Technische Universität Nürnberg

Economic assessment of negative emissions from sustainable biomass in Europe

Veronika Grimm[1] ,Kiana Niazmand[2], Philipp Runge[3]

[1,2] Technische Universität Nürnberg UTN)
[3]Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU)

Background

- No net-zero emissions by 2050 without the implementation and substantial expansion of negative emissions methods, that should be started earlier (2040)
- Nearly **400 Gt** CO_2e (total cumulative amount) must be removed globally between 2020 and 2100 (IPCC, 2023).
- In Europe, between **222 and 391** Mt CO_2e must be removed **annually** starting from 2040, with a target of **447** Mt CO_2e from 2050 and beyond (European Commission, 2024)

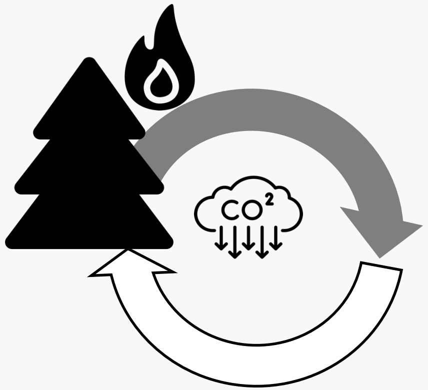
Challenges of negative emission methods

- **Land-based solutions** (LULUCF) are currently dominant, but insufficient to meet EU targets
- Technology-based CDR such as direct air capture and carbon storage (**DACCS**) and bioenergy with carbon capture and storage (**BECCS**) face challenges related to **insufficient technological maturity** and **high energy demands**
- The long-term storage of **gaseous CO_2** → CO_2 transport infrastructure and Public acceptance
- **Biochar carbon removal (BCR)** as an alternative solution

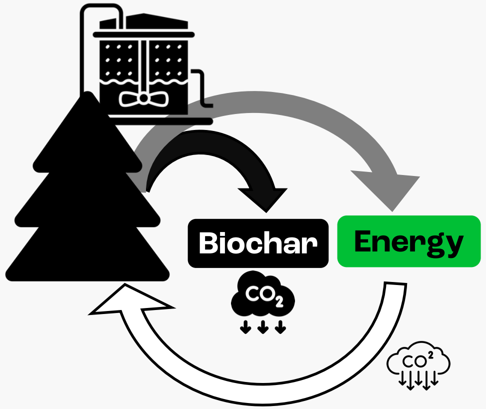
UTN

Biomass as biogenic source of carbon

- Biomass gasification or combustion (BECCS)
- Thermal decomposition using pyrolysis (in the abscence of O_2)
- Biomass undergoes pyrolysis to produce biochar, a carbon-rich solid with 65–90% carbon content
- Underground burial of biochar effectively traps its whole carbon content for centuries



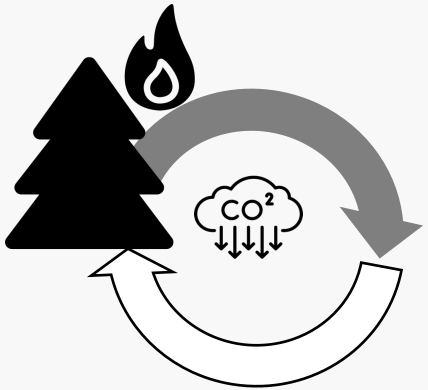
Gasification or Combustion



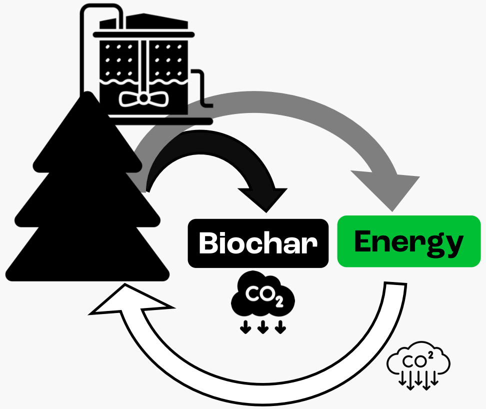
Thermal Decomposition using Pyrolysis

Biochar carbon removal (BCR)

- Also known as Pyrogenic Carbon Capture and Storage (PyCCS)
- A promising negative emission technology due to its technological readiness and potential co-benefits
- Sustainable liquid biofuel (by-product) contribute to decarbonization in sectors such as shipping and aviation, which rely on liquid hydrocarbons
- Biochar can be used in agriculture sector →still up to 80% carbon remaining sequestered for over 100 years



Gasification or Combustion

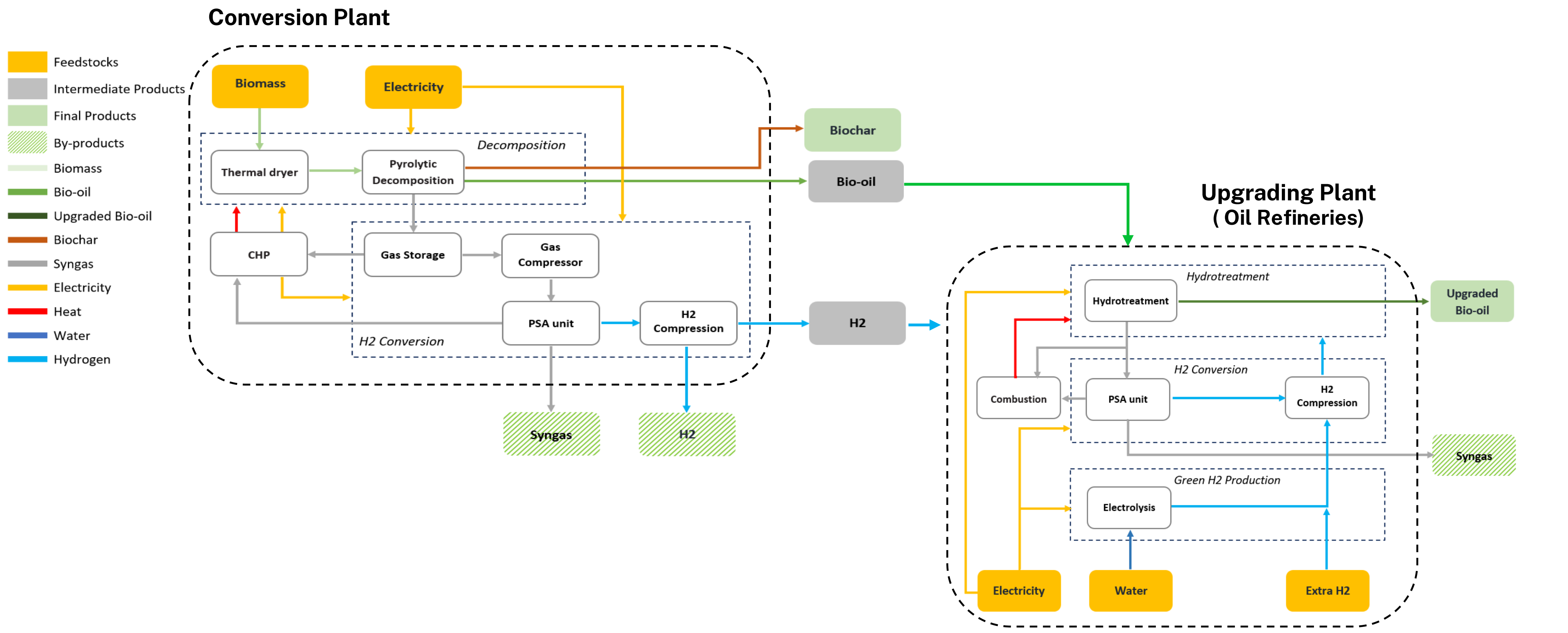


Thermal Decomposition using Pyrolysis

Research questions

- Is BCR an economically viable negative emission solution?
- Is there sufficient potential for BCR from sustainable biomass in Europe?

BCR process from a single source biomass



Economic assessment of BCR at supply chain level

To achieve maximum cost efficiency from biochar as NET, an optimal set-up of the supply chain is necessary . Why?

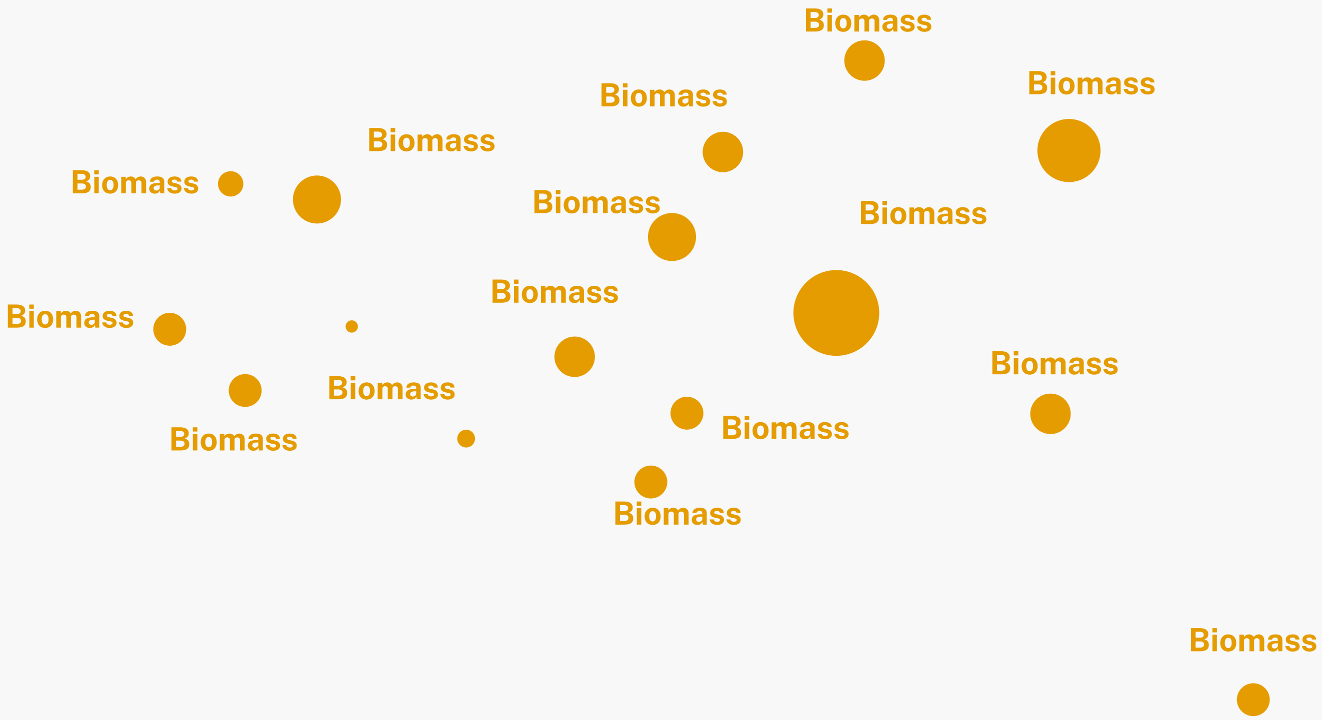
- Biomass is widely distributed, but in some cases with insufficient quantities -> high production costs of biochar due to the non-utilisation of economies of scale with a **decentralised** approach
- High transport costs of biomass-> make complete **centralization** unattractive

An optimization model to minimize total costs by :

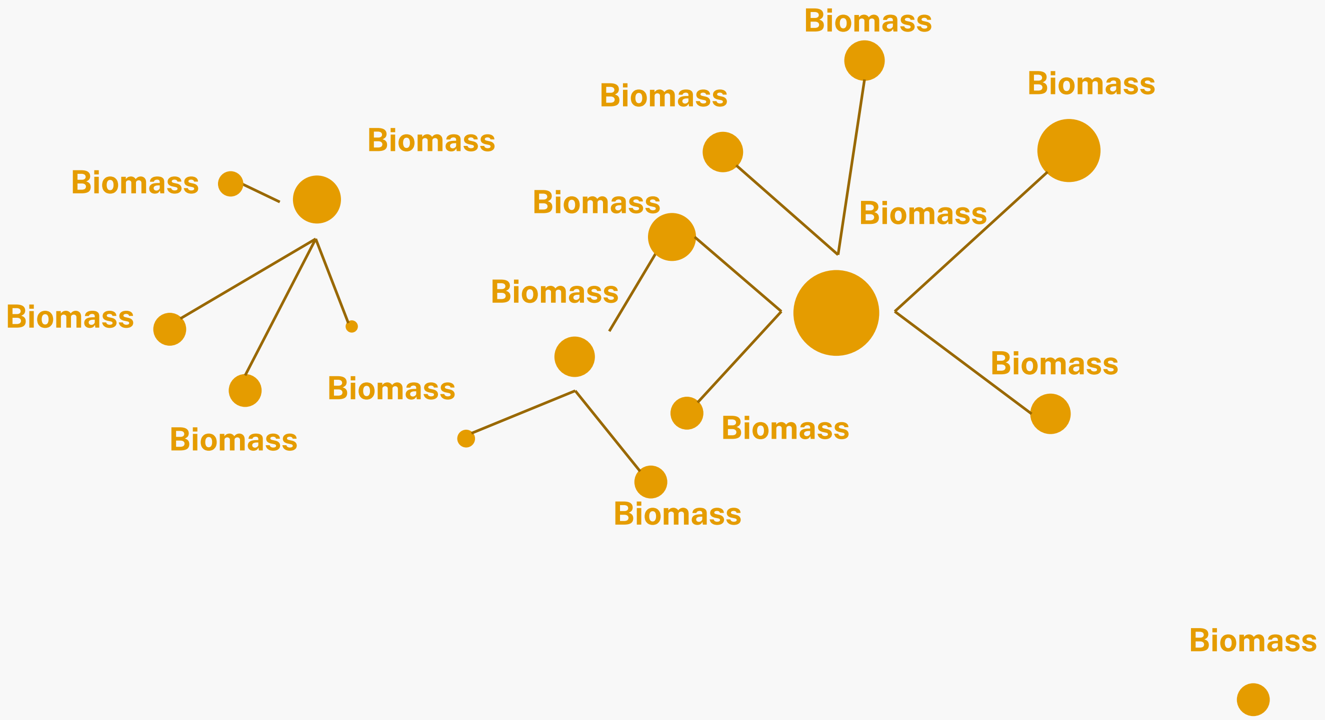
- Optimizing the **technology capacities** whitin **every single conversion and upgrading plants**
- Optimizing **the locations and capacities** of conversion and upgrading plants
- It should take the trade-off between production and transport costs into account.

Mathematical Model

BCR supply chain design

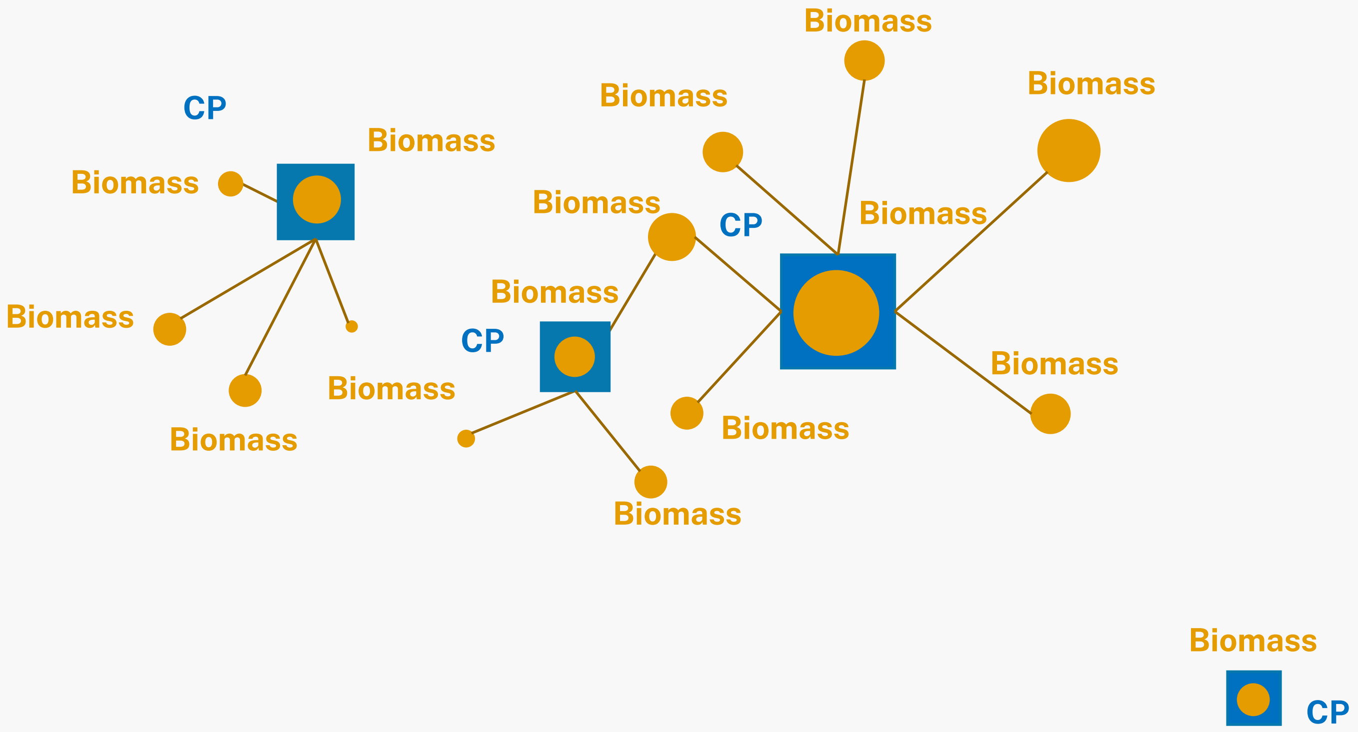


BCR supply chain design



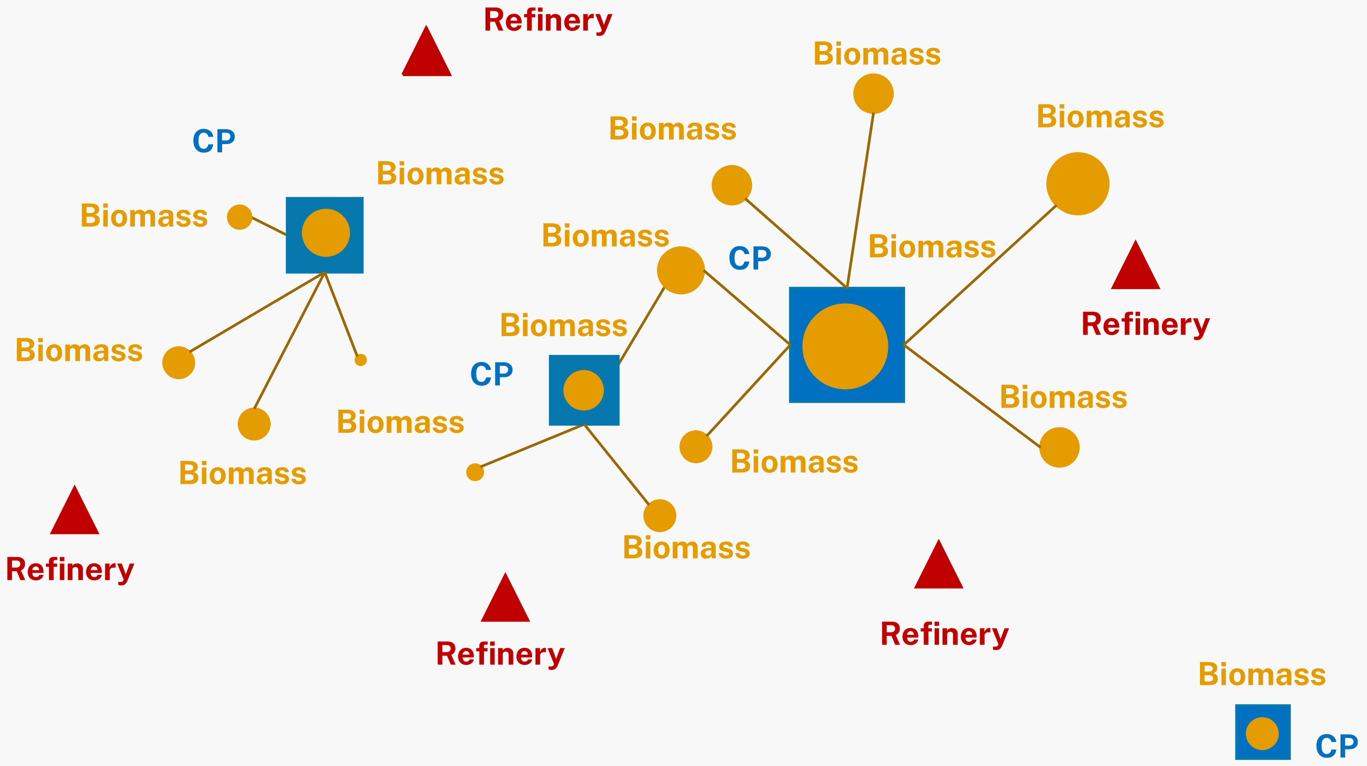
UTN

BCR supply chain design



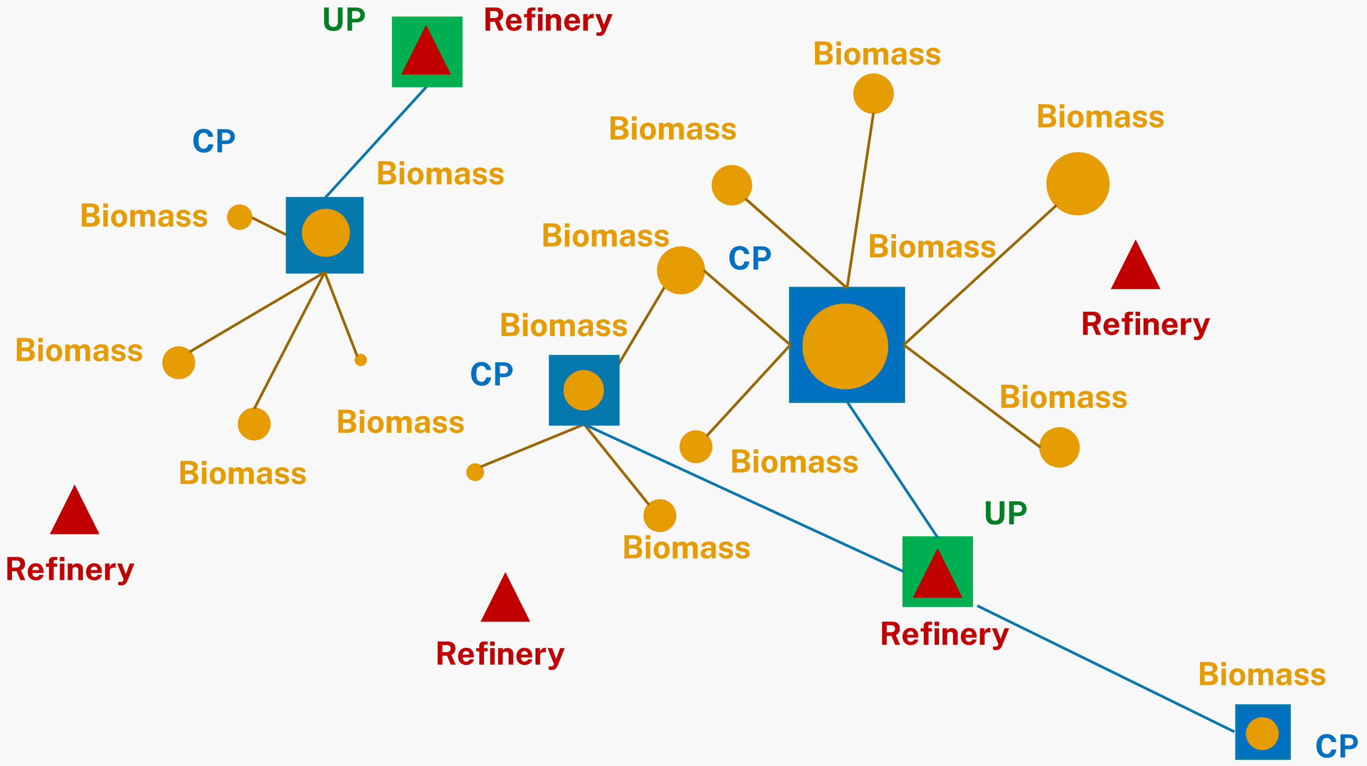
CP : Conversion plant

BCR supply chain design



CP : Conversion plant

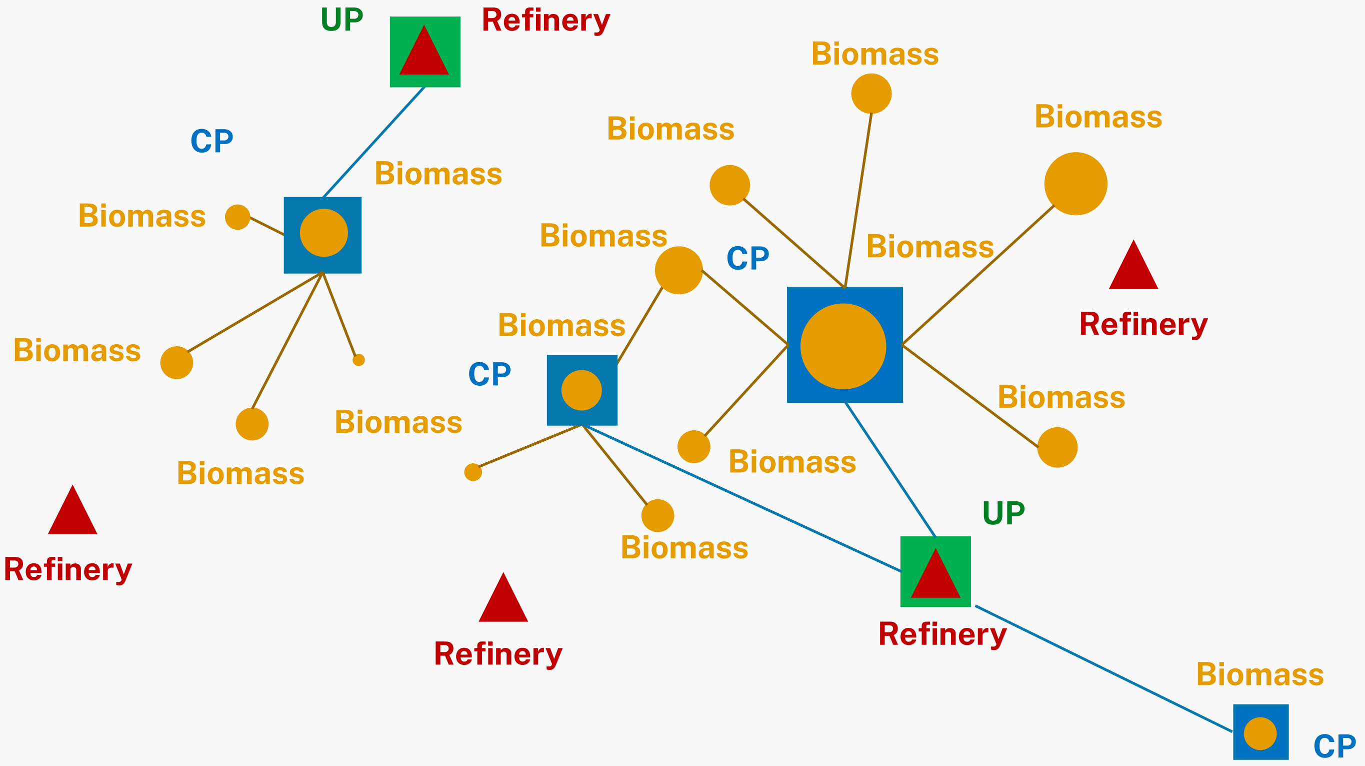
BCR supply chain design



CP : Conversion plant
UP : Upgrading plants

UTN

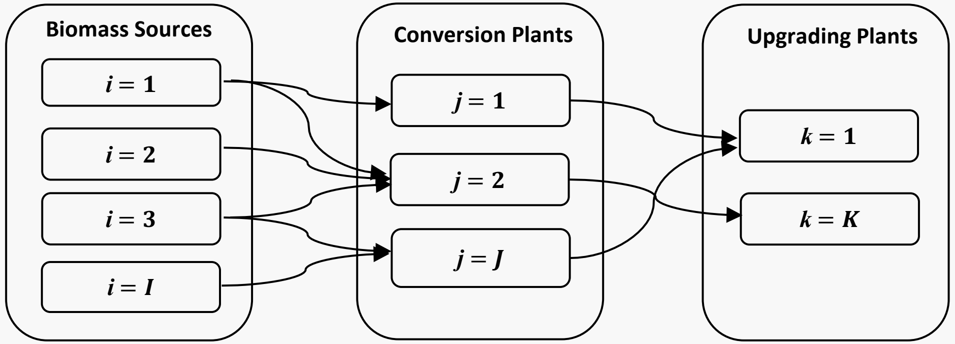
BCR supply chain design

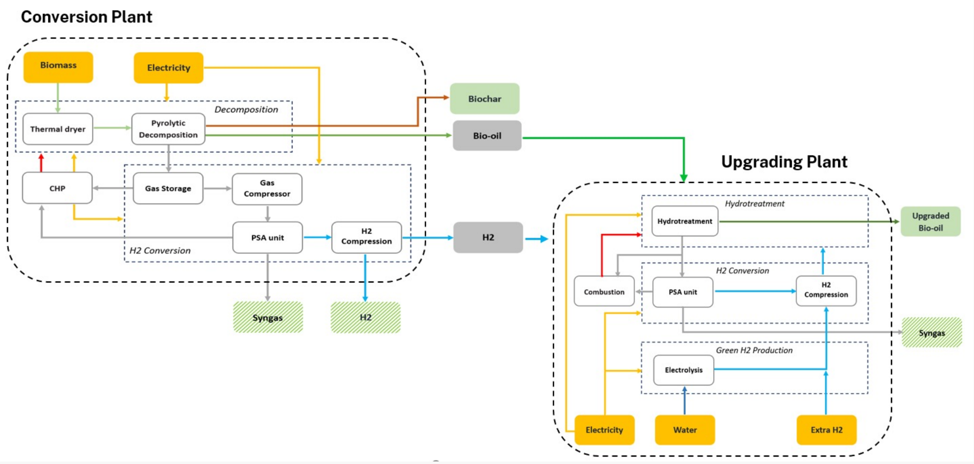


CP : Conversion plant
UP : Upgrading plants

BCR optimization model

- **Model:**
  - Cost minimization model (a mixed-integer nonlinear programming)
  - Operates with hourly production data and evaluates system performance over a one-year period
- **Objective function:**
  - To minimize the sum of annual total cost of the whole value chain
- **Model constraints:**
  - Mass and power balances
  - Technology capacity limits



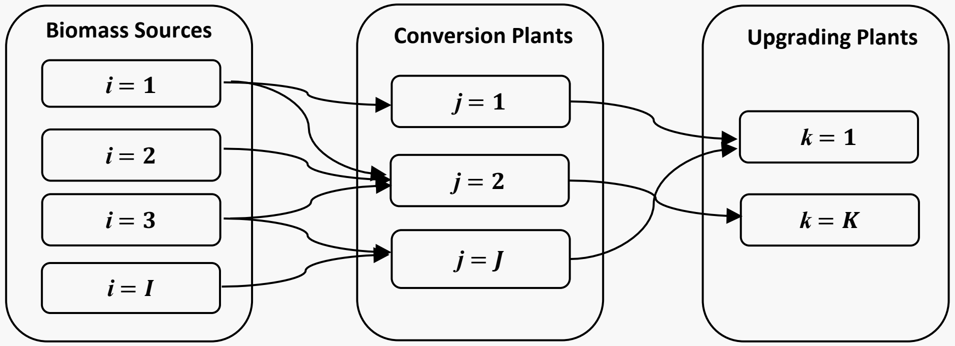


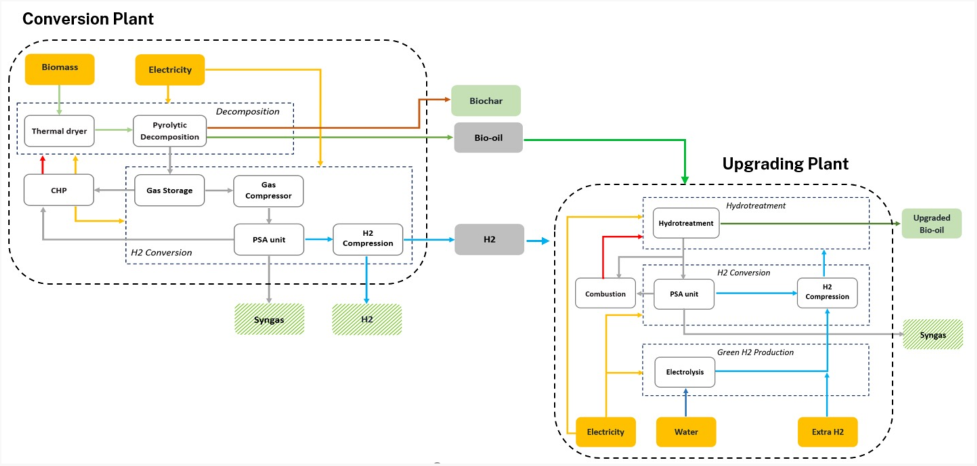
BCR optimization model

- **Parameters:**
  - Technical/chemical assumptions:
    Input data on mass and energy balances for biomass conversion and hydrotreatment processes (vary depending on the type of biomass and the process conditions)
  - Economic assumptions:
    CAPEX and OPEX of technologies
    Process efficiencies/power consumption
    Location-specific parameters such as electricity prices and interest rates

Optimal Carbon (removal) Credit:

The minimum carbon credit to ensure achieving none negative NPV.



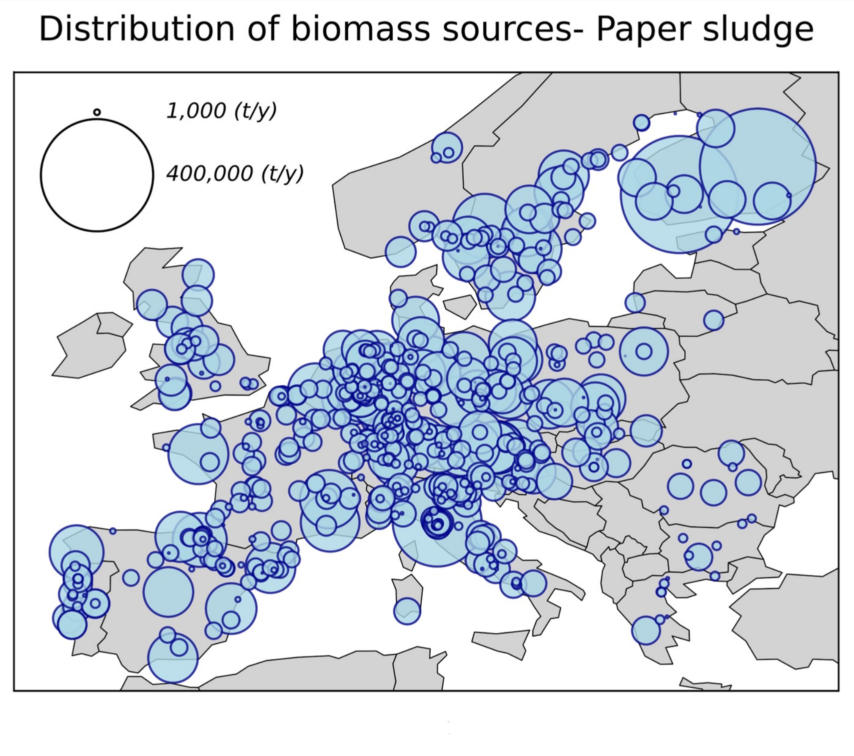


Case Study

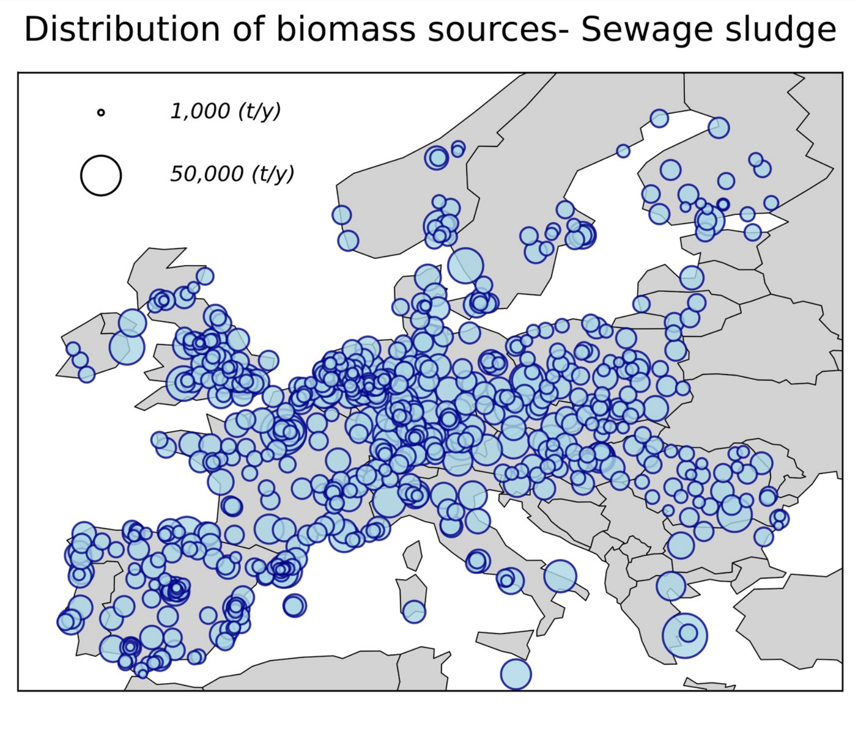
Case study

- The model is applied to two case studies
  - All available **paper sludge** and **sewage sludge** from **European countries**
  - Biomass is transformed to biochar and biofuel using the **thermo-catalytic reforming (TCR)** process
- TCR developed by Fraunhofer (UMSICHT):
  - A novel intermediate pyrolysis process
  - Suitable for diverse biomass
  - Offers the advantage of producing a more favorable liquid biofuel with a higher heating value compared to slow or fast pyrolysis (substitute to conventional diesel)
- The model is calibrated on the basis of a scenario for 2035
- The input process parameters are taken from real experimental data by Fraunhofer and oil-refinery
- Further CAPEX and OPEX of TCR process are real estimations by a paper manufacturer in Germany

Biomass distribution

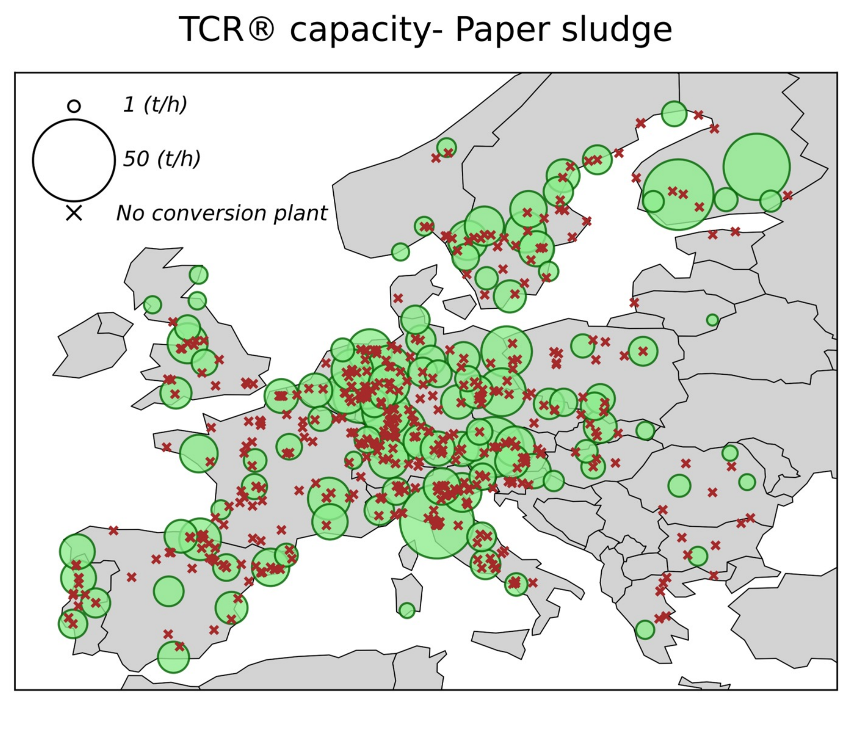


594 biomass sources
(European Environment Agency, 2024)

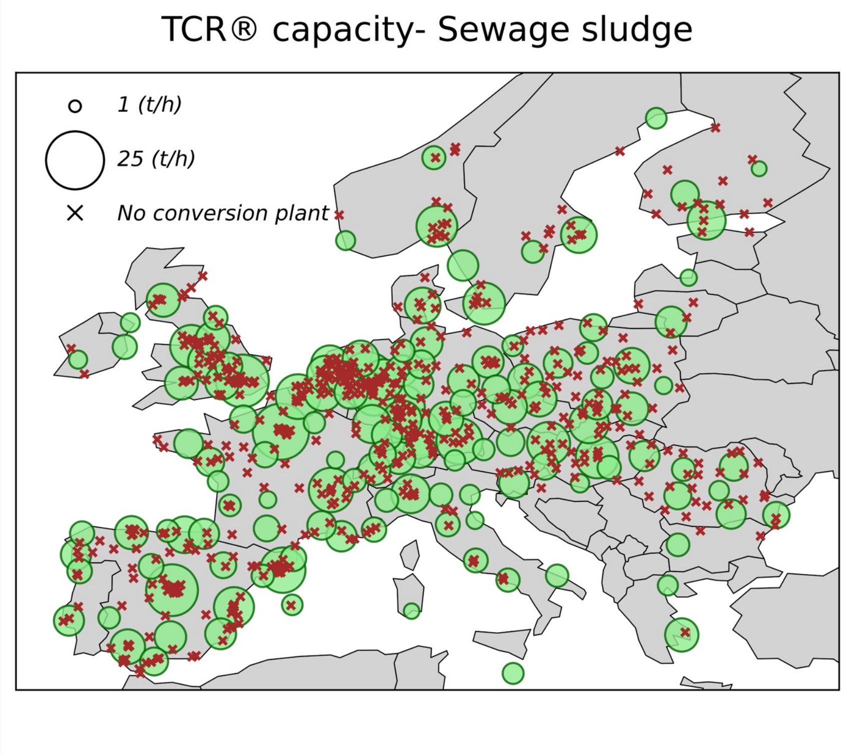


715 biomass sources
(European Environment Agency, 2024)

Results- Conversion plants

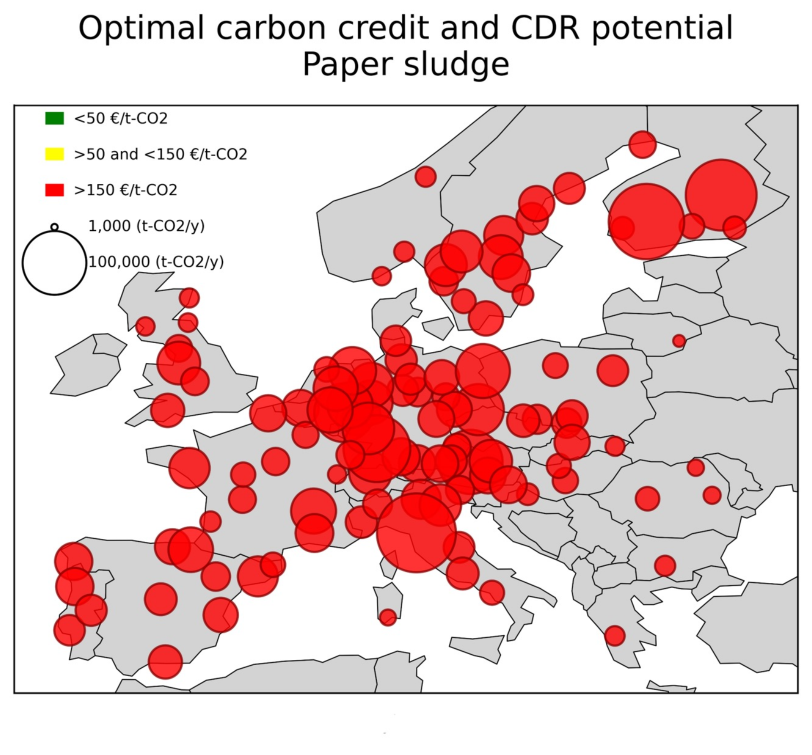


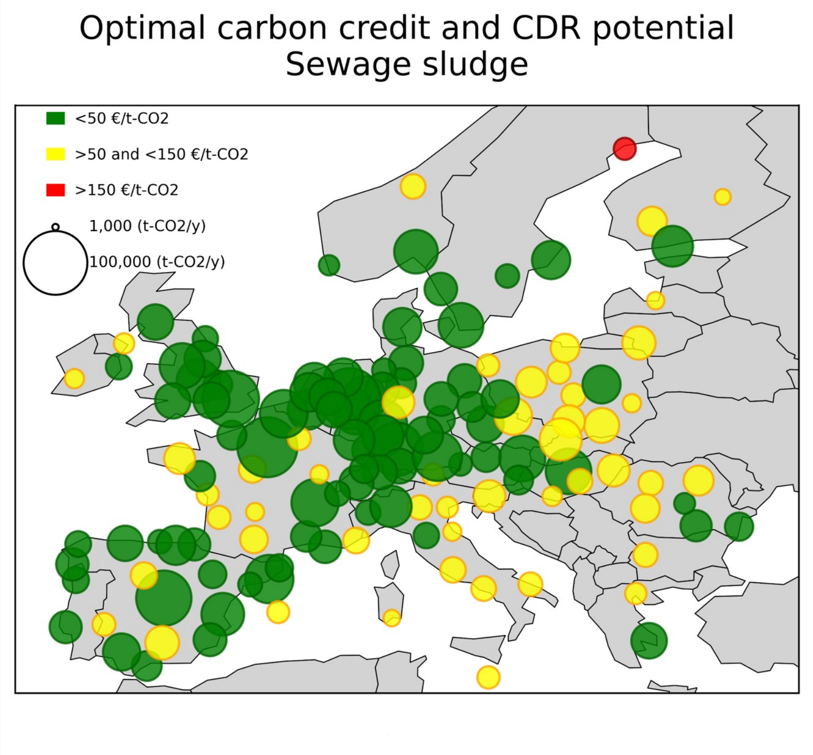
Conversion plants becomes non-viable at 482 locations out of 594 potential places



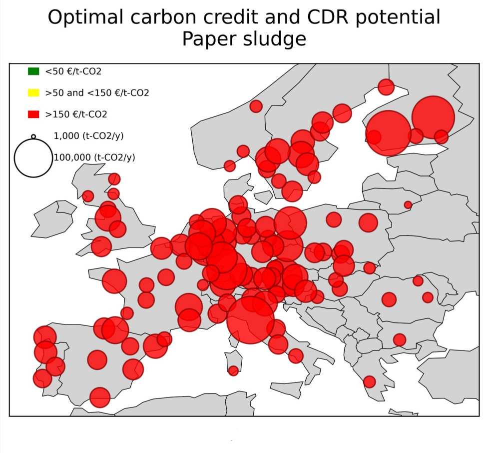
Conversion plants becomes non-viable at 577 locations out of 715 potential places

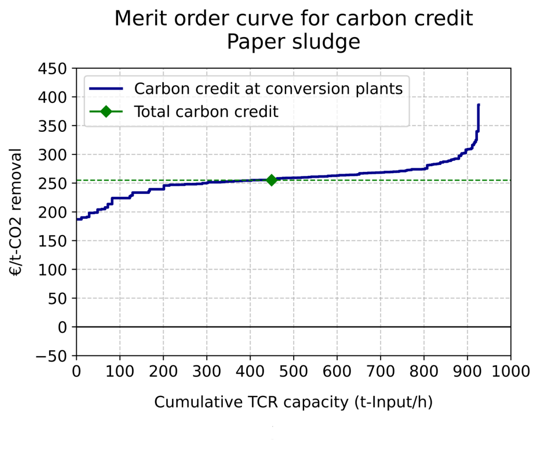
Results- Optimal carbon credit & Carbon removal potential

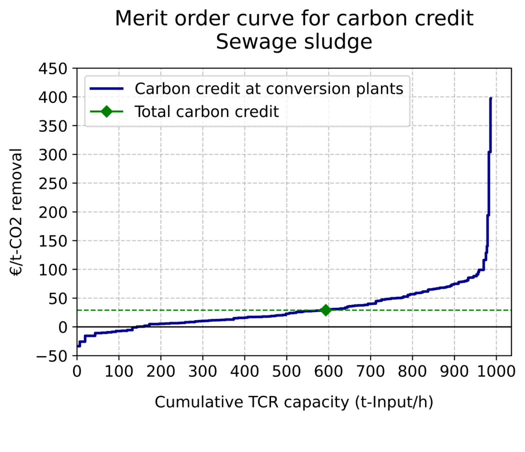


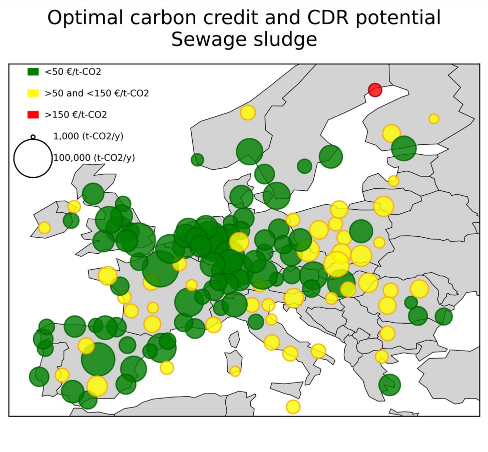


Results- Optimal carbon credit & Carbon removal potential





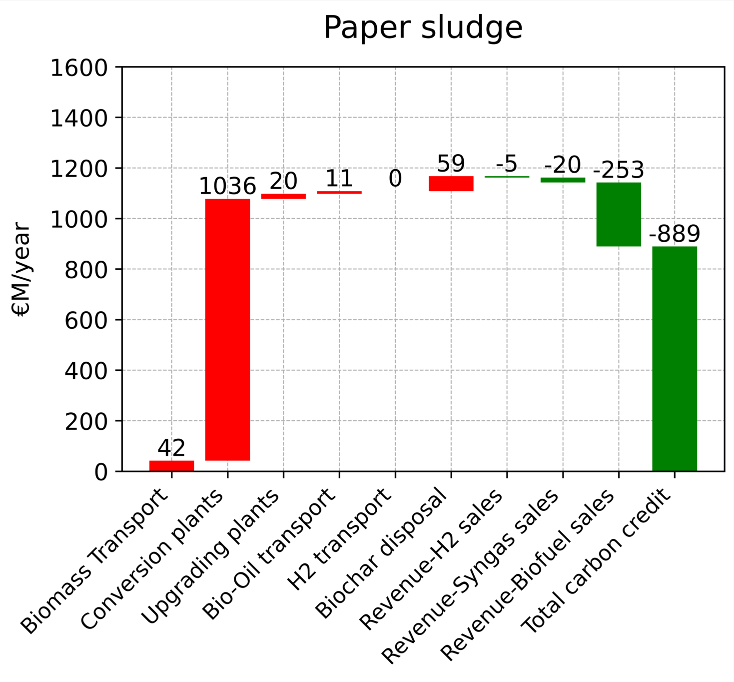


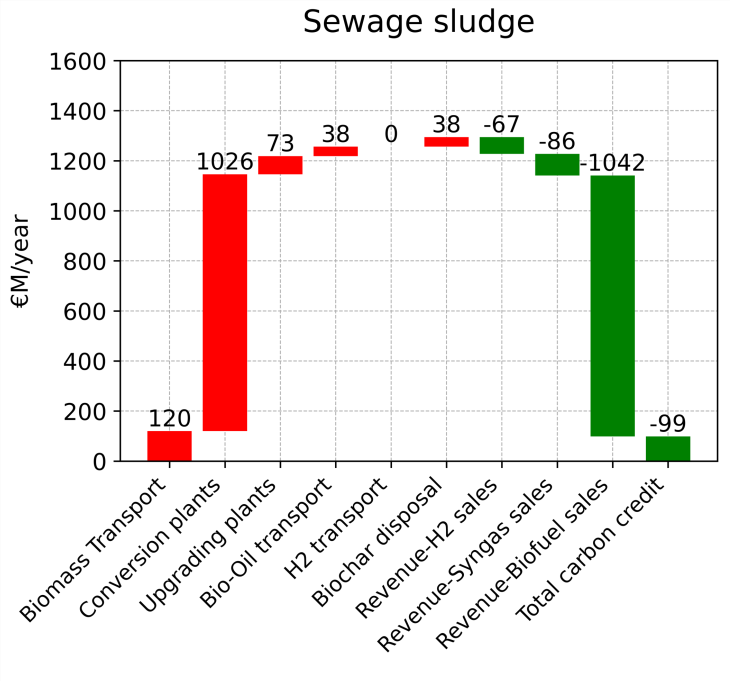


Average carbon credit for the entire system:
255 €/t-CO_2 (ranging from 187 to 386 €/t-CO_2)

Average carbon credit for the entire system:
29 €/t-CO_2 (ranging from –34 to 397 €/t-CO_2)

Total annual costs and revenue breakdown

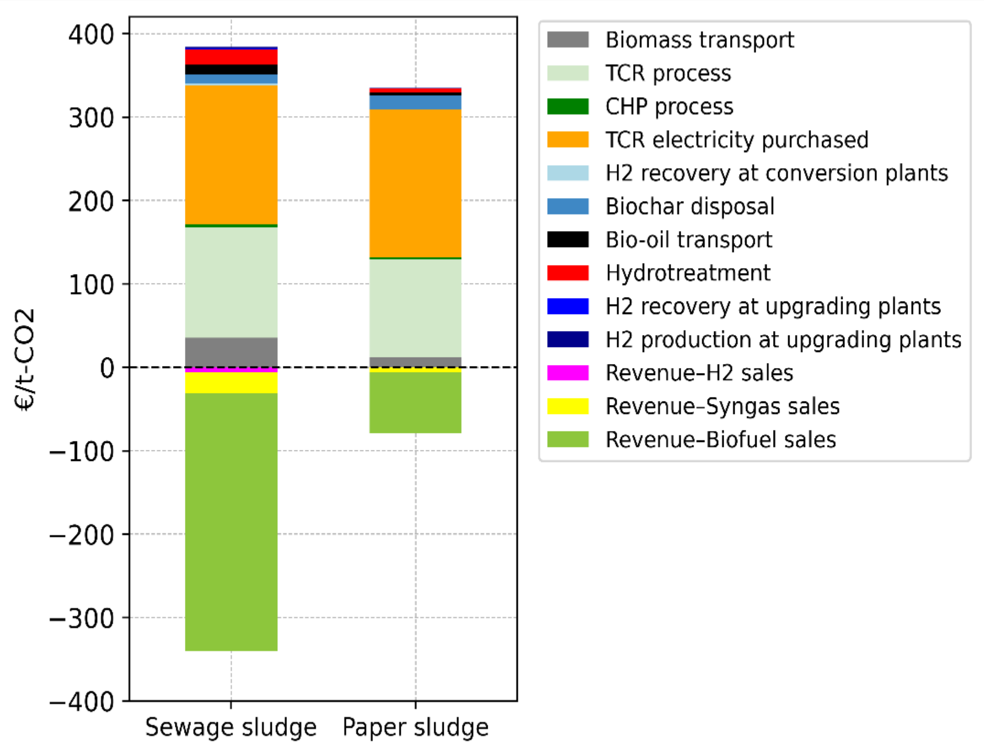




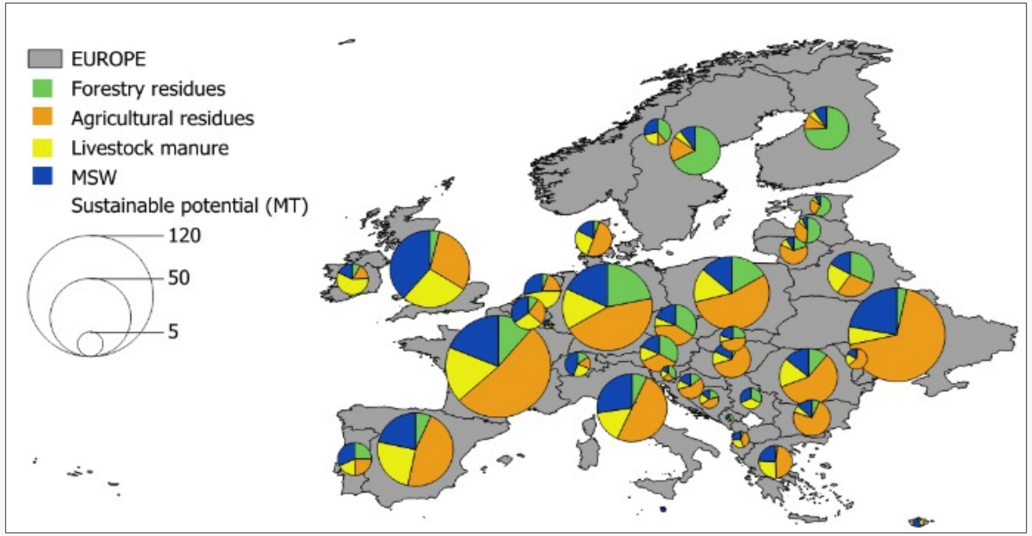
More than 90% of total costs are offset by revenue from selling by-products

Costs and revenue breakdown per ton CO_2 removal

- The cost of extra electricity required for the conversion plants accounts for the largest share of the total costs
- Followed by the capital and operational costs of the TCR process.

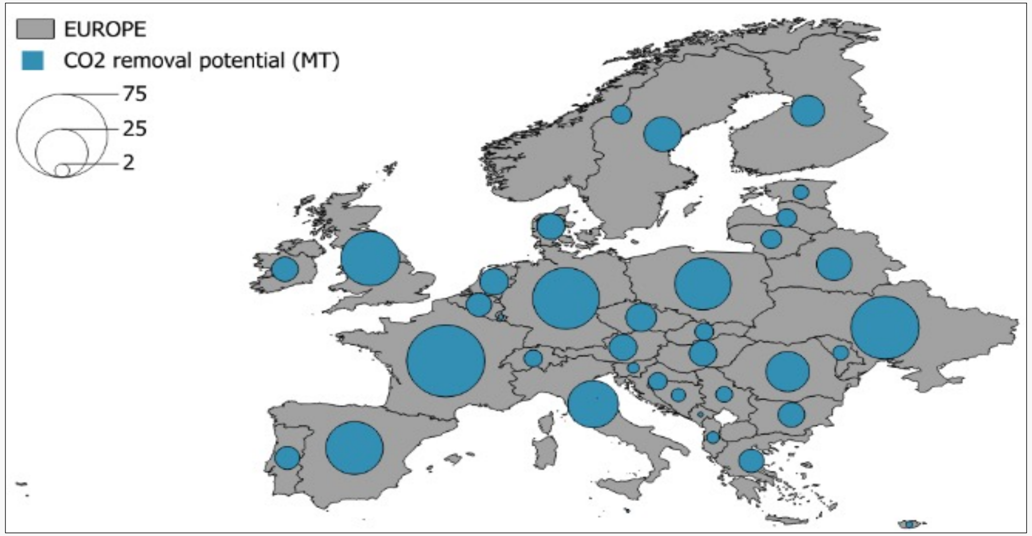


Sustainable potential of biogenic wastes and residues in Europe



Total amount of sustainable biogenic waste and residues in Europe : 443 and 801 Mt (dry matter)

BCR potential from biogenic wastes and residues using TCR in Europe



CO_2 removal potential 203–619 Mt per year, that is approximately equivalent to 8–25% of the EU total CO_2 emissions in 2023.

Conclusion

- BCR can be cost-competitive negative emission method
- Its cost-effectiveness vary by biomass type, quantity, location, and site-specific factors and require further analysis.
- Biochar from sewage sludge is more cost-effective than many other negative emission solutions.
- Potential for cost degression :
  - A 50% reduction in **TCR process investment costs** could lower the carbon credit to 189 €/t CO_2 for paper sludge and -46 €/t CO_2 for sewage sludge.
  - **Revenues from selling biochar** at market price (100 €/t)→ the carbon credit could decrease to 65 €/t CO_2 for paper sludge and - 132 €/t CO_2 for sewage sludge.

Thank you for your attention!

Kiana Niazmand
Doctoral researcher
Kiana.niazmand@utn.de

Technische Universität Nürnberg
Dr.-Luise-Herzberg-Straße 4
90461 Nürnberg
www.utn.de