From net-zero to zero-fossil in transforming the EU energy system

Presentation at ECEMP 2025, 17/10/2025, Brussels

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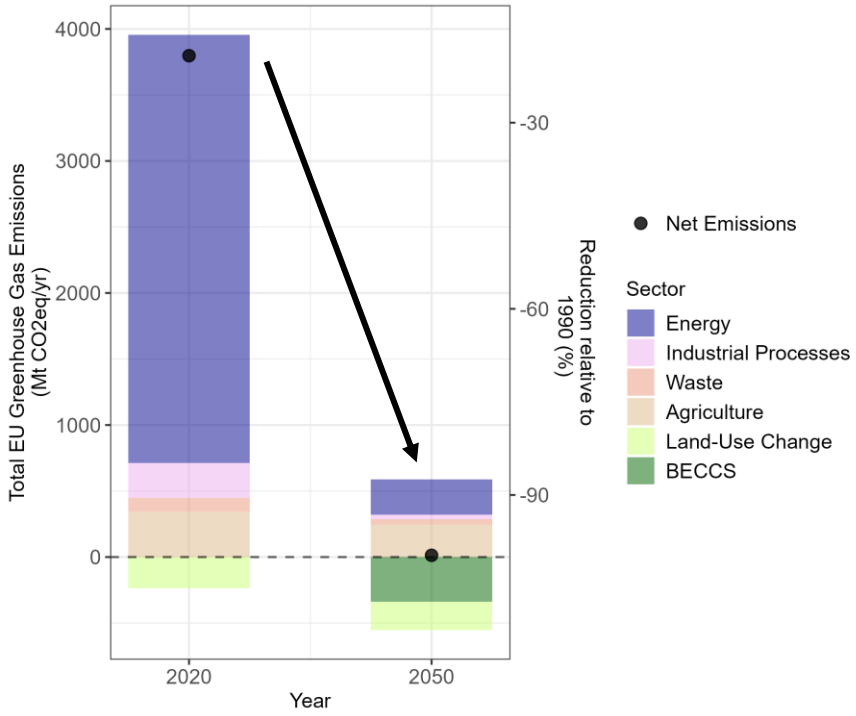
Motivation: Net-zero with low / no fossil emissions



- CDR can offset residual emissions, but limited in 2050 due to up-scaling, sustainability and institutional challenges (Fuss et al. 2018, Rosa et al. 2021, Buck et al. 2023, Kazlou et al. 2024)

- abatement of residual ('hard-to-abate') emissions active area of research (Luderer et al. 2018, van Vuuren et al. 2018, Grubler et al. 2018, Sharmina et al. 2020, Ueckerdt et al. 2021, Speizer et al. 2023, Fuhrman et al. 2024, Bachorz et al. 2024, Edelenbosch et al. 2024)

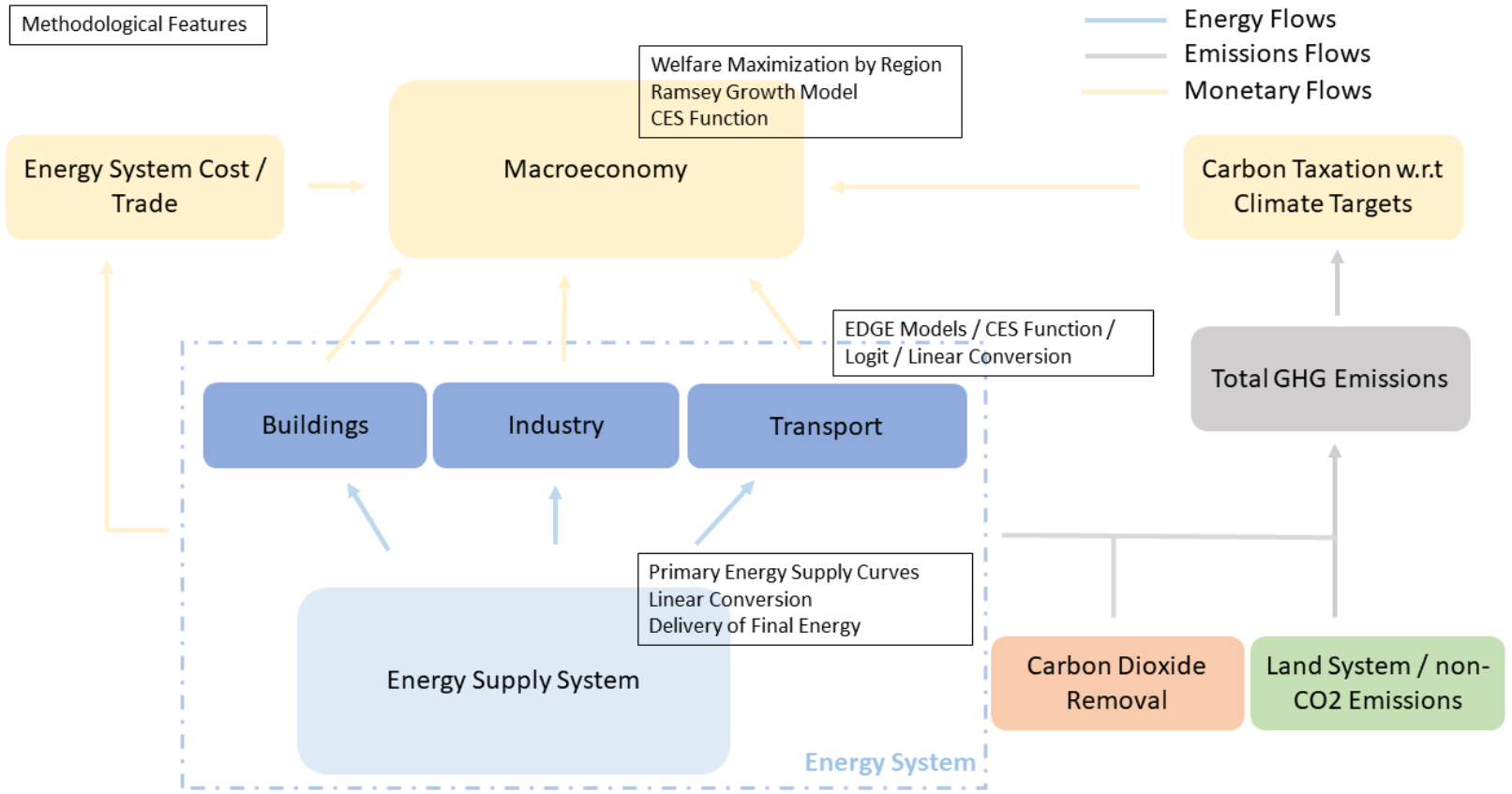
  - limits in agriculture, but also in energy?

  - cost implications of low residual emissions?

Transformation dynamics and cost implications of full EU fossil phase-out at net-zero by 2050?

Methods

Integrated Assessment Model: REMIND

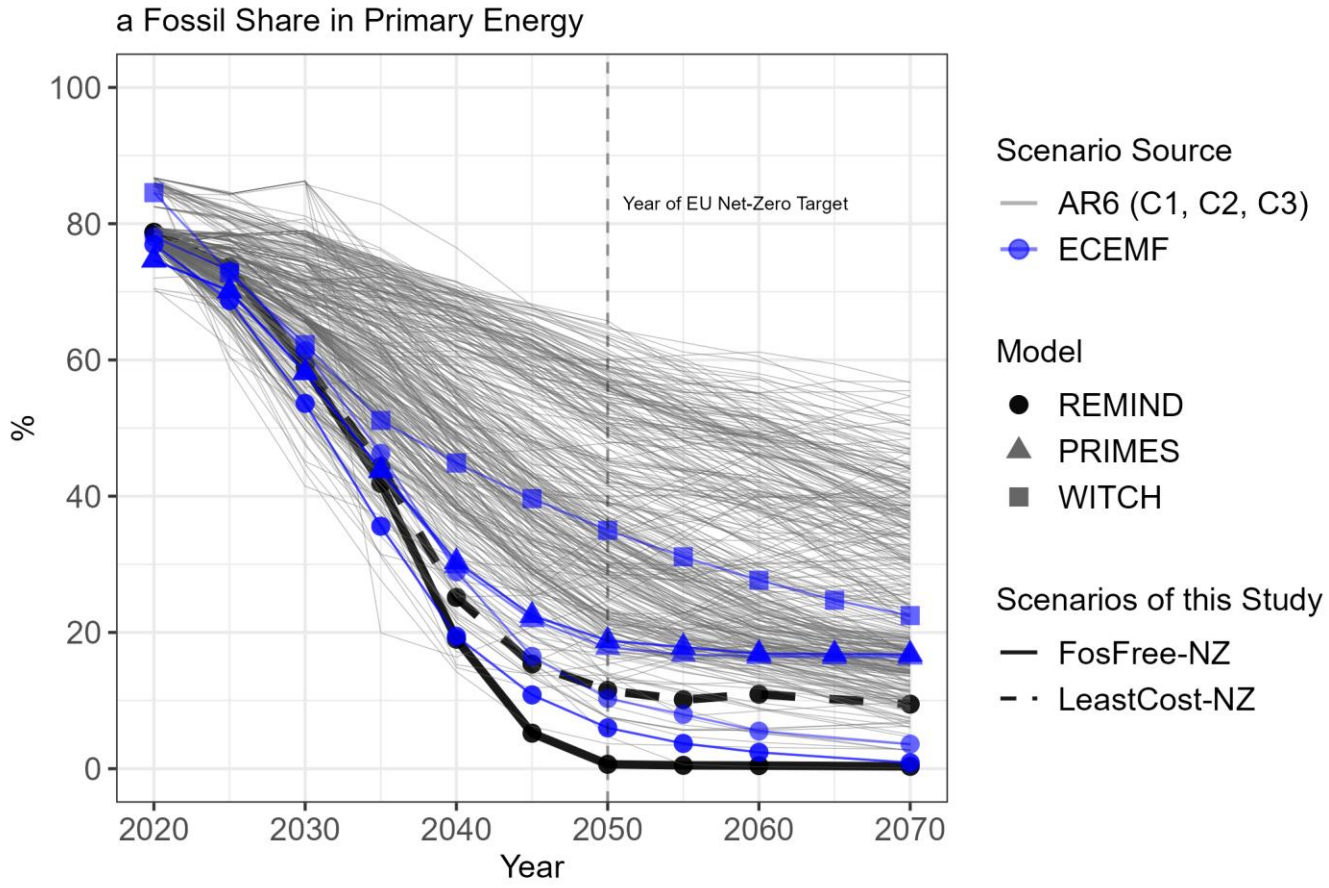


- Intertemporal welfare optimization per region
- 21 world regions, 7 EU regions
- Iterative carbon price adjustment until EU net-zero target met

Definition of Scenarios

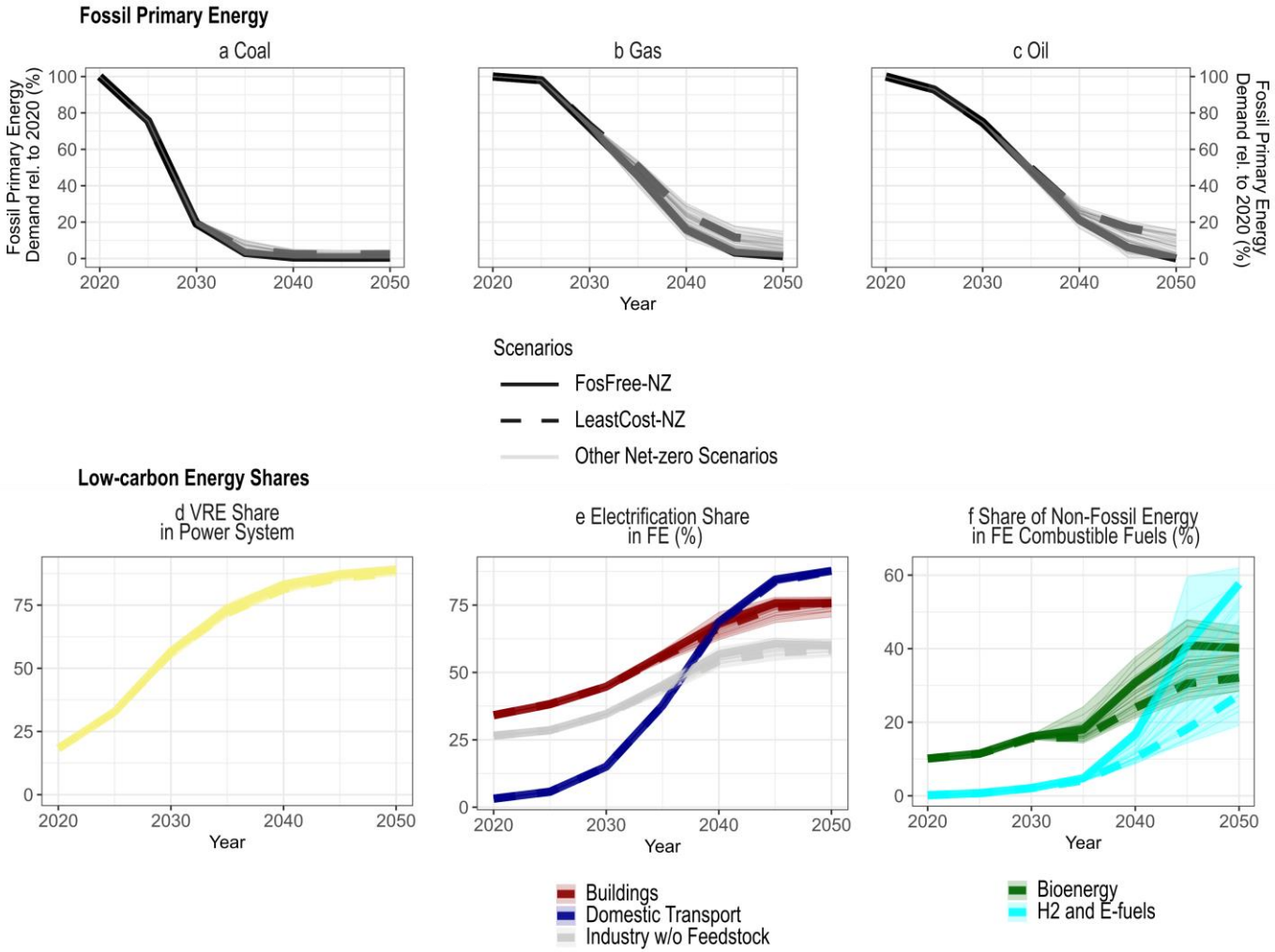
Scenarios	Scenario-specific assumptions (EU)	Standard Assumptions (EU)
Least-Cost Net-zero	Max. CCS: 2000 MtCO2/yr	2030: -55% GHG rel. to 1990 2050: net-zero GHG (incl. bunkers) Land Carbon Sink: 240 MtCO2/yr (national LULUCF accounting) 2050: half of EU e-fuel demand imported
Fossil-free Net-zero	Max. CCS: 110 MtCO2/yr	
Intermediate Net-zero	Max. CCS: 130/180/350 MtCO2/yr	
Net-zero Sensitivity Scenarios	Max. CCS: 110/180/350/2000 MtCO2/yr, sensitivities with larger biomass potential, cheap DAC, expensive green H2, no e-fuel imports etc.	

First scenarios with Full EU Fossil Phase-out



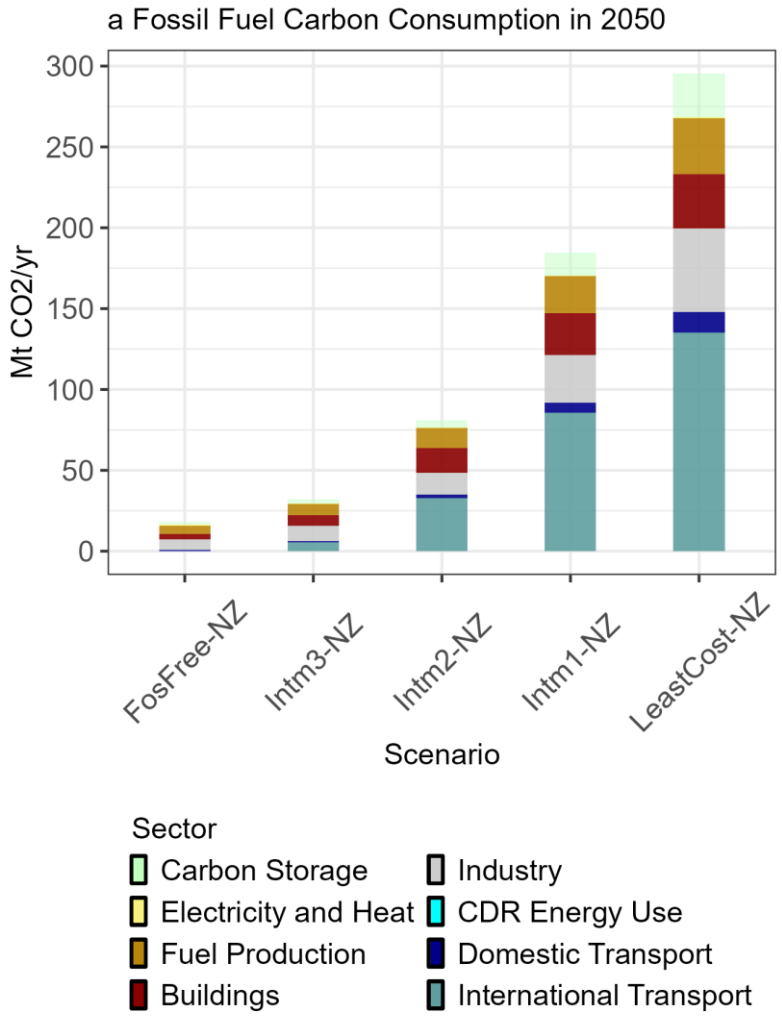
- Low-fossil / fossil phase-out scenarios not well researched in IAM literature
- Range of fossils in 2050 considerably smaller and lower: <1%-16 (share of fossils in PE)

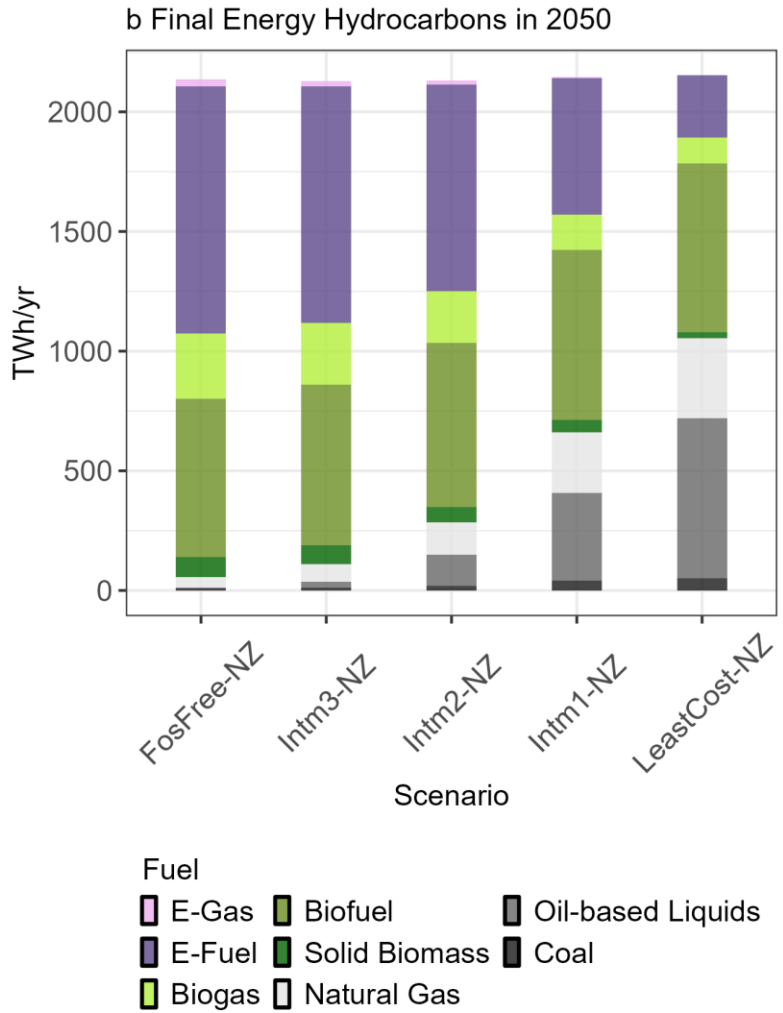
EU Fossil Phase-out in Three Steps



- EU Fossil fuel demand in 2050 rel. to 2020 (incl. sensitivities):
  - Coal: 0-5%
  - Gas/Oil: 0-15%
- 90% of fossils phased-out by renewable power, electrification (plus some biofuels / hydrogen)
- Last 10% require carbon-neutral e-fuels

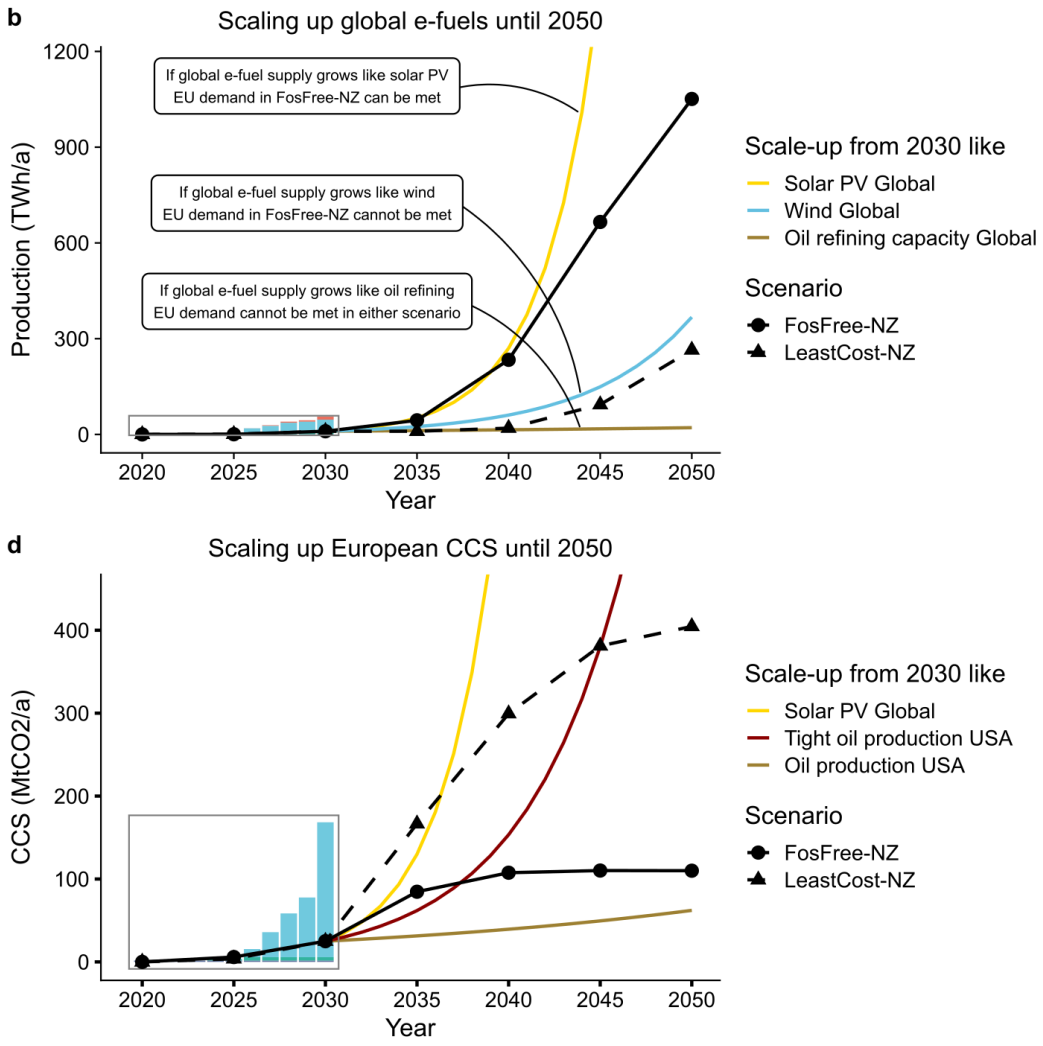
Residual Fossil Abatement





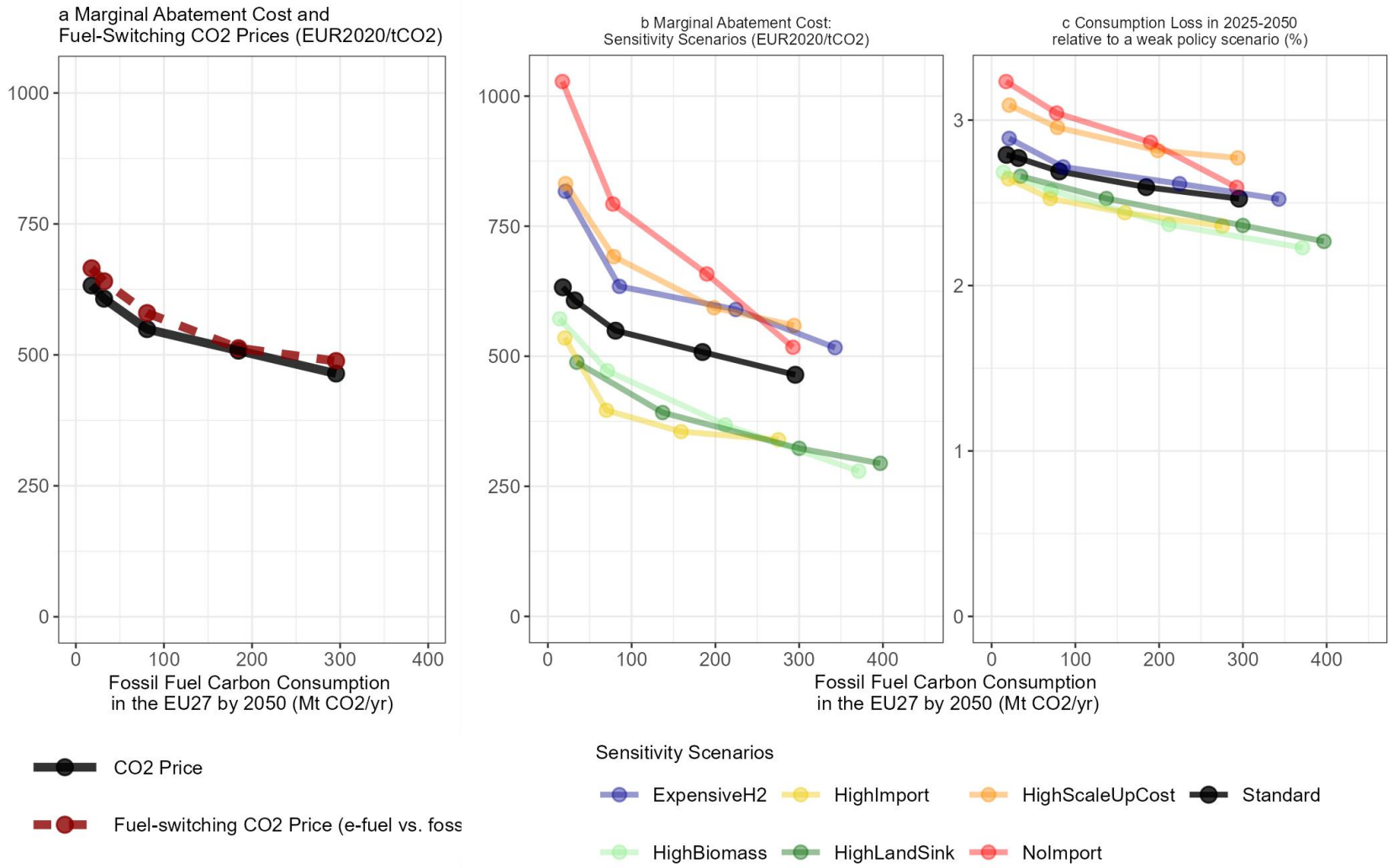
- Residual fossil emissions mainly in international transport, chemicals, refineries
- Full fossil phase-out achieved by provision of carbon-neutral e-fuels

Trade-off between CCS and e-fuel scale-up



- Massive scale-up challenges for CO2 storage or e-fuels
- In FosFree-NZ: **e-fuel supply** would need to grow as fast as solar PV in the past
- In LeastCost-NZ: **CO2 storage** would need to grow as fast as past tight oil production in US

Additional Effort of a Full Fossil Phase-Out



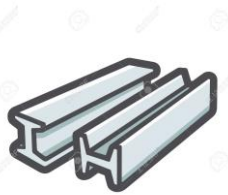
- Moderate MAC increase for last 10% of fossils
- Large range of 500-1000 €/tCO2 dep. on availability of carbon-neutral biofuels/e-fuels
- Consumption losses increase from ~ 2.5% to 3%, not as sensitive as marginal cost

Summary

- Scenarios show that pathways to a virtually full EU fossil phase-out (-99.5%) in the EU 2050 are possible
- Hardest-to-abate fossils oil-based hydrocarbons for chemicals and international transport, can be replaced by carbon-neutral e-fuels
- ~90 % of fossil carbon avoided at MAC of 450 EUR/tCO2 in 2050, for a full phase-out 650 EUR/tCO2 (500-1000), aggregate economic cost are less sensitive
- To reach net-zero by 2050 either massive scale-up of e-fuel supply or CO2 storage required

Policy Reflections

- Fossil phase-out target at net-zero would create clarity on role of fossils, but requires massive e-fuel supply
- Alternatively: partial (sectoral) fossil phase-out targets? (e.g. implemented via EU renewable targets?)

	Power	Road Transport	Buildings	Other Industry	Chemical Industry / Aviation / Shipping
					
Max. Fossils in 2050	<0.5%	<2%	<5%	<5%	<40%

(Exemplary numbers based on LeastCost-NZ scenario of our analysis)