Benefits of a Hydrogen Network in Europe

~~Can a hydrogen network replace electricity grid expansion~~
~~in a climate-neutral scenario for the European energy system?~~

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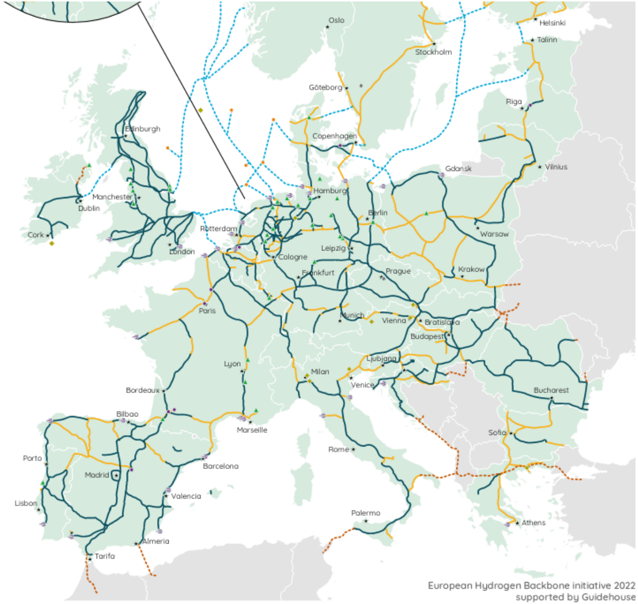
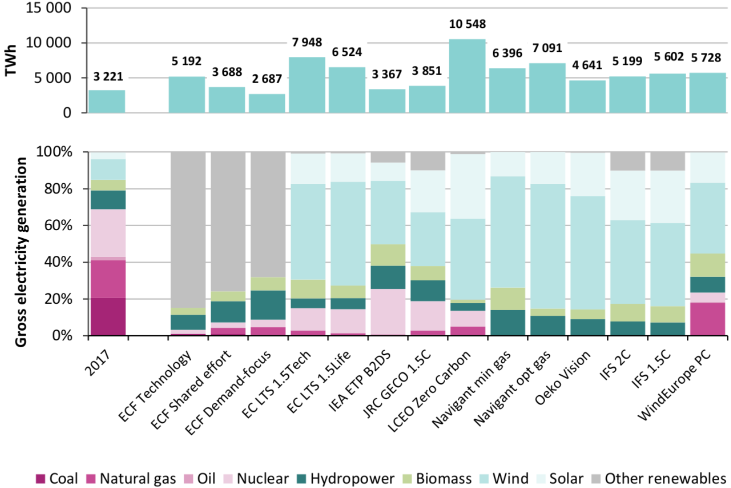


Source: European Hydrogen Backbone (April 2022)

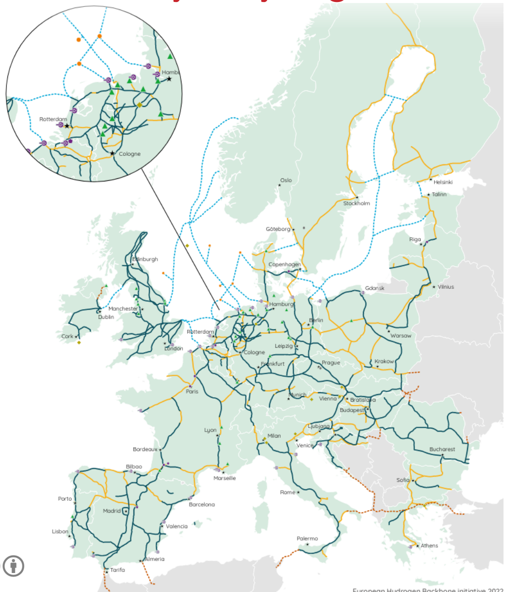
2050 scenarios for Europe: power demand doubles, mostly met by VRE



Source: JRC, 2020, https://ec.europa.eu/jrc/en/publication/towards-net-zero-emissions-eu-energy-system-2050

Problem: collides with low acceptance for power grid and onshore wind

Can electrolytic hydrogen and a hydrogen pipeline network help?



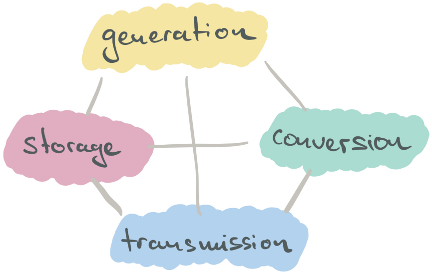
Can we substitute for power grid expansion by producing **electrolytic hydrogen** near remote high-yield generation sites and transporting it to demand clusters through a new or repurposed **hydrogen pipeline network**?

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

Modelling challenges

Challenge 1: Need spatial resolution to see grid bottlenecks & infrastructure trade-offs.
→ One node per country won't work.

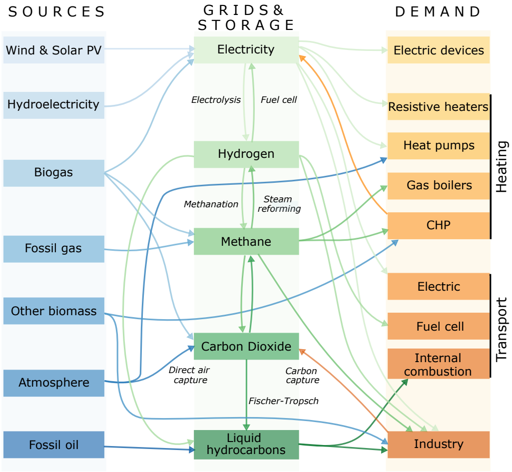
Challenge 2: Need to co-optimise balancing solutions with spatio-temporal variability.
→ Optimising separately won't work.

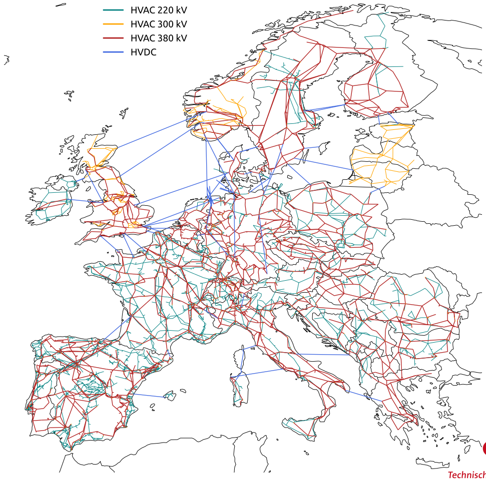


Requires **very large** LP models, lots of data, and methods for complexity management.

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

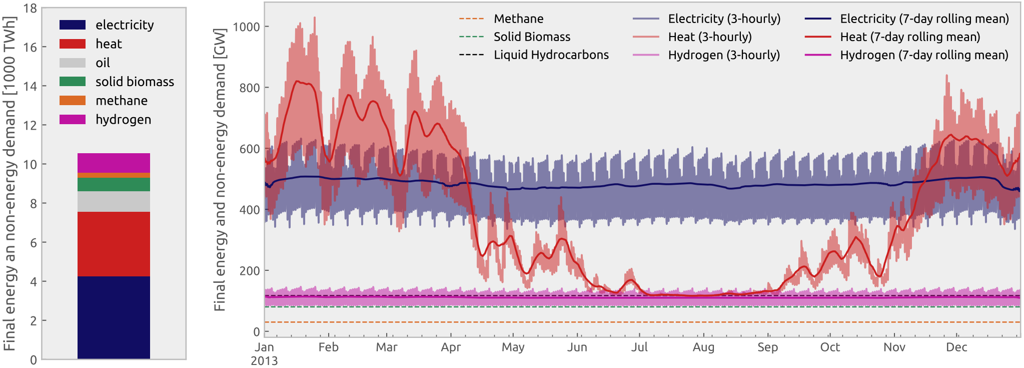
Model for Europe with all energy flows... and bottlenecks in energy networks.





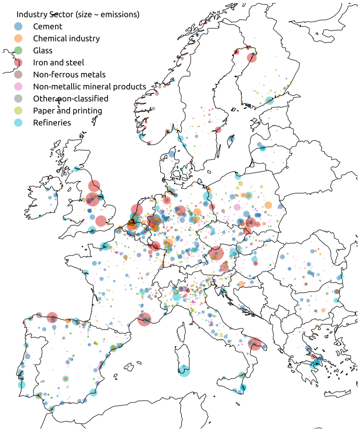
Source: https://github.com/pypsa/pypsa-eur-sec

Heat demand is strongly seasonally peaked!



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

Industry: Process Switching and Carbon Management

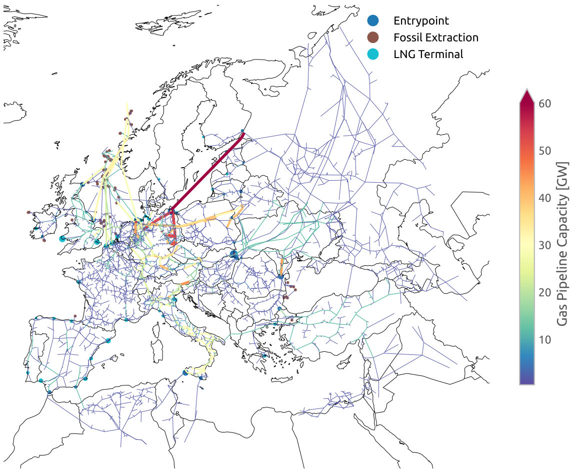


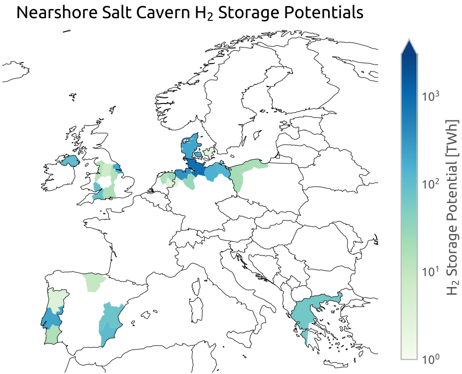
Iron & Steel	70% from scrap, rest from H_2-DRI + EAF
Aluminium	80% recycling; methane for high-enthalpy heat
Cement	Solid biomass; capture of CO_2 emissions
Ceramics	Electrification
Ammonia	Clean hydrogen
Plastics	55% recycling and synthetic naphtha
Other industry	Electrification; process heat from biomass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

Gas network with H_2 retrofitting option and cavern storage potentials

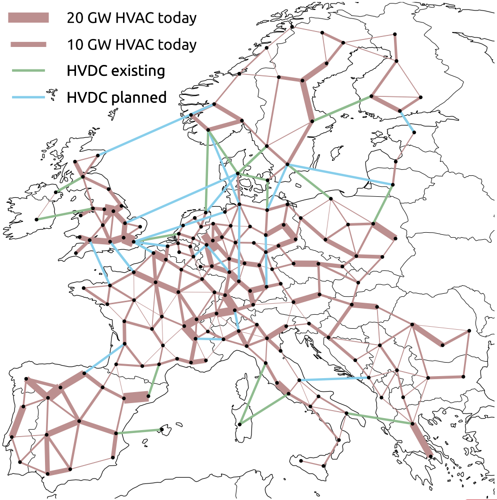




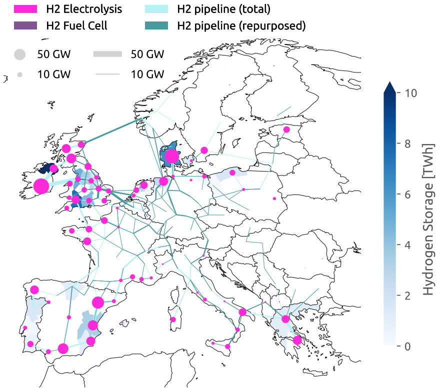
Source: SciGRID_gas and Caglayan, 2020

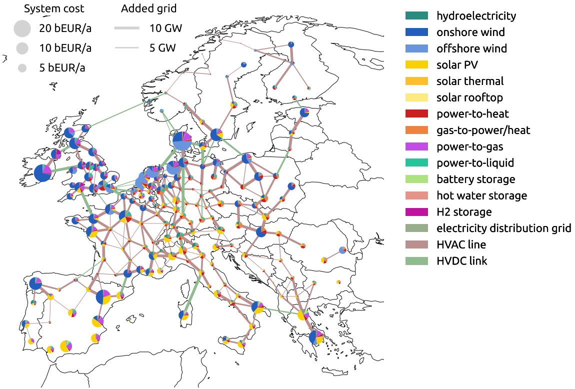
Scenarios for a Climate-Neutral European Energy System

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



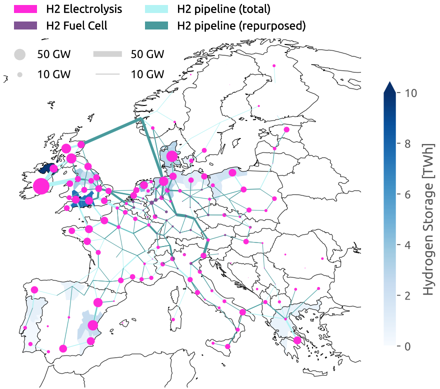
Least-cost solution – power and hydrogen network expansion

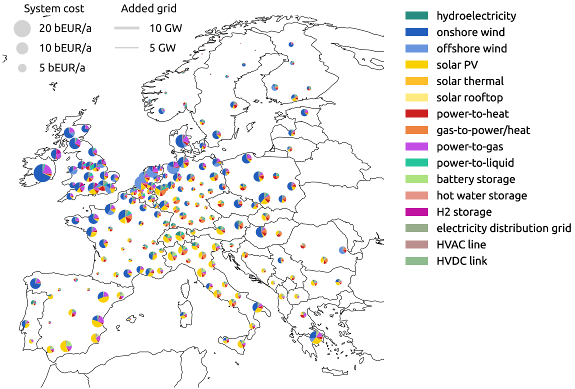




What if we restrict electricity grid reinforcements?

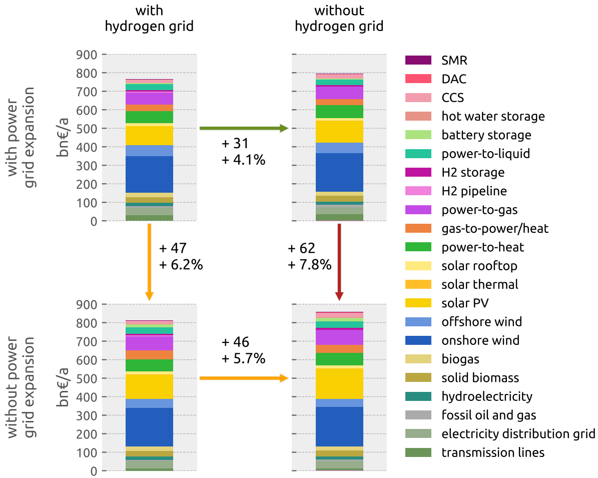
A more restricted solution – no power grid expansion





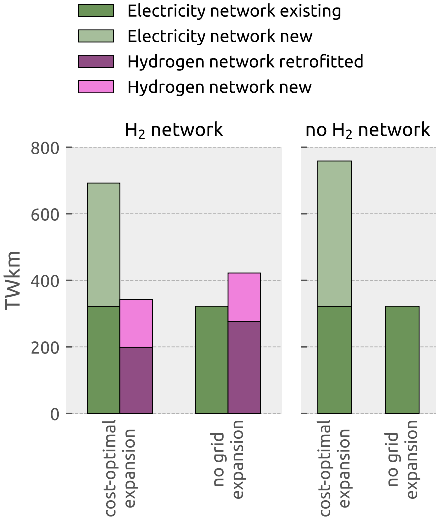
How much more expensive is this solution?

Benefit of hydrogen network infrastructure



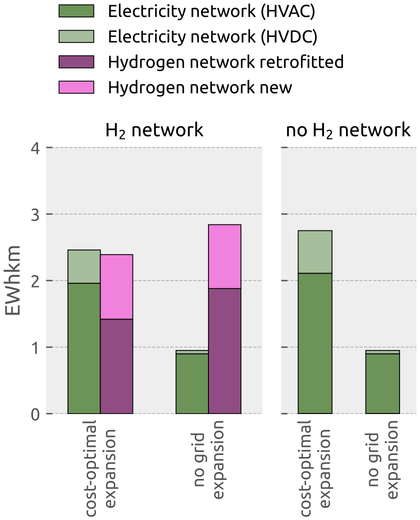
- **Cost** of hydrogen network: €6-8 billion per year
- **Net benefit** is much higher: €31-46 billion per year
- Power grid brings **more benefit**: €47-62 billion per year
- Hydrogen network can only **partially substitute**
- Systems **without any grid expansion** are also feasible
- both offer **complementary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

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, hydrogen grid **transmits 3x more energy** than electricity grid
- **utilisation rate** of hydrogen grid (59%) is much higher than power grid (35%)

Electricity and hydrogen grid expansion and level of retrofitting



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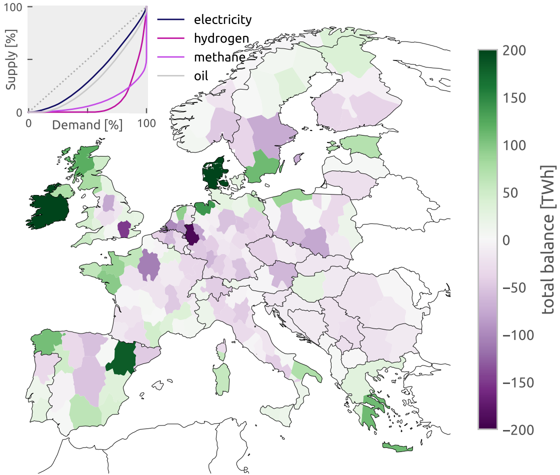
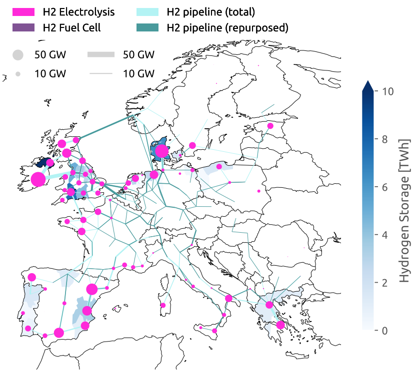
All cases: strong regional imbalance between generation and demand

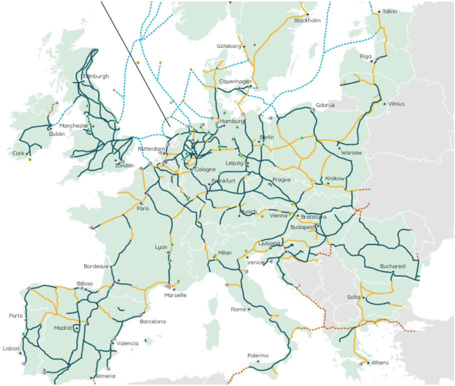


- **left:** electricity and H_2 network expansion
- **surplus and deficits** up to 200 TWh
- Roughly 60% of the hydrogen demand in regions **producing less than 1%** of the total hydrogen supply

Comparison to *European Hydrogen Backbone*



58-66% retrofitted



Source: European Hydrogen Backbone (April 2022)

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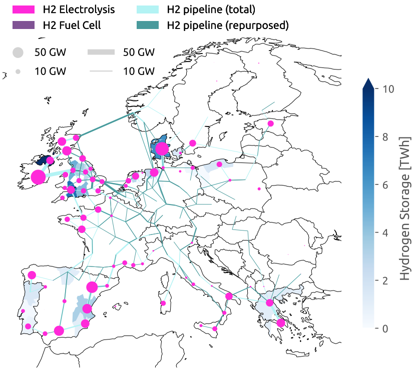
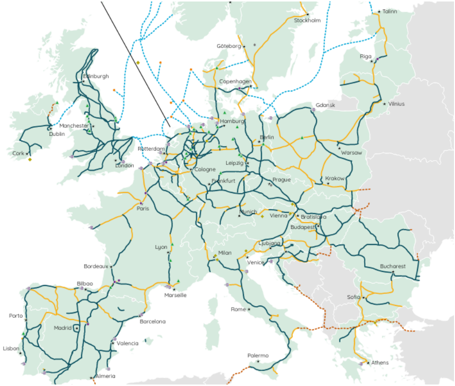
Comparison to *European Hydrogen Backbone*



58-66% retrofitted
342-422 TWkm



69% retrofitted

Source: European Hydrogen Backbone (April 2022)

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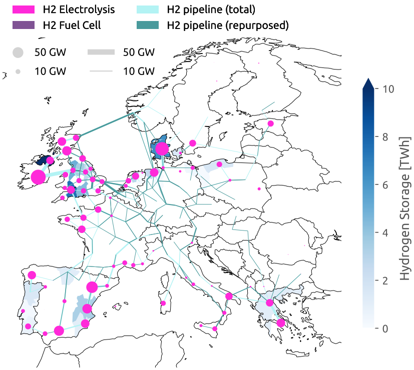
Comparison to *European Hydrogen Backbone*



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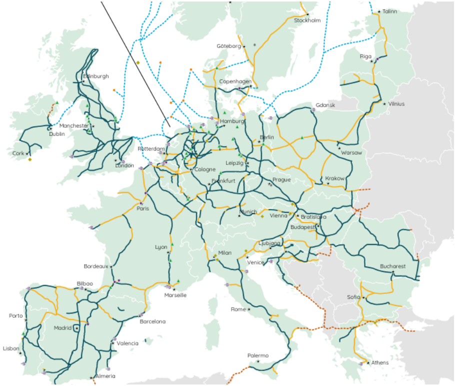

69% retrofitted
309 TWkm

Source: European Hydrogen Backbone (April 2022)

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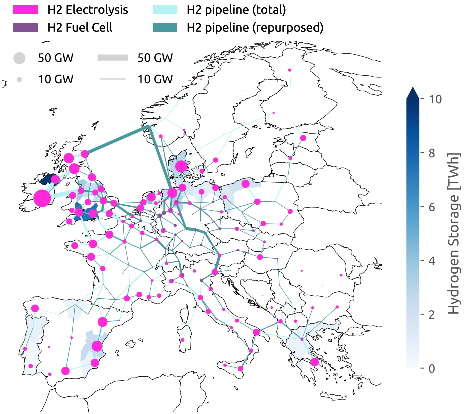
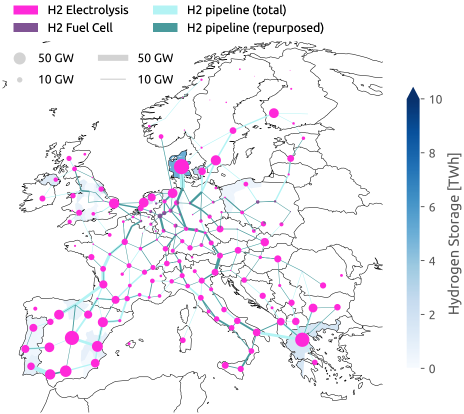
What about restricting onshore wind potentials?

With onshore: British Isles and North Sea dominate hydrogen production

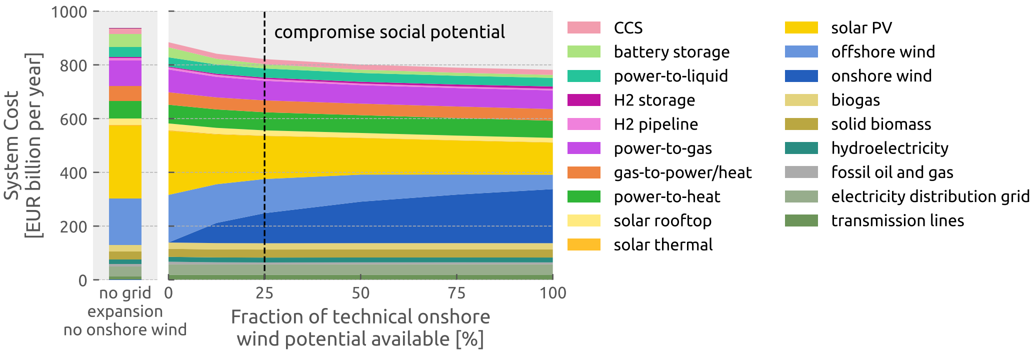


Without onshore: Southern Europe becomes much larger exporter of hydrogen



Energy imports into Europe would also alter infrastructure needs!

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**

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**

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 - therefore **openness and transparency are critical**, guaranteed by open licences for data and code

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Meta

Find the slides:

https://neumann.fyi/files/neumann-euro-2022.pdf

Find the open energy system model:

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

Find the open modelling framework:

https://github.com/pypsa/pypsa

Send an email:

mailto:f.neumann@tu-berlin.de

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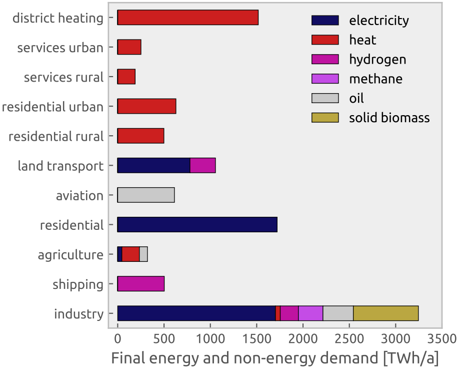
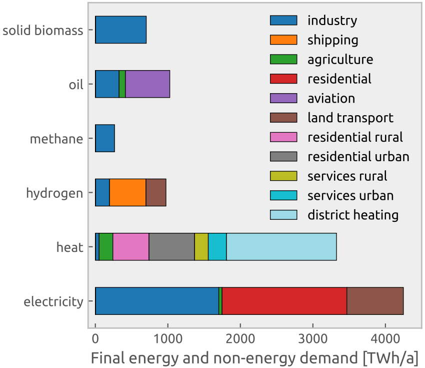
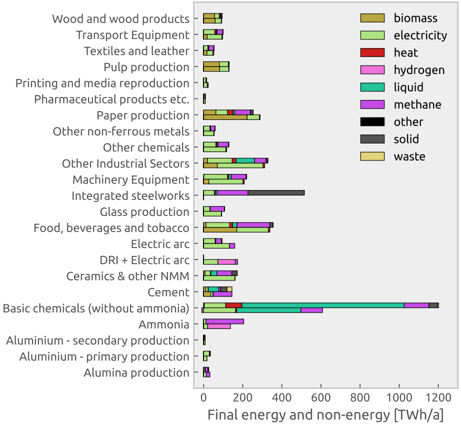
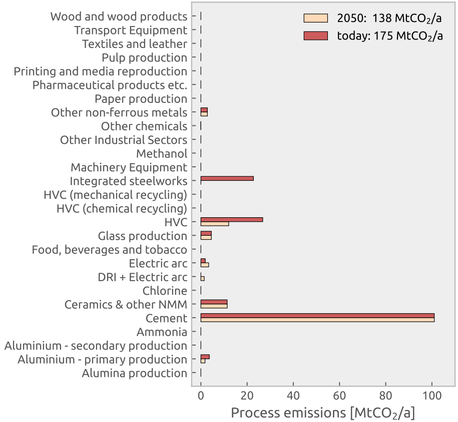
Final Energy Consumption by Carrier





Industry Sector – Demand and Process Emissions





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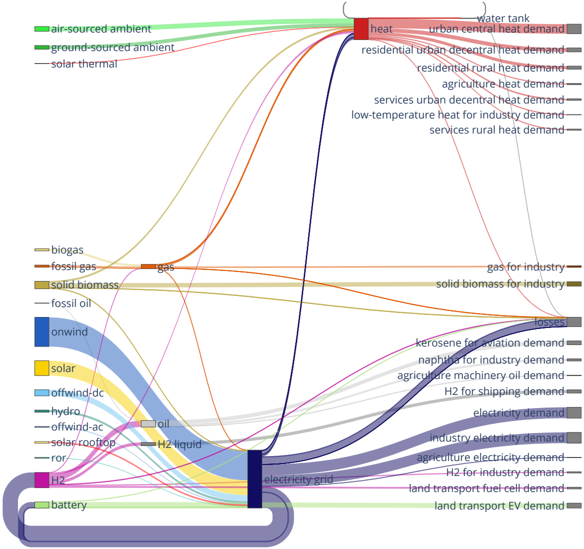
Energy Sankey Diagram – TWh/a



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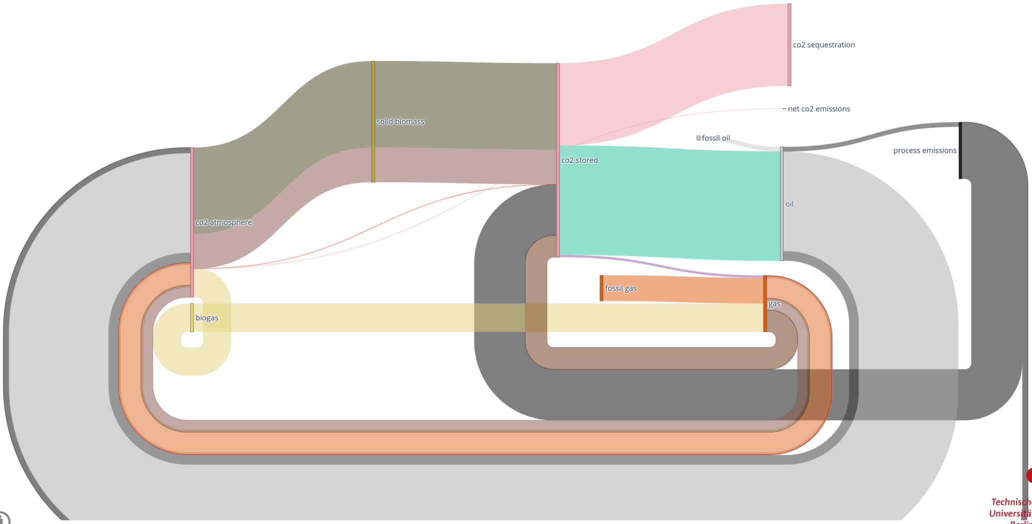
Carbon Sankey Diagram – MtCO2/a



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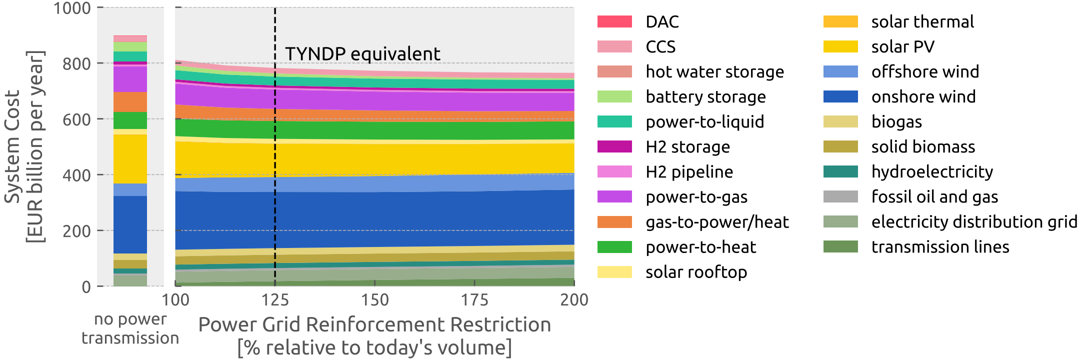
Between full and no power grid expansion



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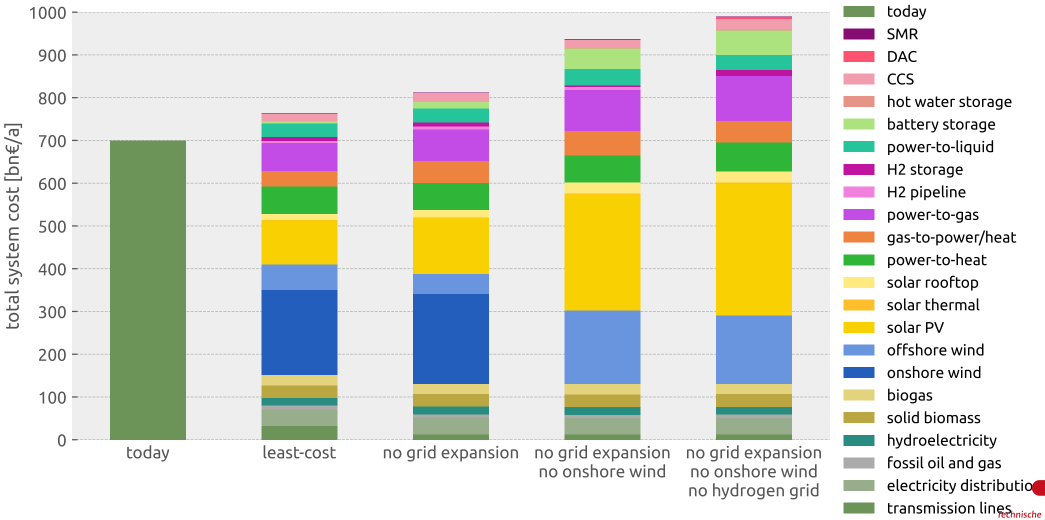
Growing Constraints on Energy System Design



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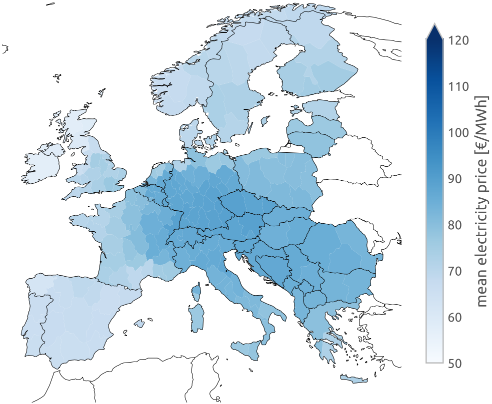
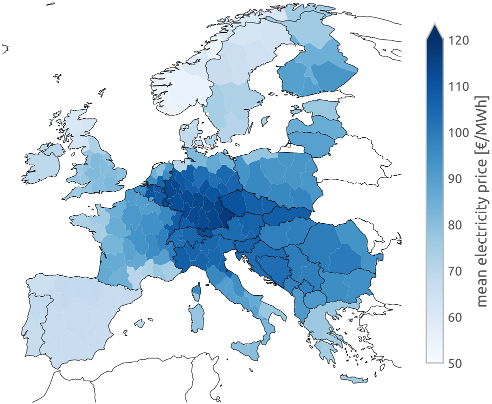
Nodal Prices Electricity

only power grid expansion



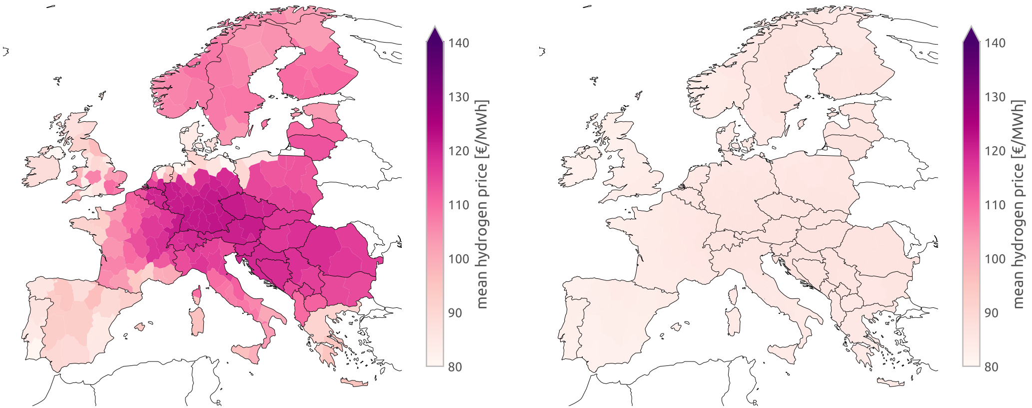
only hydrogen network expansion



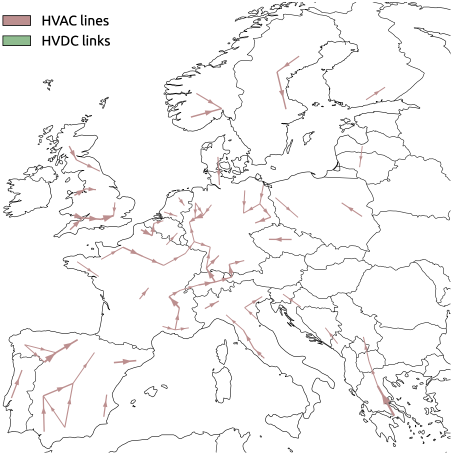
Nodal Prices Hydrogen

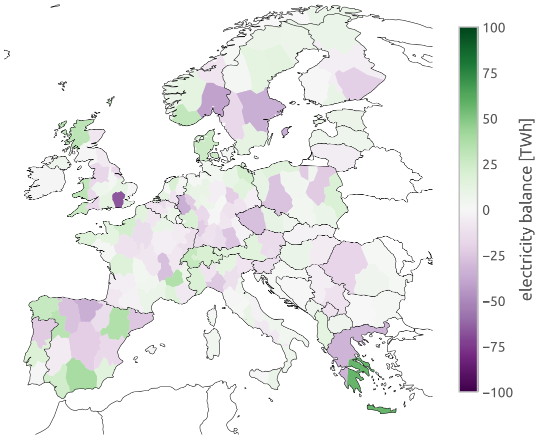
only power grid expansion

only hydrogen network expansion

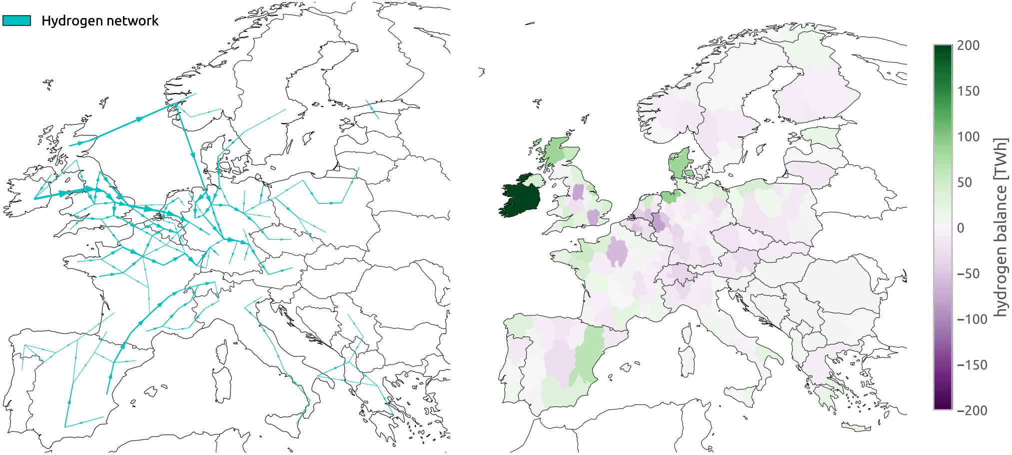


Electricity Net Flows

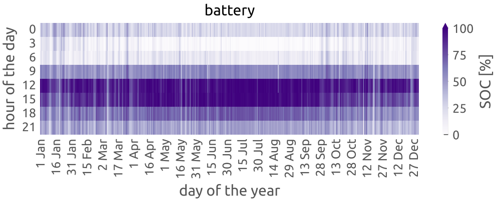


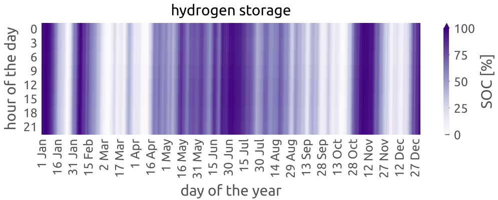


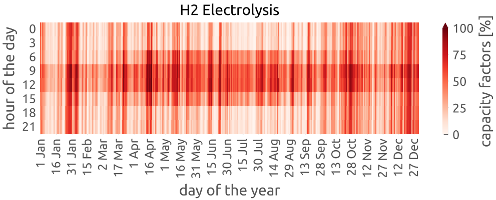
Hydrogen Net Flows

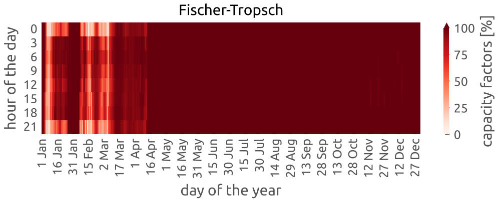


Utilisation Patterns

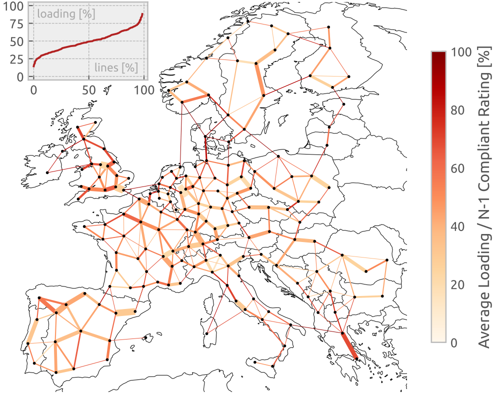


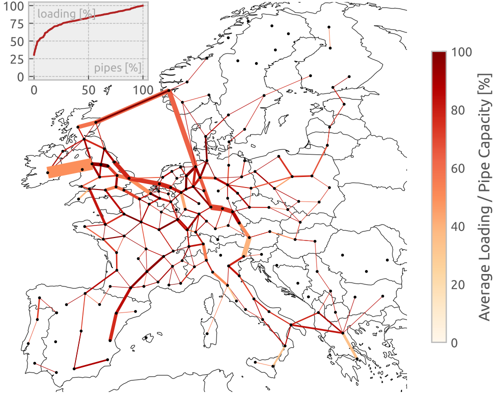






Network Loading





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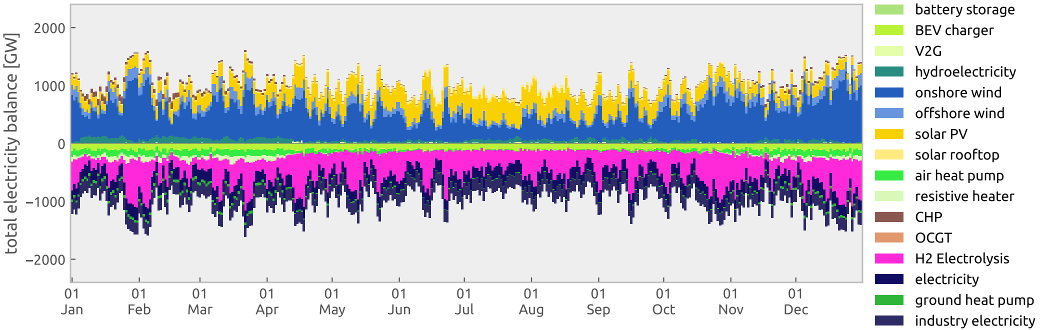
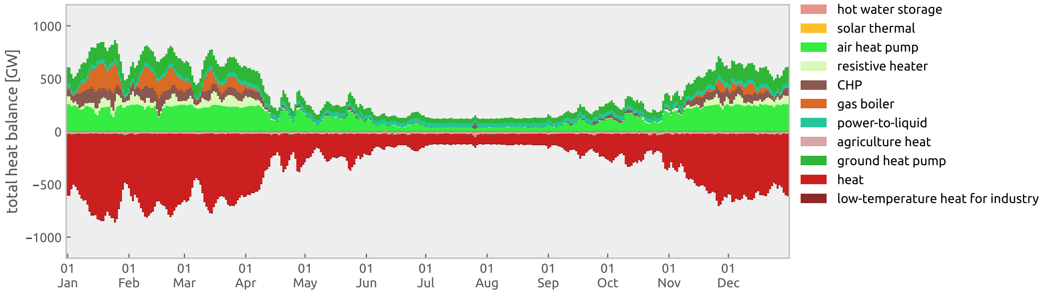
Time Series Electricity Balance



- 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

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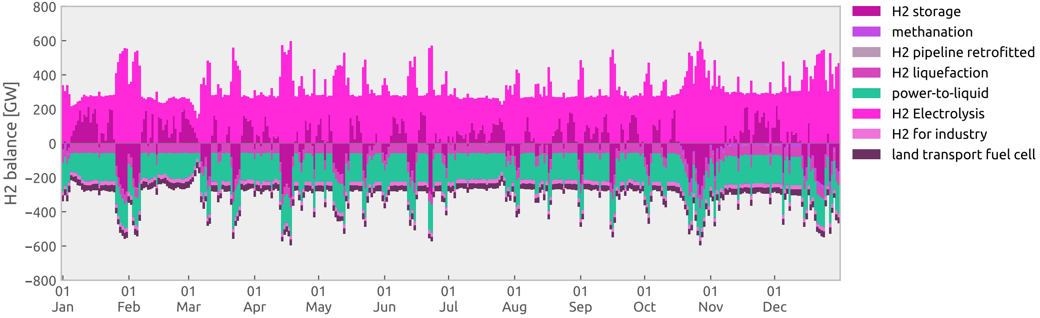
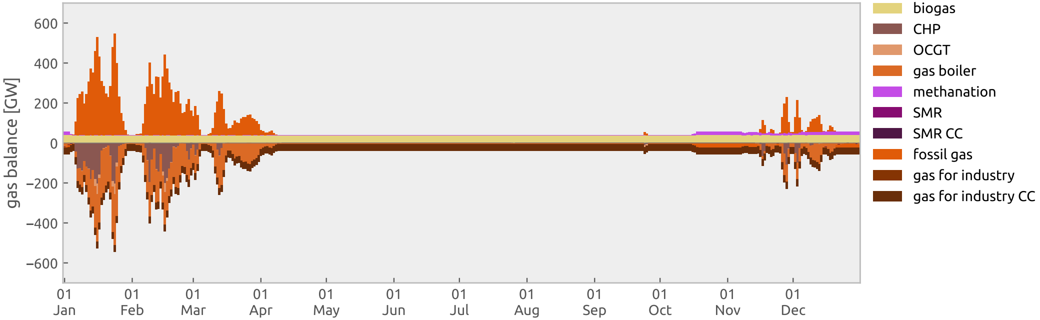
Time Series Hydrogen Balance

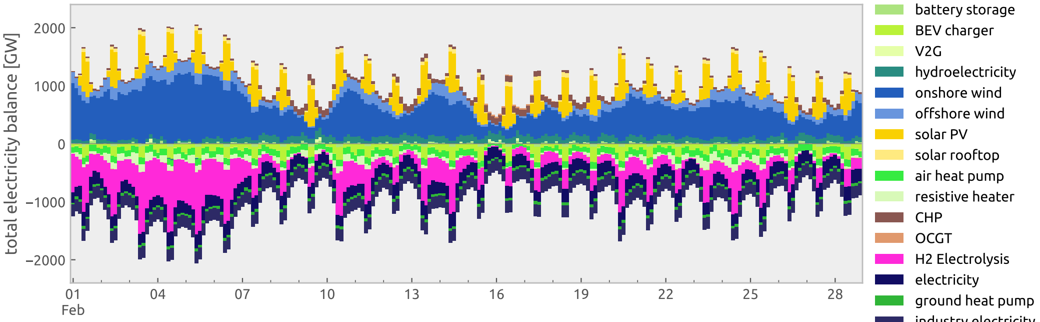


- most hydrogen demand for feedstock not end-use
- green hydrogen preferred over blue hydrogen due to limited sequestration potentials

Time Series Methane Balance



Time Series Electricity Balance – February



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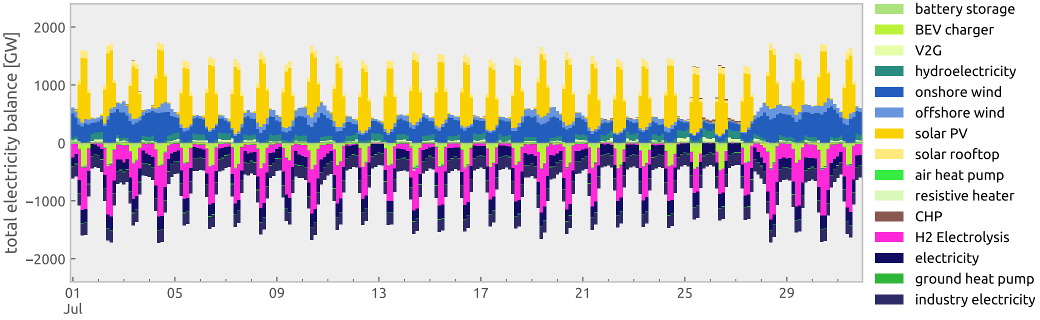
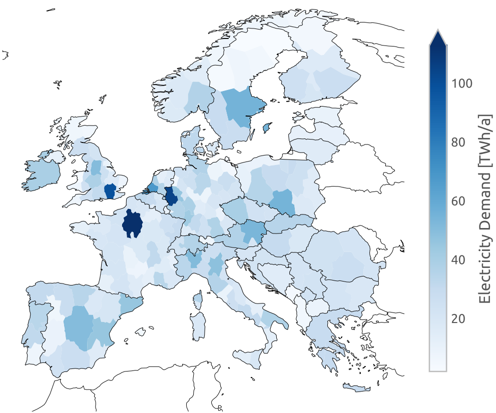
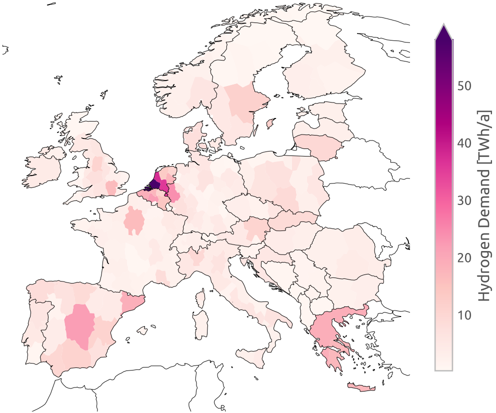
Time Series Electricity Balance – July

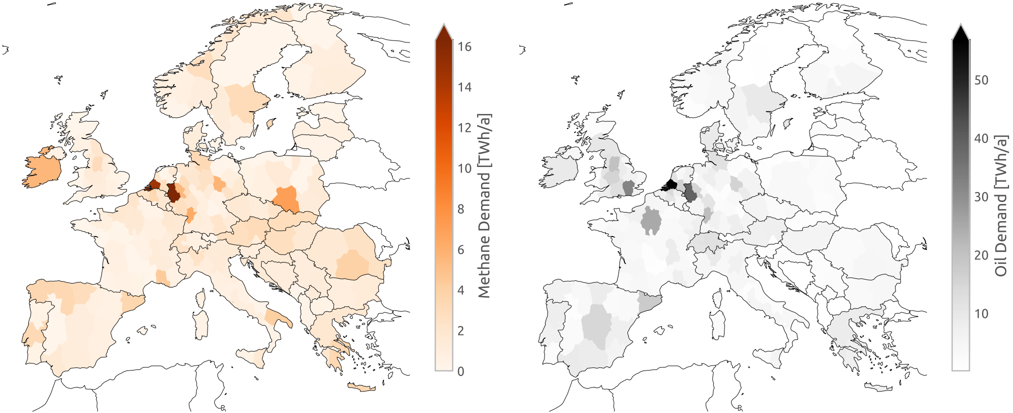


Demand Maps – Electricity and Hydrogen





Demand Maps – Methane and Liquid Hydrocarbons



Demand Maps – Heat and Solid Biomass