Diversity of biomass usage pathways to achieve emissions targets in the European energy system

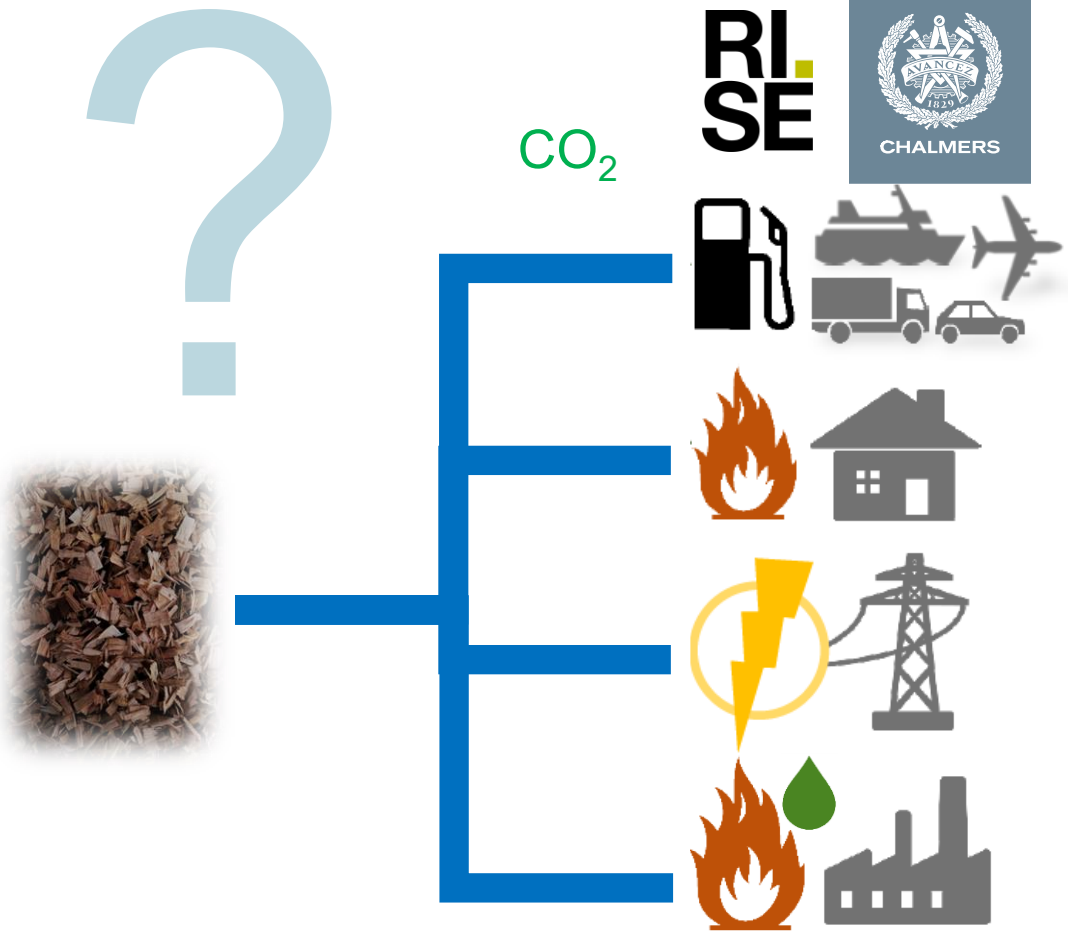
Markus Millinger | UPTAKE webinar

10 September 2025

Co-authors: Fredrik Hedenus, Elisabeth Zeyen, Fabian Neumann, Lina Reichenberg, Göran Berndes

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?



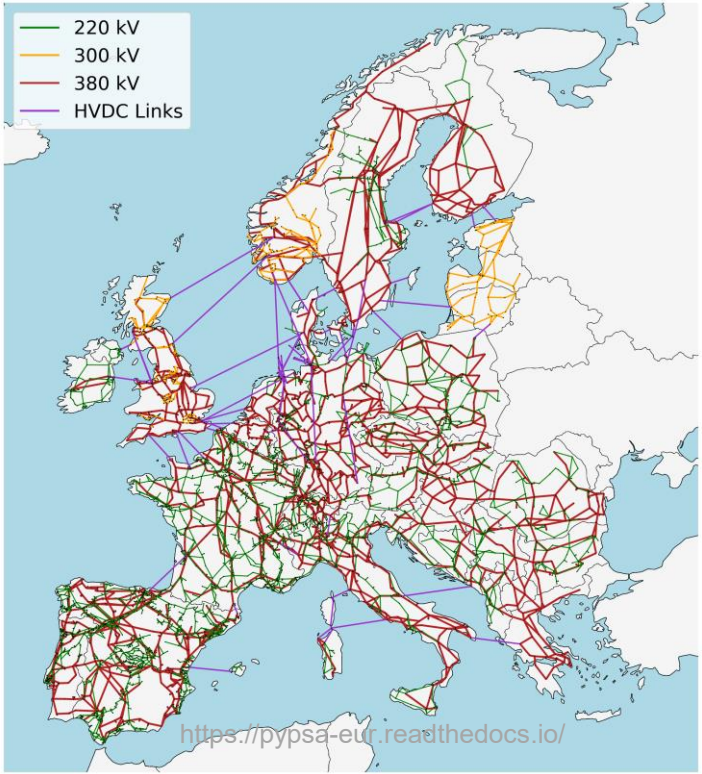
Millinger et.al. 2021:
https://doi.org/10.1039/D0SE01067G

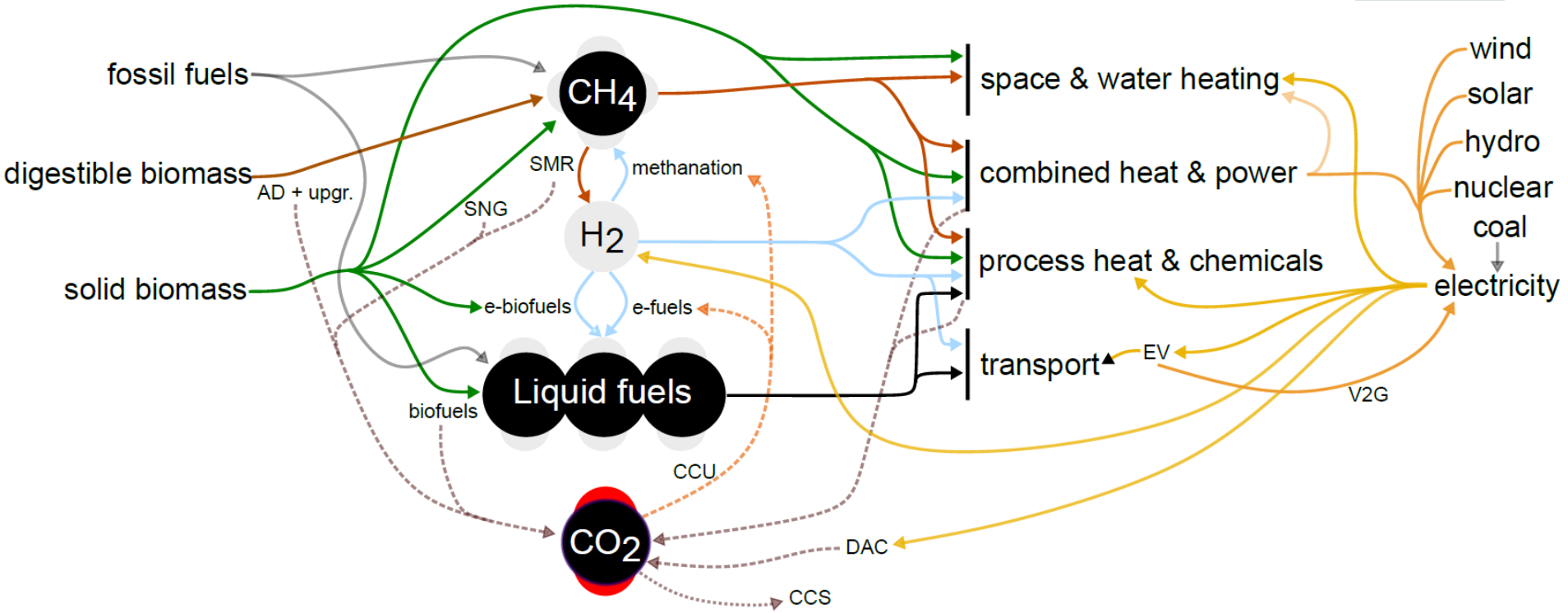
Model

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

Set-up:

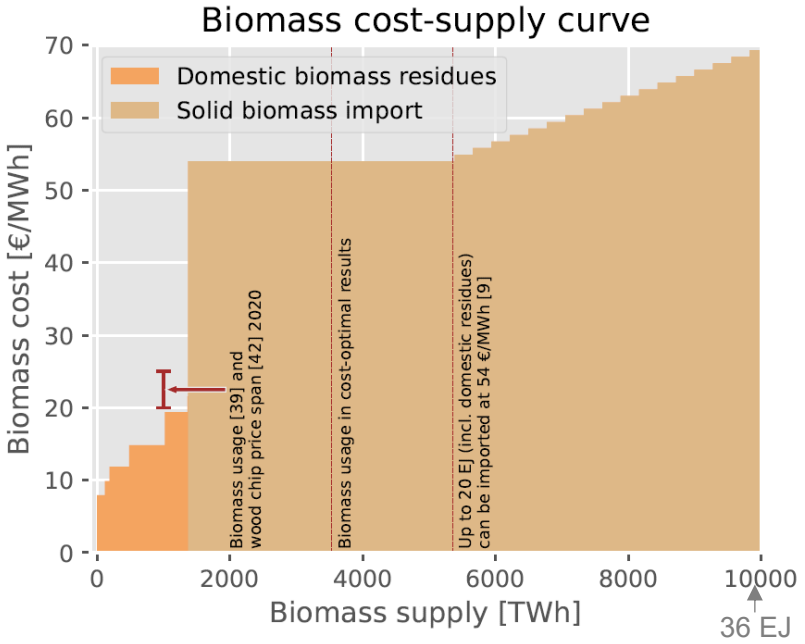
- Europe in 37 nodes, 5H temporal resolution, **overnight**
- **Net-negative** (-110%) CO_2 emissions vs 1990, with limited carbon storage
- Biomass competes with electricity- and fossil-based options in all sectors




fossil fuels
digestible biomass
AD + upgr.
solid biomass
CH4
SMR
methanation
SNG
H2
e-biofuels
e-fuels
Liquid fuels
biofuels
CCU
CO2
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

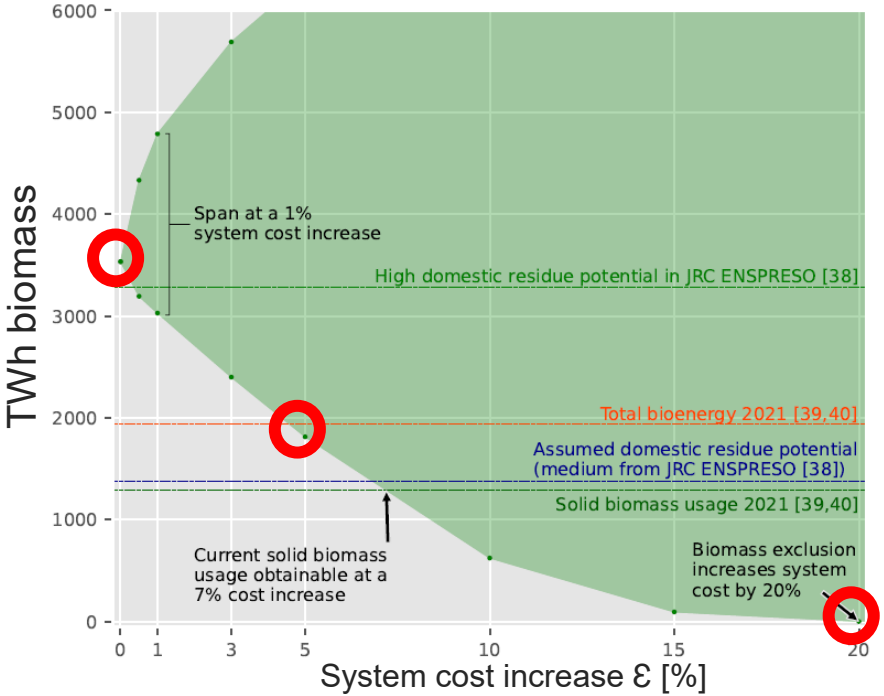


Millinger et.al. (2023): https://doi.org/10.21203/rs.3.rs-3097648/v1

RESULTS

Biomass in the energy system

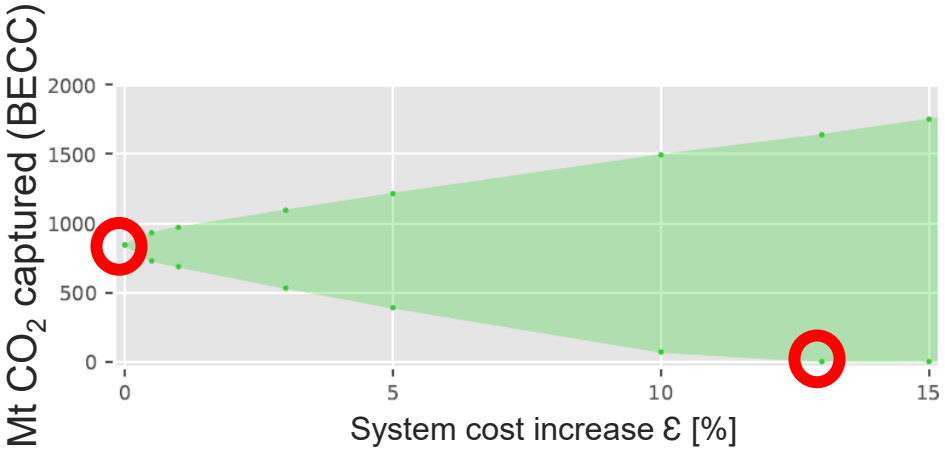
- 3500 TWh biomass cost-optimal (29% of primary energy; the rest wind, solar and some hydro)
- Biomass limited to current use corresponds to ~5% higher system cost.
- Can be excluded at ~20% higher system cost (170 B€, or ca total defense spending in EU). Similar to wind power and electrolysers!
- Biomass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



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

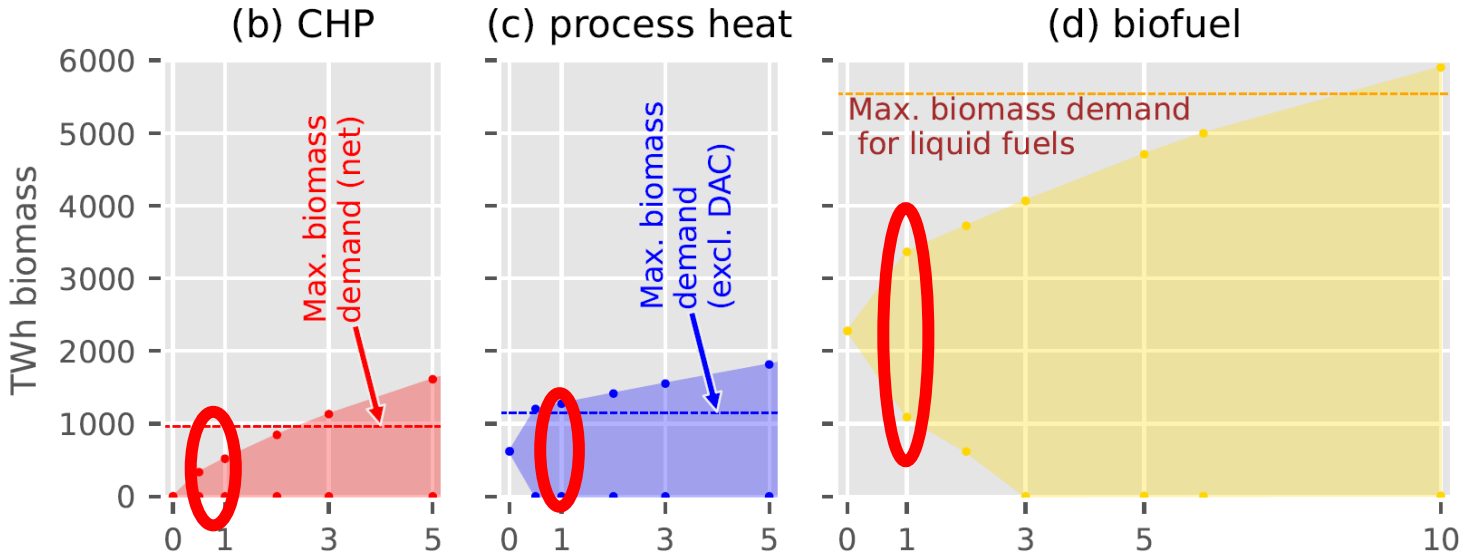
Bioenergy with carbon capture

- Around 900 $MtCO_2$ biogenic capture cost-optimal (21% of total **GHG** emissions in 2021)
- Most biomass usage linked to CC
- Can be excluded at a 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

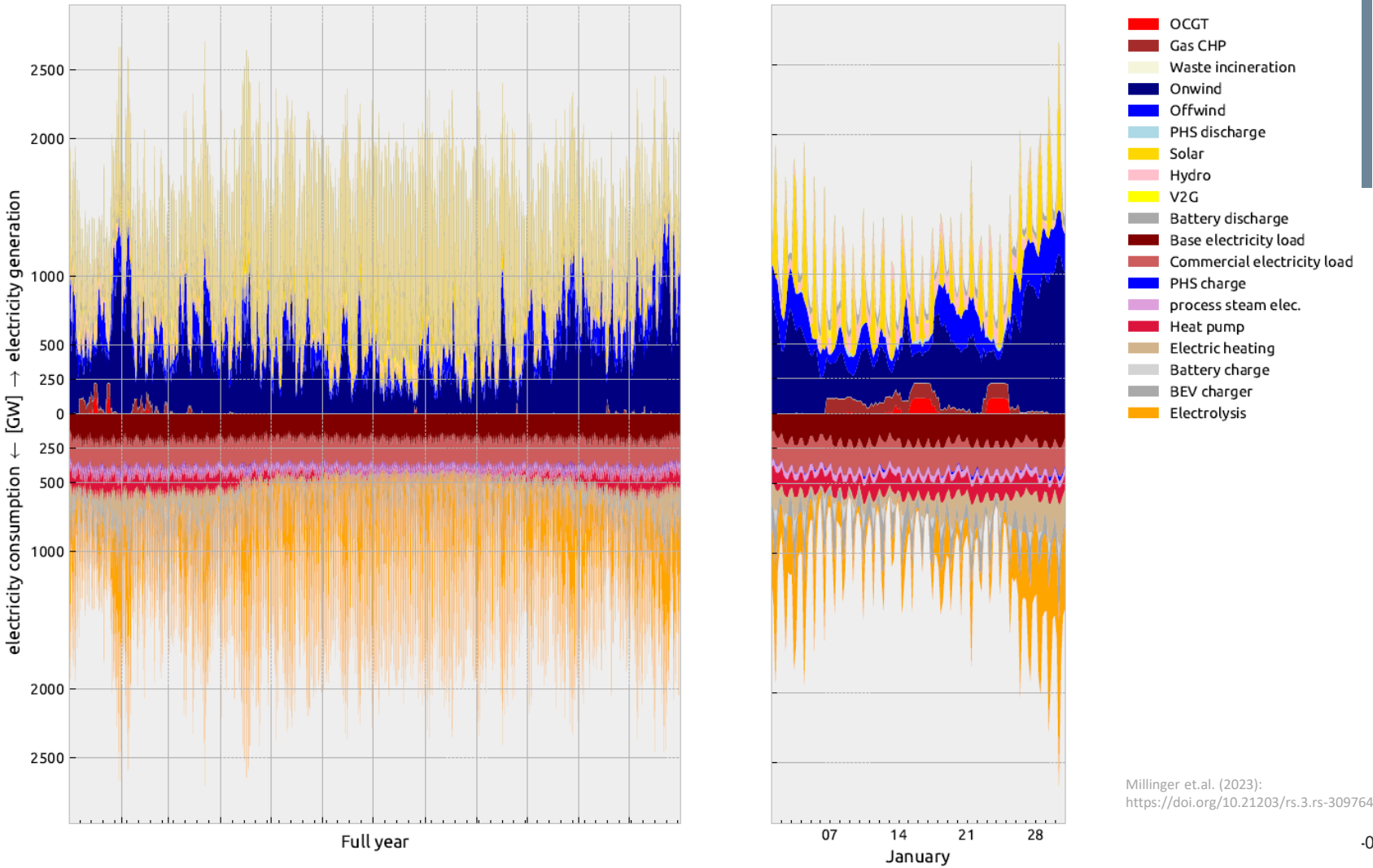


Millinger et.al. (2023): https://doi.org/10.21203/rs.3.rs-3097648/v1

Use of solid biomass



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



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

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

CHALMERS

RI.
SE