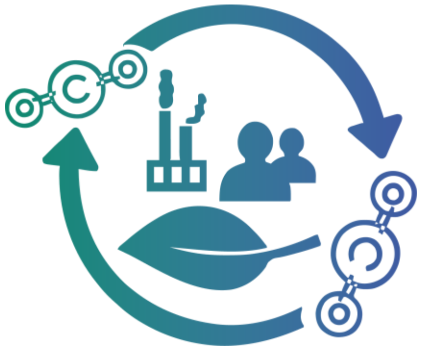
universität freiburg

Role of biomass and CO_2 limits in net-zero industry and energy system transformation

Célia Burghardt, INATECH, University of Freiburg
celia.burghardt@inatech.uni-freiburg.de

Project KoRPSA: regional potentials and systemic analysis for carbon management



- Focus: upper-rhine region / BW
- Techno-economic perspective: Modelling
  - **Carbon flows in climate-neutral European system**
  - First-mile transport modelling in the region
- Governance: Interviews
- Acceptance: Surveys, Workshops

Fraunhofer ISI | KIT | universität freiburg

Kohlenstoffmanagement in Baden-Württemberg – Weichenstellungen für Klimaneutralität und Industriestandort

Policy Brief zur Landtagswahl

Executive Summary

Baden-Württemberg hat sich Klimaneutralität bis 2040 zum Ziel gesetzt. Selbst bei konsequenter Emissionsvermeidung werden in zentralen Industrien wie Zement, Kalk oder Abfallverbrennung langfristig unvermeidbare CO_2-Emissionen verbleiben. Ergänzend zur Emissionsvermeidung braucht das Land daher eine Kohlenstoffmanagement-Strategie, die Abscheidung, Transport, Nutzung und Speicherung von CO_2 gemeinsam in den Blick nimmt. Dieser Policy Brief fasst den aktuellen Stand in Baden-Württemberg zusammen und leitet zentrale Handlungsbedarfe für die nächste Legislaturperiode ab.

Für Baden-Württemberg zeigt sich:

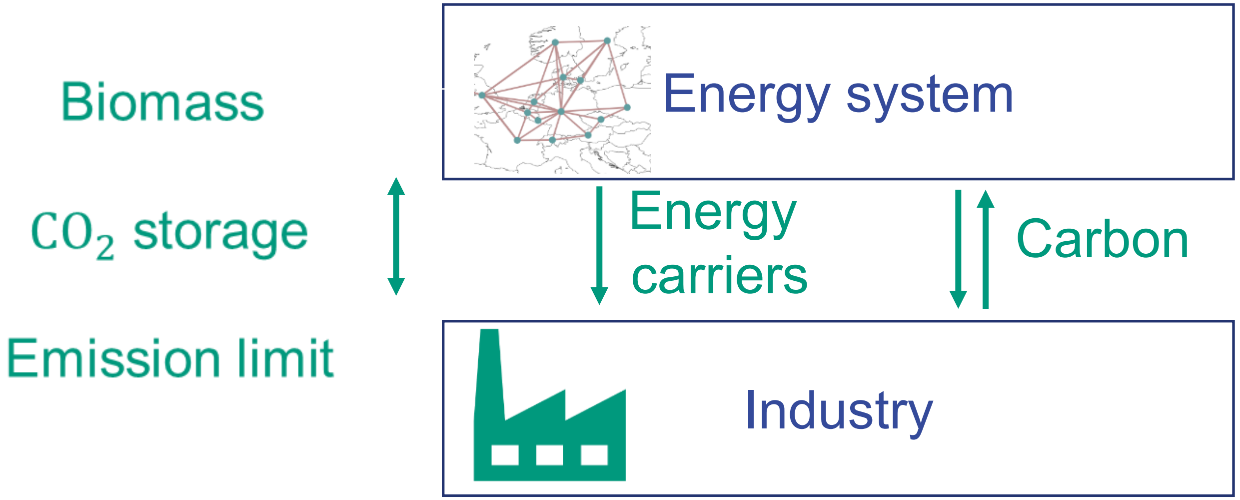
- Das Land verfügt über relevante Quellen schwer vermeidbarer Emissionen, hat aber bislang weder CO_2-Abscheideanlagen noch ein Transportnetz oder Speicherstätten.
- Geologische Speicherpotenziale im Land sind gering; für Klimaneutralität wird voraussichtlich eine Anbindung an überregionale Infrastrukturen und Nordsee-Speicher notwendig.

https://uni-freiburg.de/klimaneutralitaet-2040-optionen-fuer-ein-kohlenstoffmanagement-in-baden-wuerttemberg/

Analysis of carbon flows in a climate-neutral European industry-energy system

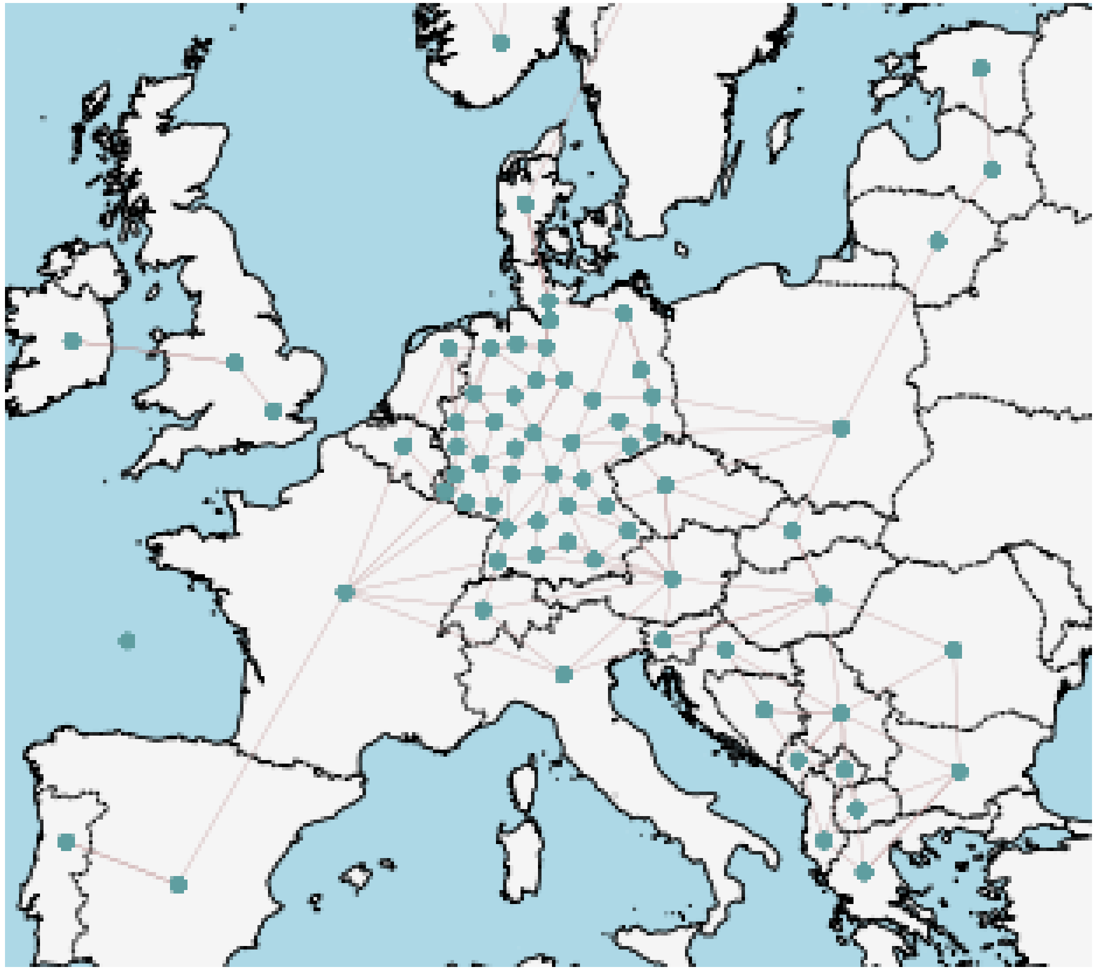
- **Greenfield cost optimization for climate-neutral system**

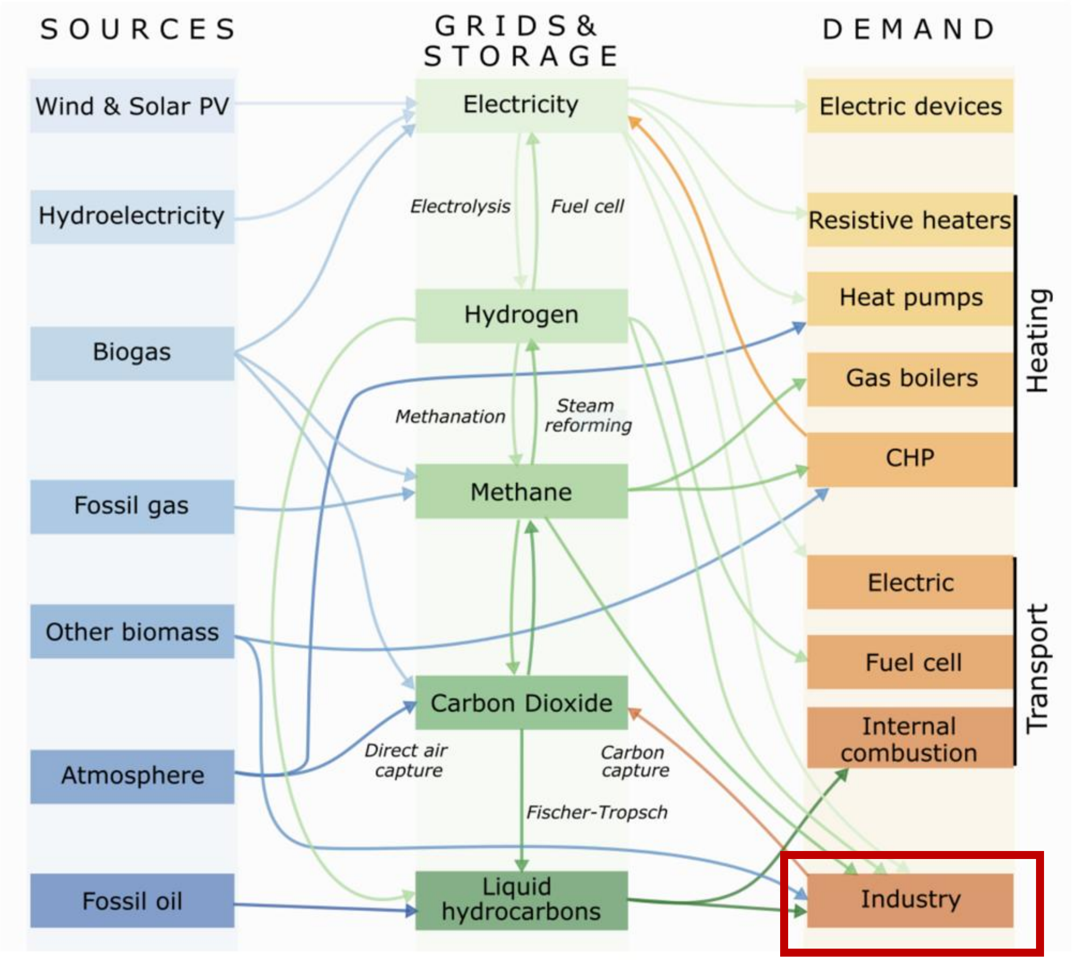
- **Co-optimization of industry and energy system**
  - Resource competition, cross-sectoral carbon flows
  - Previous study on seperate vs. coupled industry transformation showed relevance of these interactions between the sectors[1]



[1]Burghardt et al. (2025): "Coupled vs. separate optimization in industry and energy system defossilization analysis: A German case study."

Energy system model: sector-coupled PyPSA-Eur

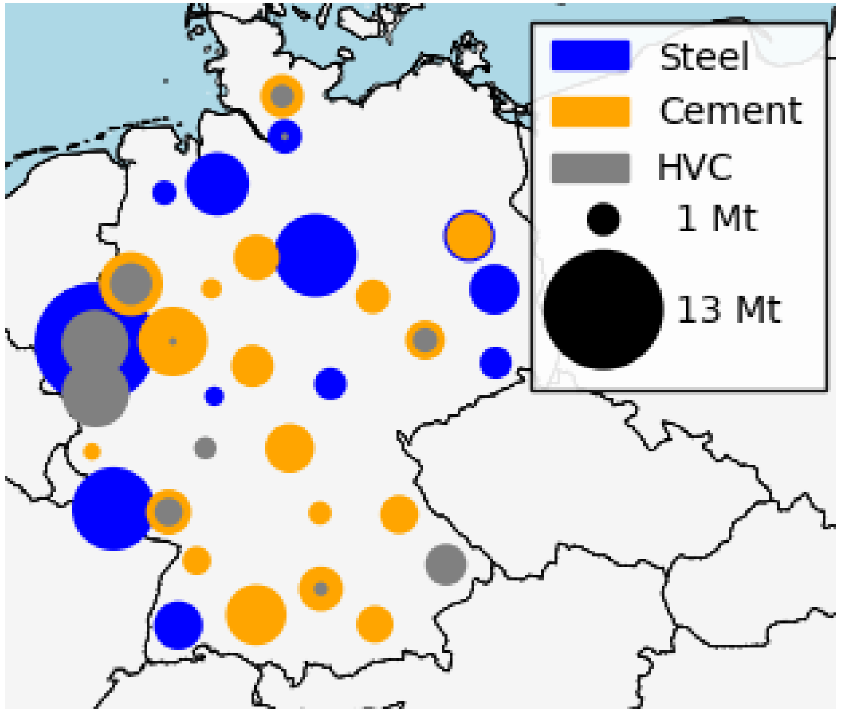




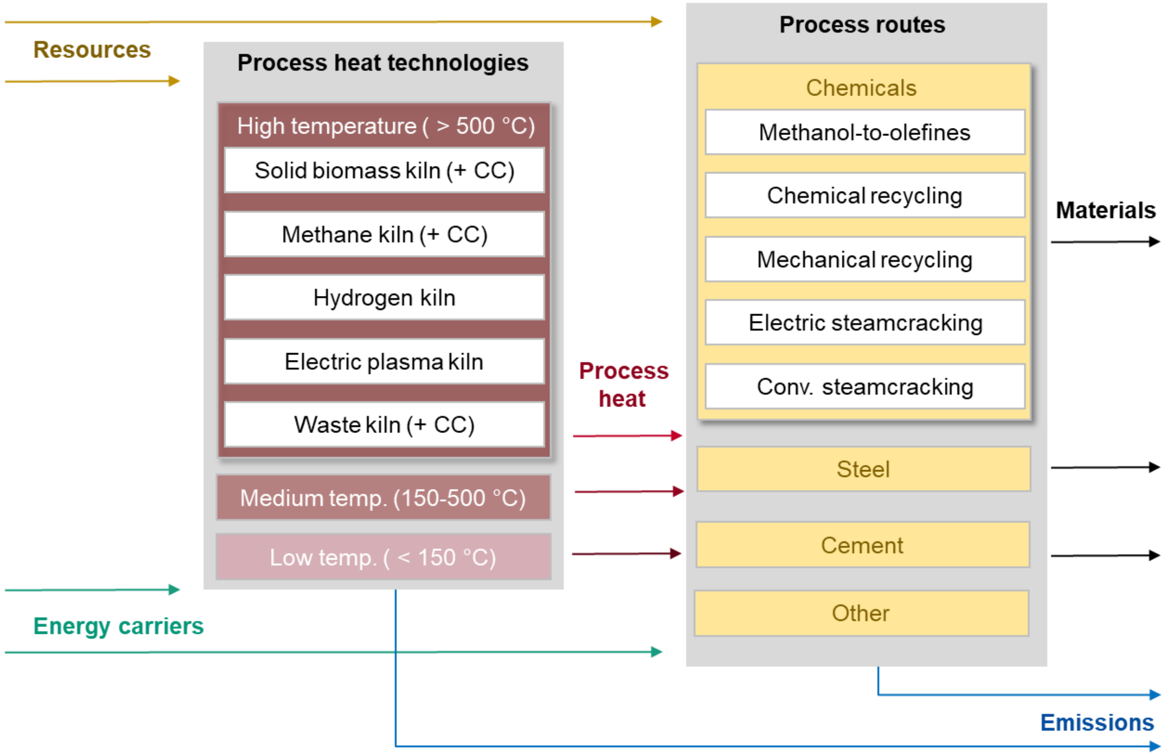
Picture source: https://pypsa-eur.readthedocs.io/en/latest/

Industry model

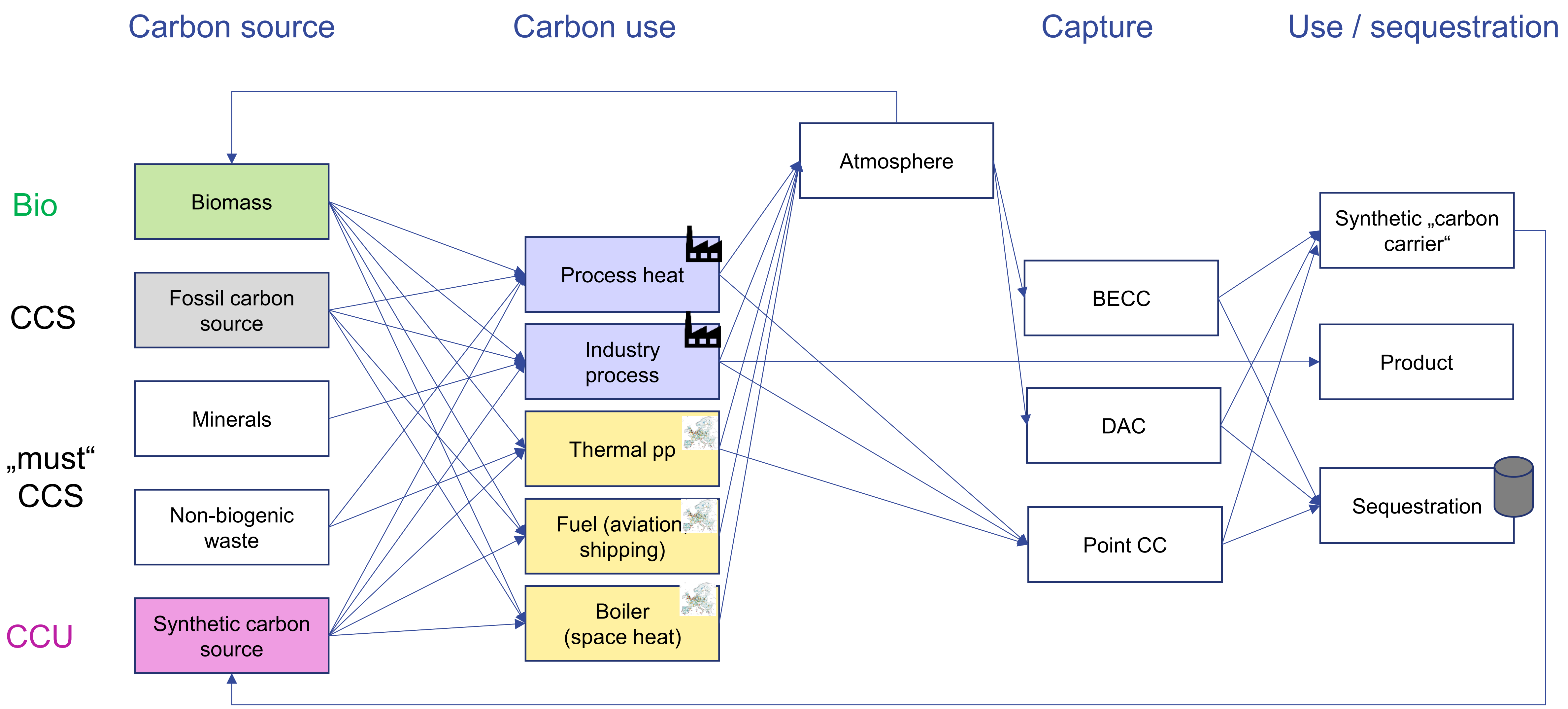
Fixed product demand and locations



Endogenous industry process choice

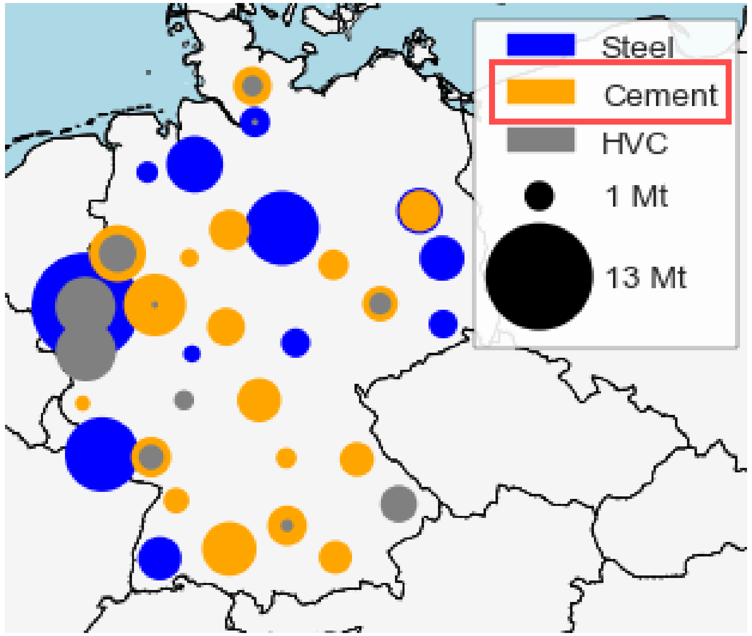


Modelled carbon flows

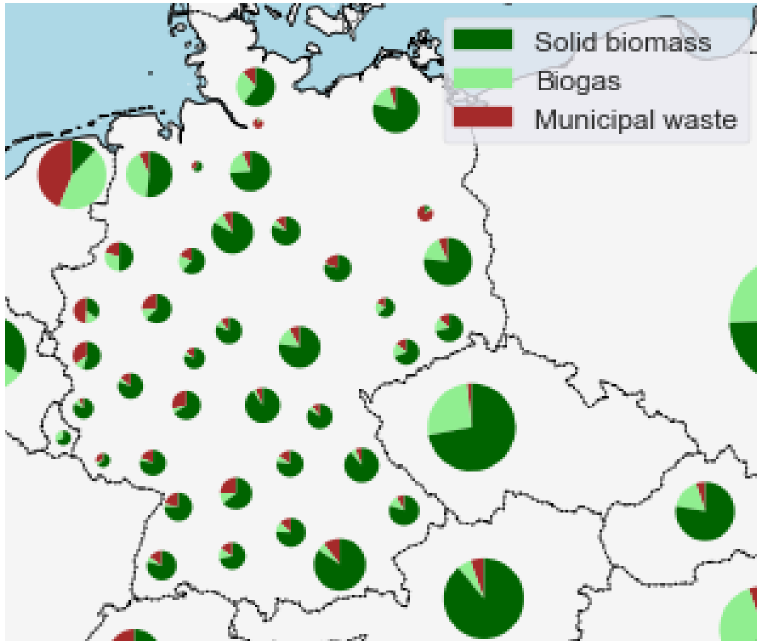


Regional differences relevant for carbon flows

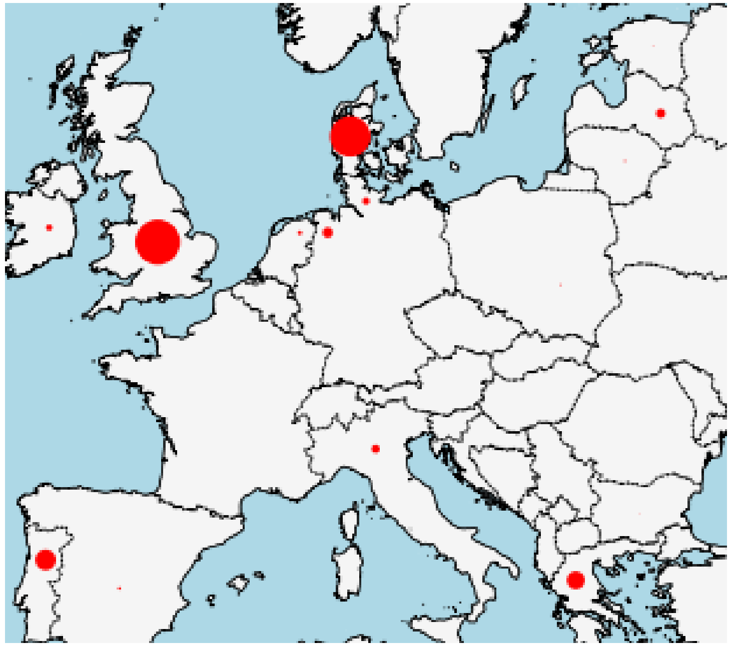
Industry structrure



Biomass potentials



CO_2 sequestration potentials



Role of biomass and CO_2 sequestration limits

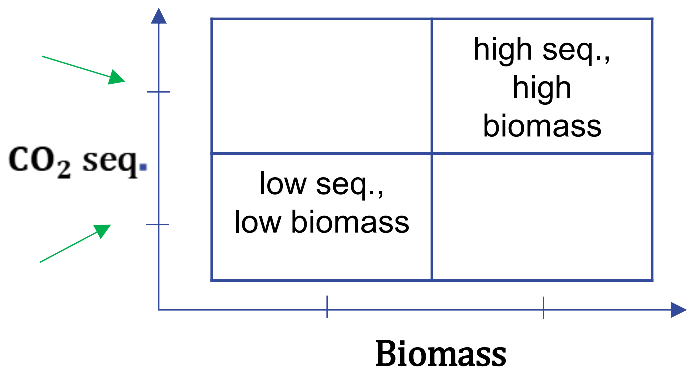
Analysis of biomass and sequestration limits variation:

1. Effect on overall system design (CCS vs. CCU vs. Bio)
2. Effect on regions with different conditions

Scenarios

Optimization of seq. capacity

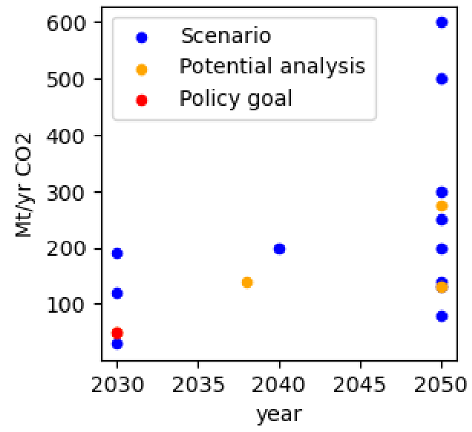
Only unavoidable emissions



Related to decisions in carbon management:

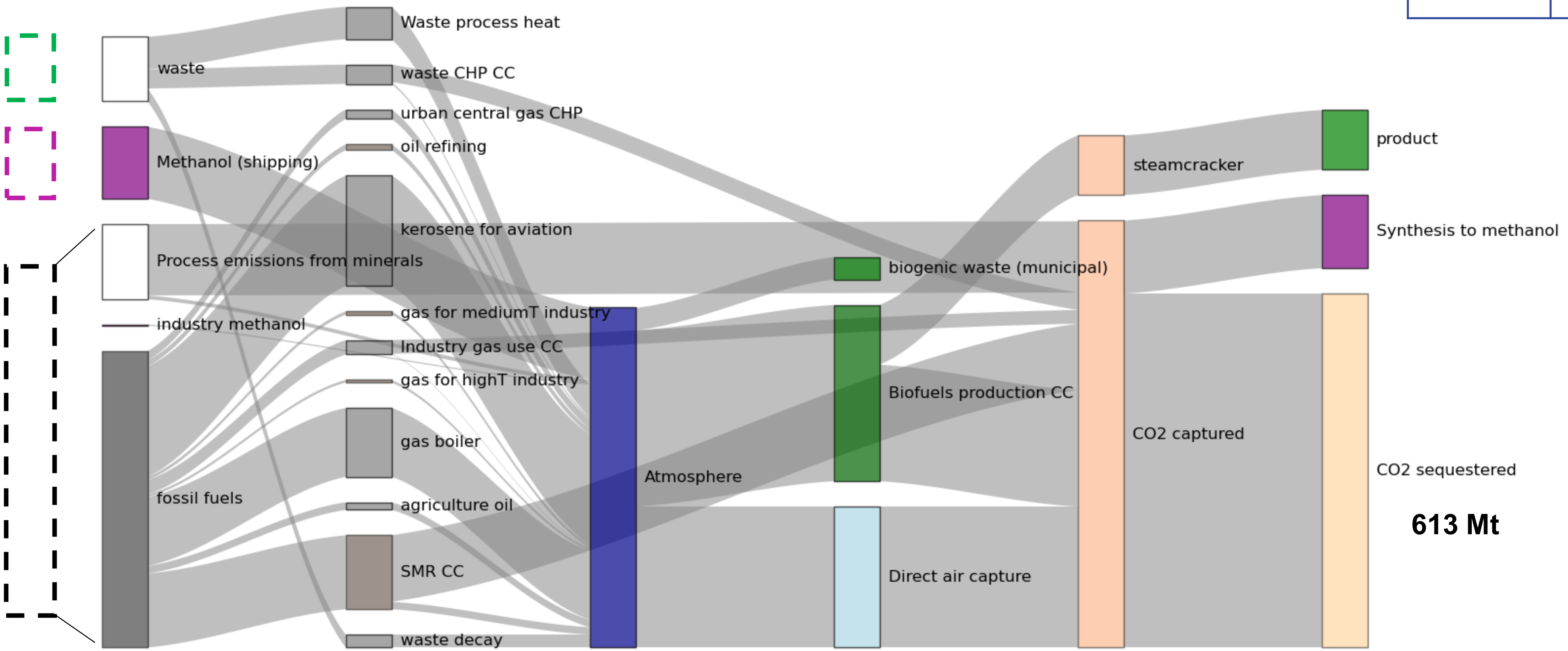
- How much CO_2 sequestration do we want to build? Which emissions do we want to allow to be captured?
- How much biomass do we want to use?

CO_2 sequestration potentials in studies



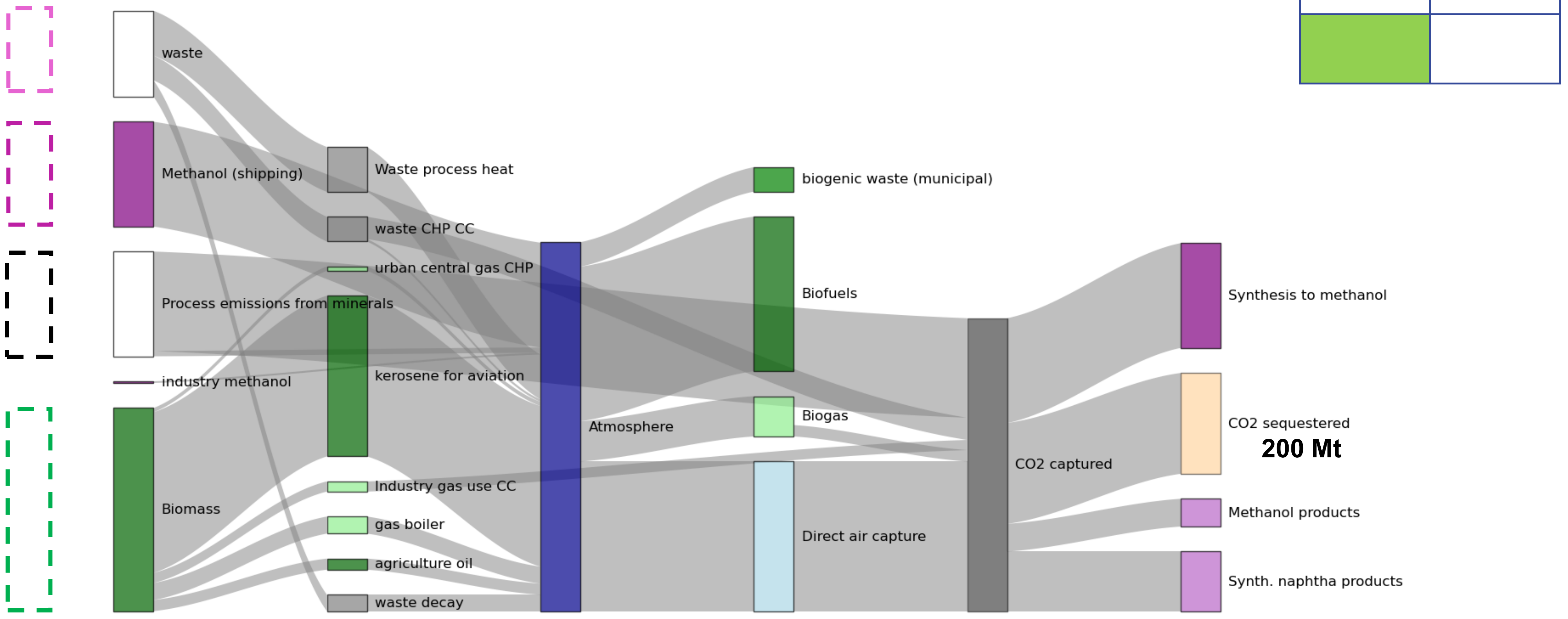
High CO_2 sequestration / biomass limits favor fossil fuels + (BE)CCS

CO_2 flows in European system



Low CO_2 sequestration / biomass limits favor CCU and biomass as fuel

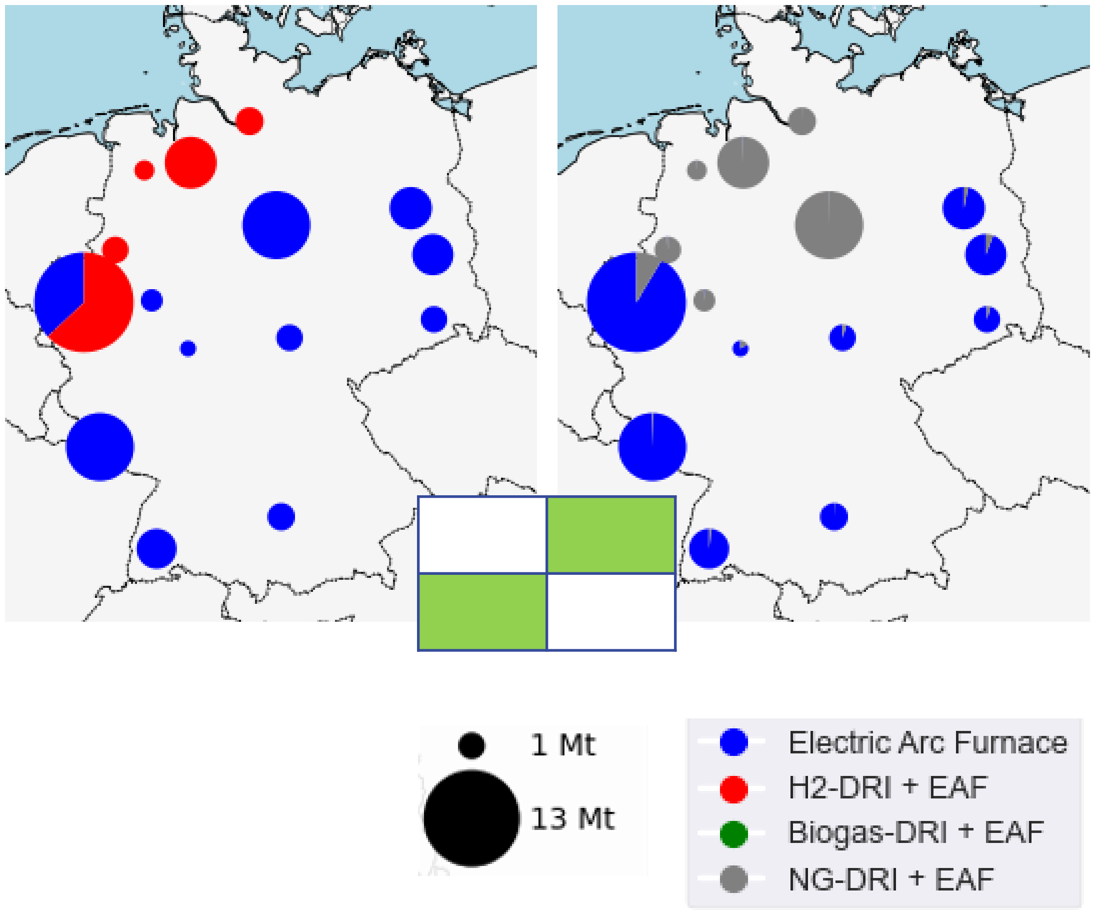
CO_2 flows in European system



Industry: lower CO_2 sequestration / biomass limits favor H_2 use

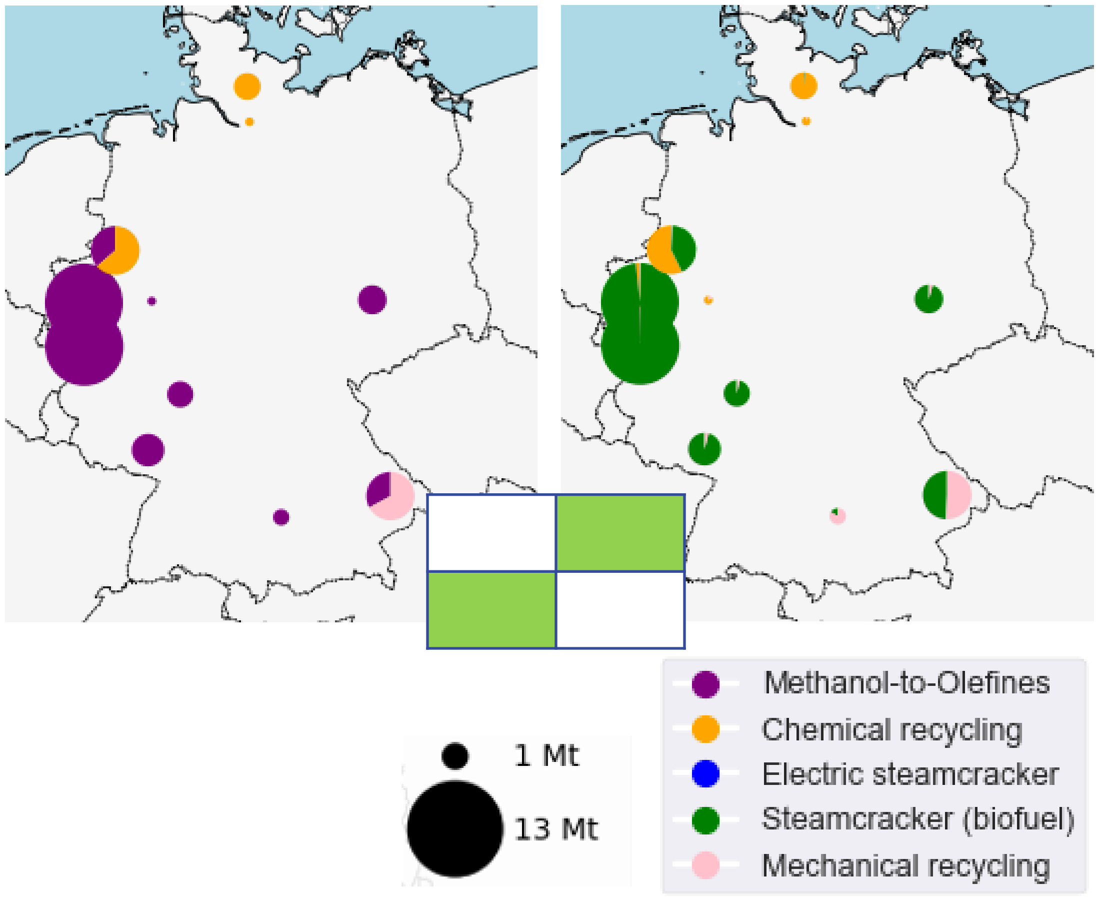
Steel

CCU-based (low seq. & bio) | CCS-based (high seq. & bio)



High value chemicals

CCU-based (low seq. & bio) | CCS-based (high seq. & bio)



Regional comparison of CCU- and CCS-based system

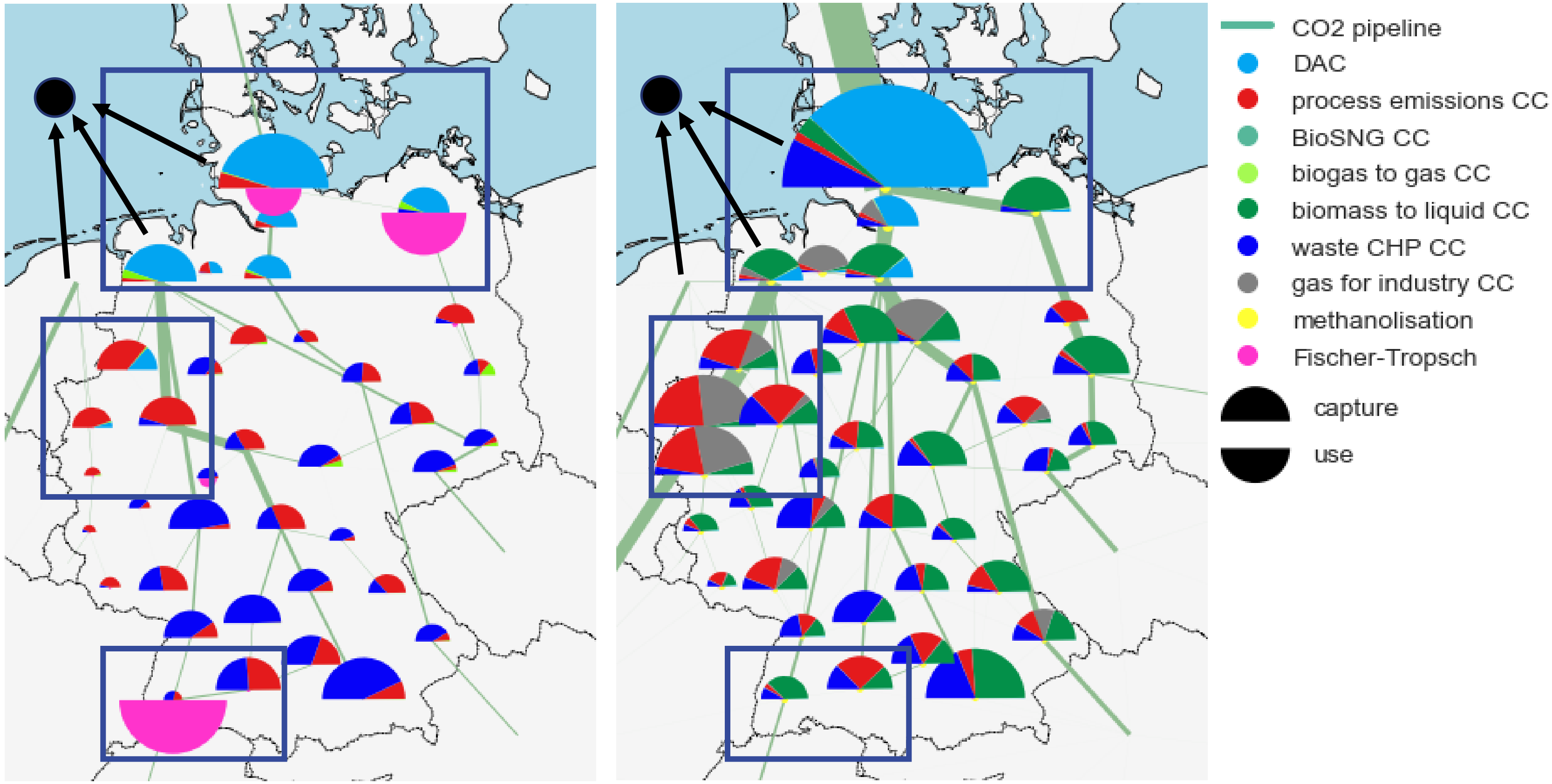
CCU-based ←→ CCS-based

1. **High RES, close to seq.**
   Low-cost electricity used for CCU ←→ for increased capturing

2. **Industry-intensive**
   Industry: H_2 ←→ gas/bio-based, more CC and larger CO_2 grid

3. **Far from sequestration**
   Regional CCU cycles ←→ larger CO_2 grid (also for transit)

CCU-based (low seq. & bio) **CCS-based (high seq. & bio)**



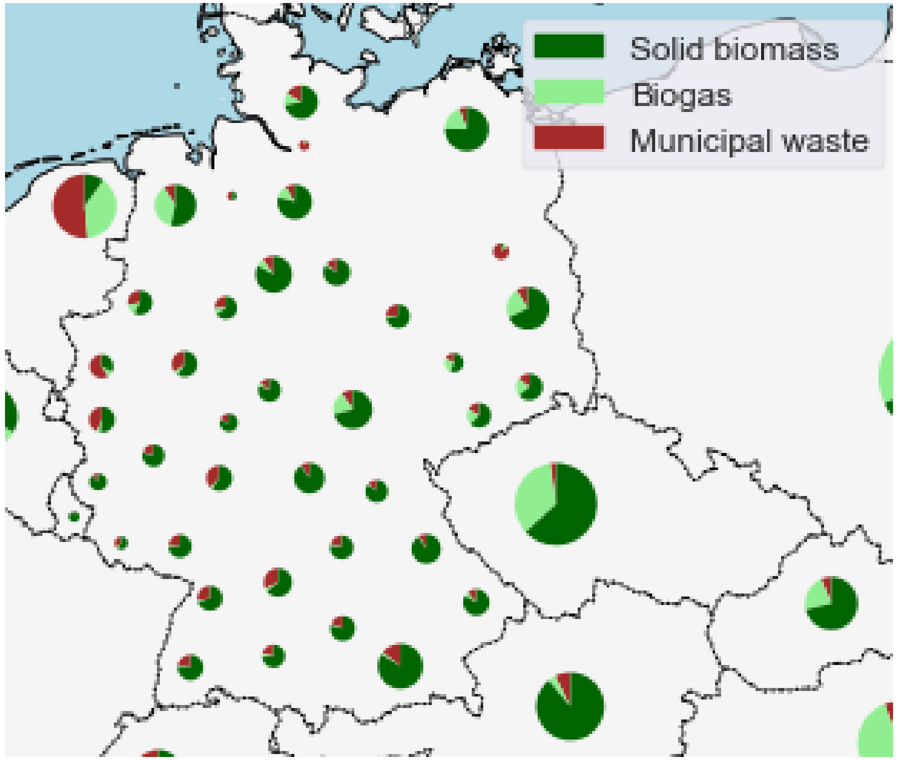
Summary: Role of biomass and CO_2 limits in net-zero industry and energy system transformation

- System cost minimization of a coupled industry-energy system model, under climate-neutrality constraint
- Sequestration and biomass availability determine the cost-optimal system design
  - Sequestration limited to unavoidable emissions → mainly CCU
  - Optimized sequestration capacity → mainly fossil + CCS
  - Regional effects differ due to distinct structures (industry, biomass / seq. availability, electricity / H_2 costs)
- Future work
  - Pathway study (now greenfield)
  - Integration of acceptance studies into modelling
  - Integration with first-mile CO_2 transport

Additional information

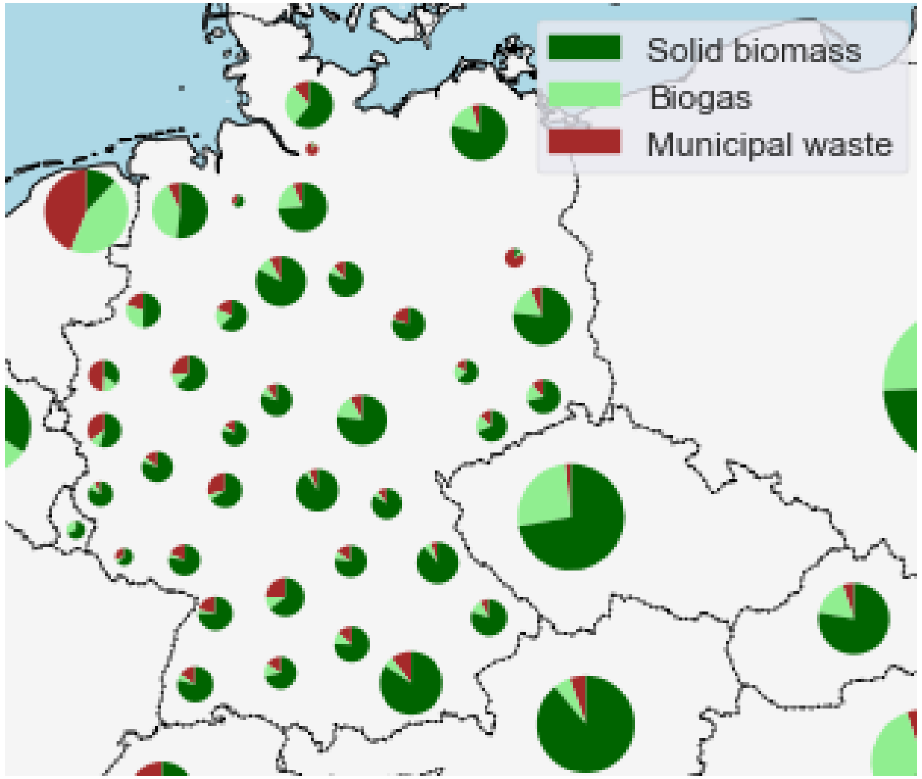
Biomass potentials

ENS-Low



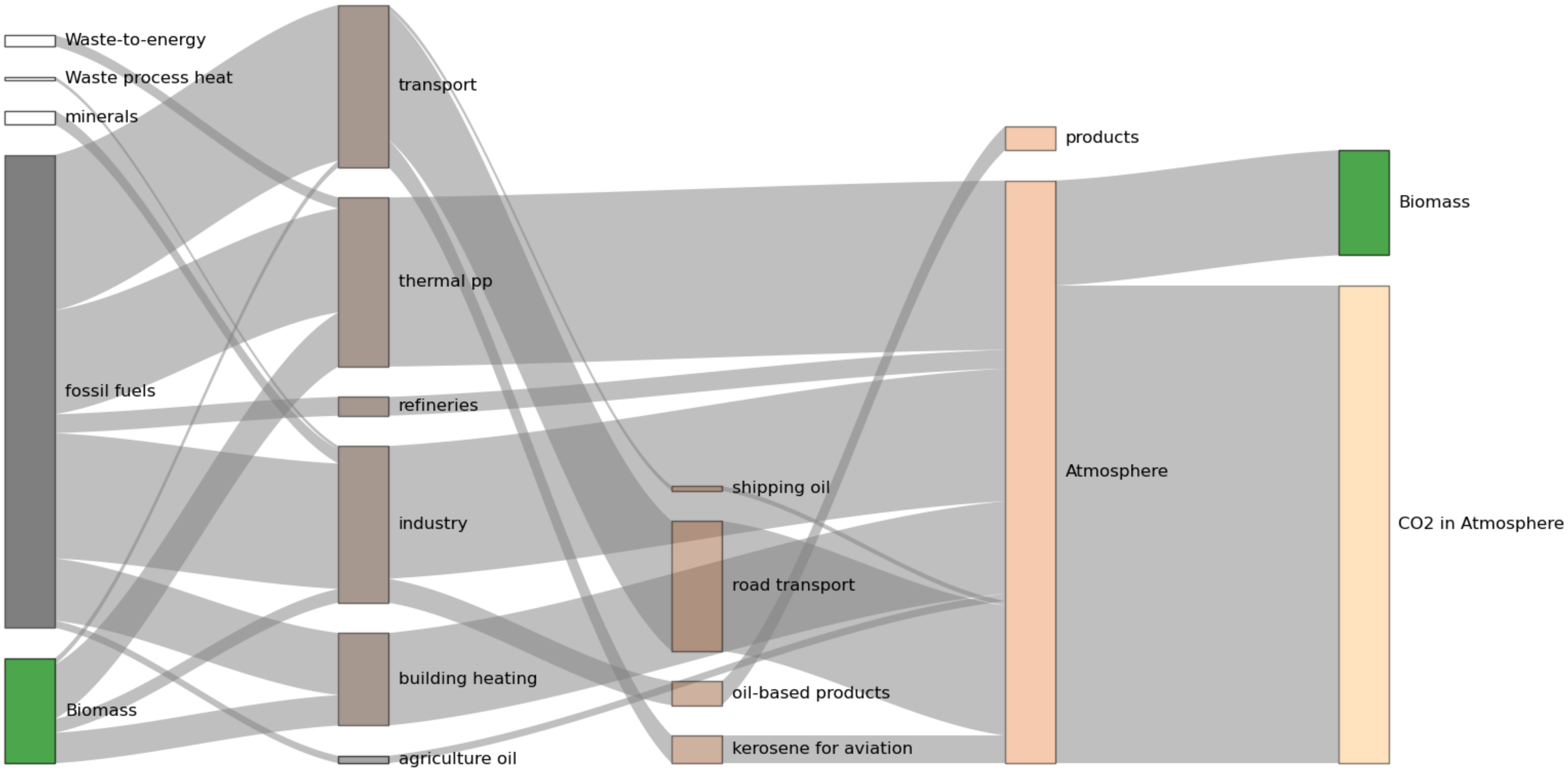
Totals:
Biogas: 173 TWh
Solid biomass: 554 TWh
Bio-msw: 113 TWh

ENS-Med



Totals:
Biogas: 347 TWh
Solid biomass: 1049 TWh
Bio-msw: 151 TWh

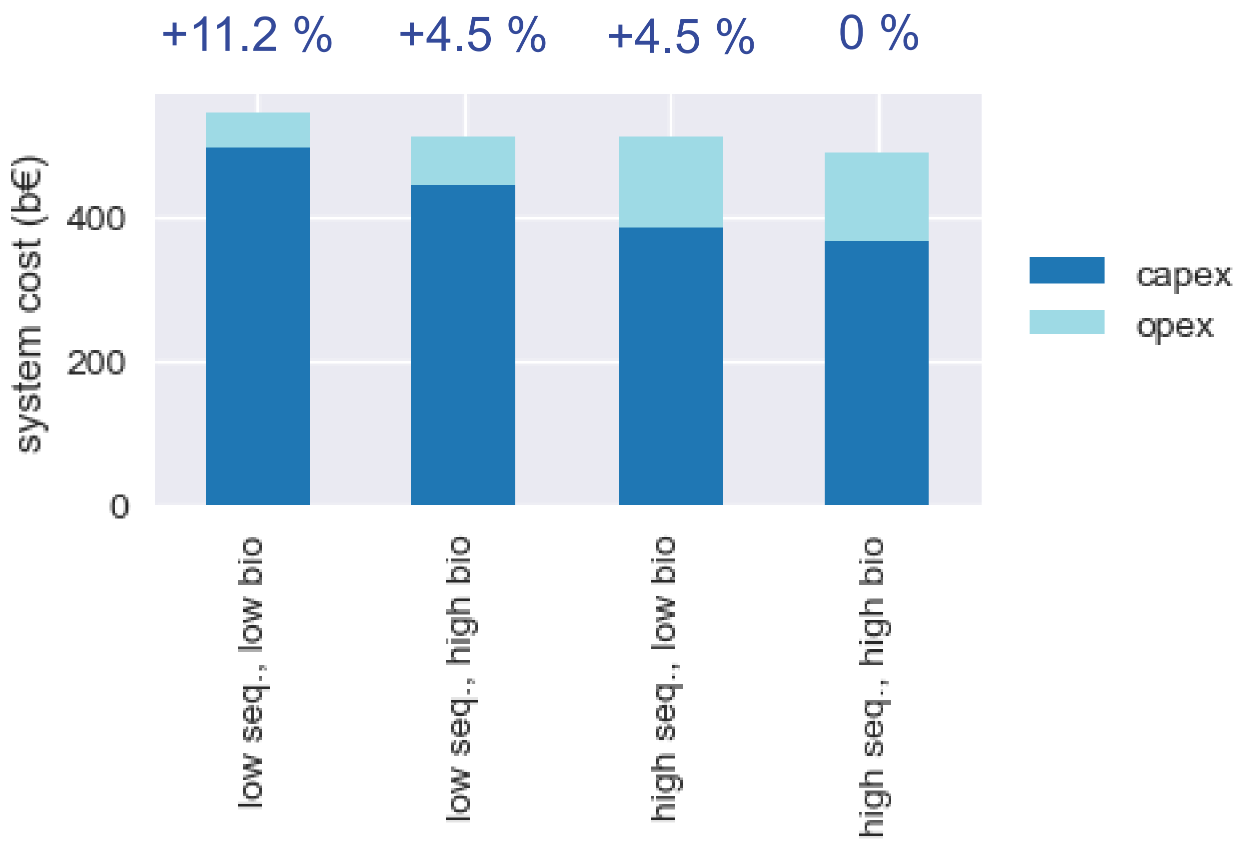
Today's CO_2 flows (Germany)



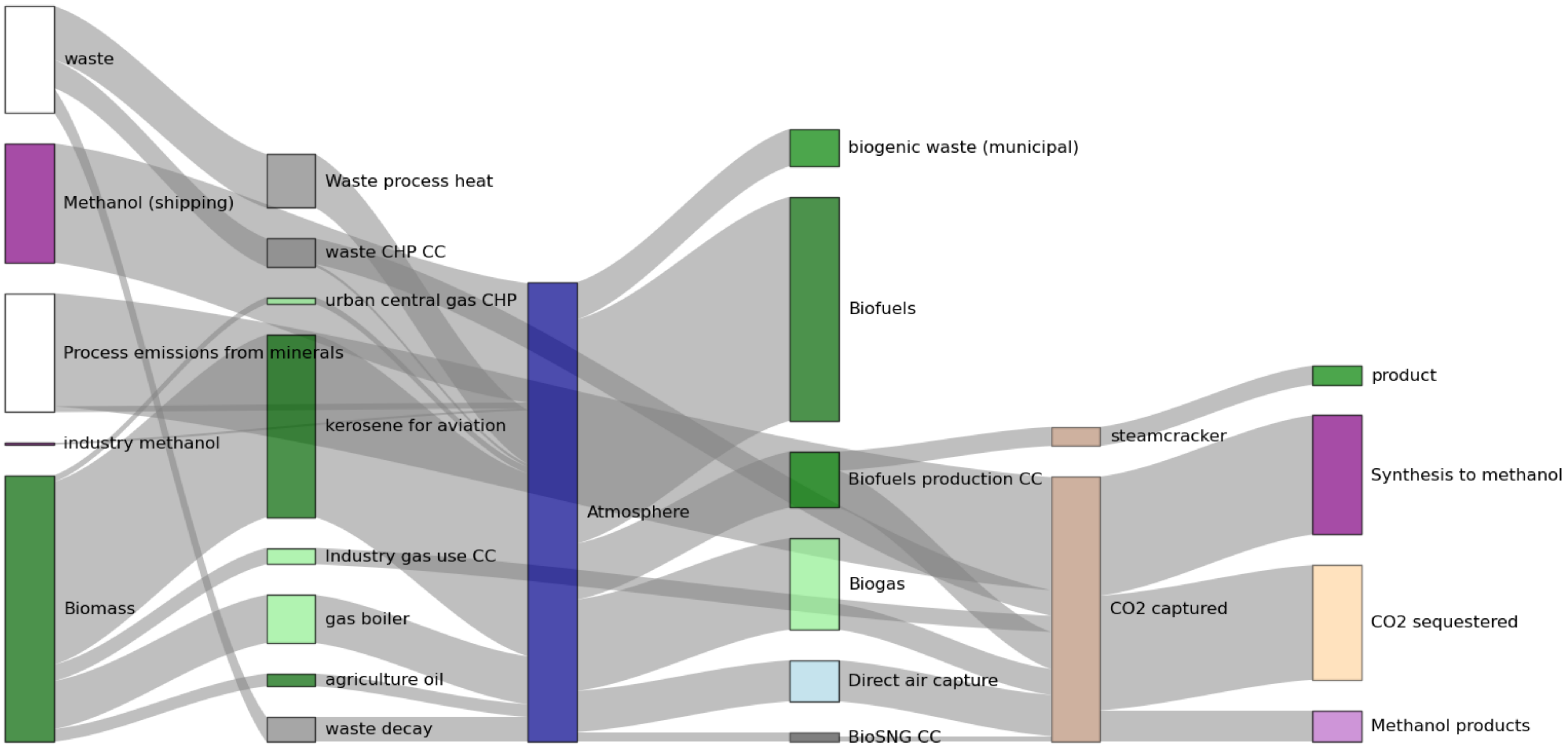
Model: CO_2 flows

Emissions	Capture	Transport	Use / Store
Energy system •Combustion for electricity / space heat generation: fossil / synthetic / bio gas, waste, biomass •Shipping / Flights: fossil / bio-based / synthetic fuels	**Energy system** •Point sources: CHPs, waste incineration •Atmosphere: direct air capture, (indirectly) biomass	**CO_2** •Pipelines •Atmosphere **Indirectly via carbon:** •Liquid fuels (methanol, naphtha, oil, kerosene): copperplate •Solid biomass: transport by trucks with specific cost per distance and t •Methane (+ biogas upgraded to methane): today‘s gas grid	• Synthesis to methanol, naphtha, kerosene, gas • Geologic CO_2 storage
Industry •Combustion for process heat: Fossil/ synthetic/ bio-based gas, waste, biomass •Process emission •SMR hydrogen production	**Industry** •Point sources: process emission (gas use; cement production), process heat •Atmosphere: (indirectly) biomass		

System cost comparison



Low storage, high biomass



High storage, low biomass