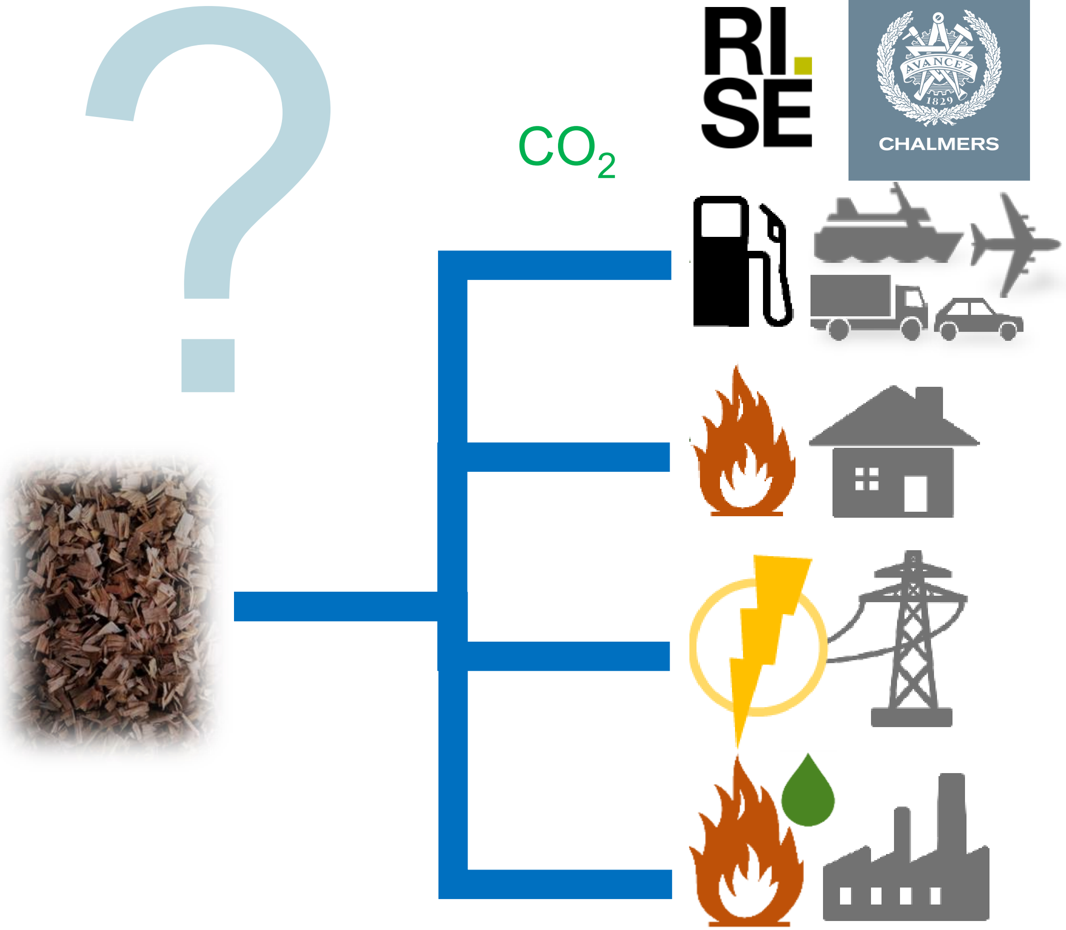
How can biomass be cost-effectively used to achieve emissions targets in the European energy system?

Markus Millinger | Svebio Fuel Market Day

25th September 2025

Biomass

- Limited resource with trade-offs
- RED III proposed to exclude forest residues
- Cost-effective use of biomass residues in the energy system?
    - Fuels?
    - Variation management / firm generation?
    - Industry?
    - Negative emissions?



Millinger et.al. 2021: https://doi.org/10.1039/D0SE01067G

Key take-aways

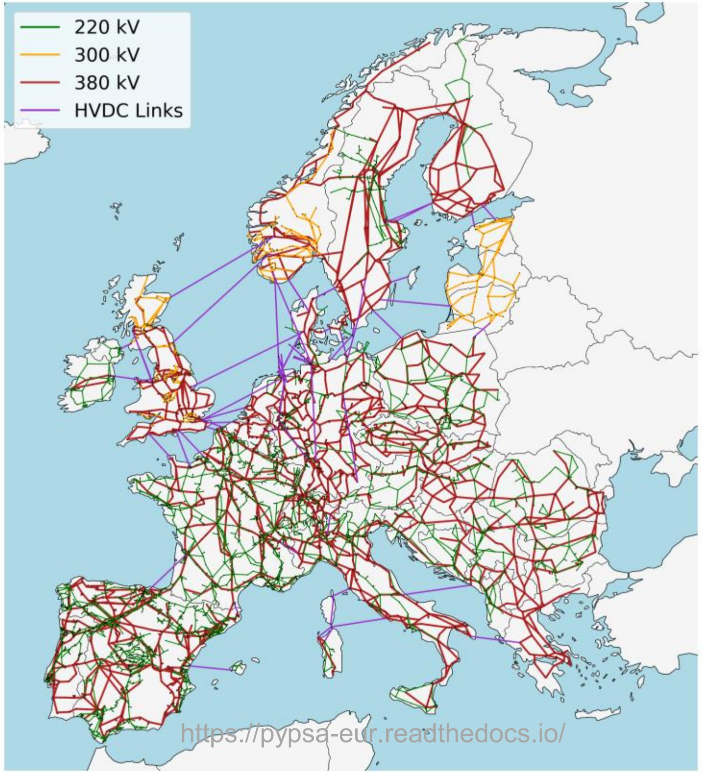
- Removing **biomass residues** results in **~20%** higher energy system cost, similar to wind power and electrolysers
- Main value of biomass is **carbon provision** for further utilisation or negative emissions
- Except for some dispatchable back-up power, it is **not crucial what biomass is used** for if it is connected to carbon capture, which strongly enhances value of biomass
- High CAPEX of carbon capture → **cost-effective in processes with high capacity factors**
- Renewable chemicals and **liquid fuels most challenging** part of the energy system

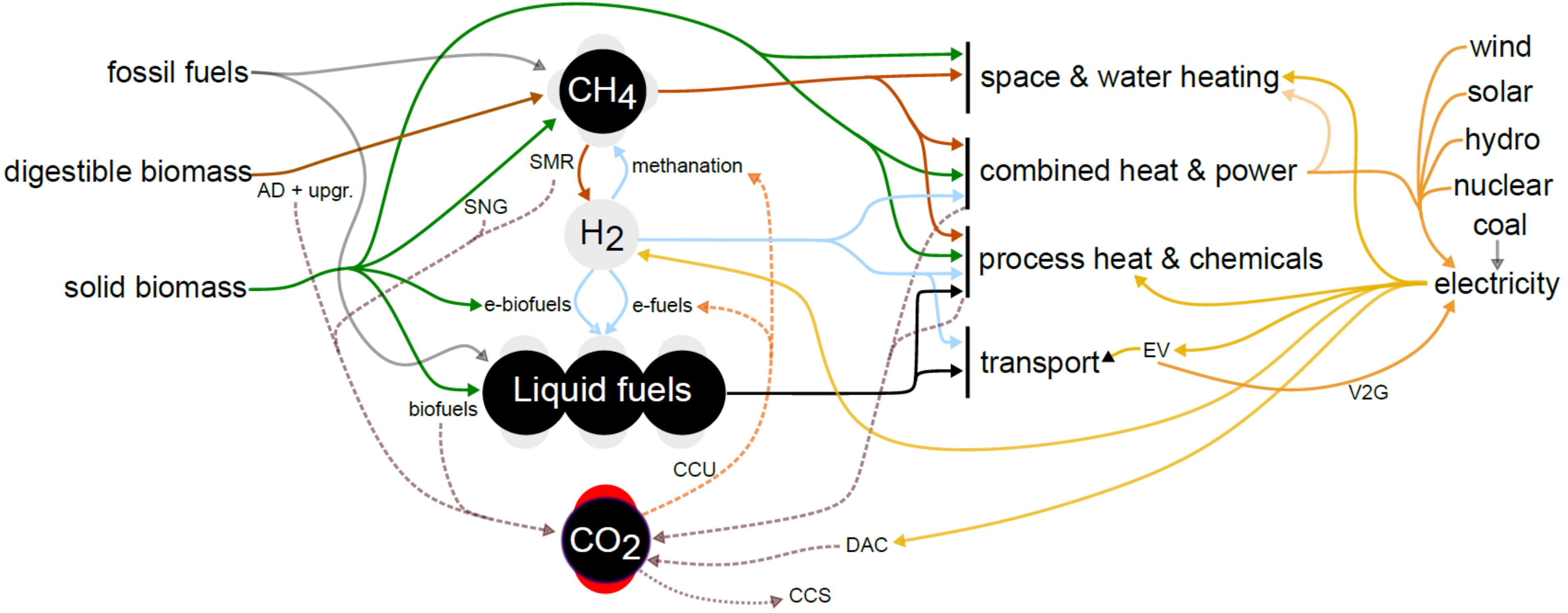
Model

- **PyPSA**-Eur-Sec. Optimisation of capacity and dispatch across all sectors. Open source.

Set-up:

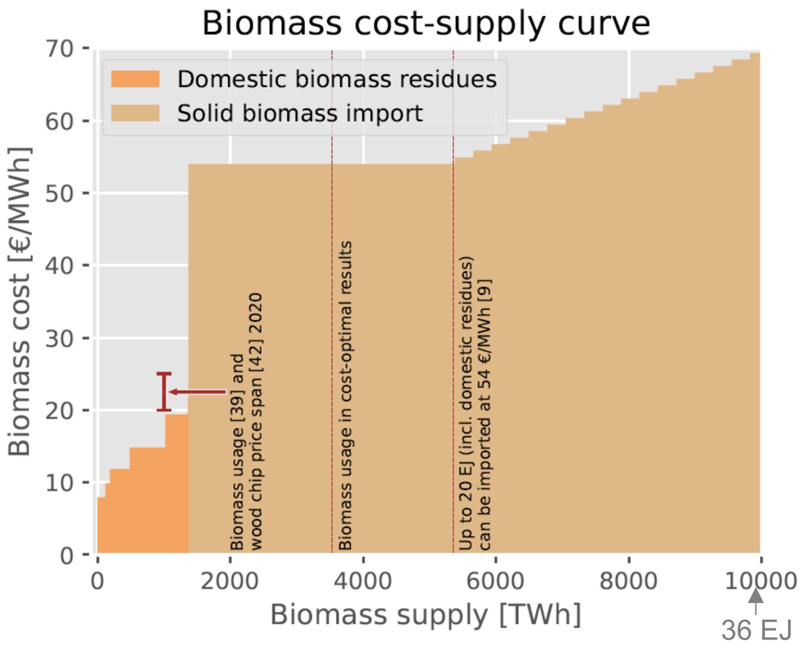
- Europe in 37 nodes, 5H temporal resolution, **overnight**
- **Net-negative** (-110%) CO_2 emissions vs 1990, with limited carbon storage
- Biomass competes with electricity- and fossil-based options in all sectors




fossil fuels
digestible biomass
AD + upgr.
solid biomass
CH_4
SMR
methanation
SNG
H_2
e-biofuels
e-fuels
Liquid fuels
biofuels
CCU
CO_2
DAC
CCS
space & water heating
combined heat & power
process heat & chemicals
transport
EV
V2G
wind
solar
hydro
nuclear
coal
electricity

Biomass

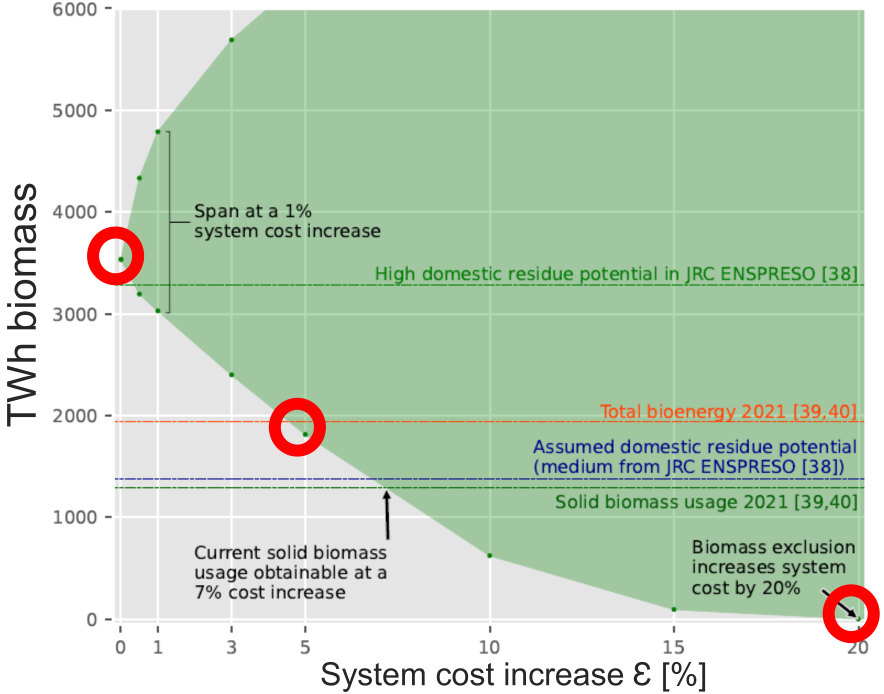
- Domestic residues and more expensive biomass imports
- All biomass processes can choose to add carbon capture (except small-scale heating)
- Carbon capture: energy penalty for added heat demand + substantial infrastructure cost



Millinger et.al. (2023): https://doi.org/10.21203/rs.3.rs-3097648/v1

Biomass in the energy system

- 3500 TWh biomass cost-optimal (29% of primary energy; the rest wind, solar and some hydro)
- Biomass limited to current use corresponds to ~5% higher system cost.
- Can be excluded at **~20%** higher system cost (170 B€, or ca total defense spending in EU). Similar to wind power and electrolysers!
- Biomass usage sensitive to **upstream emissions**



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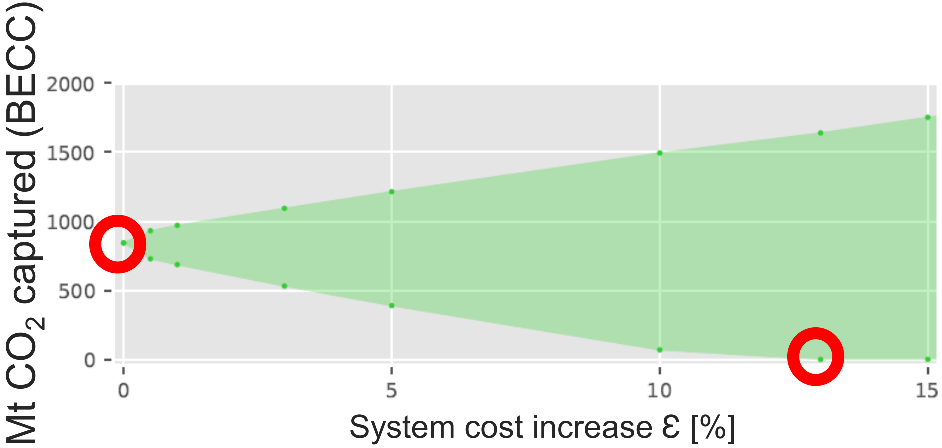
Bioenergy with carbon capture

- Around 900 $MtCO_2$ biogenic capture cost-optimal (21% of total **GHG** emissions in 2021)
- Most biomass usage linked to CC
- Can be excluded @13% higher system cost
- BECC strongly **enhances carbon efficiency** and value of biomass
- BECC is competitive to DAC also given very low DAC cost → may inhibit DAC deployment



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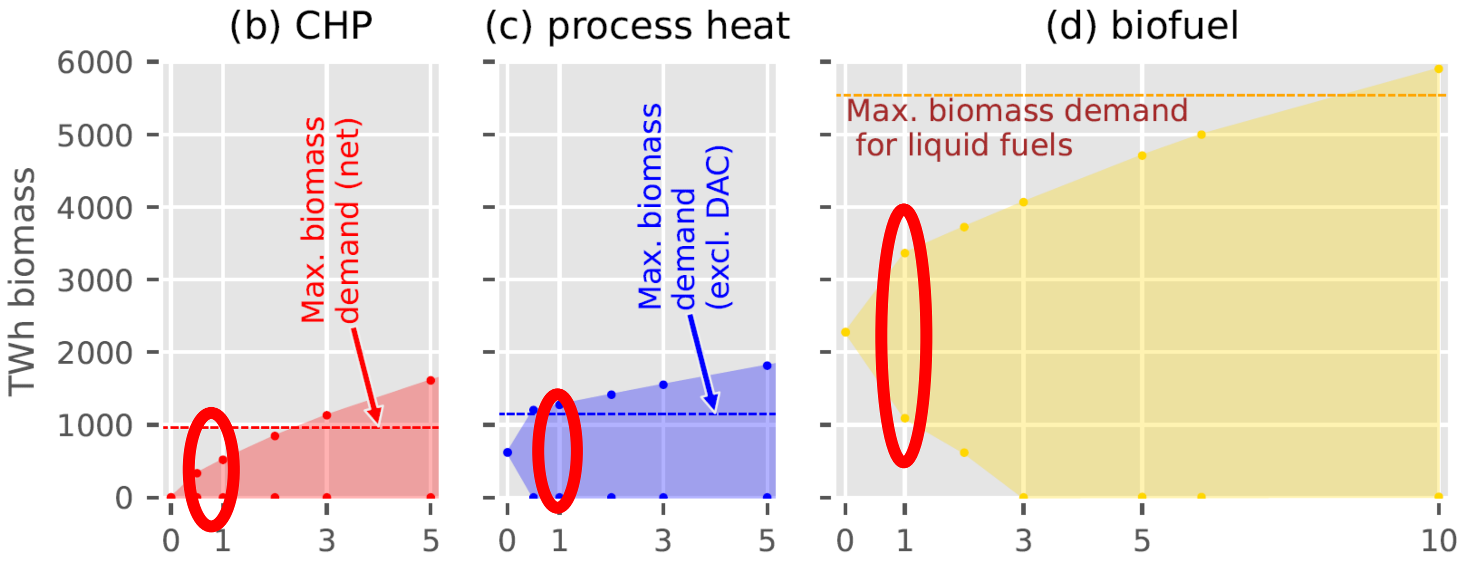
Use of solid biomass



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Role of liquid fuels and chemicals

- Challenge that biofuels enable the last steps towards net-zero, but infrastructure needs to develop well before
- Liquid pathways most affected by uncertain resource availability
- More **carbon storage** enables fossil fuel usage and reduces cost-effectiveness of CCU/e-biofuels in favour of CCS
- What are robust strategies given this uncertainty?

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Biofuels towards net-zero?

- **Upstream emissions** strongly reduce biomass value! → transition from energy crops to biomass residues
- Lignocellulosic biofuels cost-effective but capital intensive → needs **reliable policy**
- C:H ratio mismatch between biomass and fuels → excess carbon (~70%!) can be captured, or H_2 added to enhance carbon efficiency (**e-biofuels**). Depends on how much fossils we (can) enable and how much clean H_2 is available.

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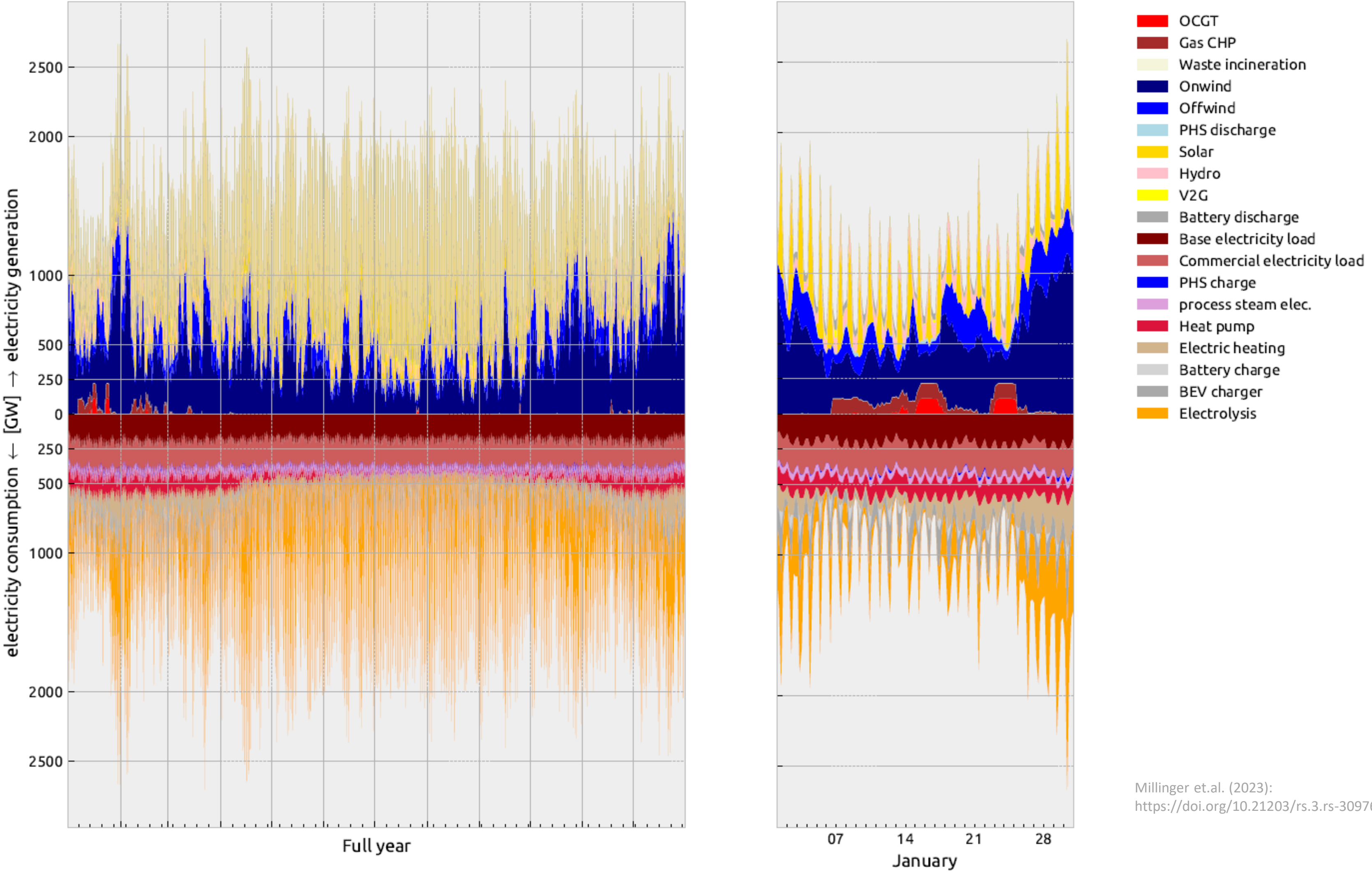

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