RENEWABLE FUELS

Electrobiofuels reduce the cost of achieving emissions targets

Markus Millinger, IEA Bioenergy Task 45 Workshop 2026, Bioenergy towards climate-neutral futures, Graz, Austria

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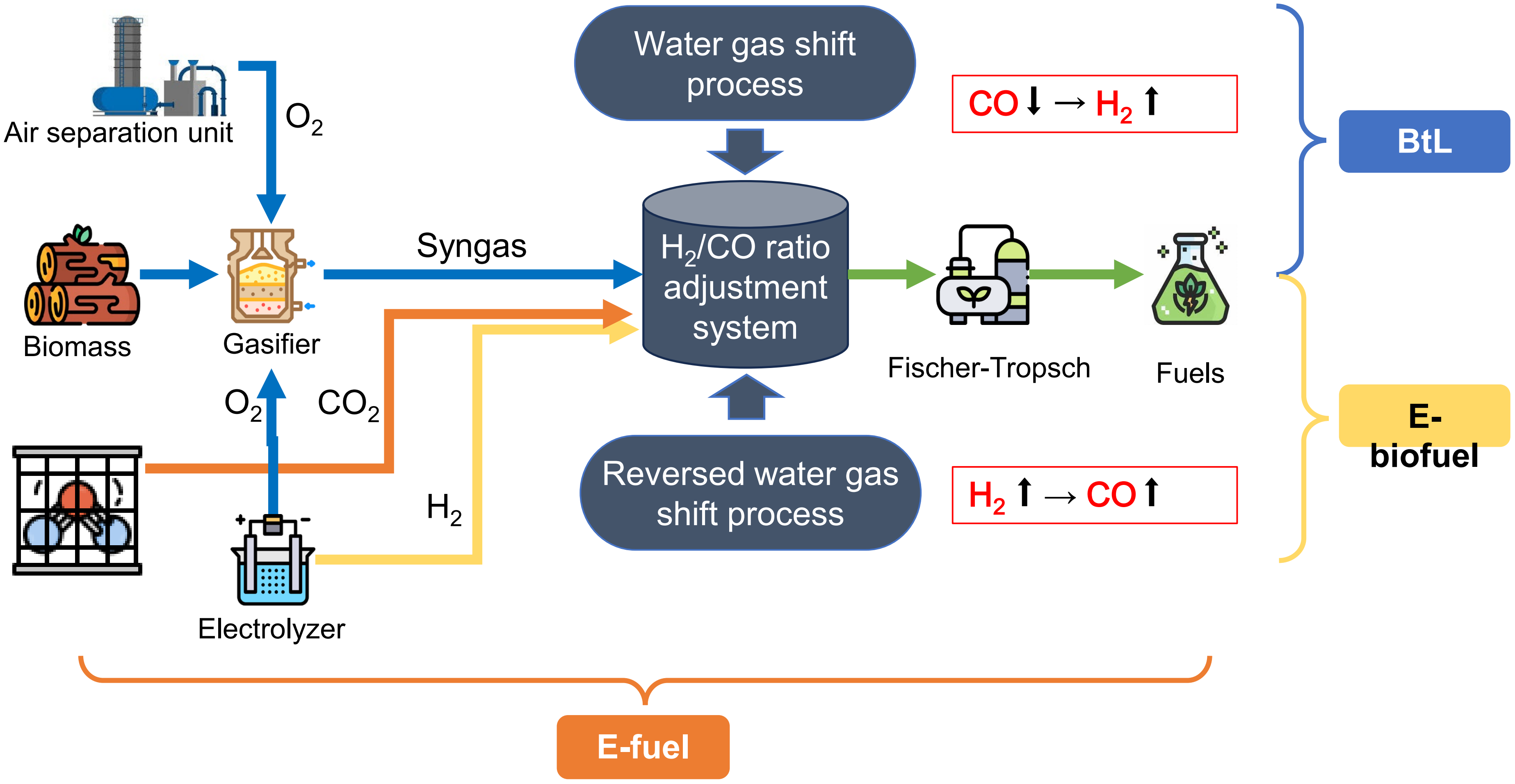
EU renewable fuel mandates

- Fuel mandates provide more certainty for investors, if
  - Mandates can be trusted
  - Interpretation of eligible fuels is clear

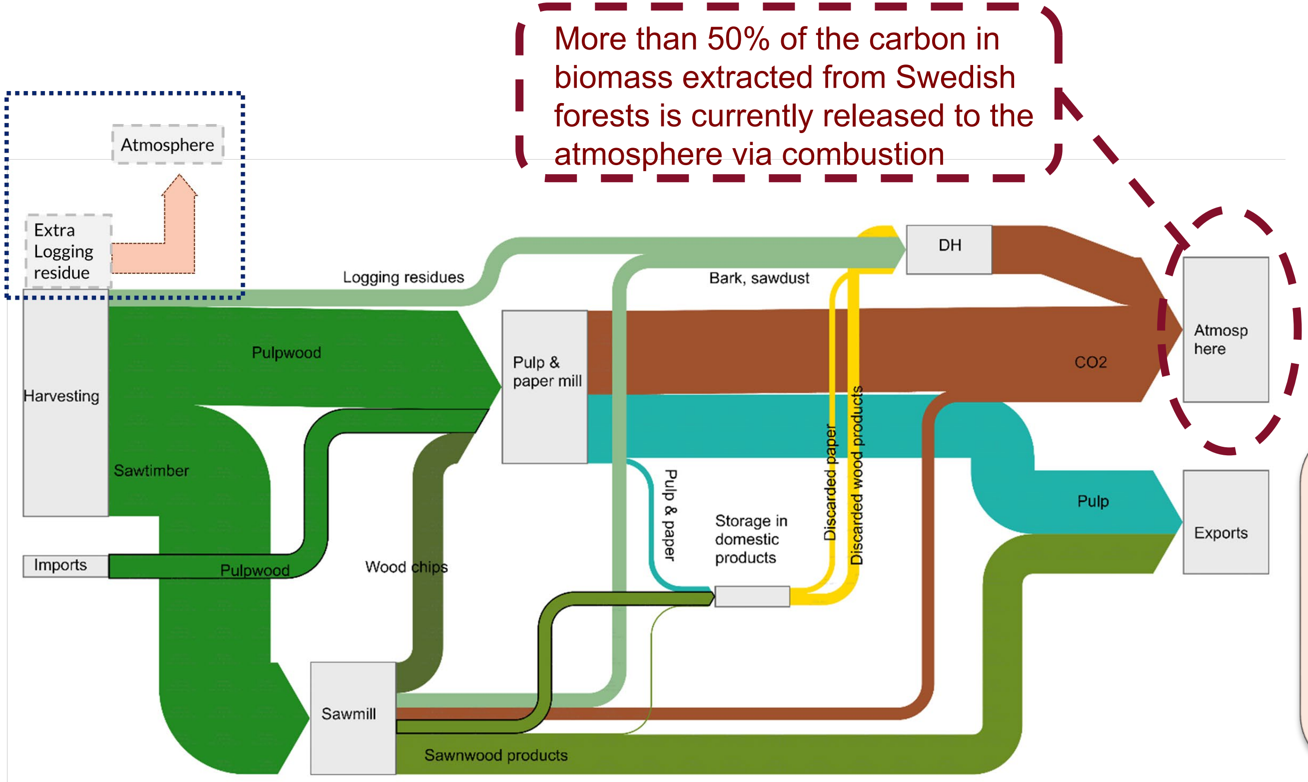
- Aviation, shipping and chemicals depend on carbonaceous fuels
- Achievement of emissions targets in these sectors is particularly challenging
- ReFuelEU aviation: 70% renewable fuels by 2050, of which half Renewable Fuels of Non-Biological Origin (RFNBO)
- "Synthetic aviation fuels from renewable hydrogen and ***captured carbon*** (in the meaning of Article 2(36) of RED and limited to liquid drop-in fuels only)"*

*https://transport.ec.europa.eu/transport-modes/air/environment/refueleu-aviation_en



Air separation unit
O_2
Water gas shift process
$CO\downarrow \rightarrow H_2\uparrow$
BtL
Biomass
Gasifier
Syngas
H_2/CO ratio adjustment system
Fischer-Tropsch
Fuels
O_2
CO_2
H_2
Electrolyzer
Reversed water gas shift process
$H_2\uparrow \rightarrow CO\uparrow$
E-biofuel
E-fuel

Increased carbon efficiency in forest-based value chains leads to significant climate benefits



The most impactful measures—based on climate mitigation per unit of carbon and per unit of electricity used—include:

- replacing biomass boilers in district heating systems and at Kraftliner mills with electrobiofuel production (co-producing heat)
- integrating CCS at kraft pulp mills
- and installing heat pump at sawmills.

<u>Production in 2050</u>

Fuels: 76 TWh

Geologically stored emissions: 15 Mt CO_2

Net electricity demand: 90 TWh

Avoided emissions: 430–490 MtCO_2 cumulatively

<u>Bio+ | Climate impact of carbon efficient forest-based value chains Bio+</u>

This project explores how Sweden's forest residues and industrial side-streams can be more efficiently utilized to produce renewable fuels and deliver negative emissions—supporting the phase-out of fossil fuels and accelerating climate mitigation

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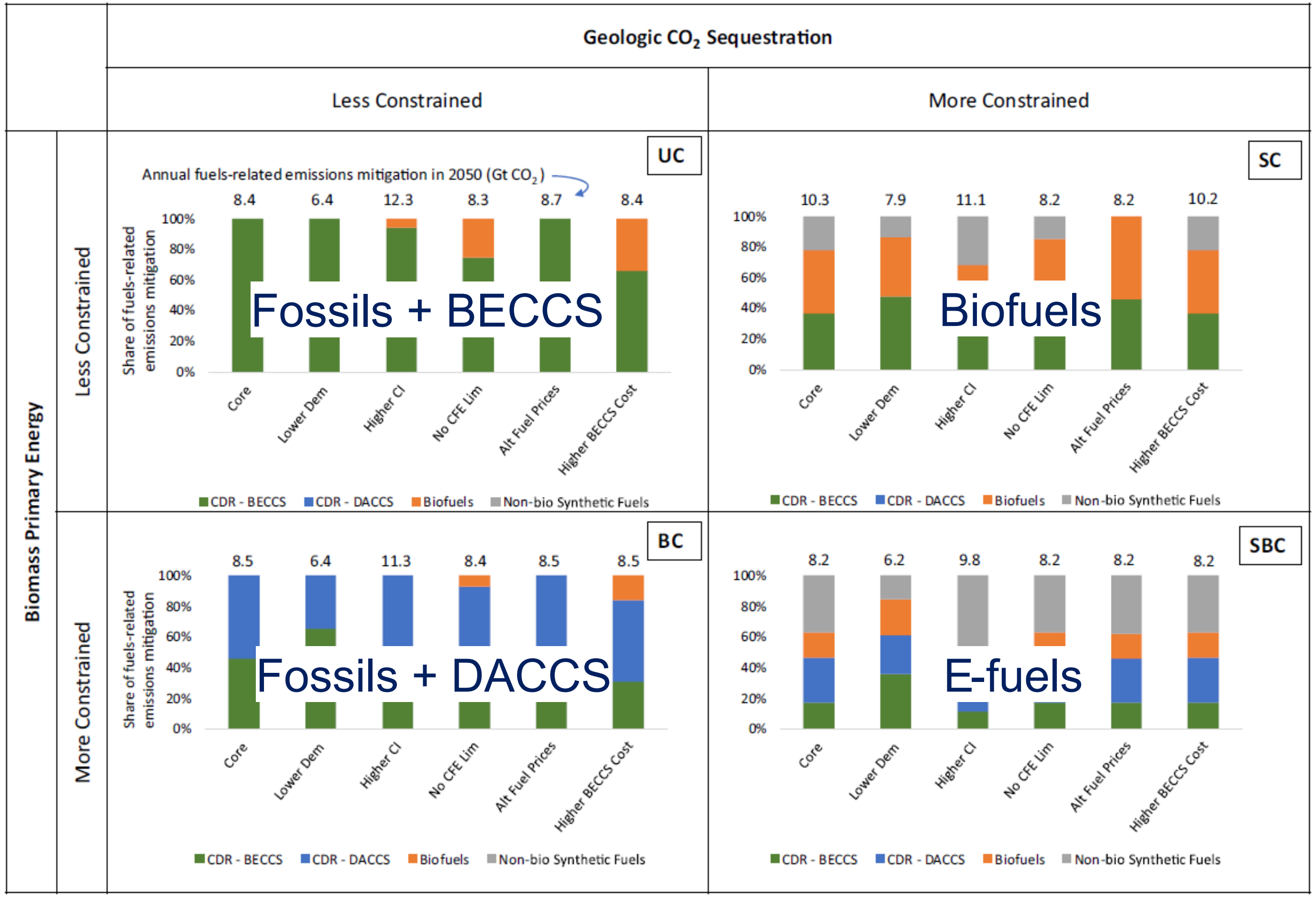
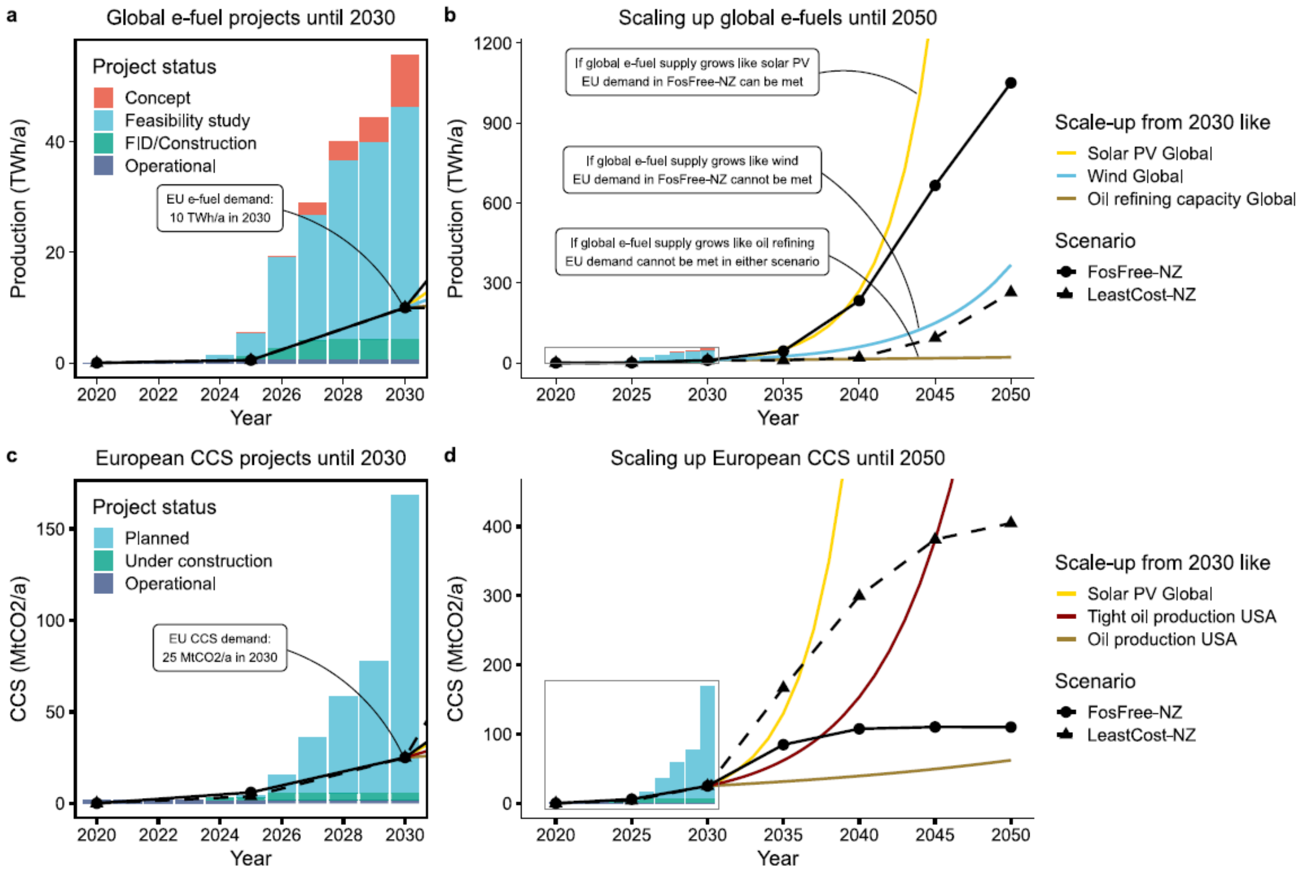


Carbon sequestration and biomass availability

- Dominant options depend heavily on carbon sequestration and biomass availability
- What role could e-biofuels play?

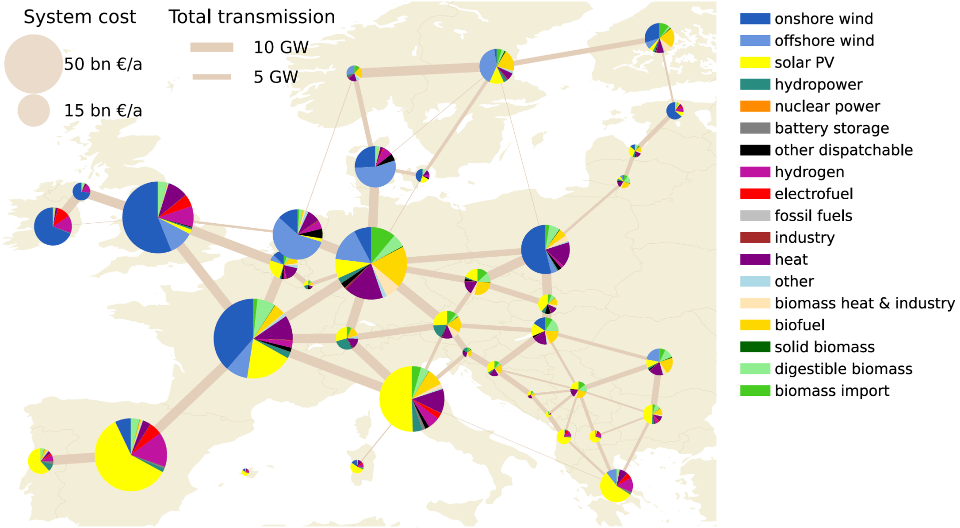
Mignone et al. (2024). Drivers and implications of alternative routes to fuels decarbonization in net-zero energy systems, Nature Communications

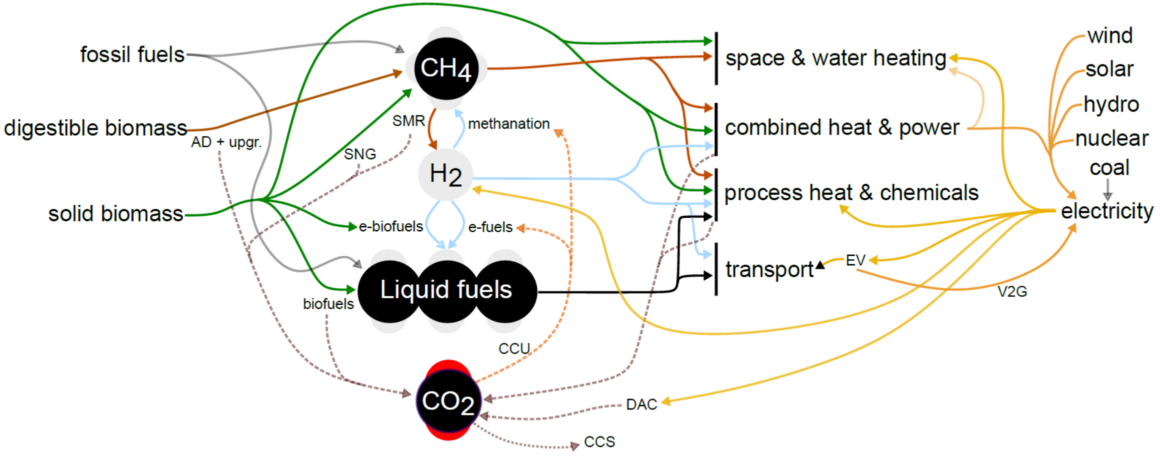


Carbon sequestration and e-fuel expansion trade-off

- How fast can e-fuels and carbon sequestration grow?
- Feasibility of scale-up for both carbon sequestration and e-fuels is a concern
  → large uncertainty for future investments
- How do e-biofuels fit in?

Schreyer et al. (2025). From net-zero to zero-fossil in transforming the EU energy system, Nature Communications





Millinger et al., Nature Energy 2025

Method and scope

- PyPSA-Eur
- Sector-coupled energy system
- Europe
- Many fuel options: bio-, e-, e-bio and fossil
- Scenarios with and without e-biofuels to assess system effects
- At different carbon sequestration levels

E-biofuels reduce system cost

- The cost-effectiveness of e-biofuels depends on carbon sequestration (CS) availability
- At CS of 200 Mt/a, e-biofuels reduce total energy system cost by 2.7%, or fuel cost by ~10%. Significant for an apparent detail!
- E-biofuels avoid substantial infrastructure for CCUS and fuel conversion
- But: requires hydrogen expansion

Investment risk mitigation?

- How to invest under uncertainty to meet net zero in hard to electrify sectors?

- E-fuel expansion today is hindered by a lack of clean H_2 and captured CO_2. There are more effective uses for H_2 until it has been sufficiently scaled up.
- Substantial biomass residues are untapped → advanced biofuels reasonable starting point for mid-term targets
- When there is more certainty about the development of carbon sequestration (i.e. feasibility of using fossils) and electrolysers, it can be decided whether to
  - capture excess carbon, or
  - add H_2 to utilise excess carbon (e-biofuels)
- Such a modular approach reduces investment risk as less infrastructure is needed

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RED is generally unclear and fails to promote resource efficiency

i. RED lacks clarifications and concrete examples and is therefore generally difficult to interpret

ii. RED is inconsistent

iii. RED does not always reward resource-, energy-, and climate-efficient concepts

According to RED, **electrobiofuels** should be classified as a blend of biofuels and RFNBO

Electrobiofuels can therefore help meet quotas for both biofuels and RFNBOs

RED fails to promote the more energy efficient production of **electrobiofuels** over electrofuels

Bio+ | Classification and sustainability criteria for renewable fuels in the EU - what actually applies? - Bio+

In this project, RED was mapped to identify value chains where different interpretations are possible and to assess their consequences. RED's ability to reward resource-efficient concepts was also evaluated.

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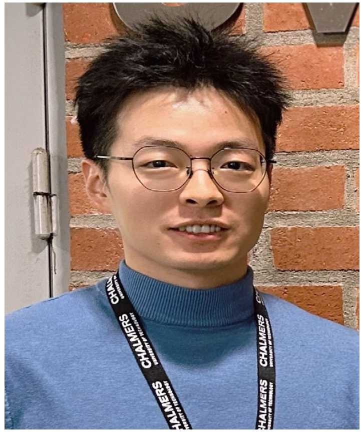


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