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KOPERNIKUS Ariadne PROJEKTE
Die Zukunft unserer Energie

The European Refinery: Effects of Carbon Accounting in the EU ETS on the Future of Fossil Oil

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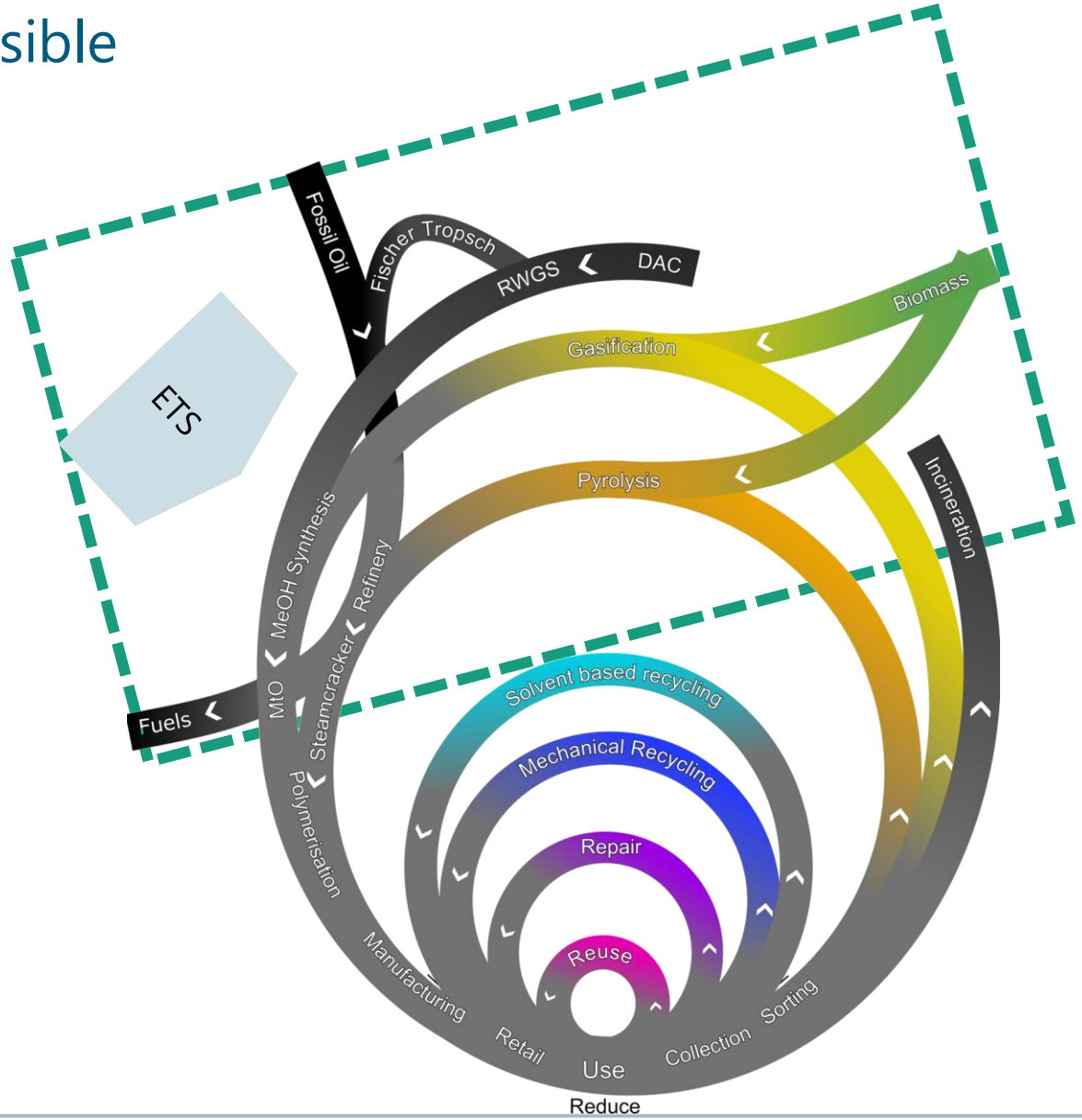
There are several Pathways for Refineries plausible

- Refineries convert fossil oil into fuels and plastics in highly integrated processes
- Fossil carbon bound into fuels and plastics is released at their end of life
- Several technologies might contribute to climate neutrality
  - Feedstocks, energy demand and product composition differ
- The process choice is highly influenced by the ETS
- However, the current ETS creates mixed incentives



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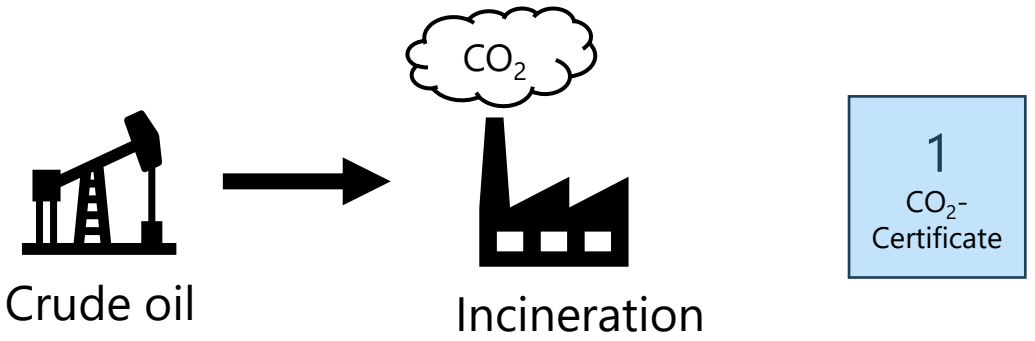
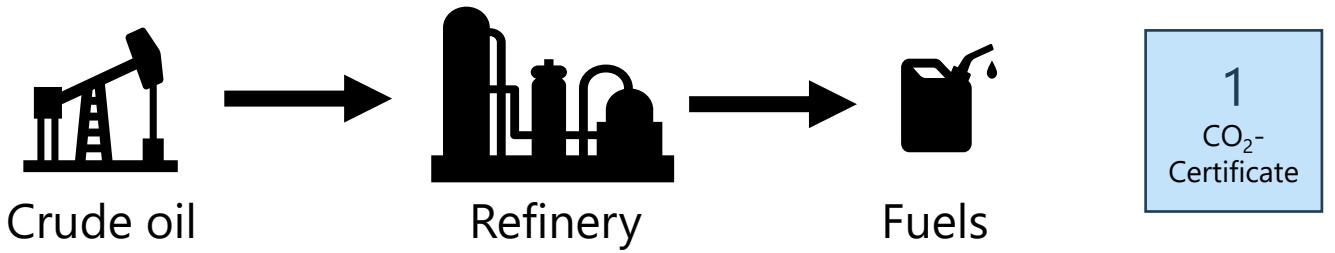
ETS 1 targets direct emissions
Background: ETS



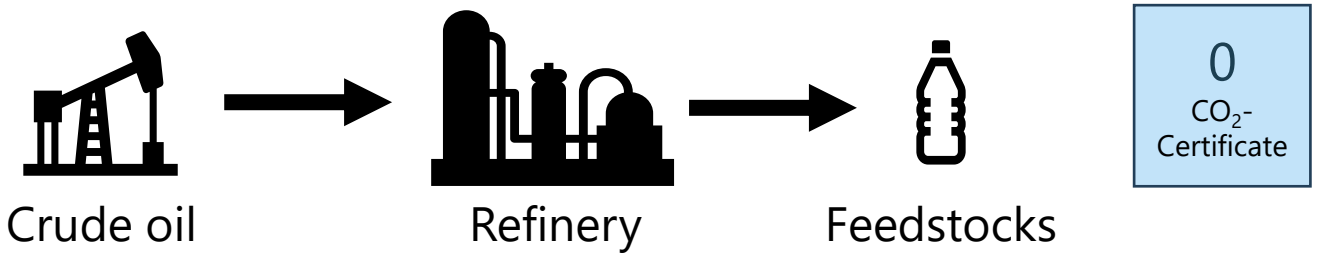
ETS 2 targets emissions from fuel produced

Background: ETS



ETS does not consider carbon temporarily bound in plastics

Background: ETS

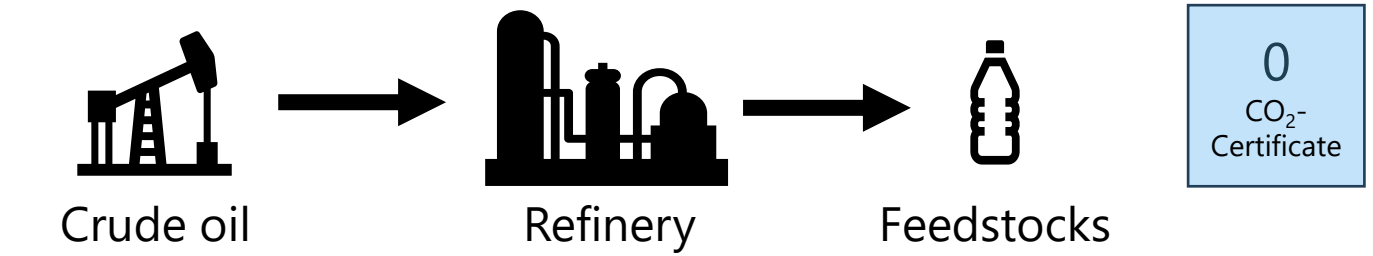


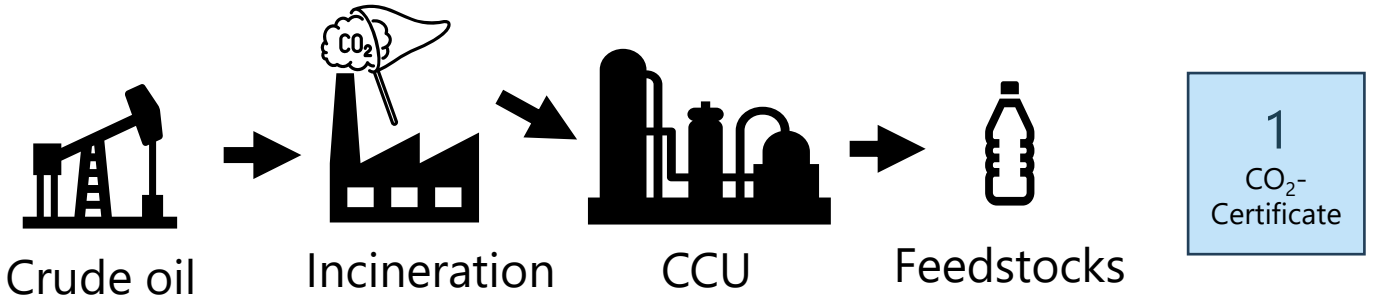
ETS does not consider carbon temporarily bound in plastics

Background: ETS

1 CO_2-Certificate Linear pricing

Not considering carbon bound in plastics





Alternatives to linear pricing are flow-based and point-of-extraction pricing

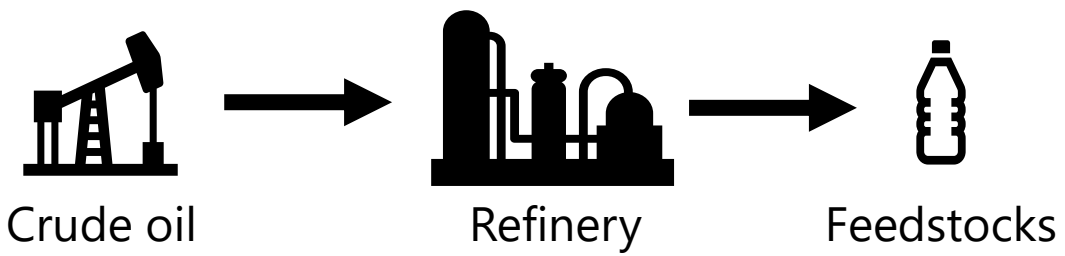
Background: ETS

1 CO_2-Certificate Linear pricing

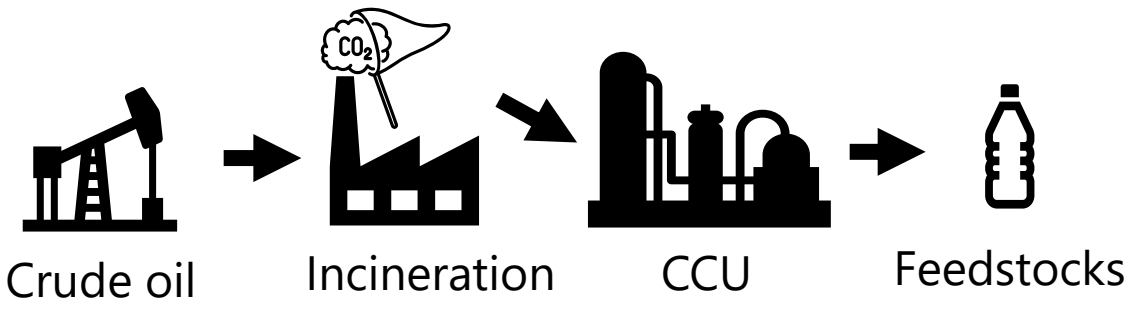
1 CO_2-Certificate Flow-based pricing

Not considering carbon bound in plastics

Considering all carbon bound in plastics to be bound



0 CO_2-Certificate	0 CO_2-Certificate



1 CO_2-Certificate	0 CO_2-Certificate

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Alternatives to linear pricing are flow-based and point-of-extraction pricing

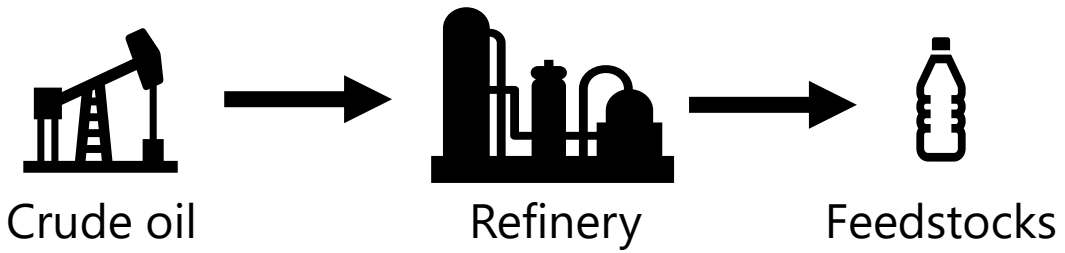
Background: ETS

1 CO_2-Certificate Linear pricing

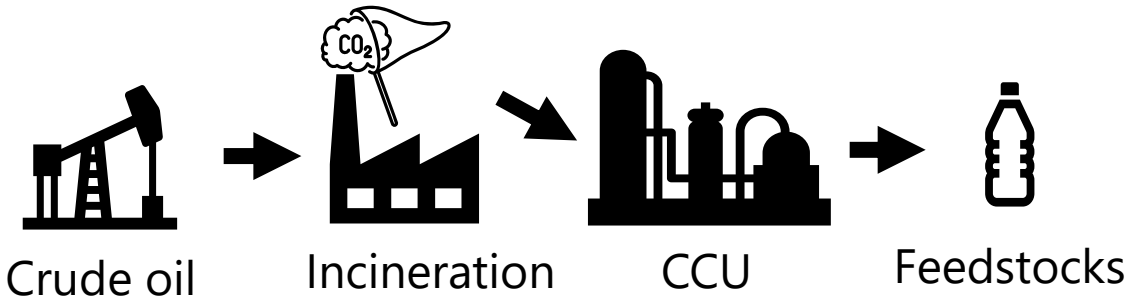
1 CO_2-Certificate Flow-based pricing

1 CO_2-Certificate Point-of-Extraction pricing

Not considering carbon bound in plastics	Considering all carbon bound in plastics to be bound	Considering no carbon bound in plastics to be bound



0 CO_2-Certificate	0 CO_2-Certificate	1 CO_2-Certificate



1 CO_2-Certificate	0 CO_2-Certificate	1 CO_2-Certificate

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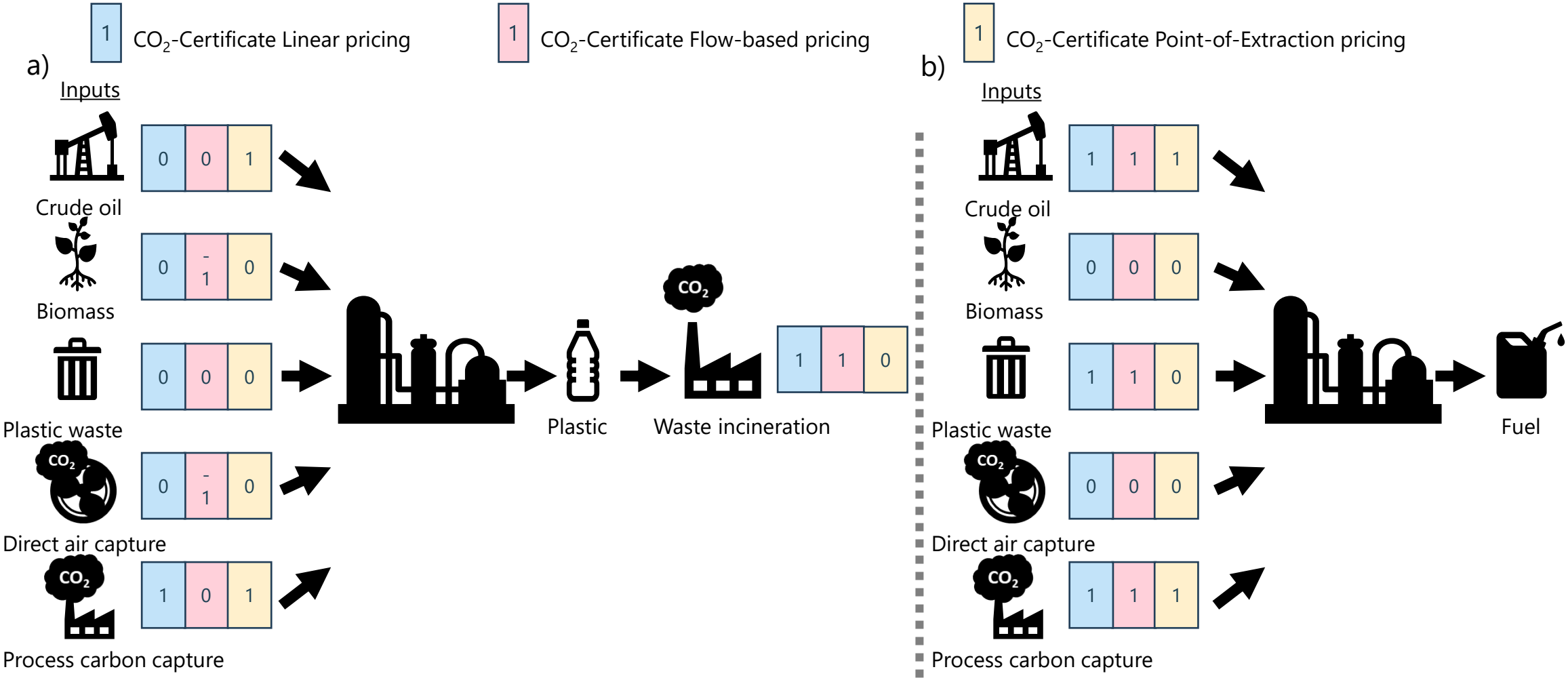
Alternatives to linear pricing are flow-based and point-of-extraction pricing

Background: ETS



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Content

Research Question

Linear pricing | Flow-Based pricing | Point-of-Extraction pricing

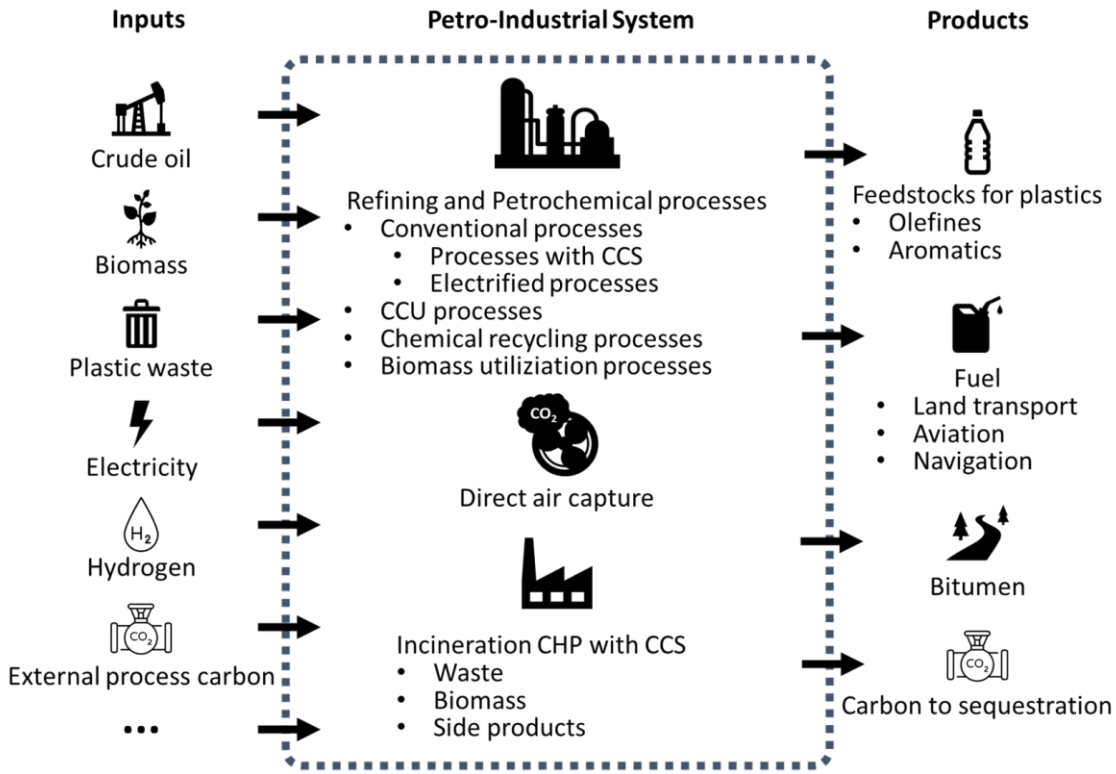
How do different carbon pricing schemes shape feedstock choice—and thereby costs, energy demand, and emissions—in the coupled production of fuels, olefins, aromatics, and bitumen, using the EU27 in 2050 as a case study?

Key refinery products

Content

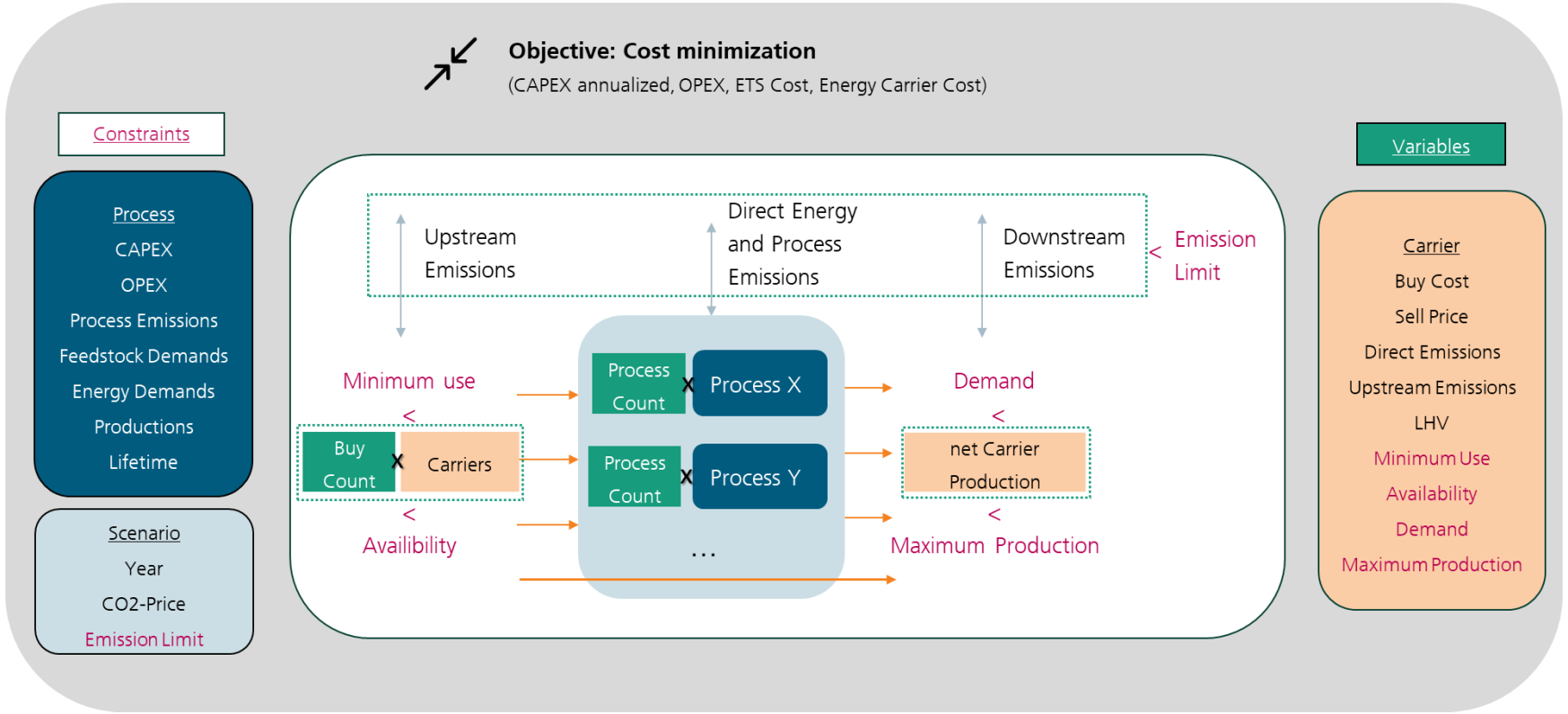
Linear Optimization of Petro-Industrial System
Methods

- **Modelling variety of process options in a coupled system**
  - Conventional processes with CCS
  - CCU processes
  - Biobased processes
  - Chemical recycling
- **Cost minimization**
  - Optimization of inputs and process utilizations under consideration of:
    - Demand for fuels, plastics and bitumen
    - Treatment of plastic waste that is not suitable for mechanical recycling
    - Availability of biomass and plastic waste
- **Including direct and lifecycle emissions through**
  - Plastic waste treatment
  - Fuel use
  - Upstream emissions of biomass and crude oil
- **Simplification: Assuming a uniform CO_2 price for ETS1, ETS2 and negative emissions**



Linear Optimization of Petro-Industrial System

Methods



Product	Carrier	Demand
Aviation Fuel	Kerosene	154.3 TWh
Land Transport Fuel	Gasolene, Light fuel oil	533.6 TWh
Navigation Fuel	Methanol, Light fuel oil, Heavy fuel oil, Gasolene, Kerosene	451.8 TWh
Olefines	Ethelyene, Proplyene and C4-Olefines	34.8 Mt
Aromatics	Benzene, Toluene, Xylene	10.5 Mt
Bitumen	Heavy vacuum residue, Lignin	6.4 Mt

Carrier	Price (Main Scenario) EUR/MWh	Availability TWh
Electricity	72	Unlimited
Hydrogen	72	Unlimited
Crude oil	47	Unlimited
Biomass	25	662
Plastic waste	18	284

Content

Considering all carbon bound in plastics to be bound

Considering no carbon bound in plastics to be bound

Flow-Based and Point-of-Extraction pricing have the same effect on process choice.
Only the costs for CO_2-Certificates for the Petro-Industrial System differ.
We focus on the comparison of Flow-Based and Linear pricing.

Flow-Based pricing reduces emissions

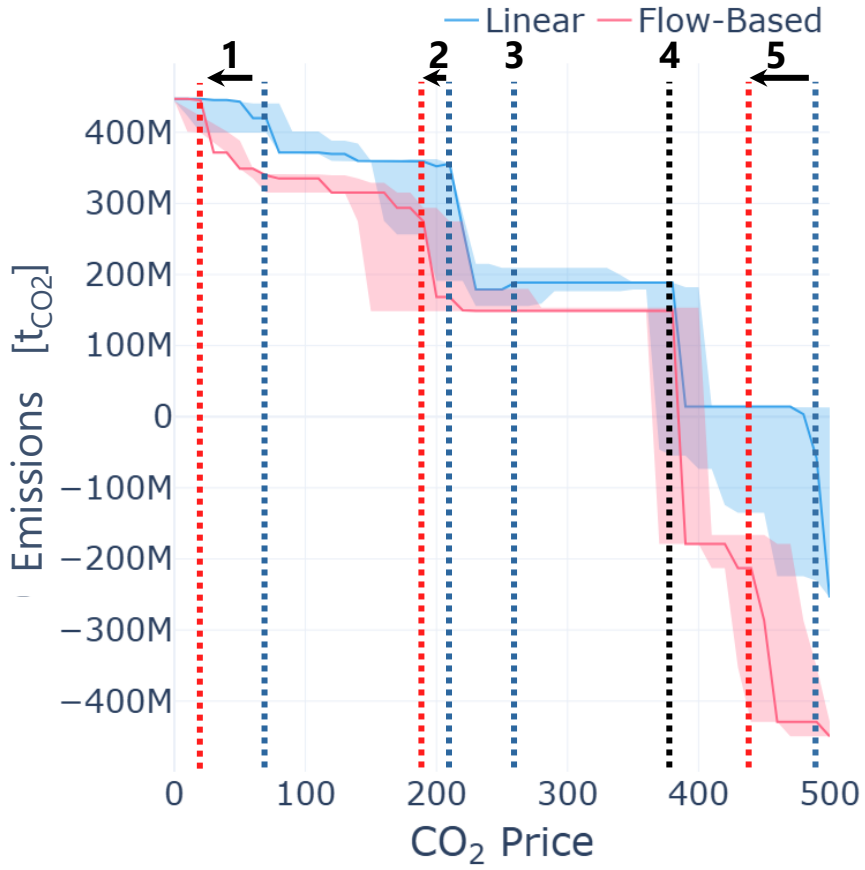
Results

Not considering carbon bound in plastics

Considering all carbon bound in plastics to be bound

- Emissions decrease with increasing CO_2-Price
- Under Flow-Based pricing the emissions are consistently lower

1. Autocombustion biomass gasification with subsequent MTO becomes viable
2. Electrification of biomass gasification enables higher methanol yields and thus methanol utilization as shipping fuel
3. Under linear pricing BECCS becomes viable and biomass-based olefine production is reduced
4. DACCS becomes viable at 390 EUR/tCO2 enabling negative emissions
   - A further increase in CO2-Price is only realistic if DACCS potentials are limited
5. FT-Synthesis becomes viable for defossilizing land and aviation fuels.

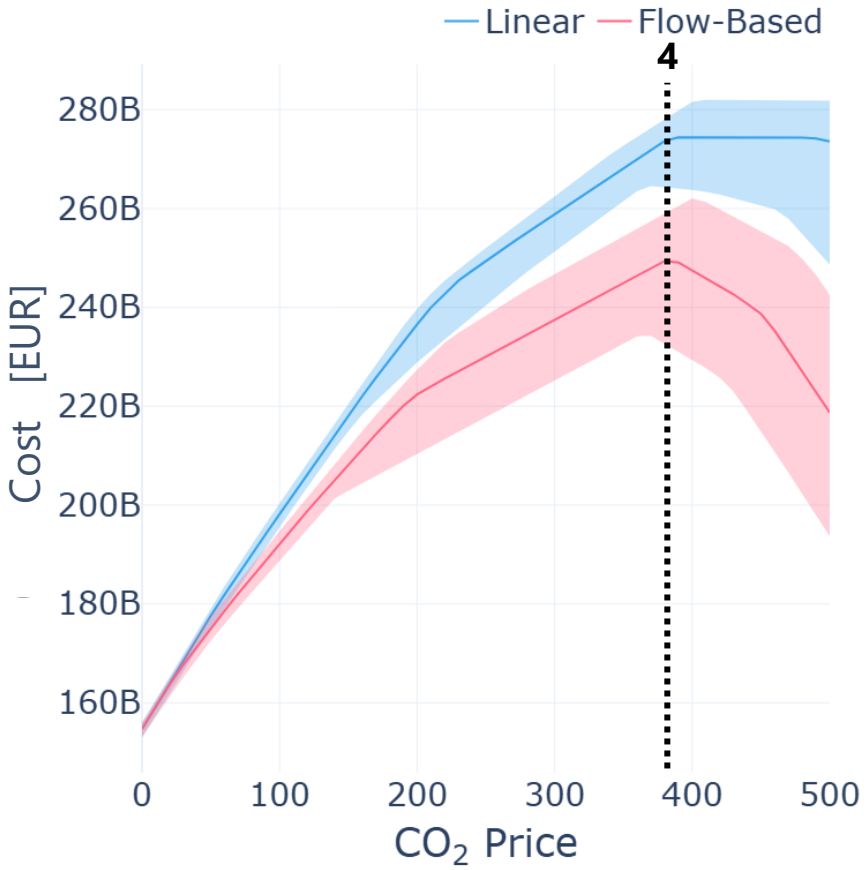


Flow-Based pricing reduces cost
Results

Not considering carbon bound in plastics

Considering all carbon bound in plastics to be bound

- Costs increase until DACCS becomes viable
  - DACCS at CO_2-Prices higher than the cost for DACCS allow gains for the optimized system
- Costs under Flow-based pricing are consistently lower than under Linear pricing



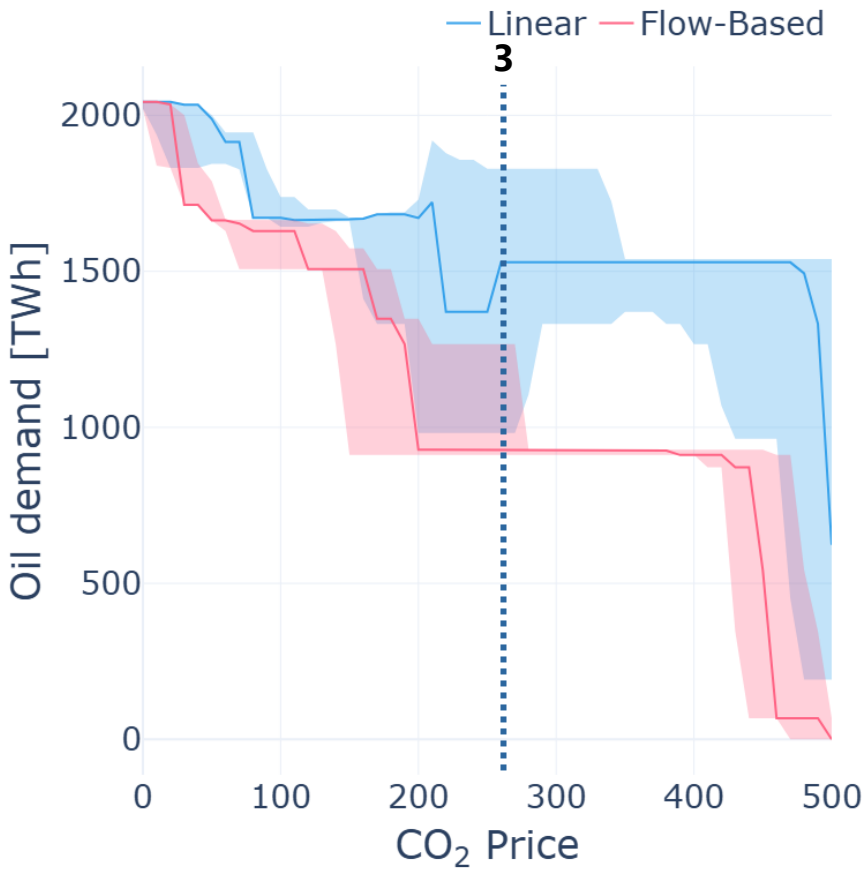
Flow-Based pricing reduces oil demand

Results

Not considering carbon bound in plastics

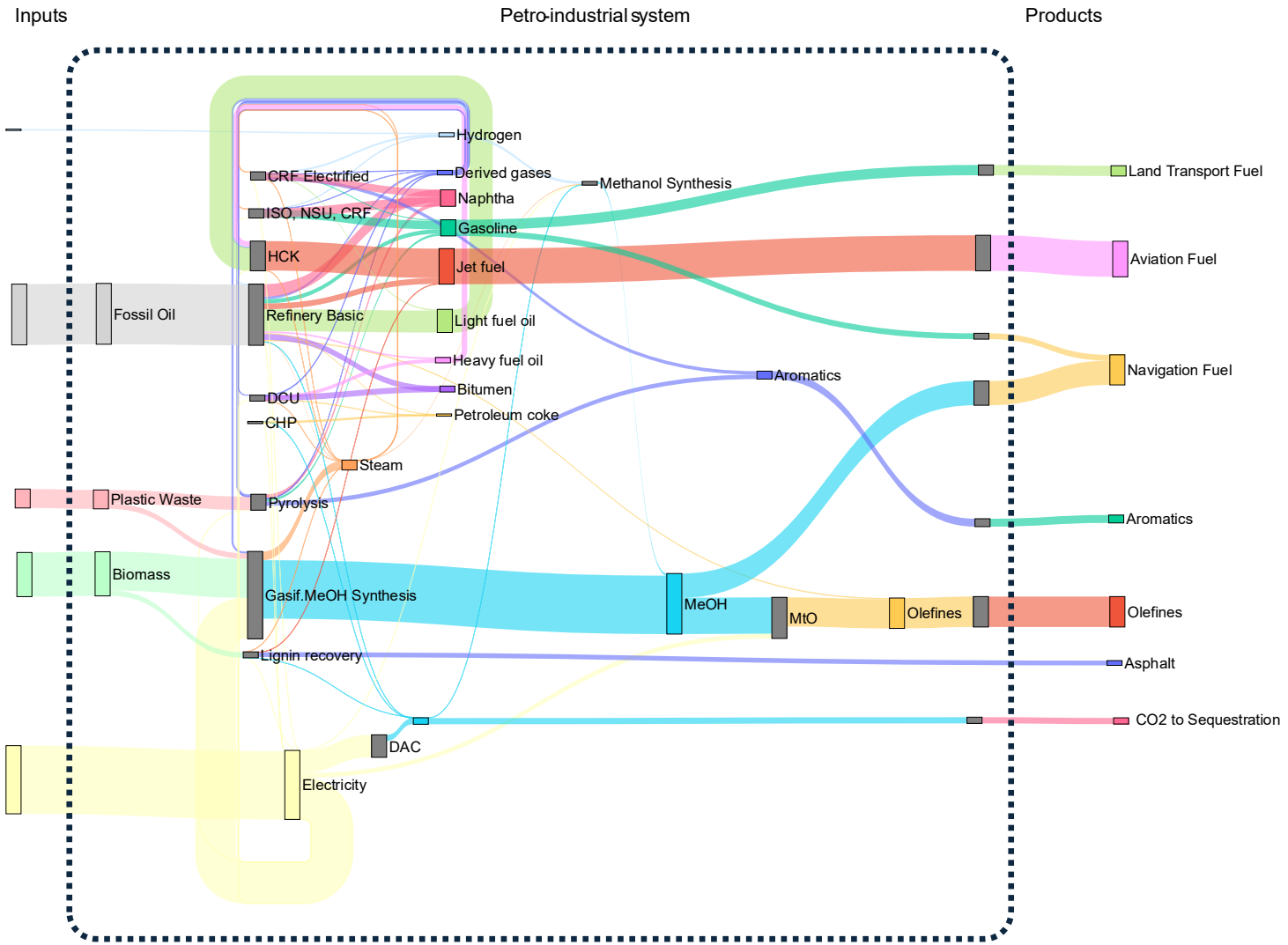
Considering all carbon bound in plastics to be bound

- Oil demand decreases with increasing CO_2-Price
- Under Flow-Based pricing the oil demand is consistently lower than under Linear pricing
- Full defossilization is reached at 500 EUR/t_{CO2} under Flow-Based pricing
- Under Linear pricing a structural dependency on oil remains



Deep dive into cost-optimal climate neutral petro-industrial system

Results



Discussion and Conclusion

Discussion and Conclusion

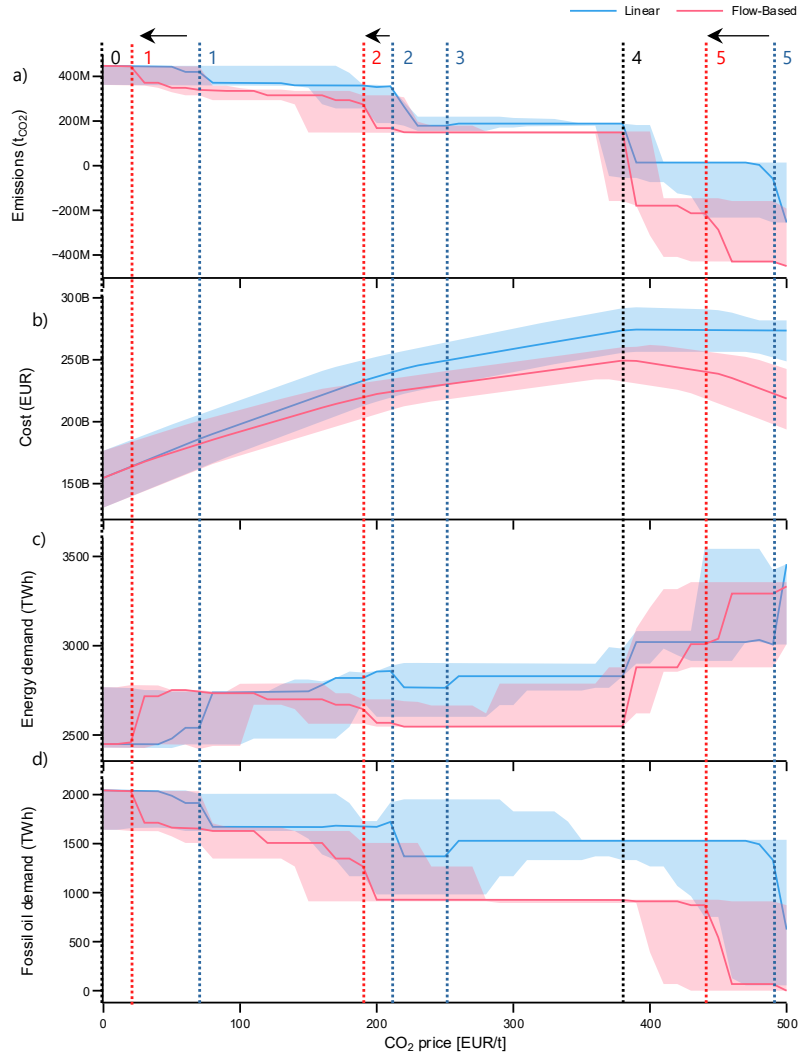
- Flow-based pricing helps to reduce emissions cost efficiently
  - Flow-based pricing shifts the viability of key technologies to lower CO_2-prices
  - The CO_2-pricing of feedstocks also influences the defossilization of fuels

- The analysis results a clear mitigation hirarchie:
  1. Chemical recycling
  2. Biomass utilization
  3. Compensated fossil fuels
  4. E-Based chemicals and fuels (DACCU)

- Further considerations
  - The proposed adjustments of the ETS could impact other sectors
  - The adjustments could affect climate targets
  - It is important to consider trade and establish credible border adjustment mechanisms
  - Full defossilization leads to very high electricity and hydrogen demands which would require large scale imports

Not considering carbon bound in plastics

Considering all carbon bound in plastics to be bound



Content

Six key take aways:

ETS Update Needed:
Emission Trading System requires update to consider feedstocks

Chemical Recycling & Biomass:
Utilizing local potentials reduces emissions at low cost

Challenges for CCU:
Carbon Capture and Utilization faces high costs and energy demand

Process Selection:
Choice of processes depends on multiple factors and carries uncertainty

Full Defossilization Costs:
Transitioning to full defossilization entails high energy demands and costs

Potential Implementation:
Fossil feedstocks could be added to the ETS2 or temporarily bound carbon could be considered in the ETS 1

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Thank you for your attention!

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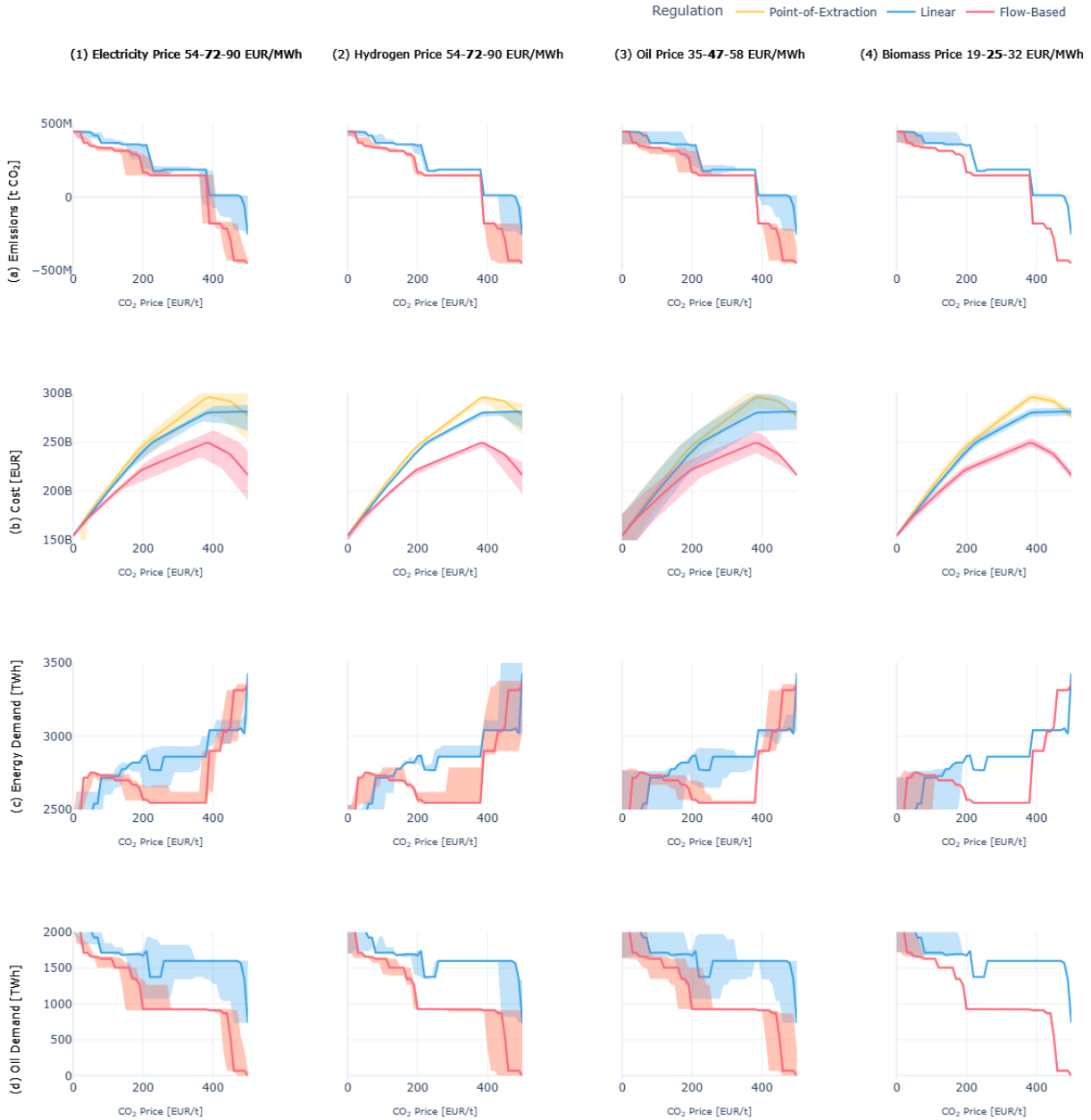
Figure 3



Emissions (a), Cost (b), Energy demand (c) and Oil demand (d) over CO2 price for deviating prices for electricity (1), hydrogen (2), oil (3) and biomass (4) by +/- 25 % from reference (shaded) and reference (line) for flow-based and linear accounting. For consistency, when analyzing the emissions, all CO_2 bound in products—whether from biomass, DAC, or processes—is treated as stored, independent of regulatory classification.