Benefits of a Hydrogen Network in Europe with Repurposed Gas Pipelines

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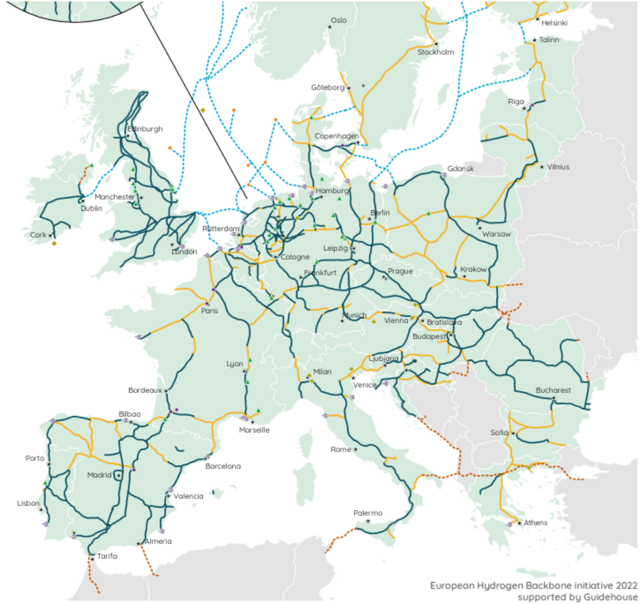
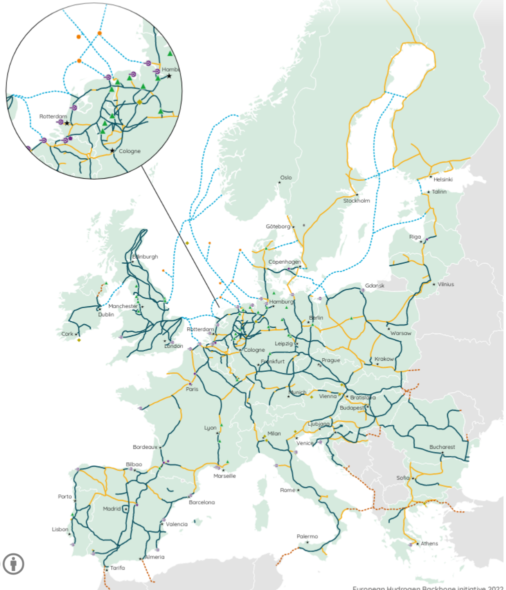


Source: European Hydrogen Backbone (April 2022)

Large-scale electrification to meet CO_2 targets collides with low acceptance for power grid and onshore wind

Can electrolytic hydrogen and a hydrogen pipeline network help?



Can we substitute for power grid expansion by producing **electrolytic hydrogen** near remote high-yield generation sites and transporting it to demand clusters through a new or repurposed **hydrogen pipeline network**?

Source: European Hydrogen Backbone (2022), https://gasforclimate2050.eu/wp-content/uploads/2022/04/EHB-A-European-hydrogen-infrastructure-vision-covering-28-countries.pdf

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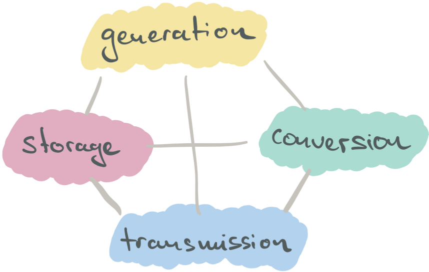
Modelling challenges

Challenge 1: Need spatial resolution to see grid bottlenecks & infrastructure trade-offs.

Challenge 2: Need to co-optimise balancing solutions with spatio-temporal variability.



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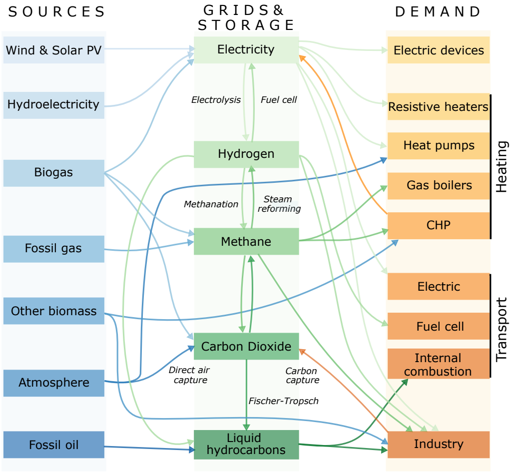
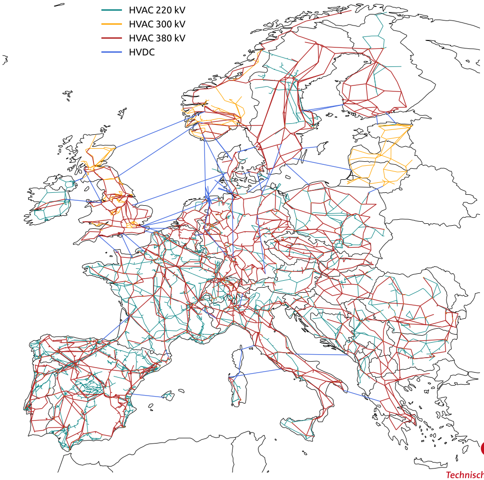
What is PyPSA-Eur-Sec? - Open Sector-Coupled Model of Europe

Model for Europe with all energy flows... ...and bottlenecks in energy networks...





Source: https://github.com/pypsa/pypsa-eur-sec

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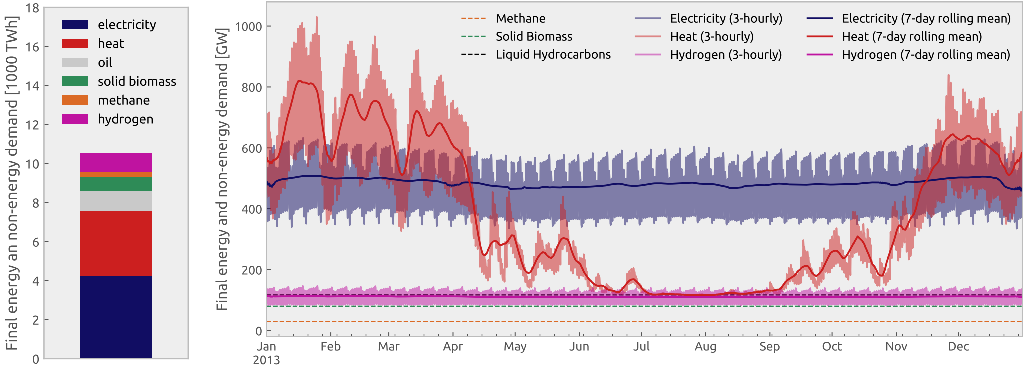
... and temporal variability in demand and supply.



There are difficult periods in winter with **low** wind and solar, **high** space heating demand **low** air temperatures, which are bad for air-sourced heat pump performance

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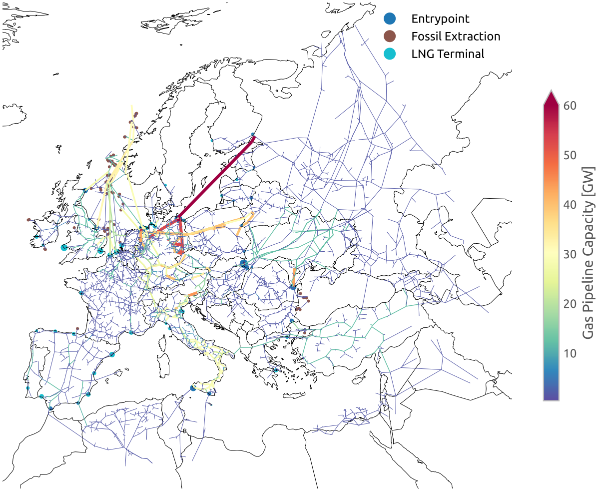
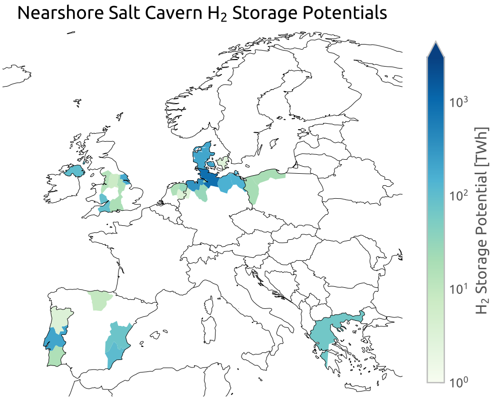
Gas network with H_2 retrofitting option and cavern storage potentials

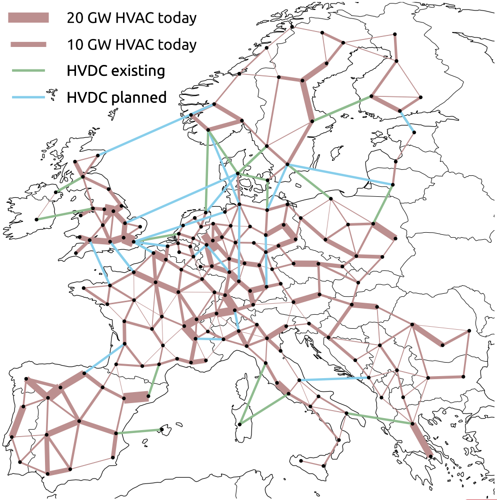




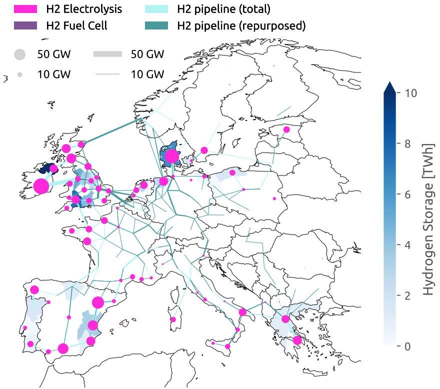
Source: SciGRID_gas and Caglayan, 2020

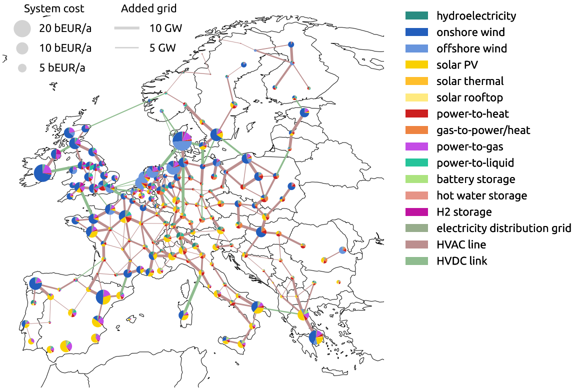
Scenarios for a European energy system with net-zero CO_2 emissions

- Couple **all energy sectors** (power, heat, transport, industry, agriculture, international aviation & shipping)
- Cluster to 181 regions, 3-hourly time series
- Reduce net CO_2 emissions **to zero**
- **Technology assumptions** for 2030 (DEA)
- Europe energy **self-sufficient** *more later!*
- **CO_2 sequestration** limited to 200 Mt/a
- Vary allowed electricity and hydrogen **network expansion**



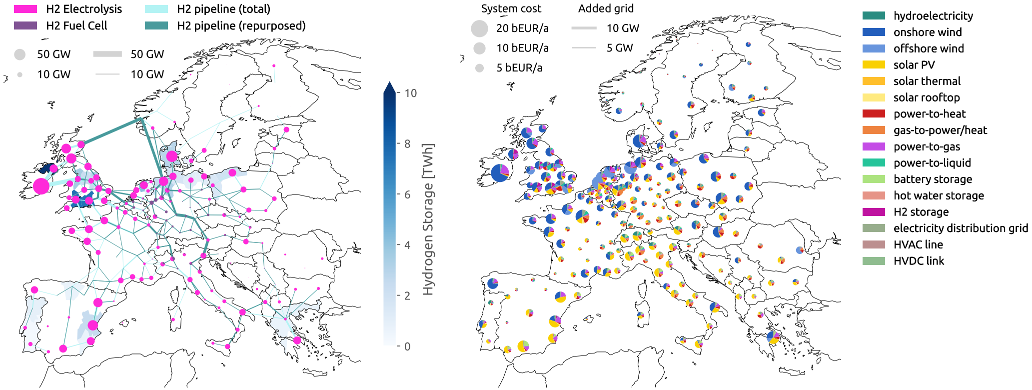
Least-cost solution – power and hydrogen network expansion





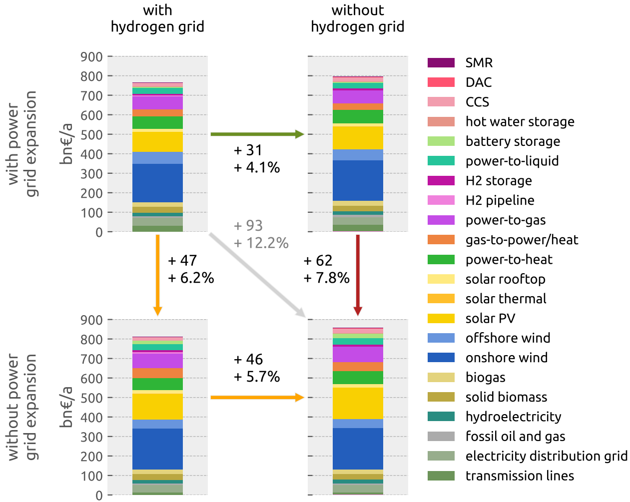
What if we restrict electricity grid reinforcements?

A more restricted solution – no power grid expansion



How much more expensive is this solution?

Benefit of hydrogen network infrastructure



- **Cost** of hydrogen network: €6-8 billion per year
- **Net benefit** is much higher: €31-46 billion per year
- Power grid brings **more benefit**: €47-62 billion per year
- Hydrogen network can only **partially substitute**
- Systems **without any grid expansion** are also feasible

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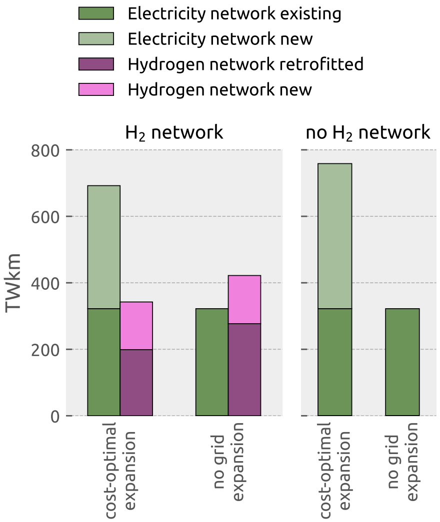
Electricity and hydrogen grid expansion and level of retrofitting



- **Up to 66%** of hydrogen backbone can repurpose existing gas network
- **Up to a third** of the gas transmisison network is retrofitted
- If grid expansion is disallowed, H_2 grid **transmits 3x more energy** than AC grid

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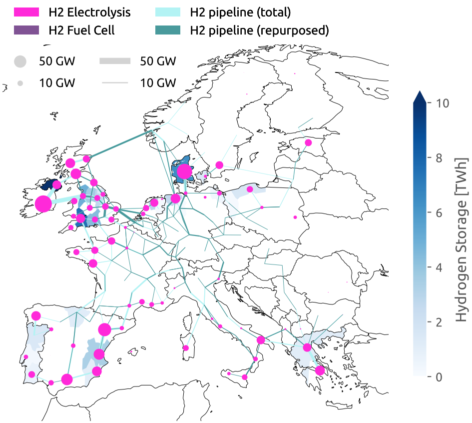
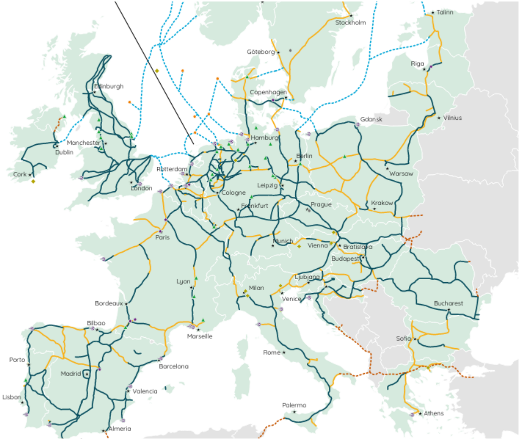
Comparison to *European Hydrogen Backbone*



58-66% retrofitted



Source: European Hydrogen Backbone (April 2022)

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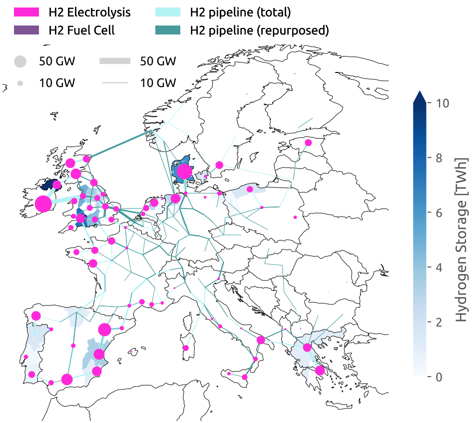
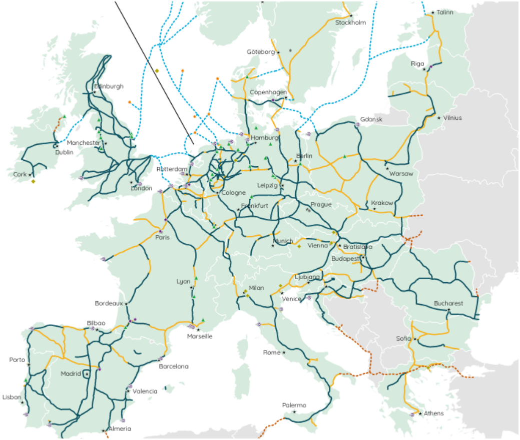
Comparison to *European Hydrogen Backbone*



58-66% retrofitted
342-422 TWkm



69% retrofitted

Source: European Hydrogen Backbone (April 2022)

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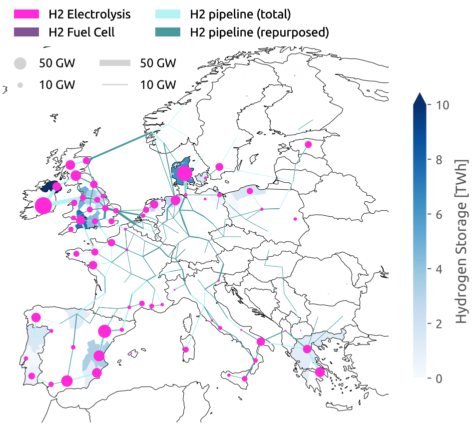

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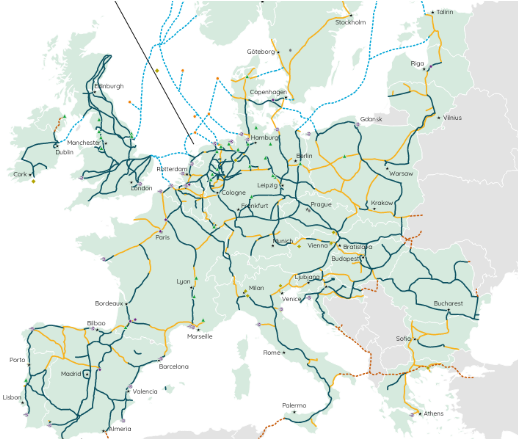

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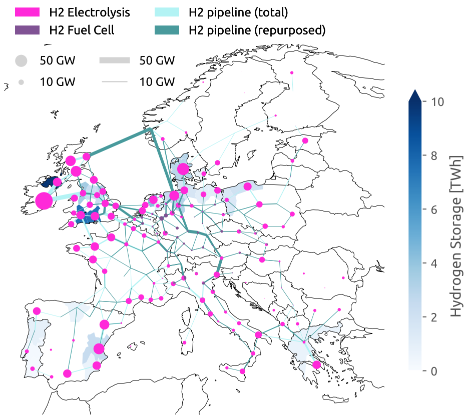
Source: European Hydrogen Backbone (April 2022)

Limited onshore wind potentials shuffle hydrogen exporting countries

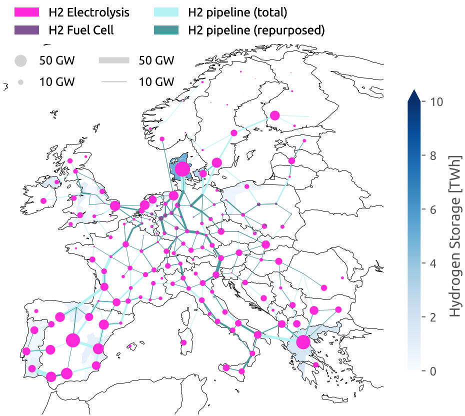
With onshore:

British Isles & North Sea dominate H_2 production

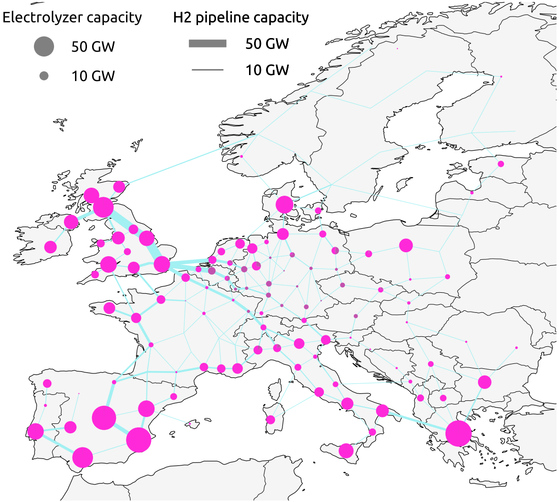


Without onshore:

Southern Europe becomes larger exporter of H_2

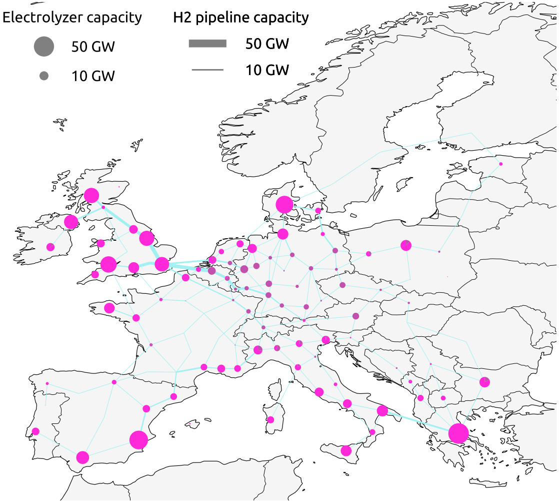


Imports of energy into Europe diminish hydrogen network benefit



- So far we looked at scenarios for **self-sufficient** energy supply
- But when H_2 and derivatives are imported (shipping, aviation, industry, trucks), **hydrogen network benefit drops to 1%**.
- **Residual benefit** of €5 billion per year comes from transporting energy to **fuel cell CHPs** to renewable-poor and grid-poor inner-European nodes.

Imports of energy into Europe diminish hydrogen network benefit



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Conclusion

- hydrogen backbone **reduces system costs by up to 6%**, highest without grid expansion
- between **58-66%** of hydrogen backbone uses **retrofitted gas network pipelines**
- **benefit of power grid expansion is higher** than of hydrogen network (6% vs 8%)
- no network expansion also feasible, but **together reduce costs by up to 12%**
- All results **depend strongly on assumptions** and modelling approach - e.g. volume of **energy imports**, onshore **wind potentials**, options for **industry relocation**

Meta

Find the slides:
https://neumann.fyi/files/enerday-spatial-sector.pdf

Find the preprint:
https://arxiv.org/abs/2207.05816

Find the open energy system model:
https://github.com/pypsa/pypsa-eur-sec

Send an email:
mailto:f.neumann@tu-berlin.de

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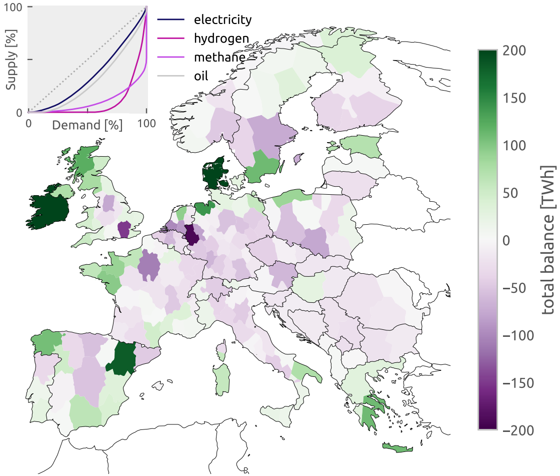
All cases: strong regional imbalance between generation and demand

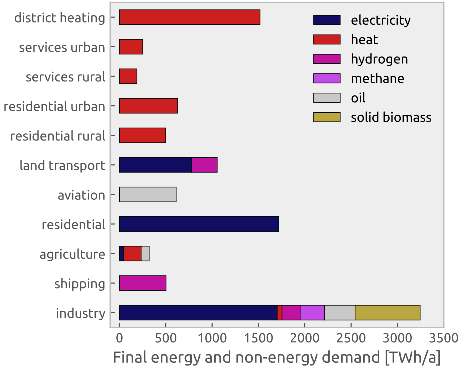


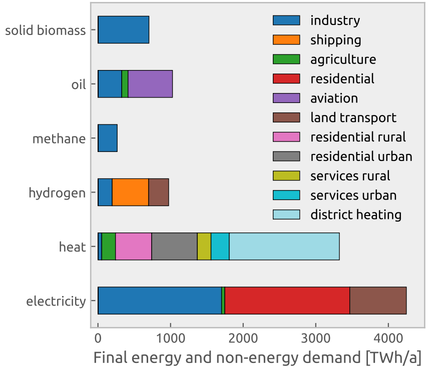
- **left:** electricity and H_2 network expansion
- **surplus and deficits** up to 200 TWh
- Roughly 60% of the hydrogen demand in regions **producing less than 1%** of the total hydrogen supply

Future work

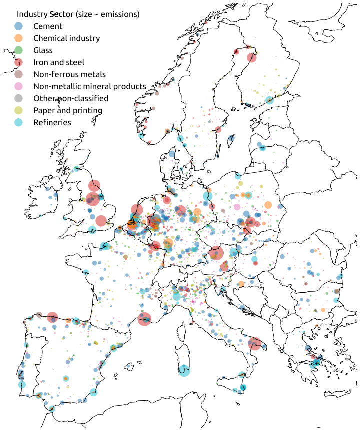
- **pathway** of investments now-2050 (with **technological learning**)
- more endogenous model decisions for **fuel and process switching** in industry
- comparison of local production with import of **synfuels from outside Europe**
- extend offshore wind potentials with **floating wind** and **wake effects**
- spatial optimisation of **CO_2 transport and sequestration infrastructure**

Final Energy Consumption by Carrier





Industry: Process Switching and Carbon Management

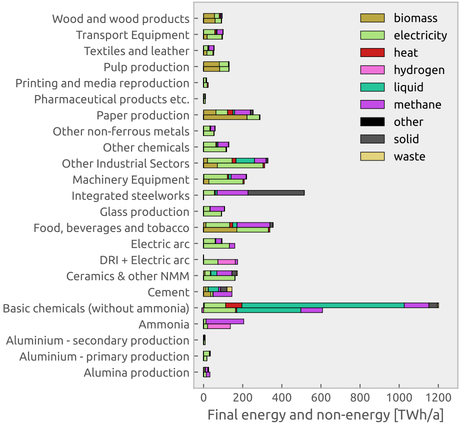


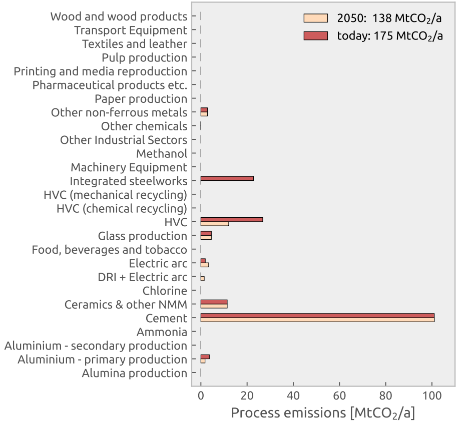
Iron & Steel	70% from scrap, rest from H_2-DRI + EAF
Aluminium	80% recycling; methane for high-enthalpy heat
Cement	Solid biomass; capture of CO_2 emissions
Ceramics	Electrification
Ammonia	Clean hydrogen
Plastics	55% recycling and synthetic naphtha
Other industry	Electrification; process heat from biomass
Shipping	Liquid hydrogen
Aviation	Kerosene from Fischer-Tropsch

Carbon is tracked through system: up to 90% of industrial emissions can be captured; biomass; direct air capture (DAC); sequestration limited to 200 $MtCO_2/a$; carbon in plastics releases into atmosphere

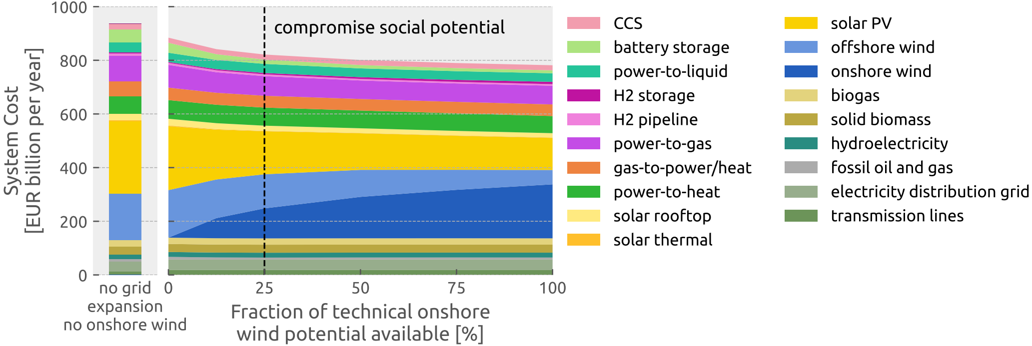
Source: Hotmaps Industrial Sites Database

Industry Sector – Demand and Process Emissions



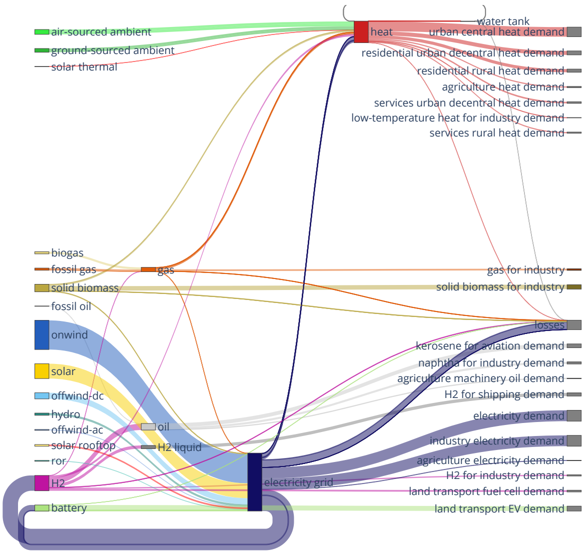


Benefit of high onshore wind potentials



- costs rise by ≈ €104 bn/a (12%) as we **eliminate onshore wind** (25% grid expansion)
- rise drops to ≈ €64 bn/a (7%) if we allow **a quarter of the technical potential**

Energy Sankey Diagram – TWh/a



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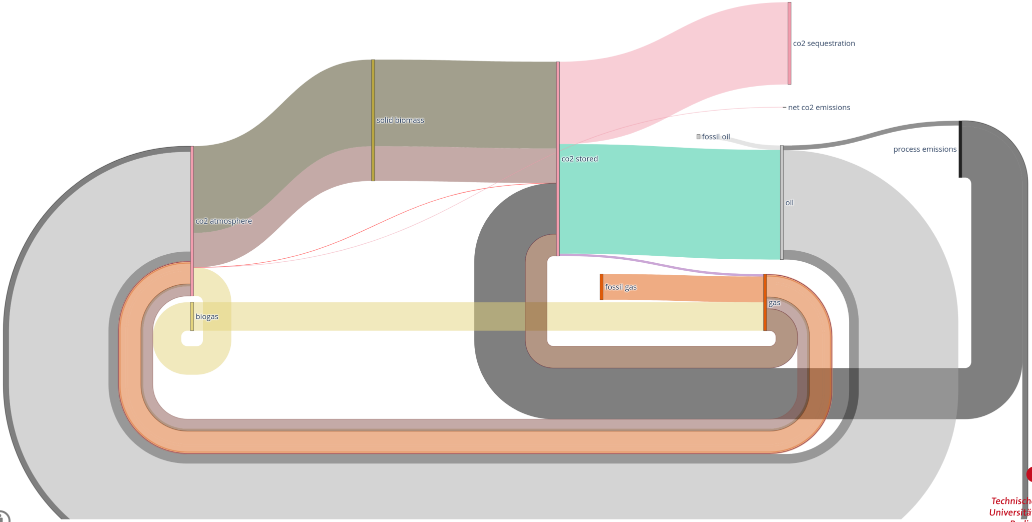
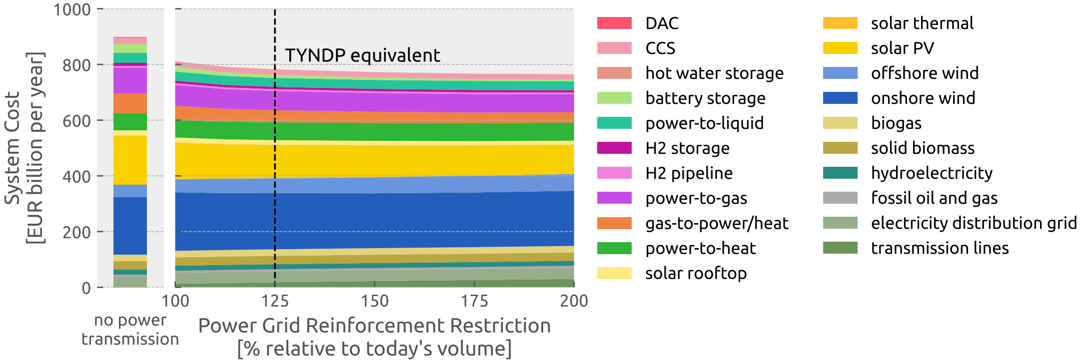
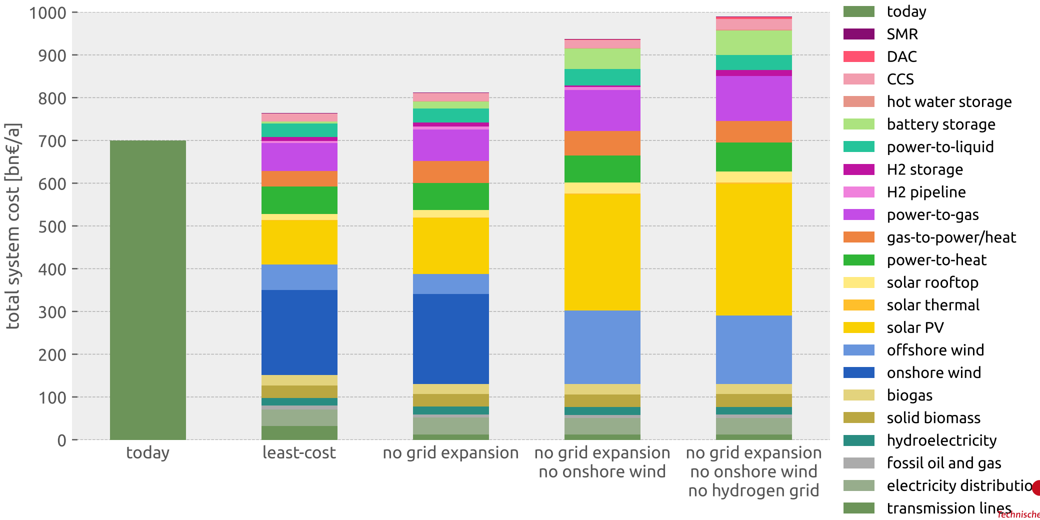
Carbon Sankey Diagram – MtCO2/a



Between full and no power grid expansion

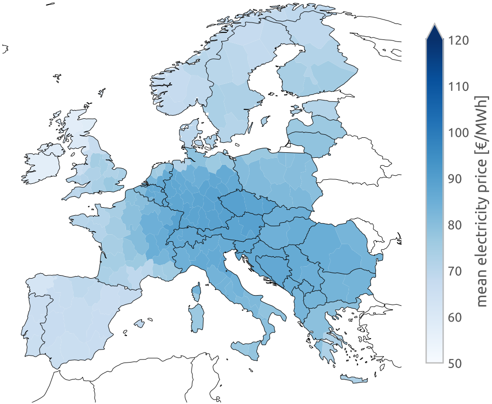


Growing Constraints on Energy System Design

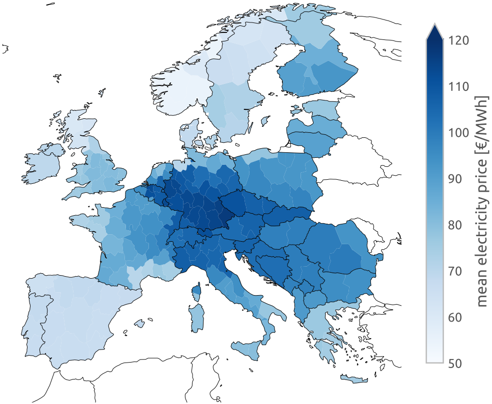


Nodal Prices Electricity

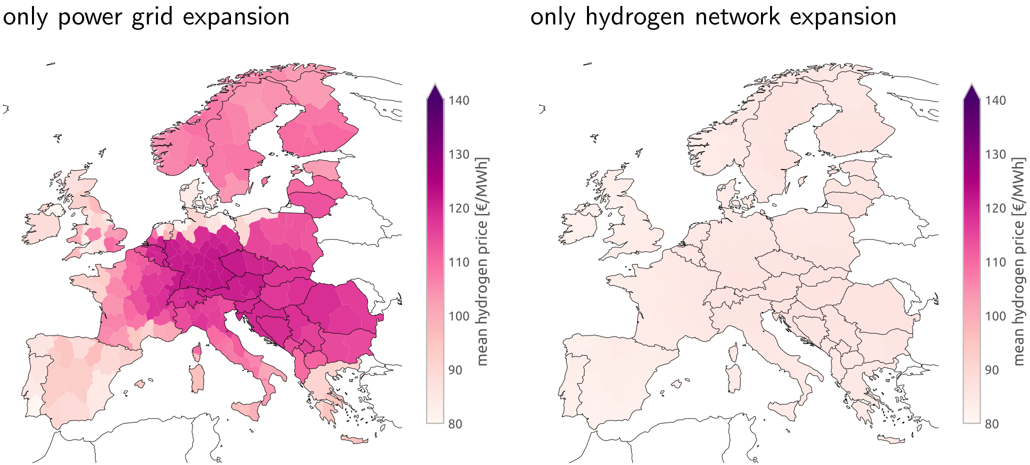
only power grid expansion



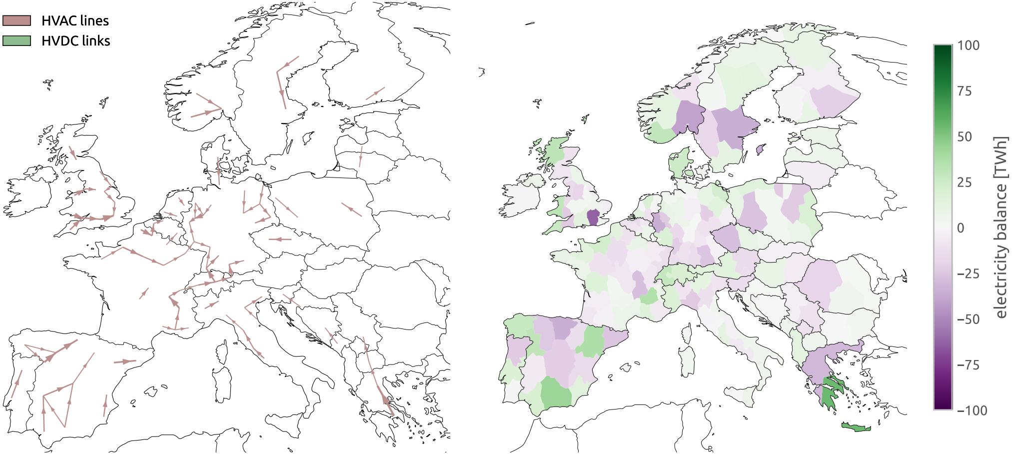
only hydrogen network expansion



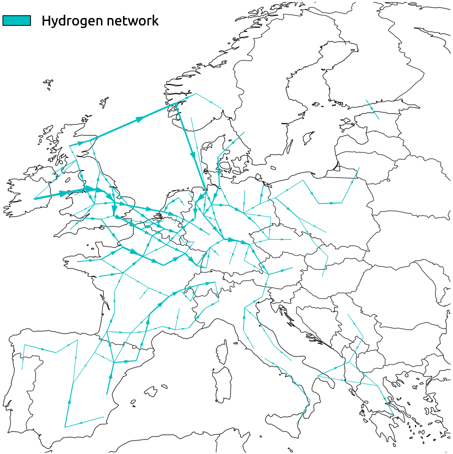
Nodal Prices Hydrogen

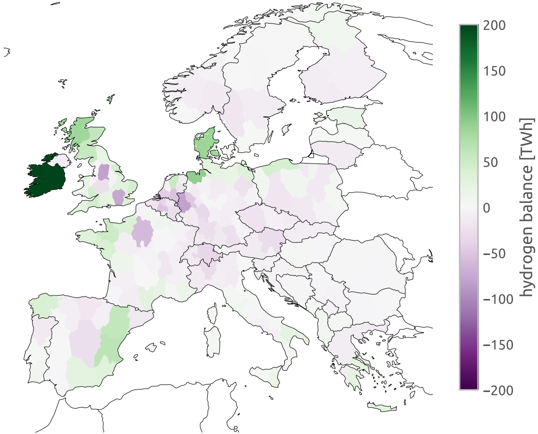


Electricity Net Flows

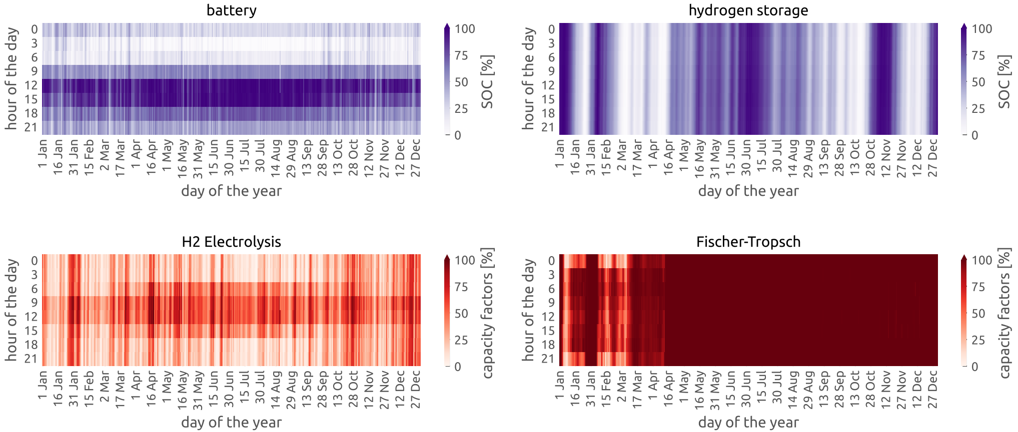


Hydrogen Net Flows

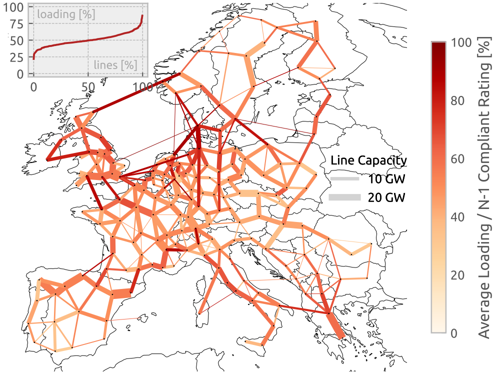


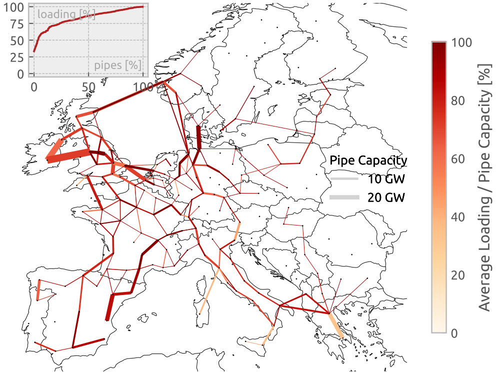


Utilisation Patterns

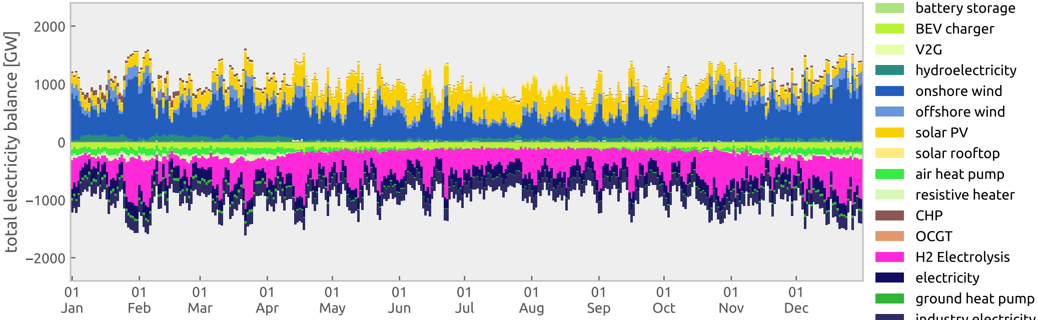


Network Loading



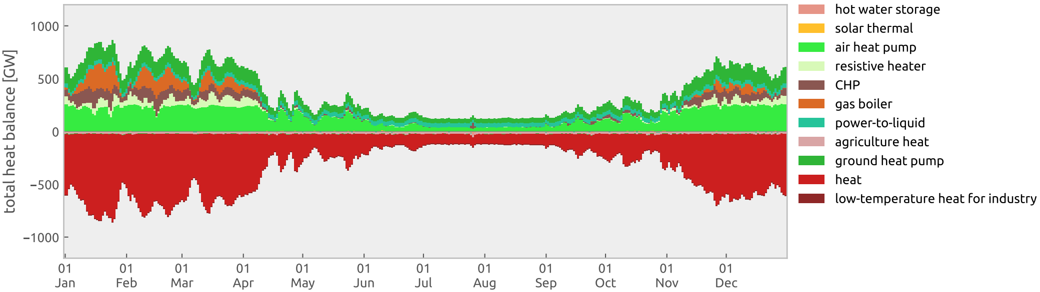


Time Series Electricity Balance



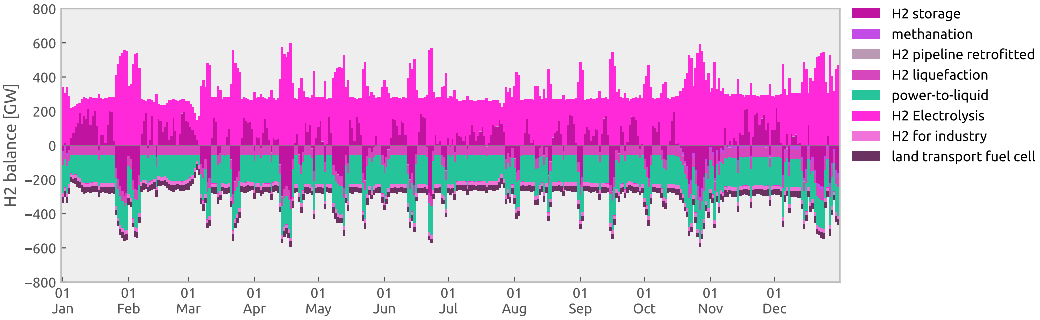
- little firm capacity (100-200 GW)
- CHP and OCGT power backup

Time Series Heat Balance



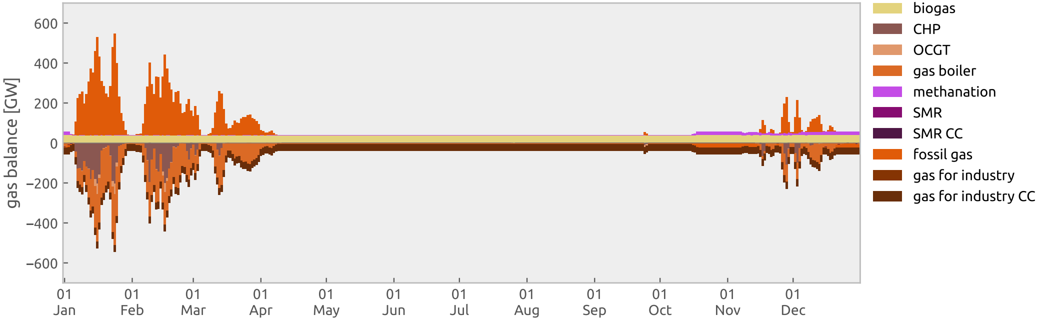
- strong seasonality of heat demand
- waste heat recovery from synfuel production in district heating

Time Series Hydrogen Balance

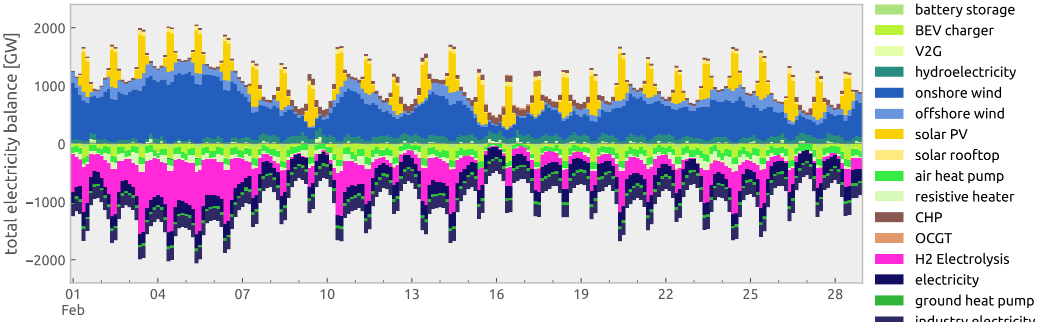


- most hydrogen demand for feedstock not end-use
- green hydrogen preferred over blue hydrogen due to limited sequestration potentials

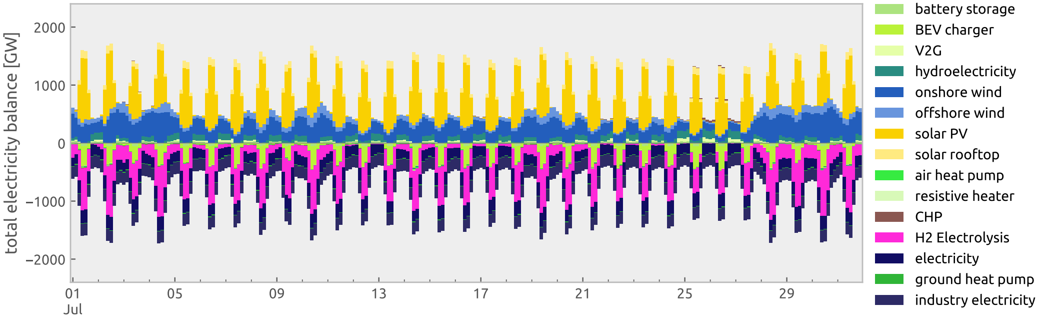
Time Series Methane Balance



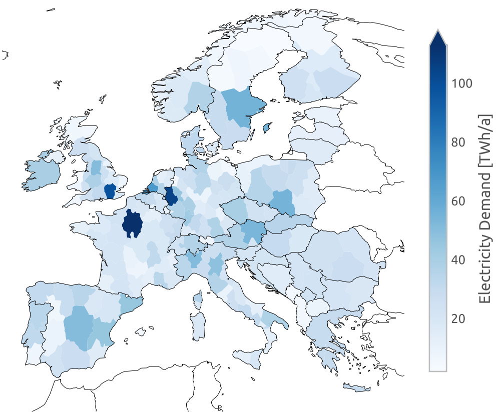
Time Series Electricity Balance – February

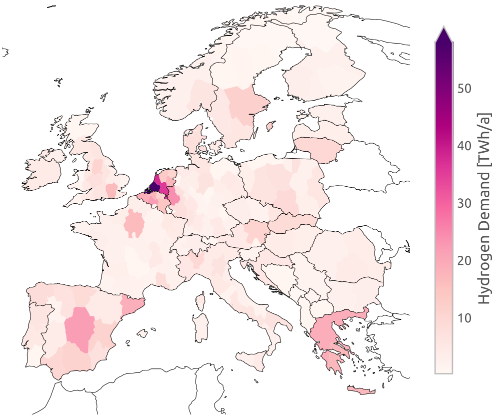


Time Series Electricity Balance – July



Demand Maps – Electricity and Hydrogen





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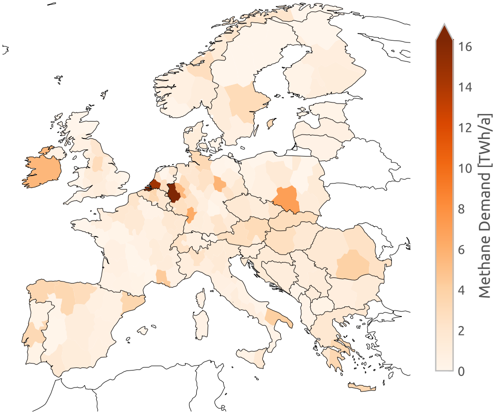
Demand Maps – Methane and Liquid Hydrocarbons



Demand Maps – Heat and Solid Biomass