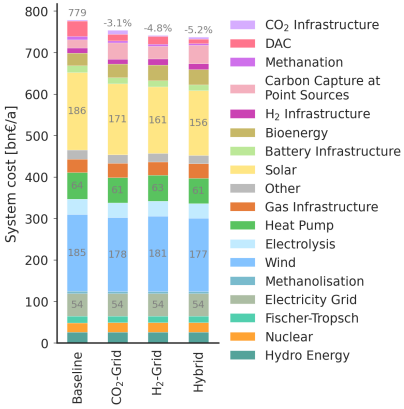
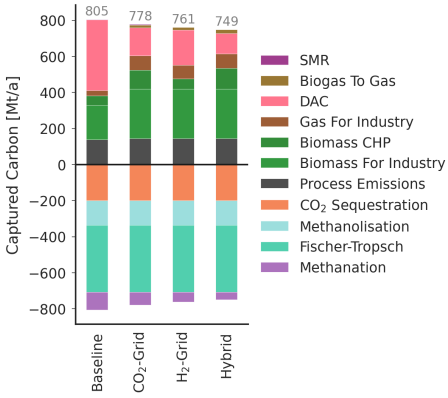
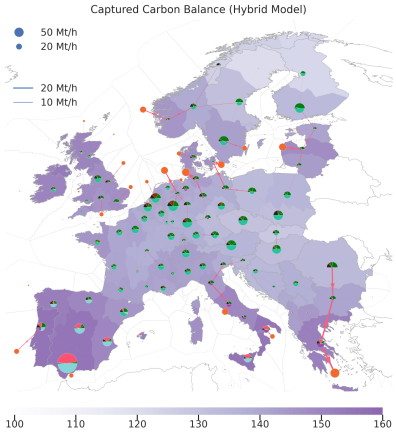
Carbon management: capture, use, transport and sequestration

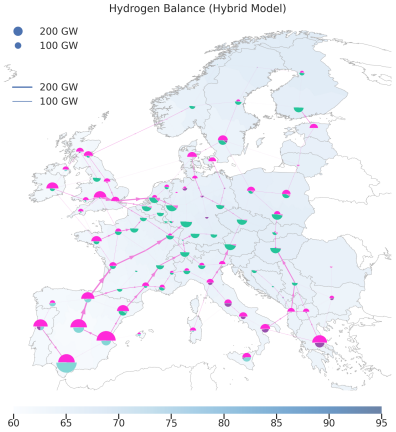




- CCS for process emissions (for instance, in cement industry)
- CCU for e-synfuels and e-chemicals (in particular, shipping, aviation, plastics)
- CDR for unabatable and negative emissions (to offset imperfect capture rates)

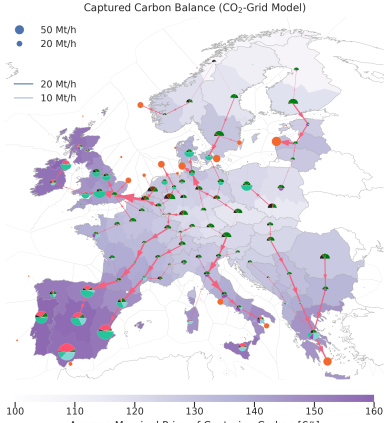
Transporting CO_2 to H_2 or transporting H_2 to CO_2?

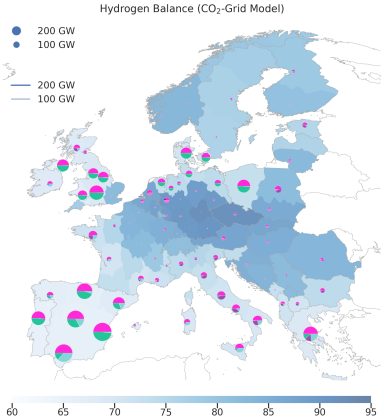




Source: work under review

Cost benefit of CO_2 **pipelines** strongest without H_2 network.





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