

PSI

Center for Nuclear Engineering and Sciences
Center for Energy and Environmental Sciences

Future background scenarios in LCA

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Laboratory for Energy Systems Analysis
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Talk content

- Definition of scenarios
- Foreground vs. background scenarios
- Integrated Assessment Models
- PREMISE workflow and open-source tools
- Effects of temporally-adjust inventories
- Study cases using temporally-adjusted background LCA
- Upcoming developments
- System-wide prospective LCA

What is a scenario?

A scenario is a description of how the future may develop, based on a coherent and internally consistent set of assumptions...

about key drivers including demography, economic processes, technological innovation, governance, lifestyles, and relationships among these driving forces (IPCC 2021)

Different kinds of scenarios

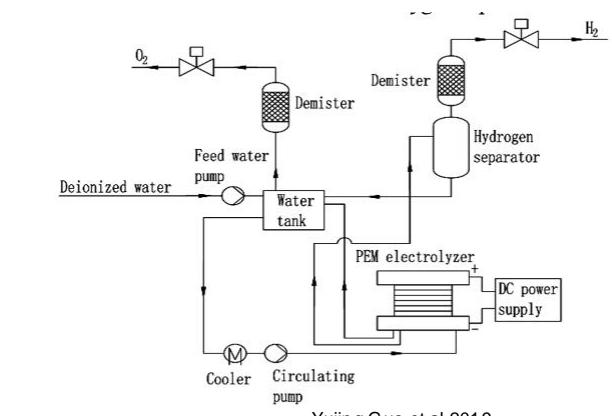
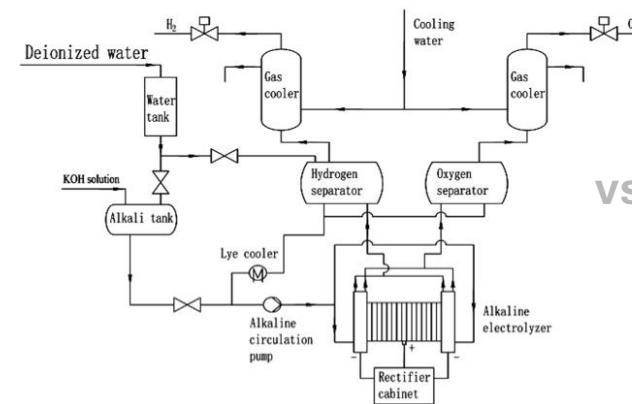
Broad (global) scenarios

- For the global economy (CGE models, IAM)
- Relevant for prospective LCAs in general
 - **Background scenarios**



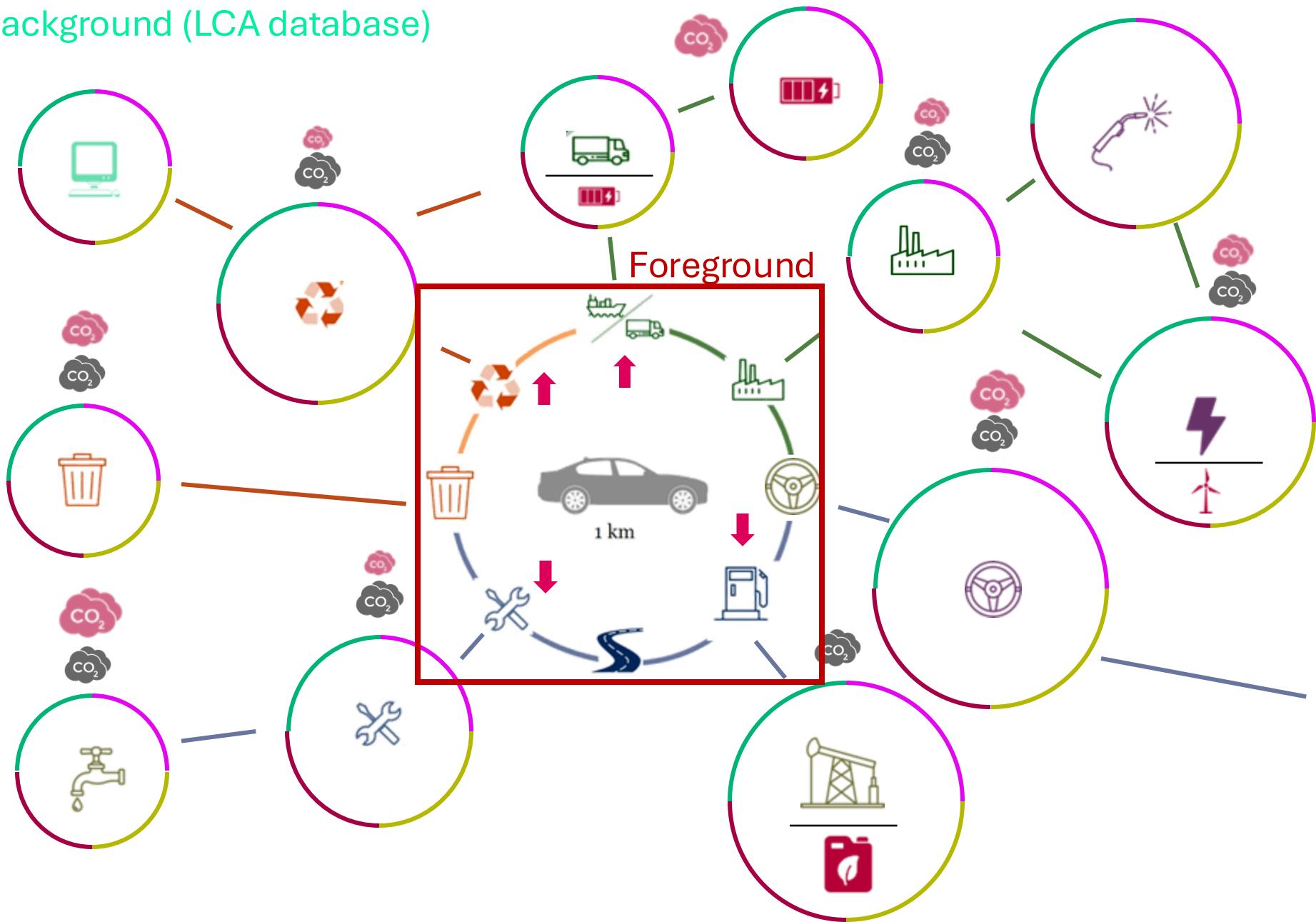
Narrow (local) scenarios

- For specific technologies (hydrogen)
- Limited to a specific prospective LCA
 - **Foreground scenarios**



vs

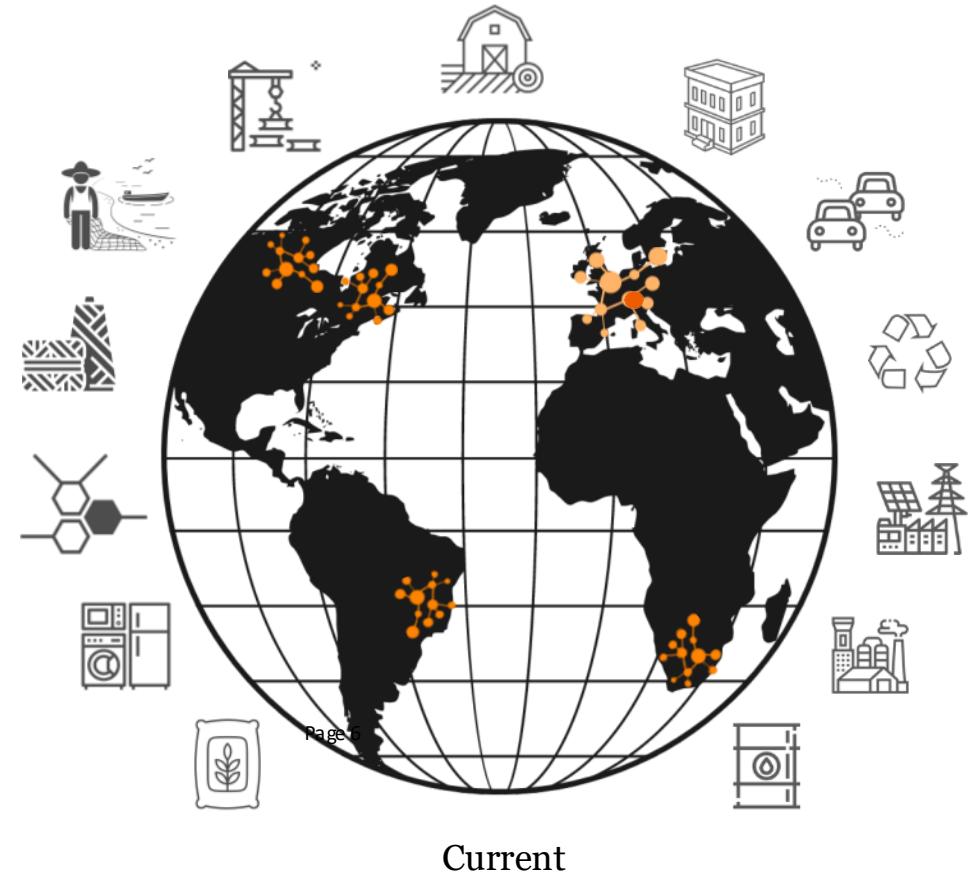
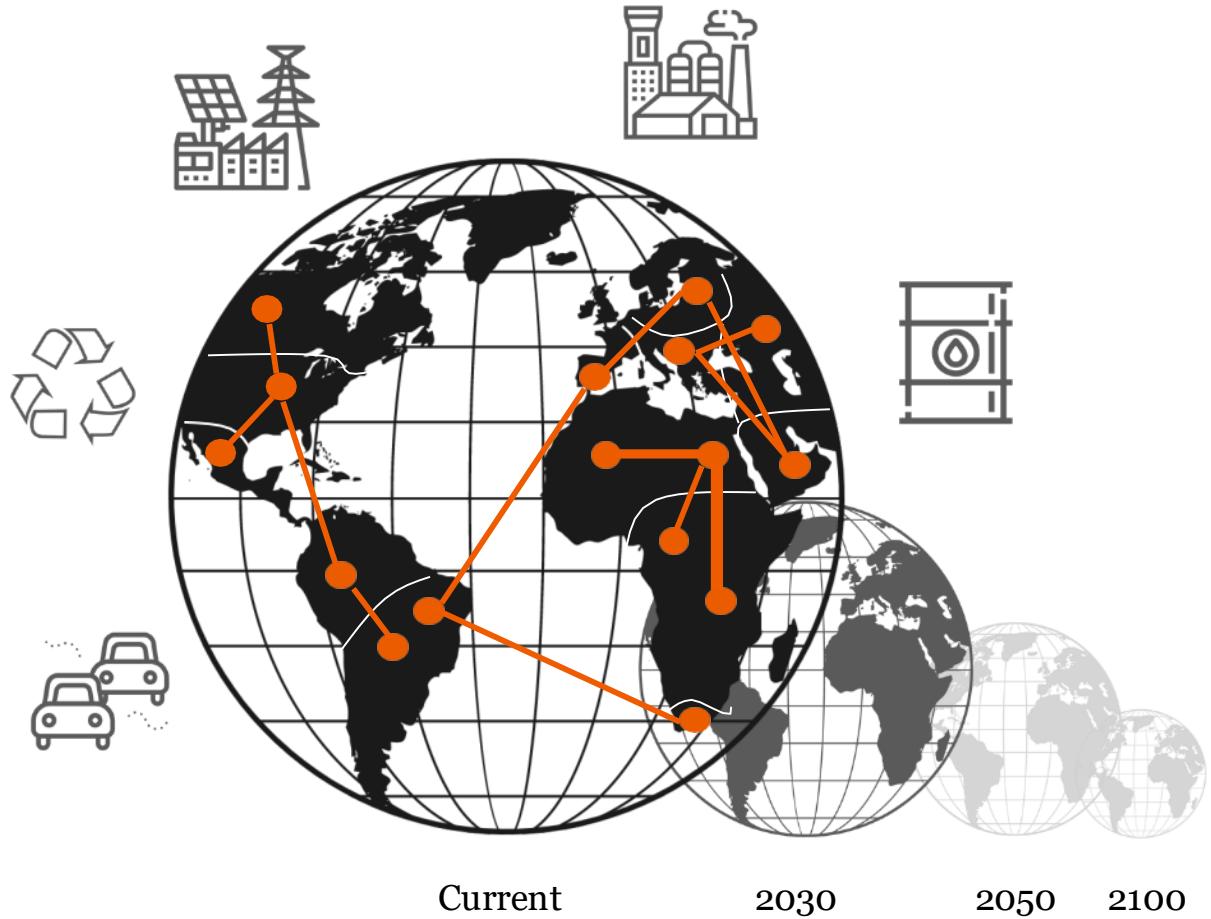
Background (LCA database)



LCA is about PSI
systematically accounting for environmental impacts associated with a service, considering supply chain relations between processes.

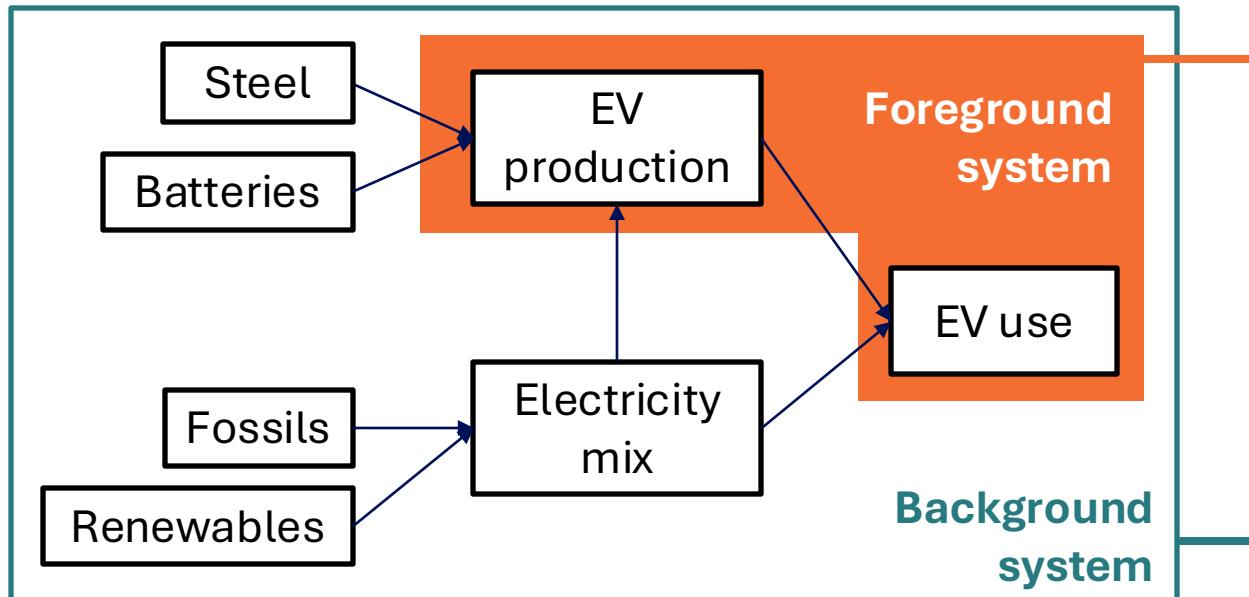
pLCA is about projecting changes in process efficiency and supply chain relations, both in foreground and background, following on a coherent storyline.

INTEGRATED ASSESSMENT MODELS (IAM) VS. LCA



Foreground and background scenarios

A car manufacturer wants to make an LCA for an EV (electric vehicle) in 2030:



Foreground scenarios:

*How will the **EV** of 2030 look like? How will it be used?*

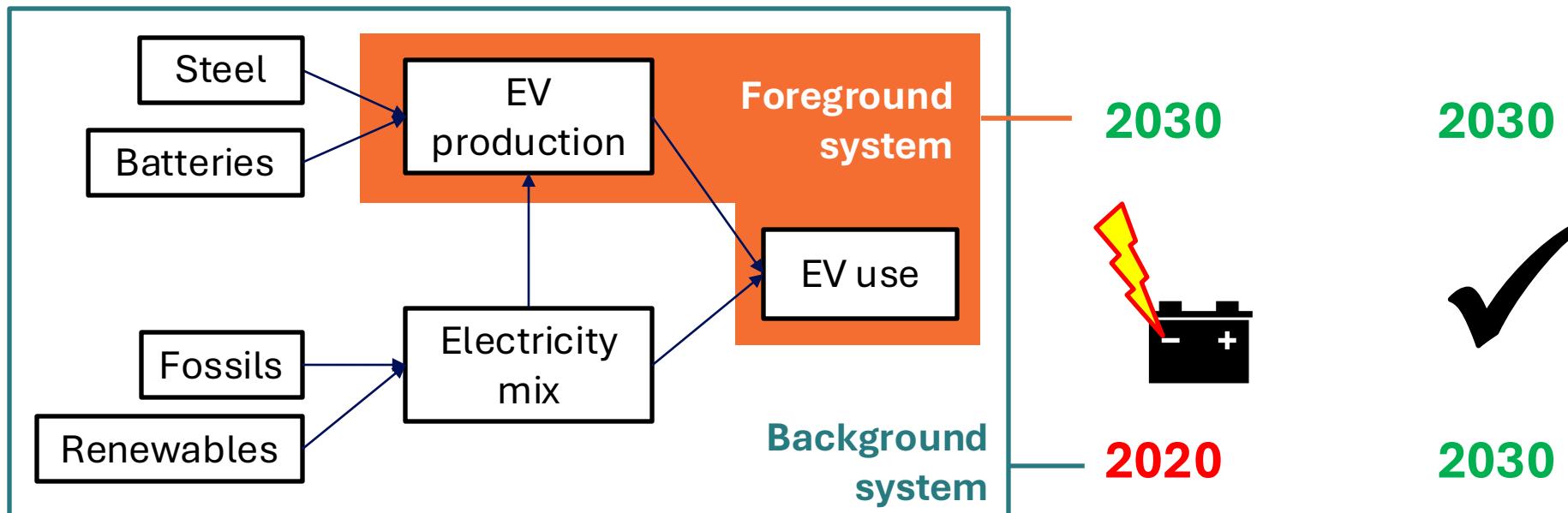
Background scenarios:

How will supply chains in the wider economic system of 2030 look like?

- Important, but difficult to consider (at least by individual stakeholders)

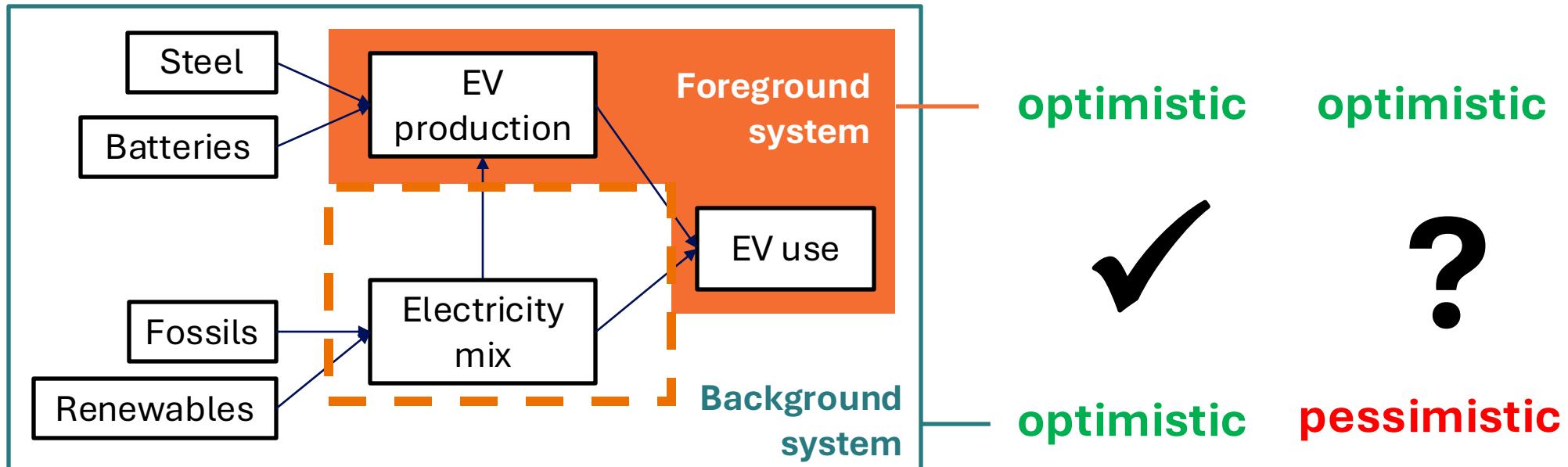
Temporal consistency

A car manufacturer wants to make an LCA for an EV (electric vehicle) in 2030:



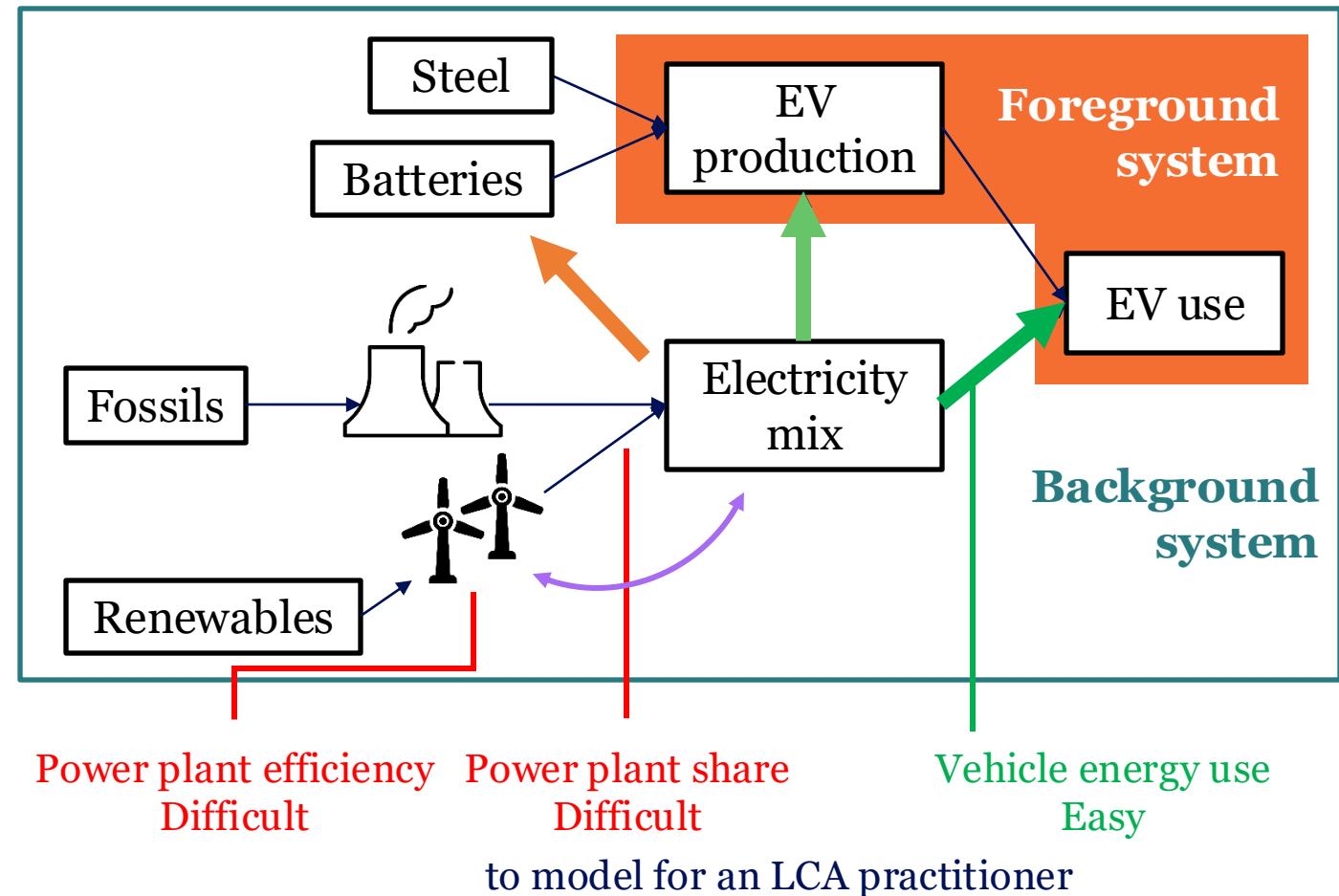
Narrative consistency

A car manufacturer wants to make an LCA for an EV (electric vehicle) in 2030:



Our economy is deeply interlinked!

- E.g., electricity mix affects:
 - EV use
 - EV production
 - Materials/components production
 - But greener raw materials also improve the electricity mix *and most other products!*
 - Feedback loops
- Broad future (background) scenarios help LCA practitioners to consider the combined effect of future changes

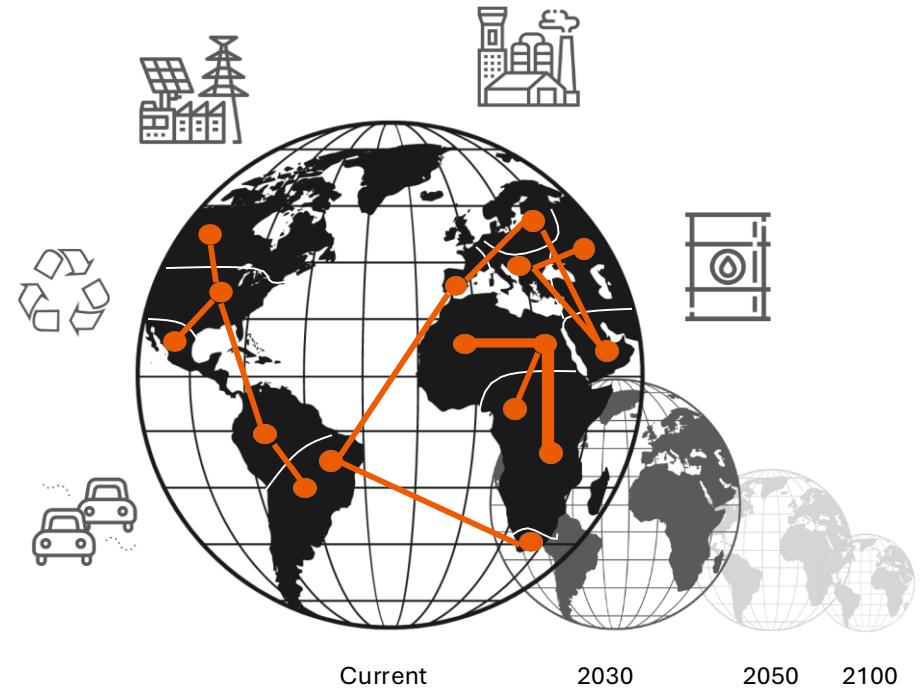


to model for an LCA practitioner

Terminology “pLCI database”

pLCI database = ***prospective life cycle inventory database***

- The difference with a regular LCI database is that it represents the economy, industrial activities, and trade for a **future point in time** under a given **scenario**.



A short and incomplete history of pLCI databases

NEEDS project (2004-2009)

- First systematic approach to generate future scenarios of the ecoinvent database (electricity supply and other sectors)

THEMIS model (Gibon 2015; Hertwich 2015)

- Hybrid (MRIO-LCA) model including IEA energy and NEEDS scenarios

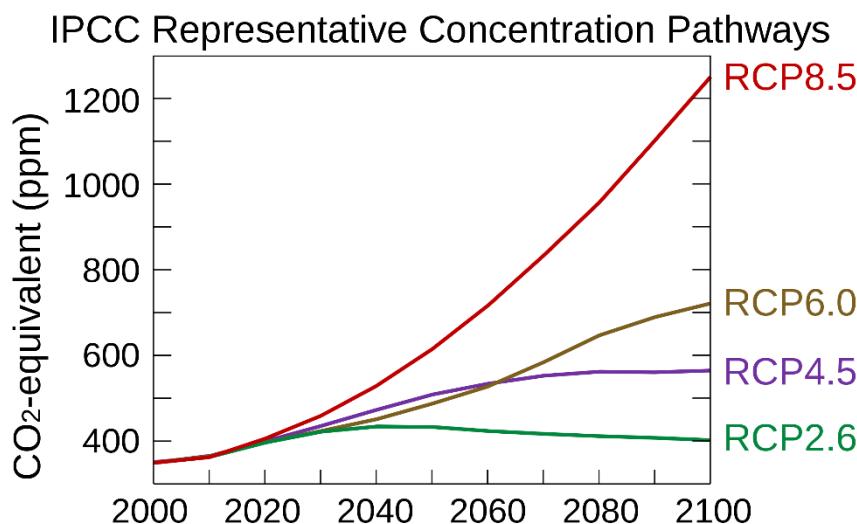
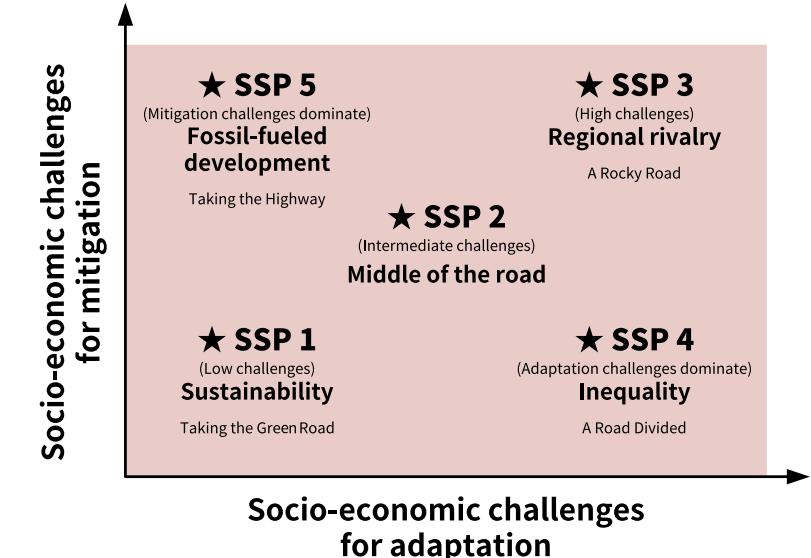
“When background matters” (Mendoza and Cox 2018)

- Combine data from the integrated assessment model IMAGE and ecoinvent (focus electricity supply)
- IAMs model SSPs (Shared Socio-economic Pathways) and RCPs (representative concentration pathways)

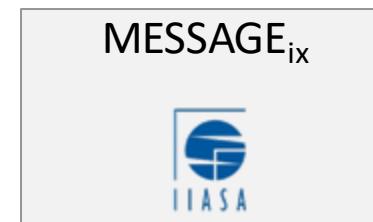
wurst: python package for systematic modifications of LCI databases (Mutel, 2017)

premise (Sacchi 2022)

- python package for generating pLCI databases
- Strongly based on IAM data (IMAGE, REMIND)
- Electricity, steel, cement, transport, fuel



INTEGRATED ASSESSMENT MODELS (IAM)



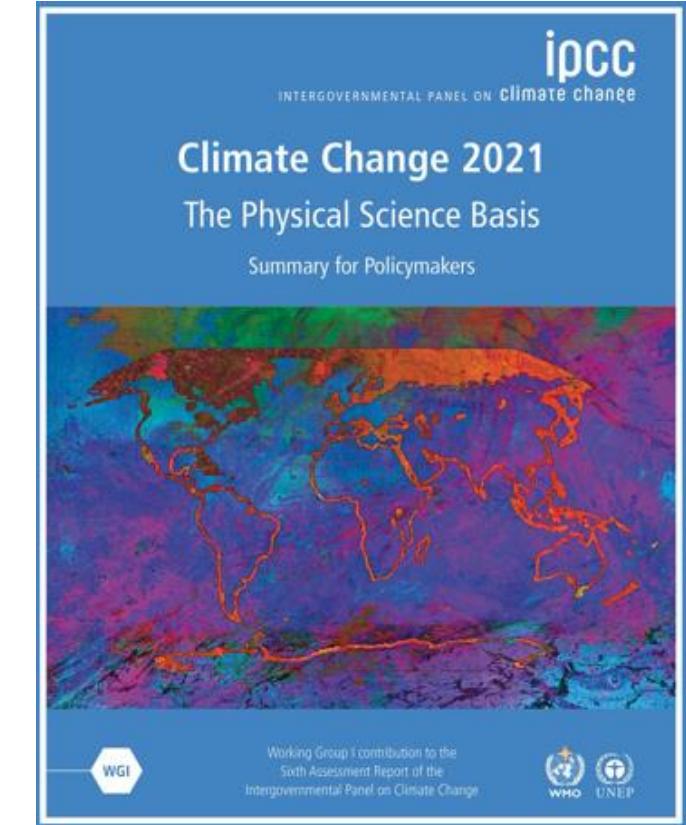
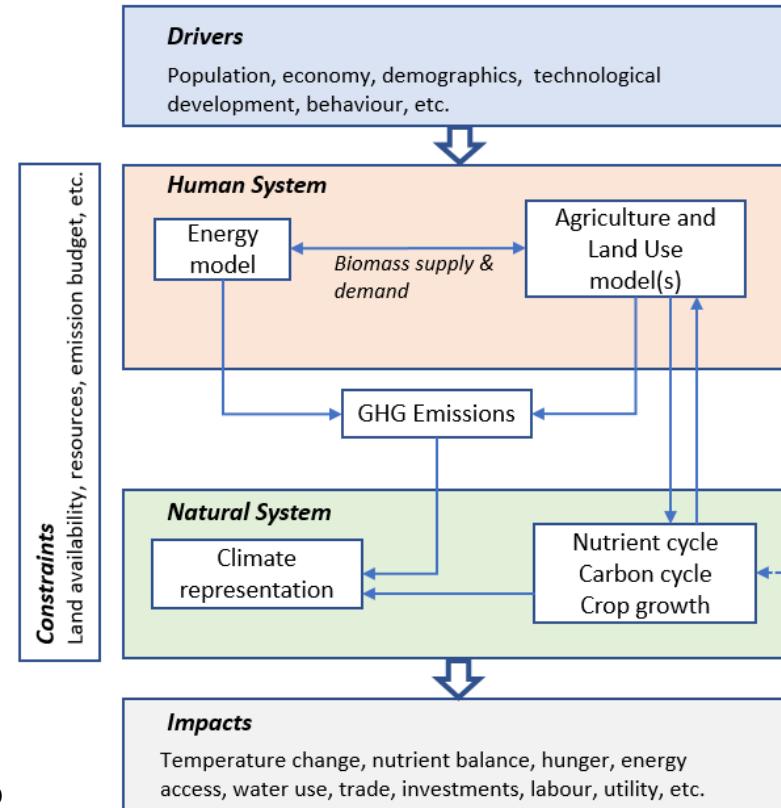
Integrated Assessment Models (IAMs) assess the interactions between **human** and **natural** systems

Contain stylized representations of

- Energy system
- Agricultural economy
- Climate
- Land system

Bridge the Science/Policy interface

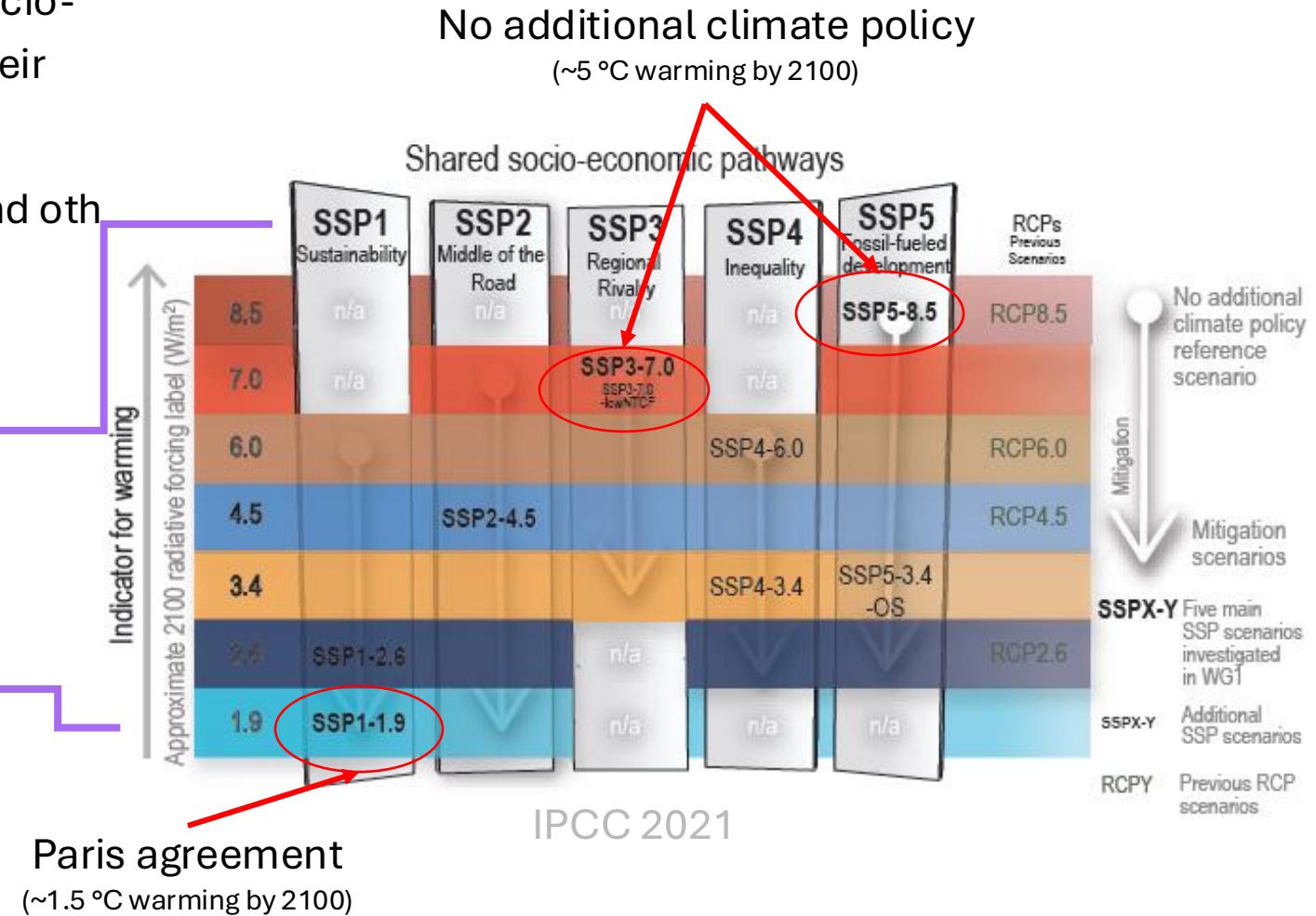
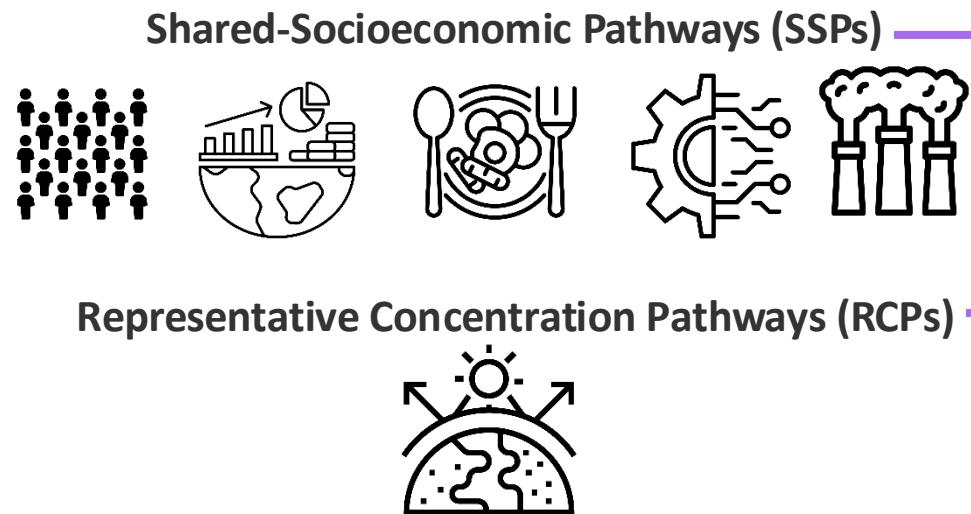
- Scenario Analysis: *What if?*
- What are the drivers or constraints of change?
- How do technology and policy choices lead to different outcomes?
- Uncertainties? Sensitivities?



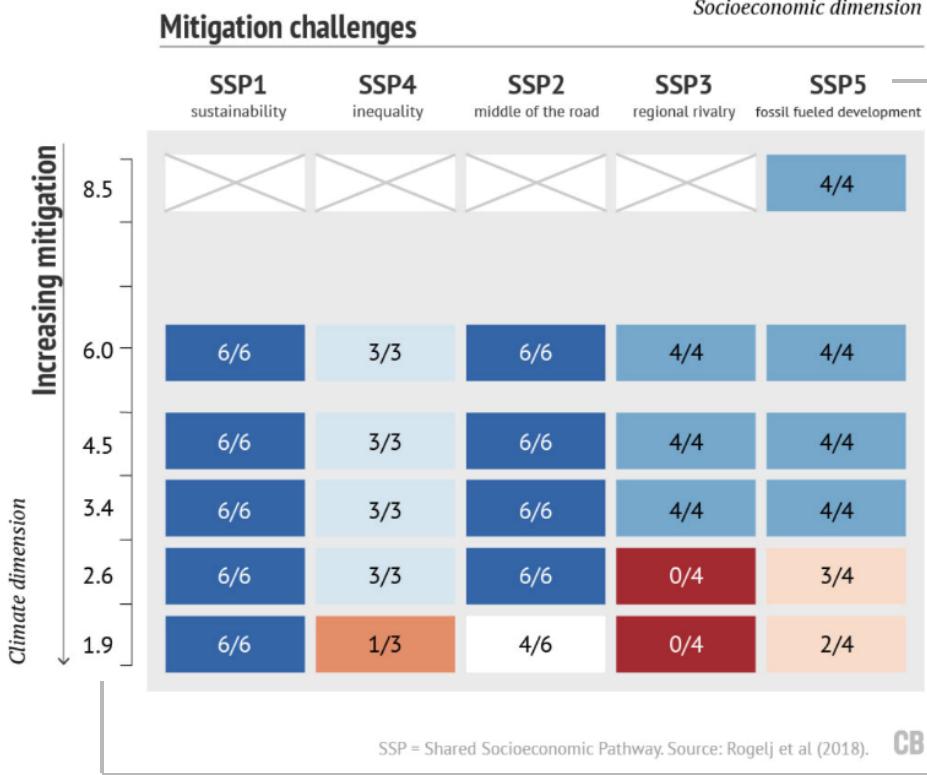
INTEGRATED ASSESSMENT MODELS (IAM)

Global regionalized models that consider broad socio-economic and technological developments and their consequences over time.

Used to inform policymakers on climate change and other environmental or socio-economic criteria.



Socio-economic and climate constraints



Credit: CarbonBrief, Zeke Hausfather, 2018.

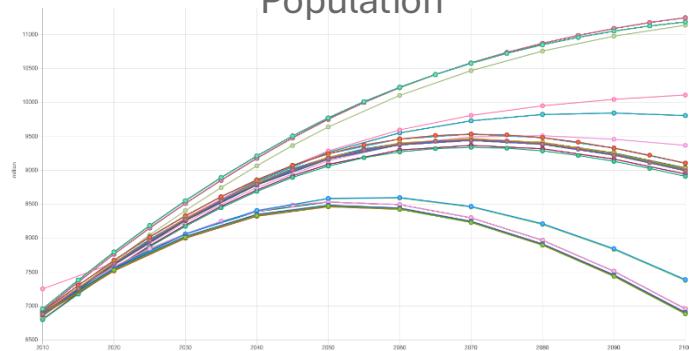
<https://www.carbonbrief.org/explainer-how-shared-socioeconomic-pathways-explore-future-climate-change>

Socio-economic constraints (SSP)

Food demand

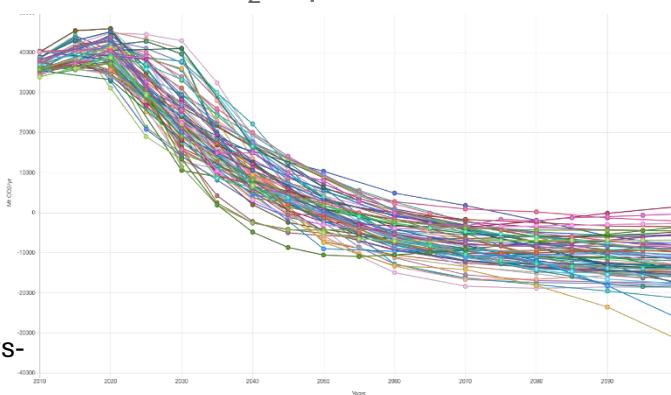


Population

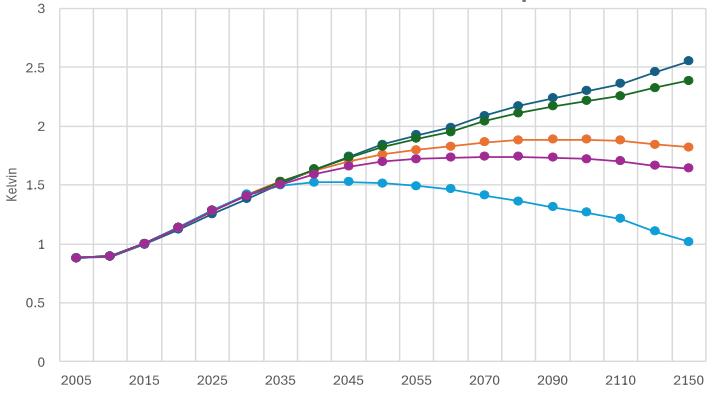


Climate constraints (RCP)

CO₂-eq emissions



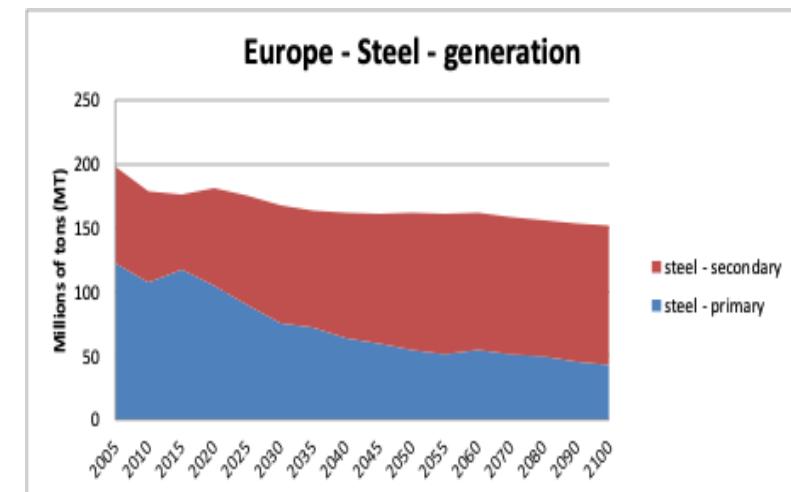
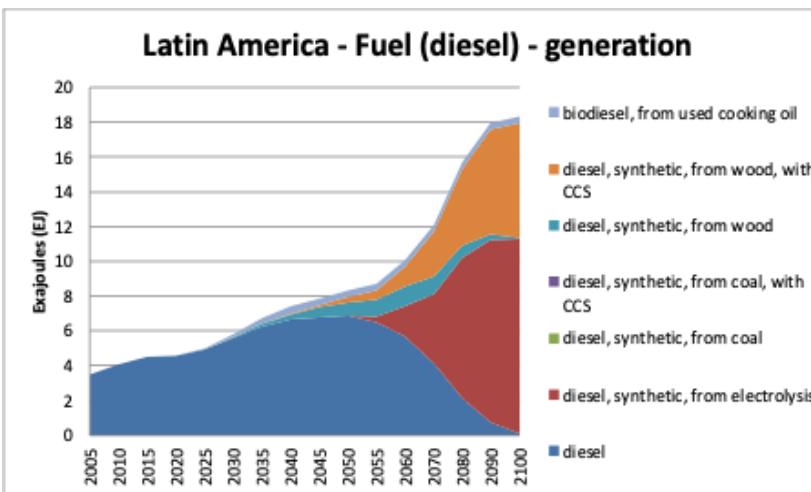
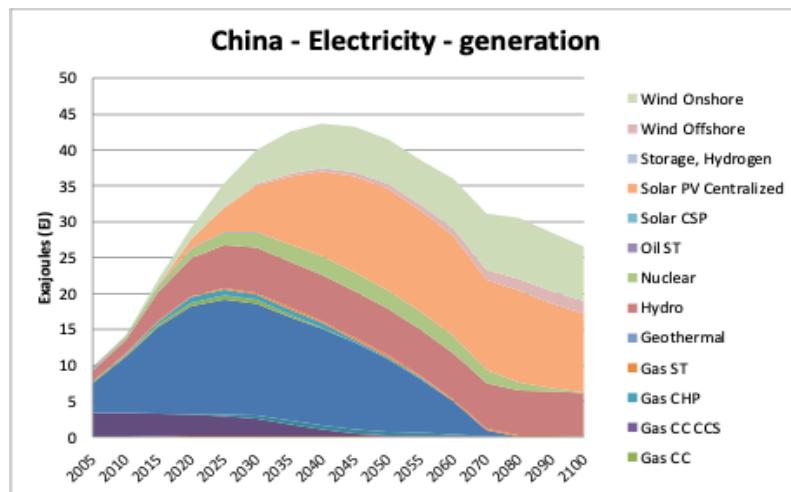
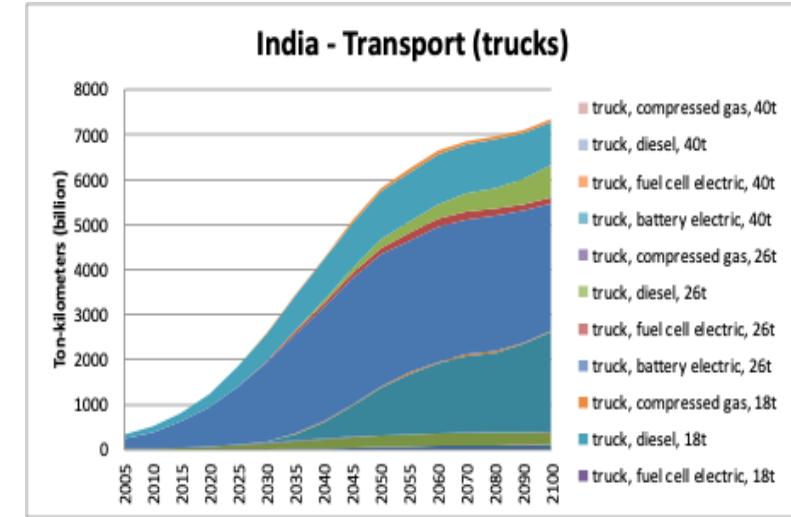
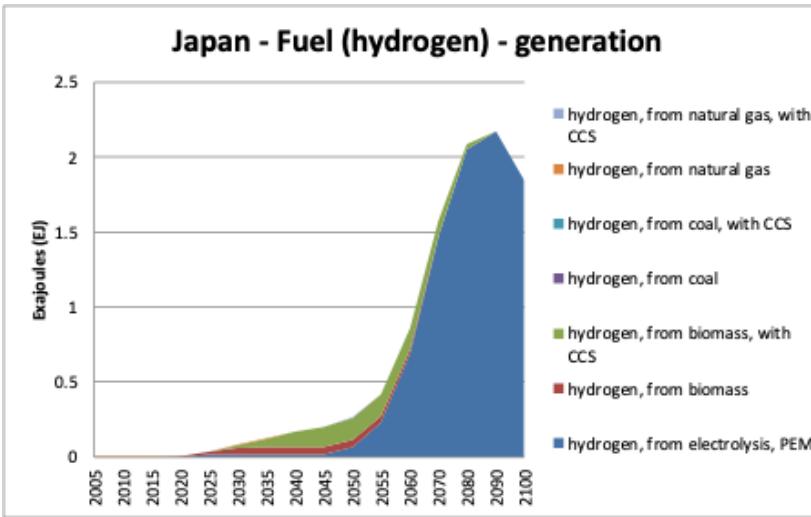
Global Mean Surface Temp. Increase



Projections on energy-intensive sectors

For each time step:

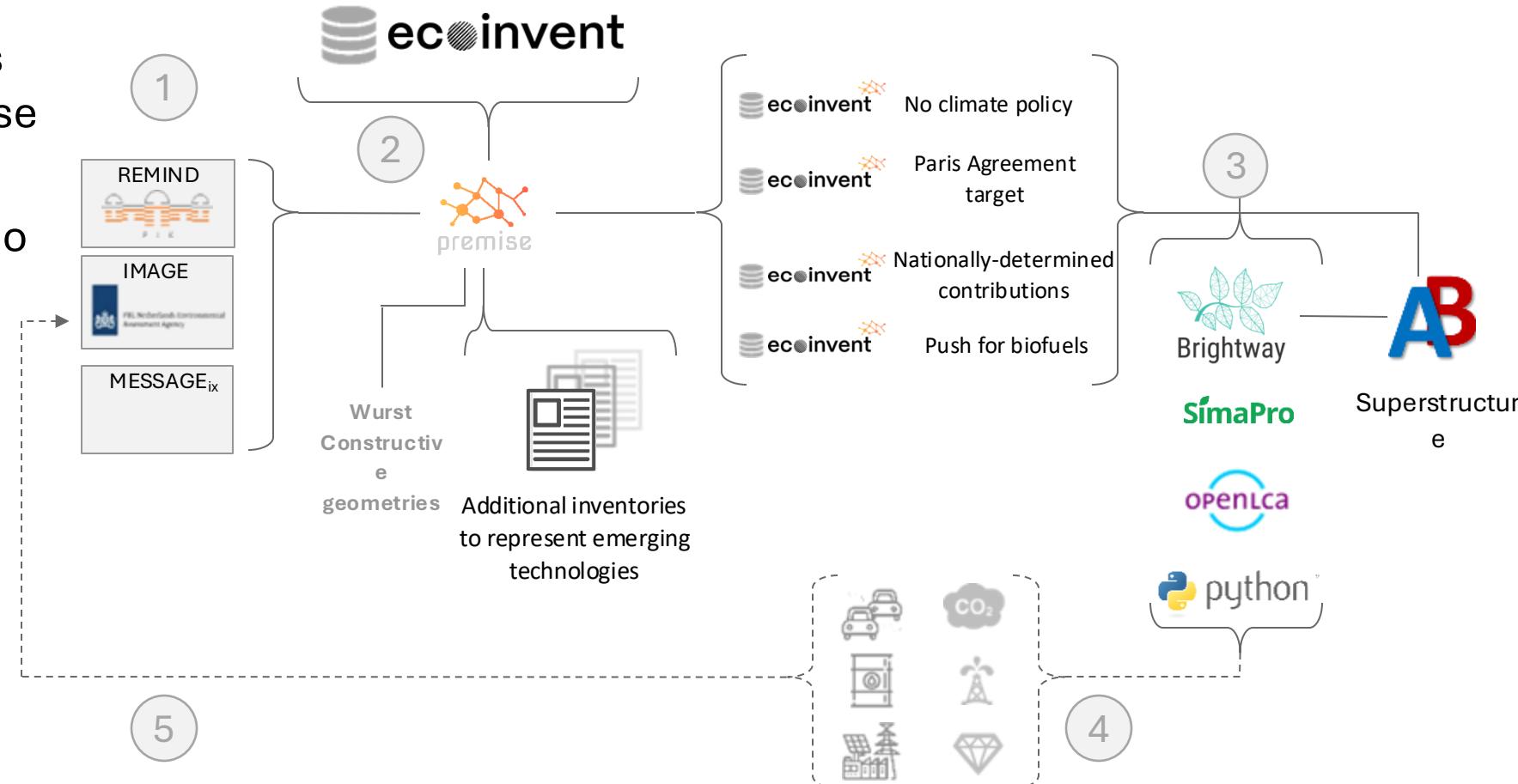
- Technology investments
- Capacity build-up
- Generation
- [Link to dashboard](#)



Premise workflow

Steps

- 1)** Input data: future scenarios from IAMs and the LCI database ecoinvent
- 2)** Integration of future scenario data with the LCI database via premise
- 3)** Export of pLCI databases in various formats
- 4 & 5)** optional feedback of environmental indicators to IAMs



Premise workflow: Open-source python packages

Brightway: LCA framework

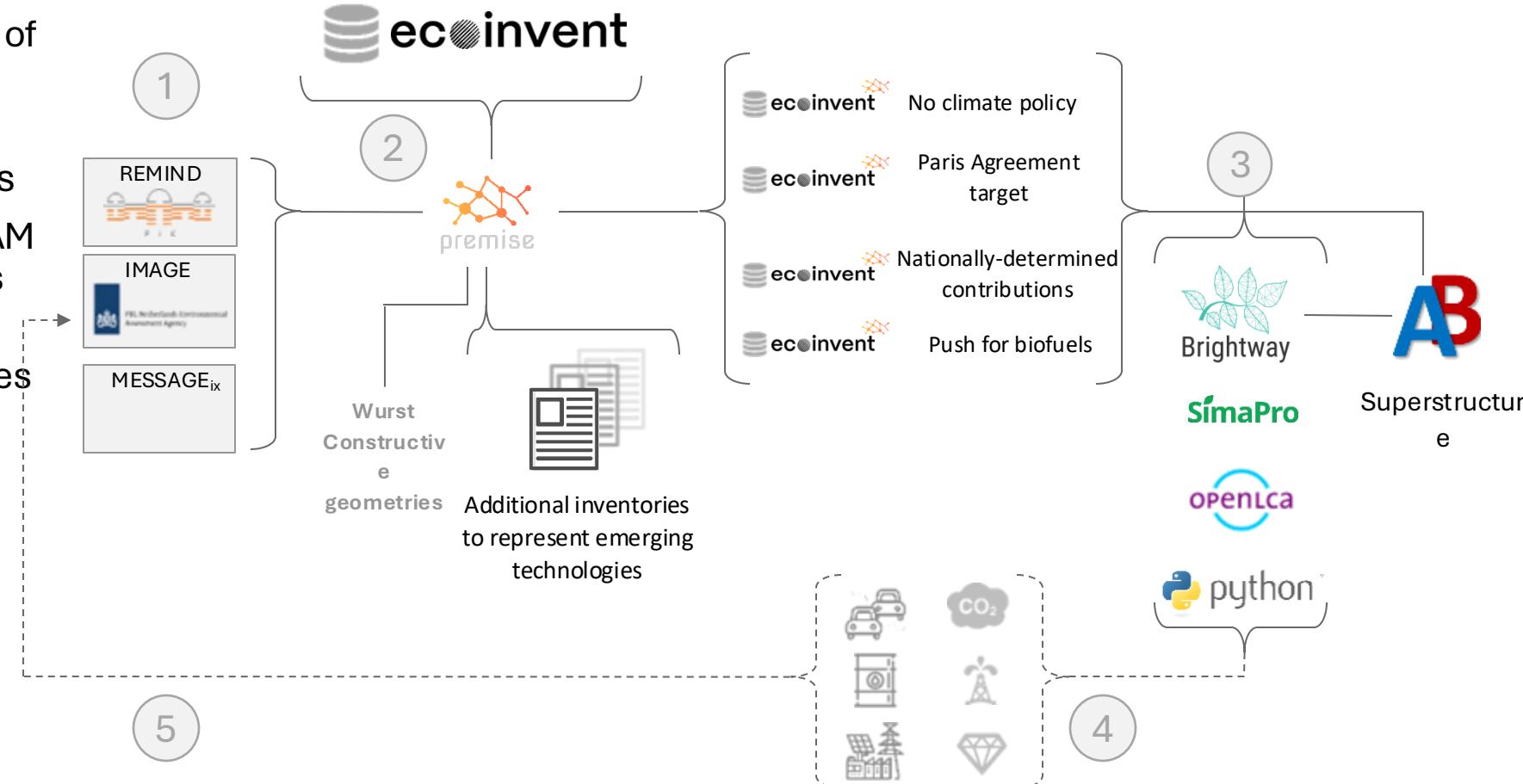
Wurst: systematic transformations of LCI datasets

Constructive geometries: handling of ecoinvent geographies

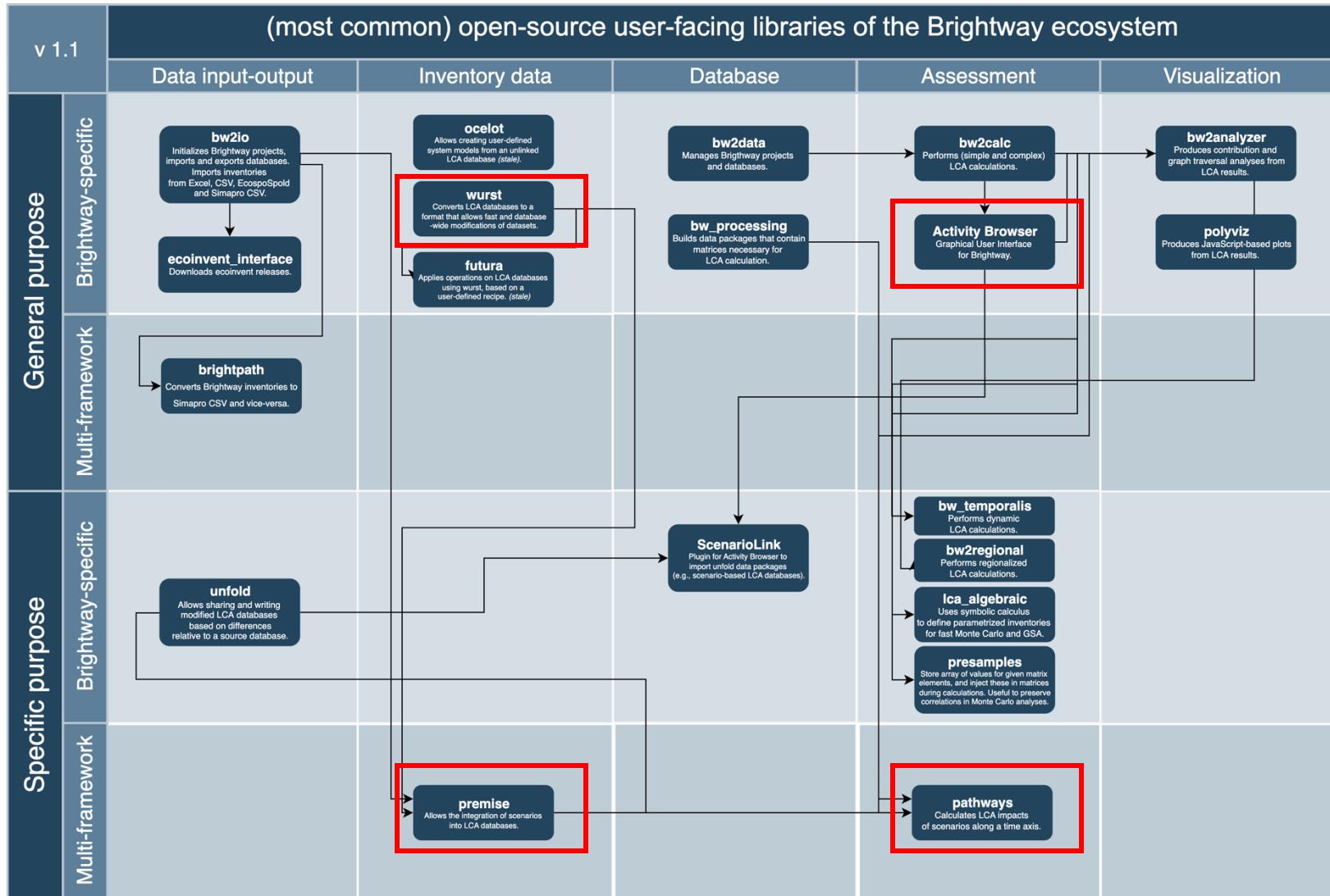
Premise: integration software for IAM (and other) data with LCI databases

Superstructure approach: conversion of multiple LCI databases into a single LCI database (superstructure) and a scenario difference file [based on Brightway]

Activity Browser: graphical user interface to Brightway; implements “scenario-LCA” based on superstructure approach [based on brightway]



OVERVIEW of open-source tools in the BRIGHTWAY ecosystem



What does premise do?



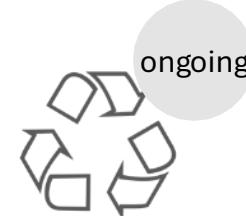
Power

Create regional electricity markets
Adjust power plant efficiency



Fuels

Create regional fuel markets
Add new production pathways (synthetic fuels)



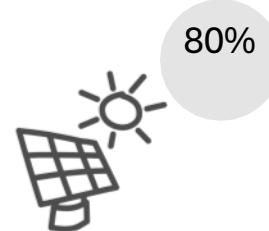
Metals recycling

Adjust critical raw materials use
Adjust future recycled content



Hot pollutant emissions

Adjust hot pollutant emission from GAINS



80%

Renewables

Adjust solar PV and windturbines efficiency



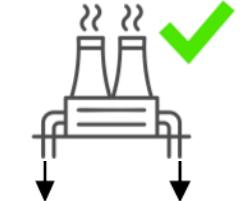
Transport

Create market for passenger and freight road transport



Industry

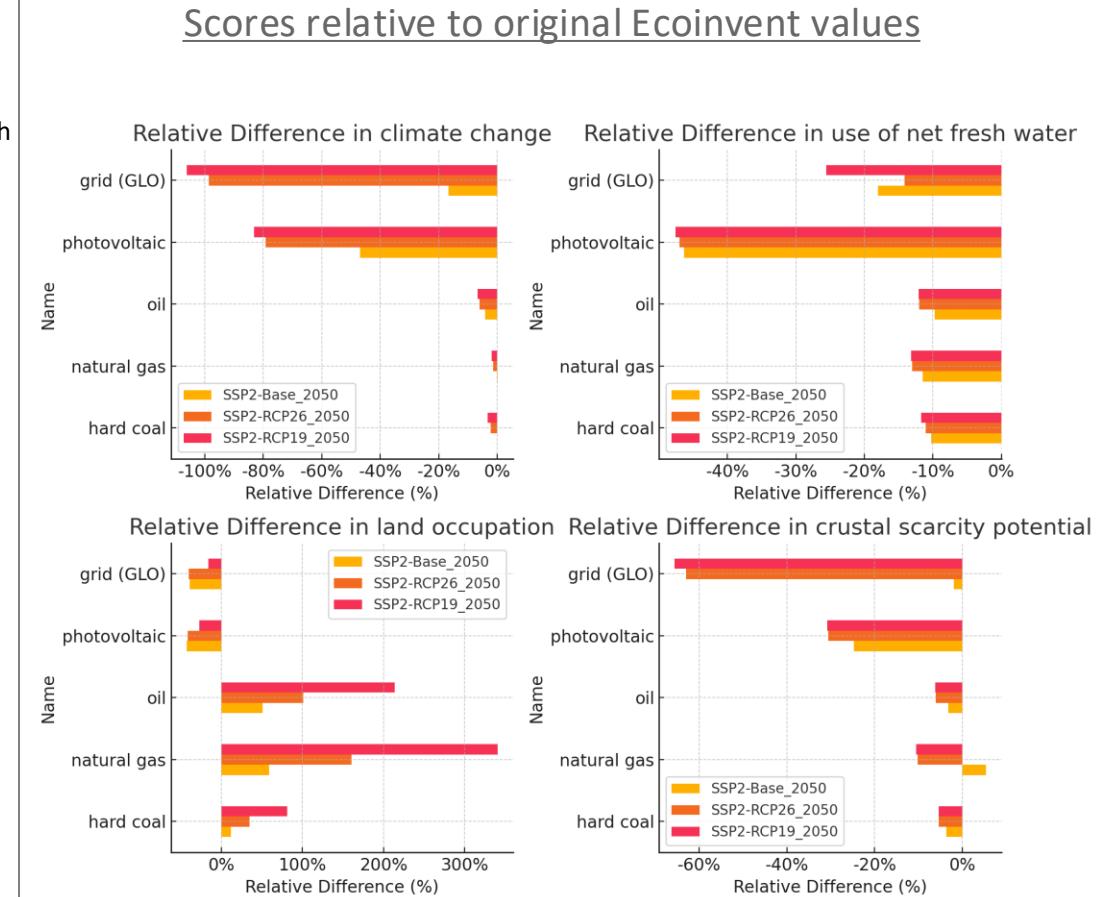
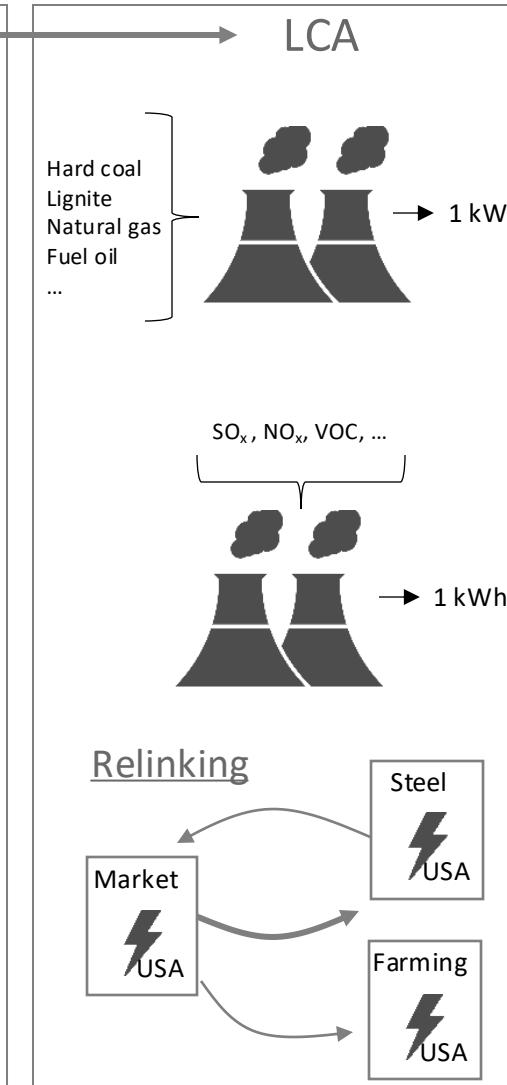
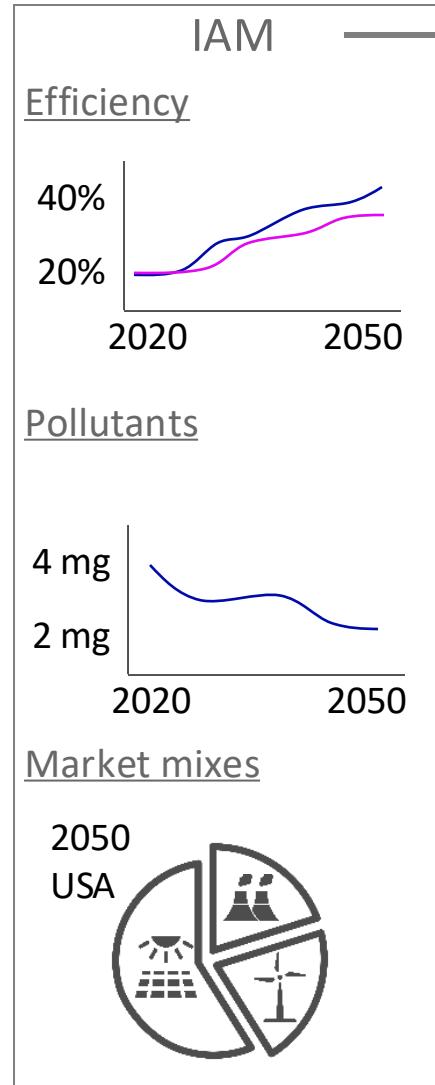
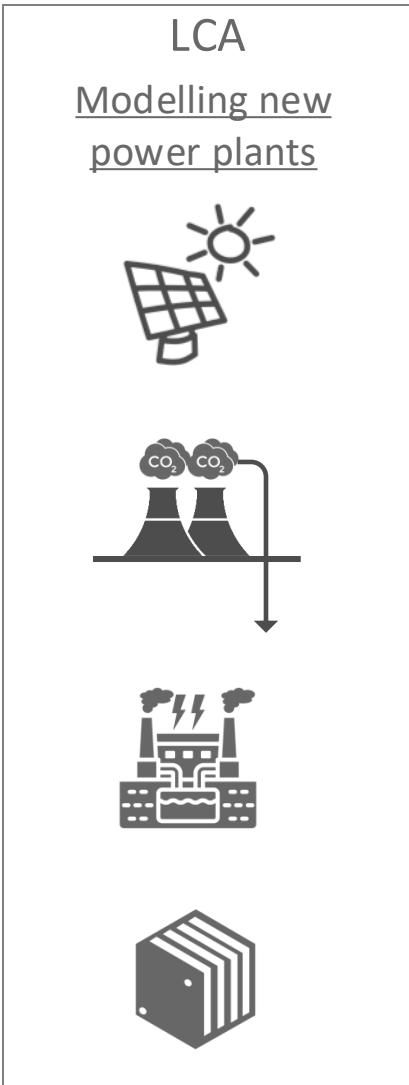
Adjust efficiency for cement and steel production (fuel mix, process efficiency, material composition, etc.)



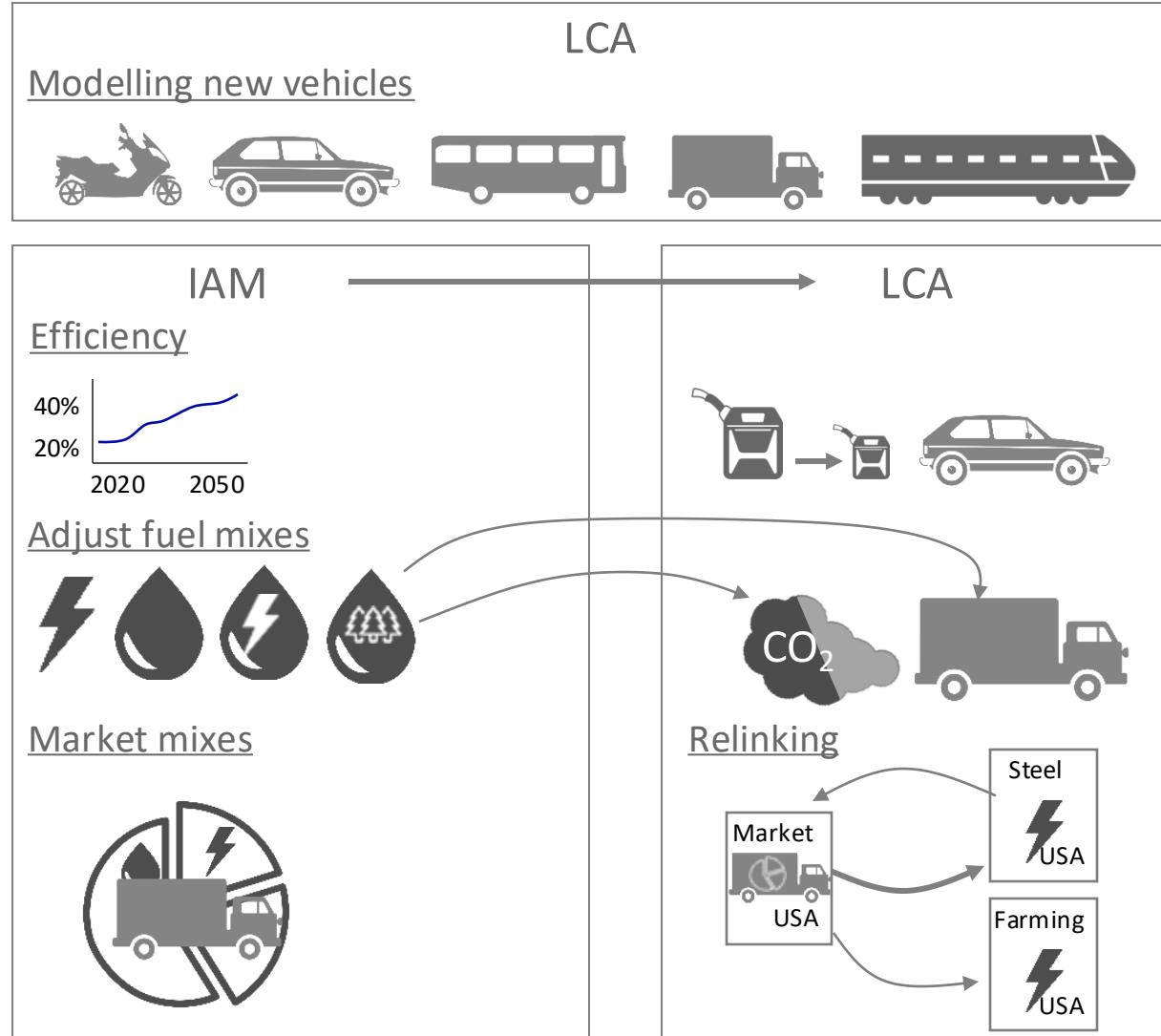
Carbon capture and storage

Add carbon capture and storage where needed

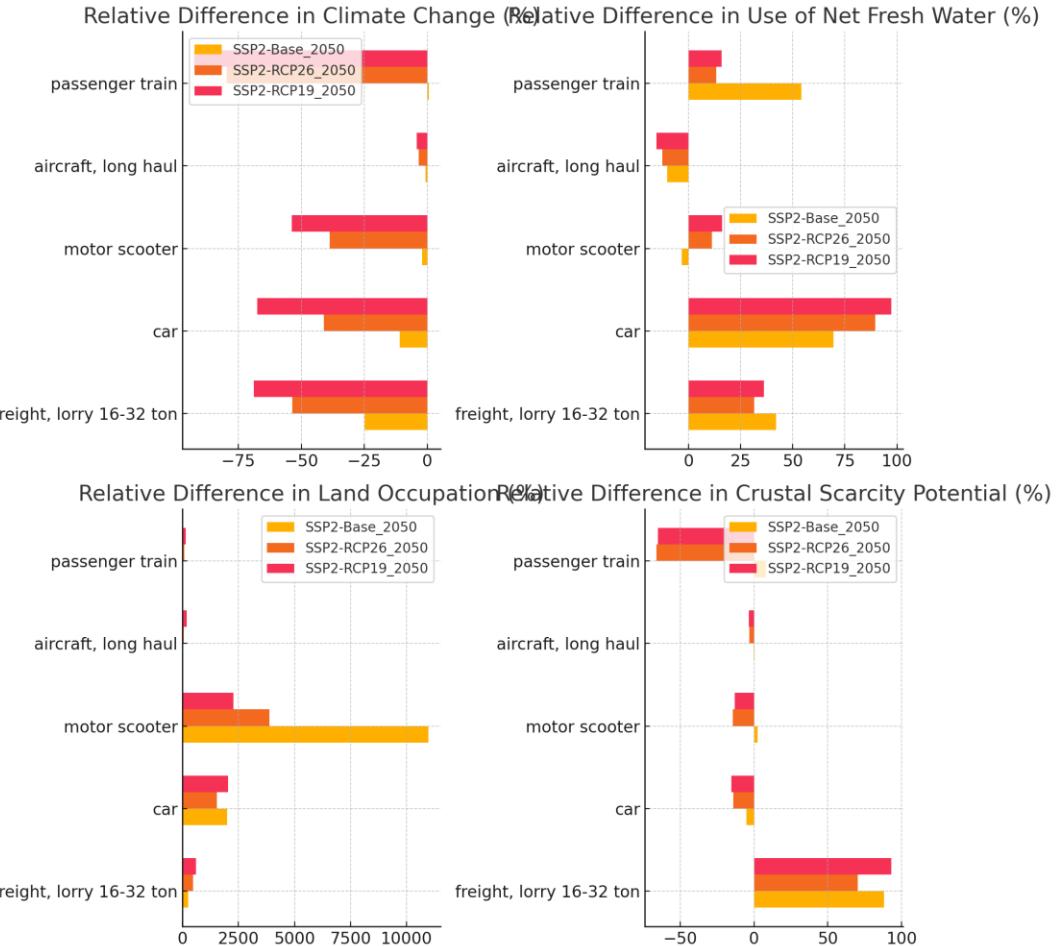
Example of SECTOR-SPECIFIC transformation: power generation



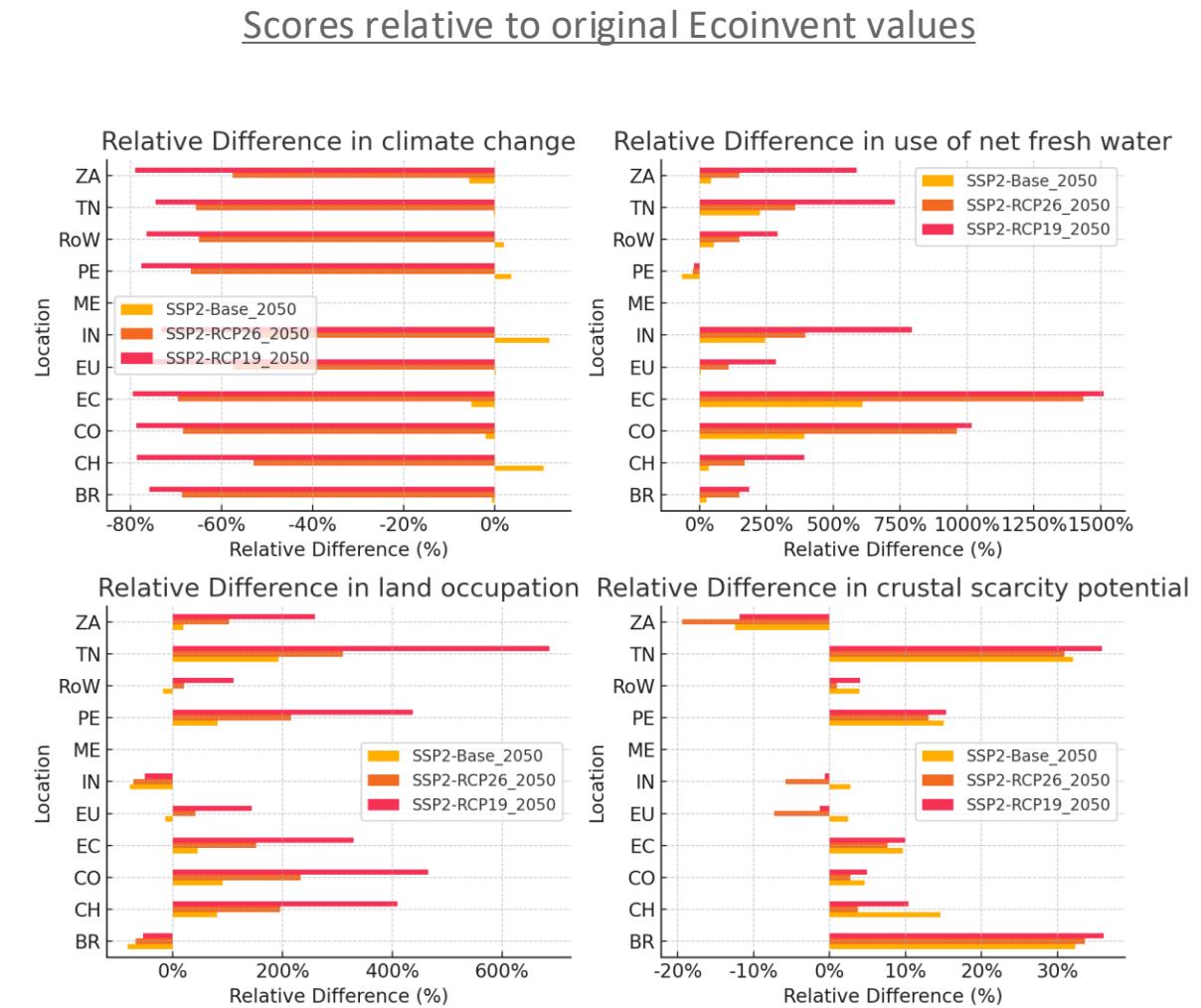
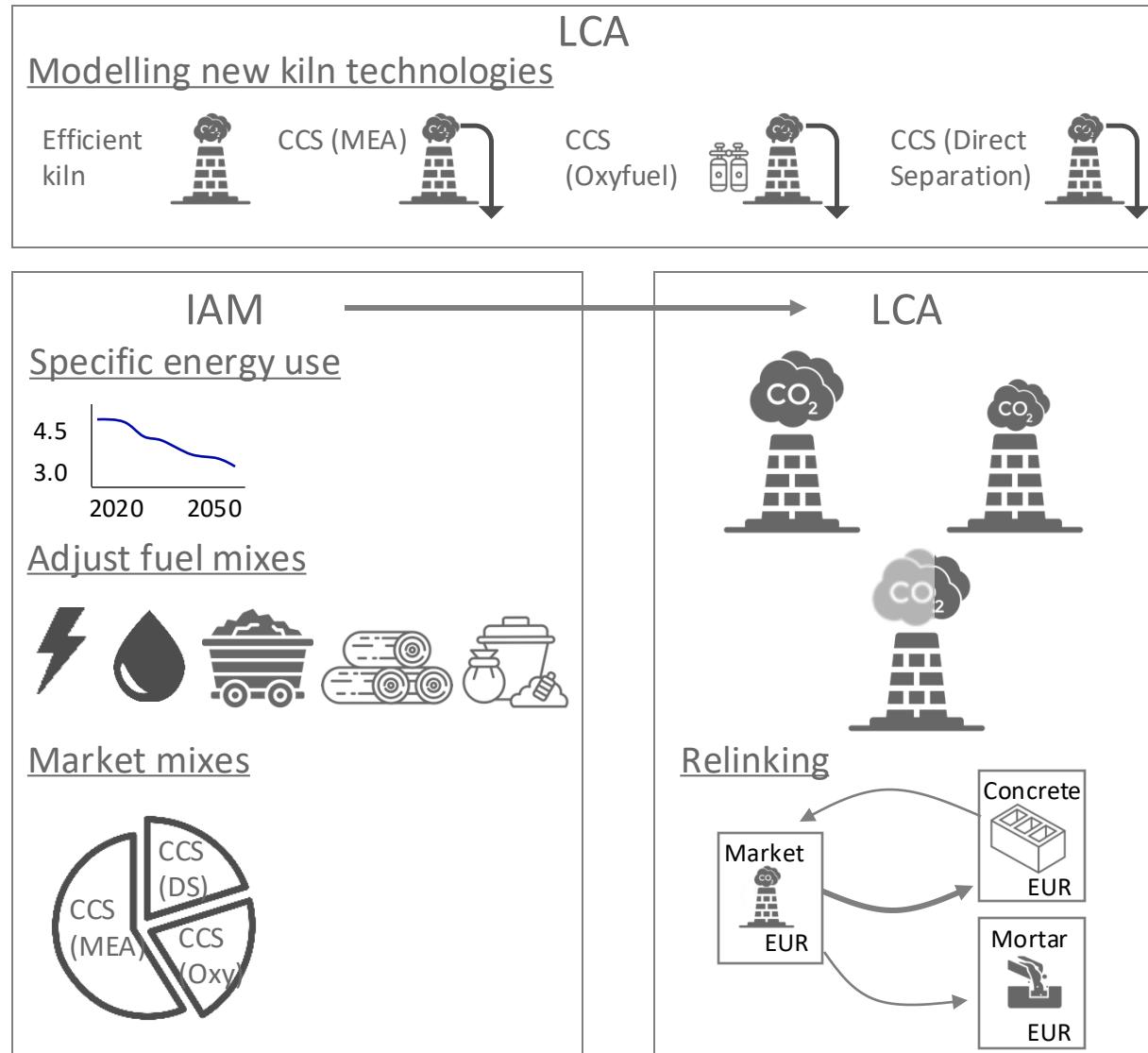
Example of SECTOR-SPECIFIC transformation: TRANSPORT



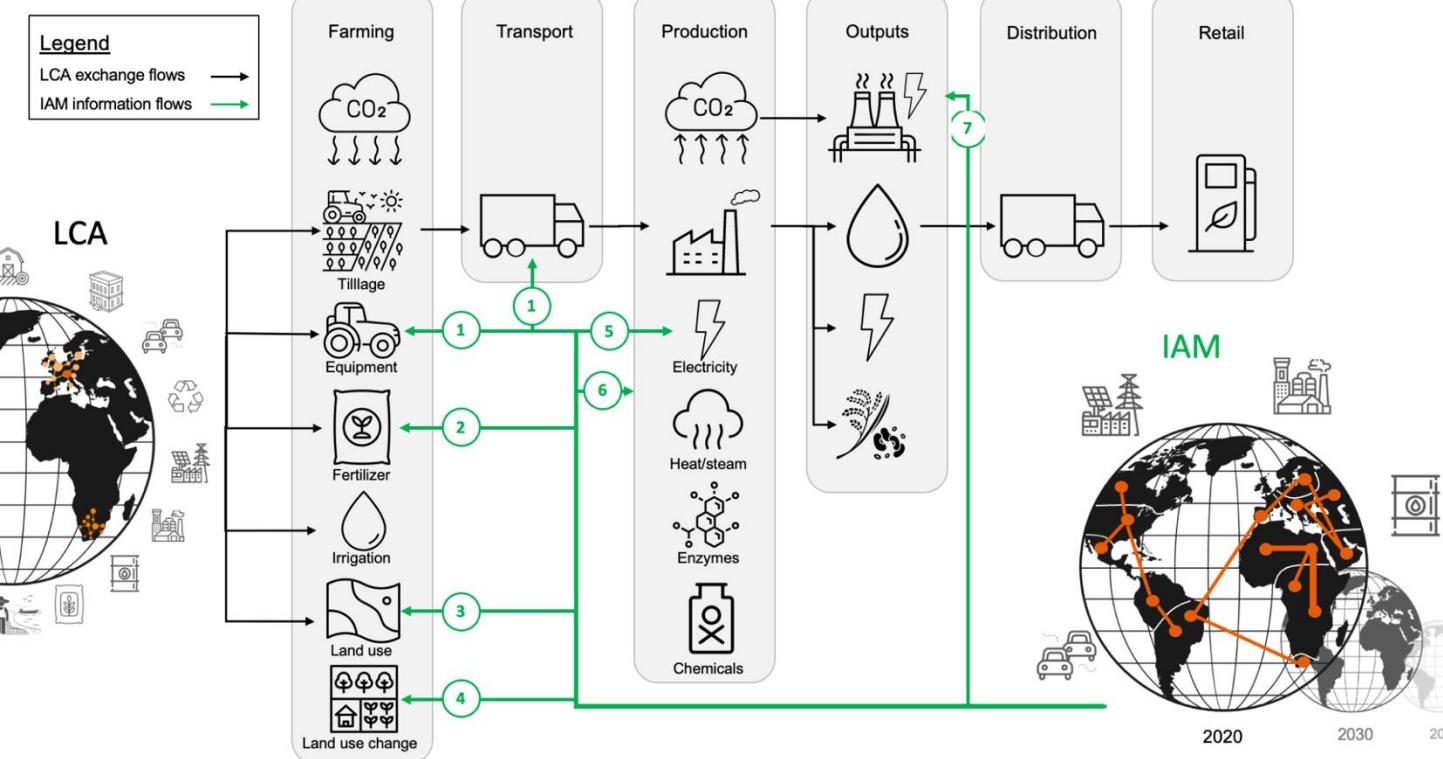
Scores relative to original Ecoinvent values



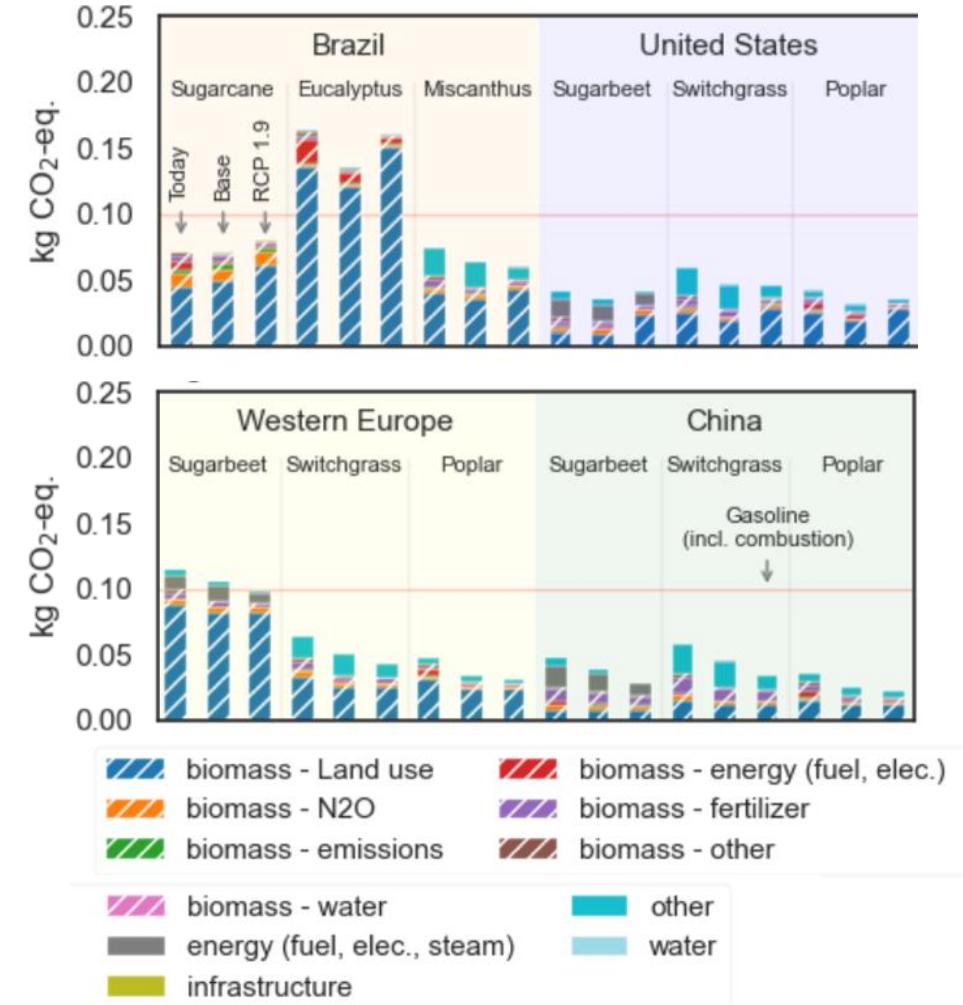
Example of SECTOR-SPECIFIC transformation: CEMENT



Example of transformation: BIOFUELS



(1 MJ biofuel, including combustion)

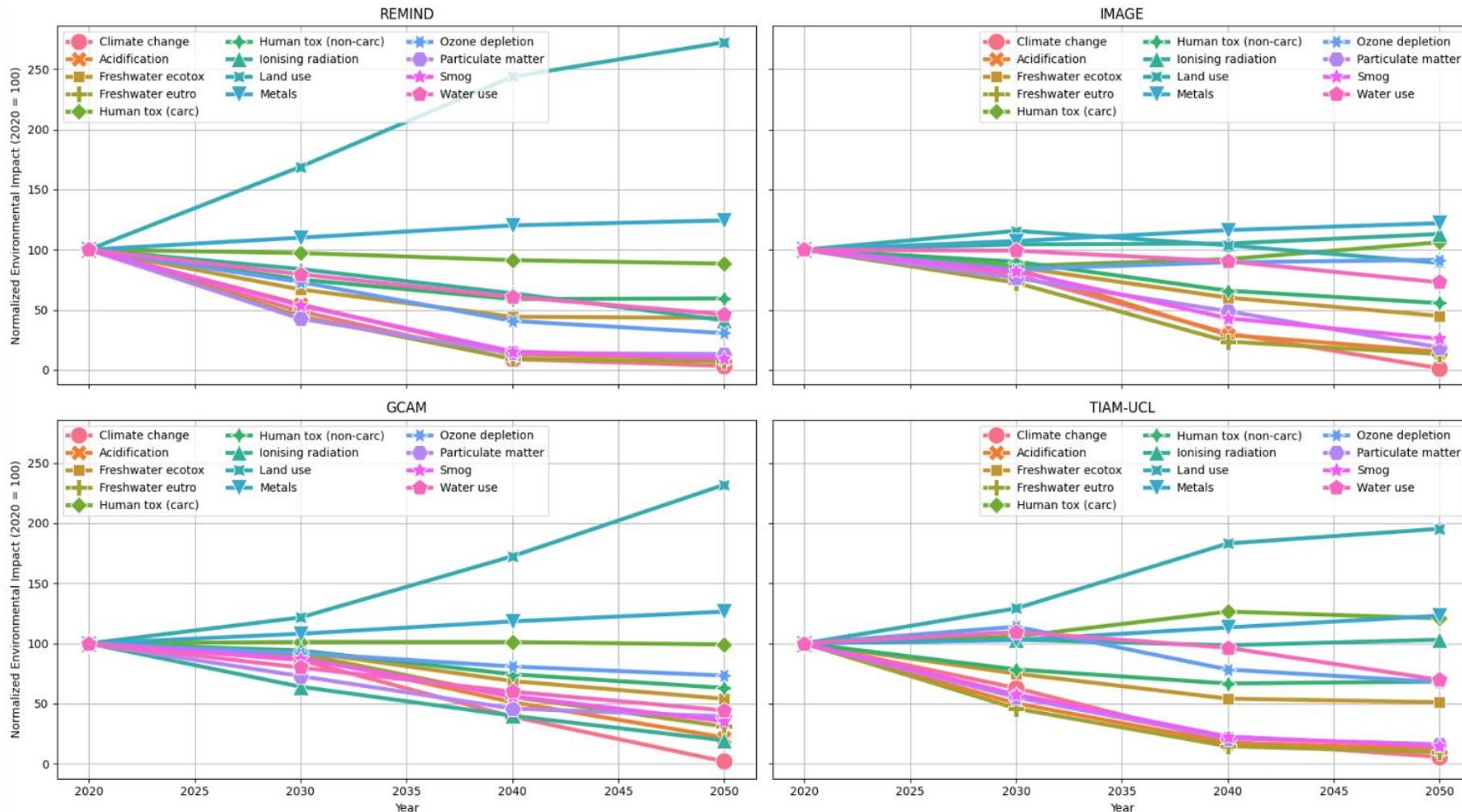


Indicators evolution across IAM models for <2 °C scenarios

Impacts of 1 kWh of global electricity, relative to 2020

GHG emissions decrease, but some resource use indicators increase.

Indicators relating to toxicity and ozone depletion are uncertain, but still relevant (e.g., what'll happen if we do not change our current practices?).

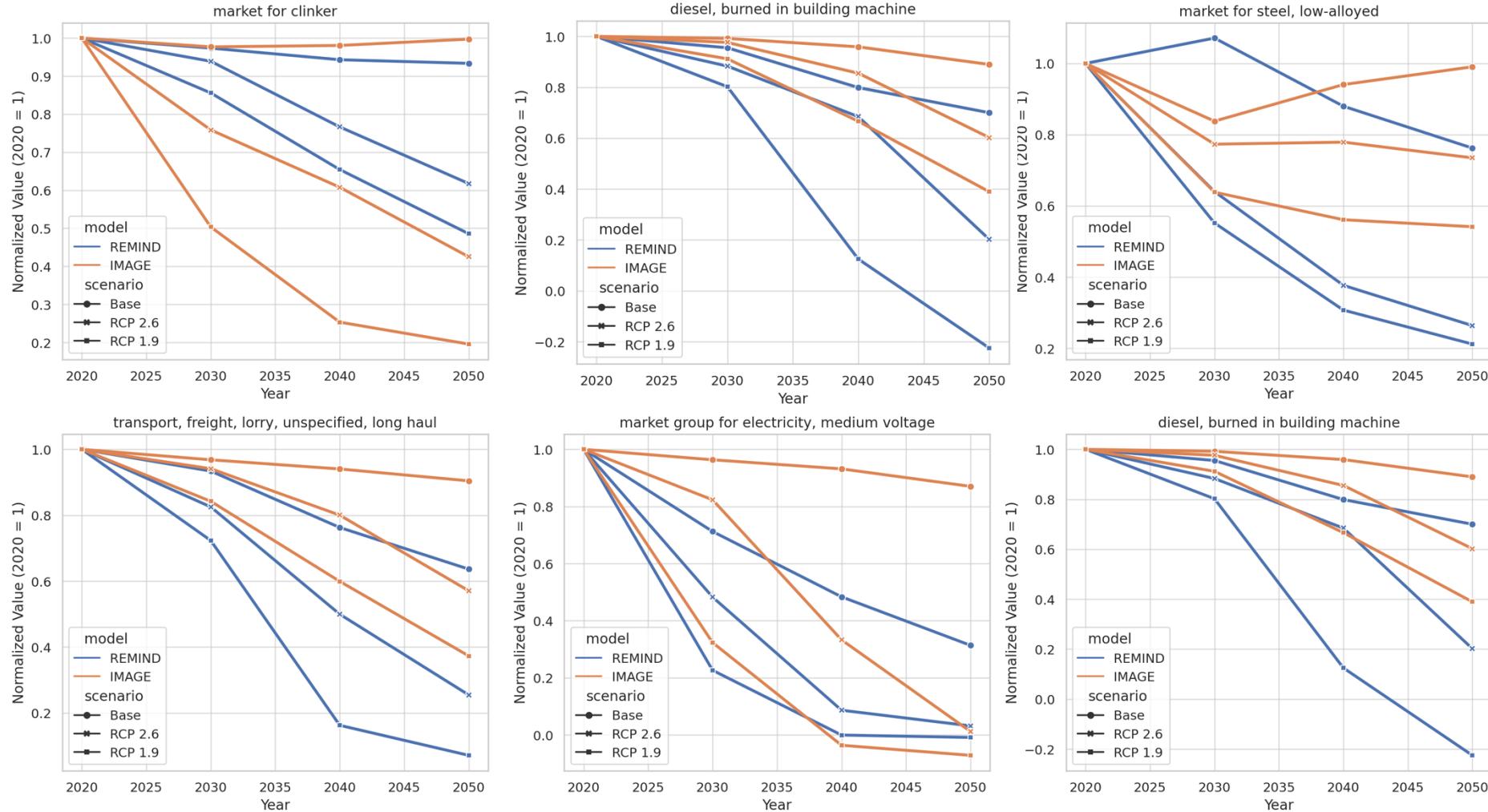


Climate change impacts across time and scenarios

Substantial impact reductions across sectors

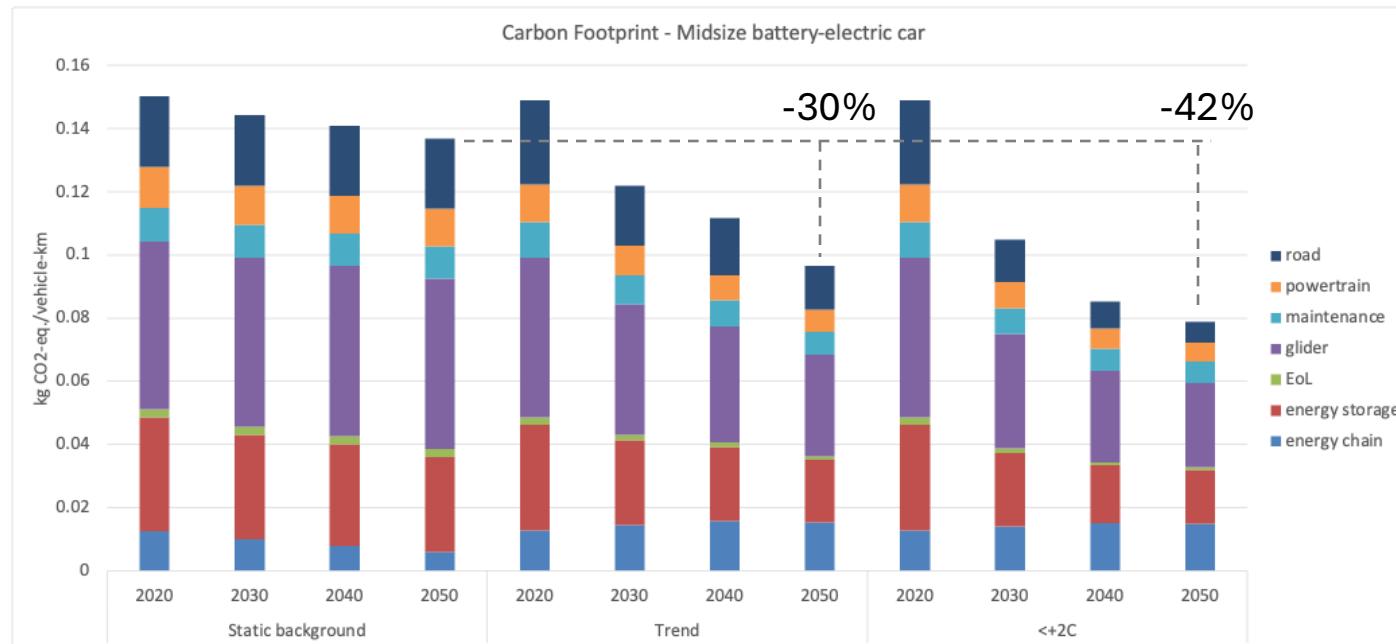
Much is due to lower GHG per kWh of electricity and electrification

Results strongly depend on the scenario and the IAM

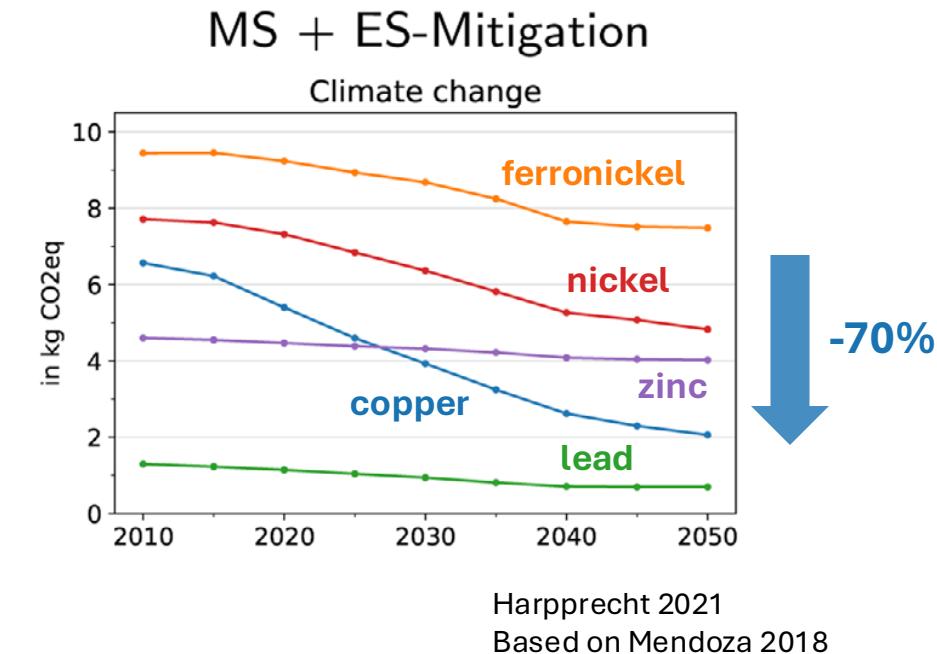


CASE USING pLCA DATABASE: Electric vehicles and Metals

Climate change results for a large size battery electric car operated in Europe, using a «static», reference and <2 C REMIND energy scenarios.



Climate change results for metals, including electricity change, ore degradation, technology mix, and recycling



CASE USING pLCA DATABASE: ammonia production

(Boyce et al., 2024)

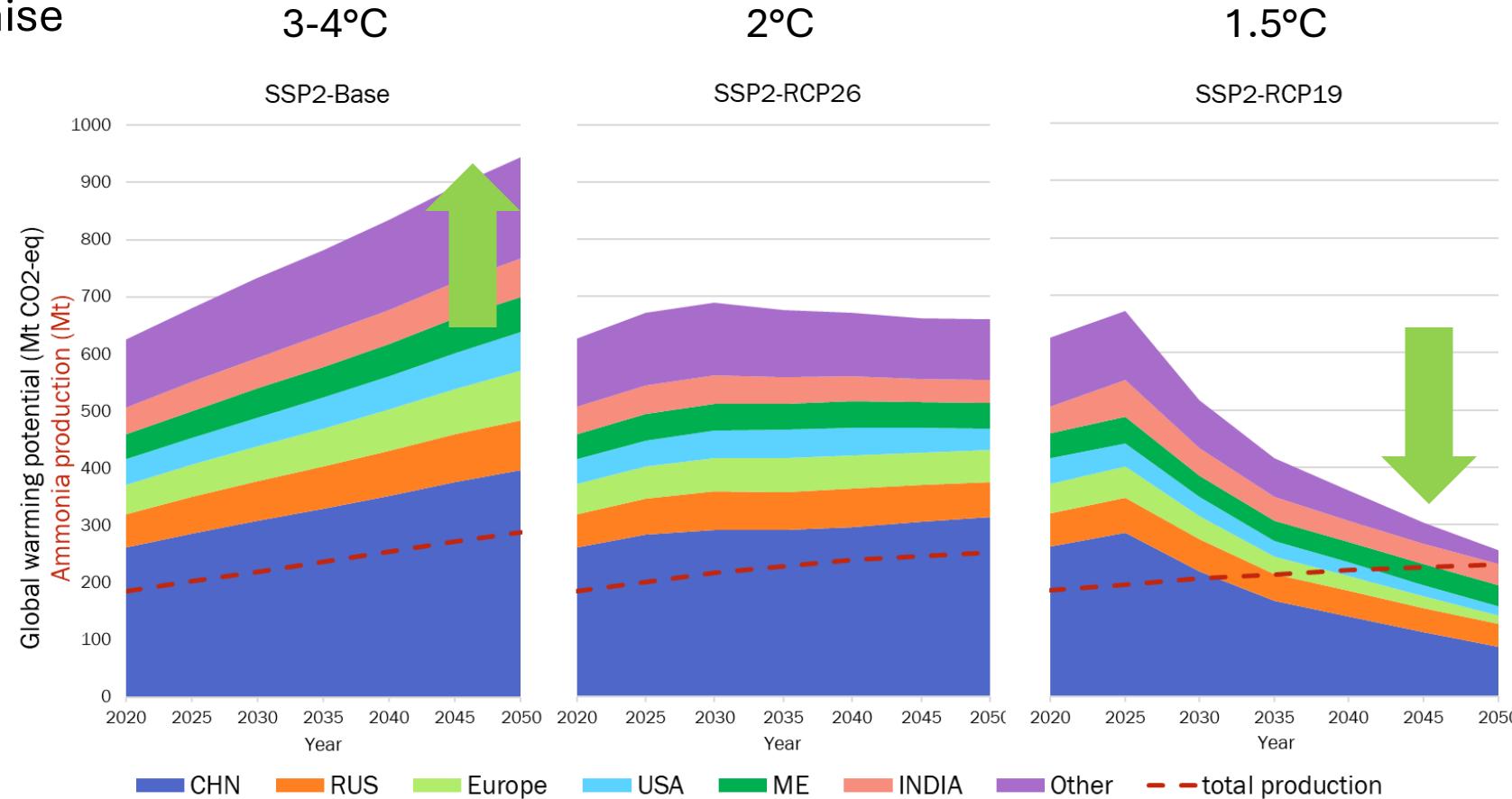
- IEA ammonia scenarios + premise
- GHG emissions from global ammonia production can be substantially lowered

Key factors:

- future demand
- supply of clean electricity
- shift to green hydrogen
- CCS

Key limitation:

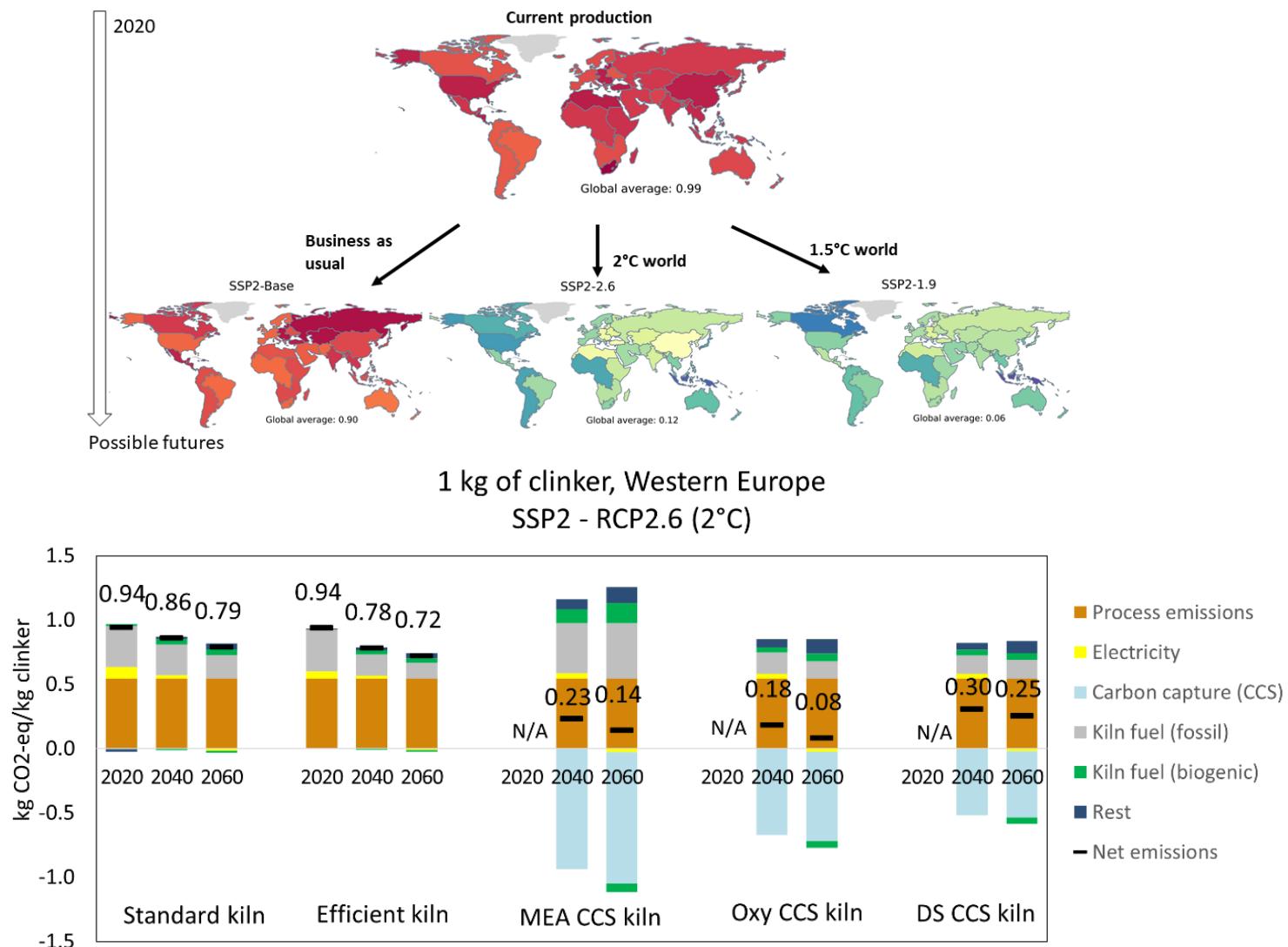
- Need for urea delays H2-based options



CASE USING pLCA DATABASE: cement production

(Müller et al., 2024)

- Based on IMAGE scenarios + premise
- GHG emissions from global cement production may be substantially lower in the future
- CCS is a major factor in this (next to electricity) and so there is considerable uncertainty to these results
- There may also be trade-offs with other environmental impact categories

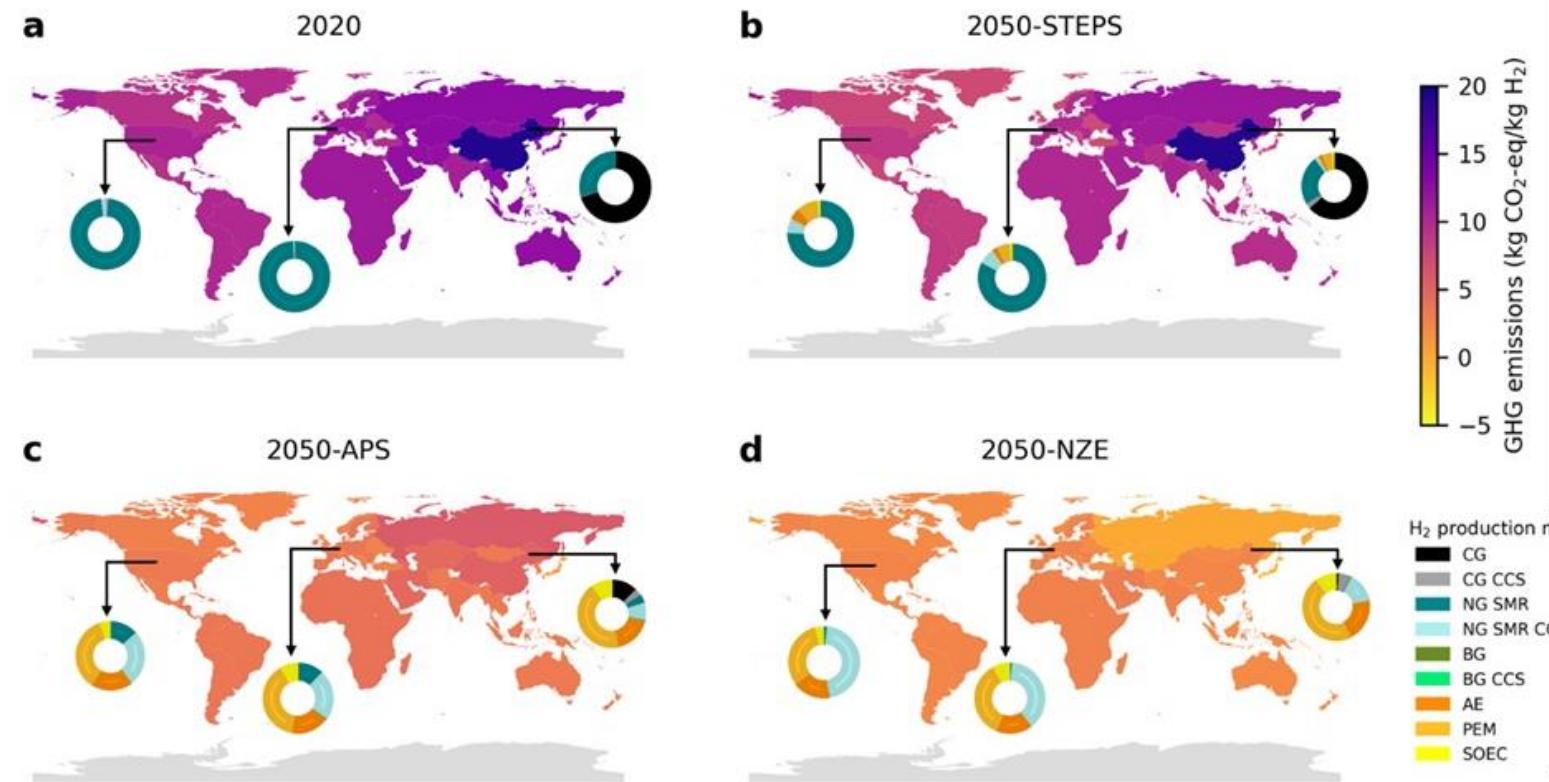


CASE USING pLCA DATABASE: HYDROGEN

(WEI et al., 2024)

- Based on IEA H₂ scenarios + premise
- Fossil fuel-based technologies have limited potential without CCS
- Global H₂ production grow four to eight times by 2050 but GHG emissions may already peak between 2025 and 2035.
- Cumulative GHG emissions may correspond to almost 12% of the remaining carbon budget to meet the 1.5°C target.
- Investments in natural gas steam methane reforming with carbon capture and storage, as projected by the IEA, lead to the risk of carbon lock-in.

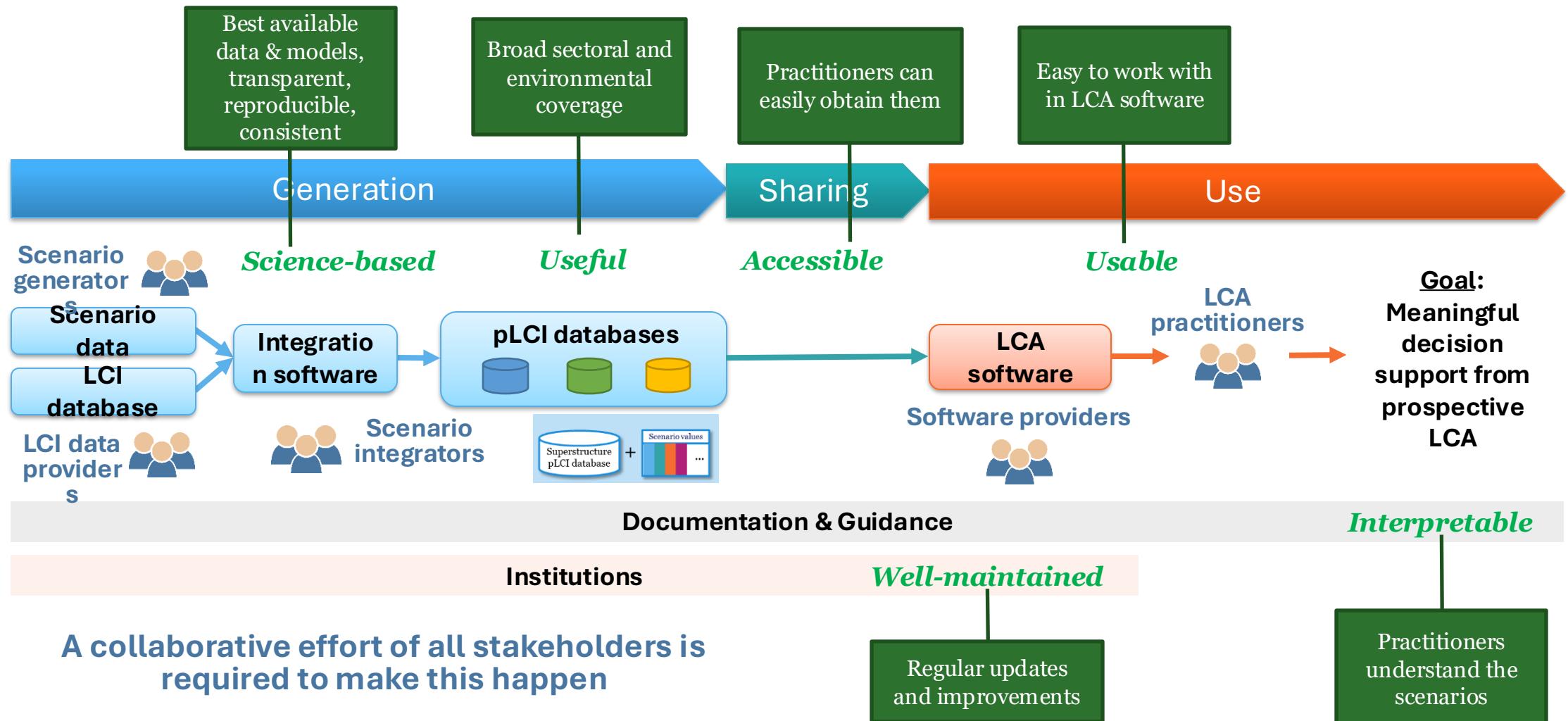
GHG emissions of one kg H₂ of regional markets in 2020 and 2050. a shows GHG emissions of per kg H₂ from 15 regional H₂ market, as well as market share of different H₂ technologies in China, USA and EU in 2020



Challenges for generating and using pLCA databases

Challenge	Description
Temporal consistency FG/BG	<i>Ensure that the TRL and deployment foreground technology is consistent with the background scenario.</i>
Narrative consistency FG/BG	
Sectoral coverage	<i>What are the most important sectors' projections to integrate in LCA?</i>
Environmental coverage	<i>IAM and energy model projections focus on energy and climate. Non-climate impacts are less robust and consistent (e.g., biodiversity, ozone depletion).</i>
Consistency vs. Quality/Detail	<i>Should LCA process be 100% consistent with the scenario (efficiency, lifetime) or should we focus on completeness?</i>
Harmonization & acceptance	<i>Which scenarios should be considered? IPCC's marker scenarios?</i>
Sharing/distribution	<i>Licensed IAM and LCA data hamper distribution.</i>
Software	<i>Only Brightway and Activity-Browser handle scenario-based LCA databases.</i>
Interpretation	<i>Exploratory scenarios, not predictions!</i>

Vision: “Qualities” of pLCI databases



How DO I obtain premise databases?

Premise databases rely on the underlying ecoinvent database: license restrictions! Two options:

1) I create my own databases

- Install and get familiar with Python
- Install premise
- Run premise, generate databases and export in the desired format



2) I import databases via Activity Browser:

- ScenarioLink plugin (you need a locally installed version of the ecoinvent database)



ScenarioLink Plugin, Activity Browser

The screenshot shows the ScenarioLink Plugin integrated into the Activity Browser. At the top, there's a navigation bar with tabs: Welcome, LCA Setup, Activity Details, Parameters, and ScenarioLink. Below the navigation bar, the main area is titled "ScenarioLink". It has a section for selecting a datapackage, with a radio button for "Online datapackages" (which is selected) and another for "Local datapackages". There's also a "Clear datapackage cache" button. A table lists several datapackages with columns for creation date, scope, model, scenario, source database, and download status. Below the table, a "Database linking" section shows mappings between ecoinvent and biosphere3 databases. At the bottom, there's a section for choosing scenarios to install, listing "remind - SSP2-Base - 2020" and "remind - SSP2-Base - 2025" with checkboxes. Finally, there are "Cancel" and "OK" buttons at the bottom right.

creation date	scope	model	scenario	source database	downloaded
2023-12-05	Global	remind	SSP2-Base	ecoinvent 3.9 cutoff	<input checked="" type="checkbox"/>
2023-12-05	Global	remind	SSP2-NDC	ecoinvent 3.9 cutoff	<input type="checkbox"/>
2023-12-05	Global	remind	SSP2-NPi	ecoinvent 3.9 cutoff	<input type="checkbox"/>
2023-12-05	Global	remind	SSP2-PkBudg1150	ecoinvent 3.9 cutoff	<input type="checkbox"/>
2023-12-05	Global	remind	SSP2-PkBudg500	ecoinvent 3.9 cutoff	<input type="checkbox"/>

FUTURE DEVELOPMENTS



Heat integration

Currently, only mobile heat generators decarbonize



Metals tracking

Mining inventories for ~80 specialty metals
MFA → recycling rates, ore degradation



Scenarios from three additional IAMs

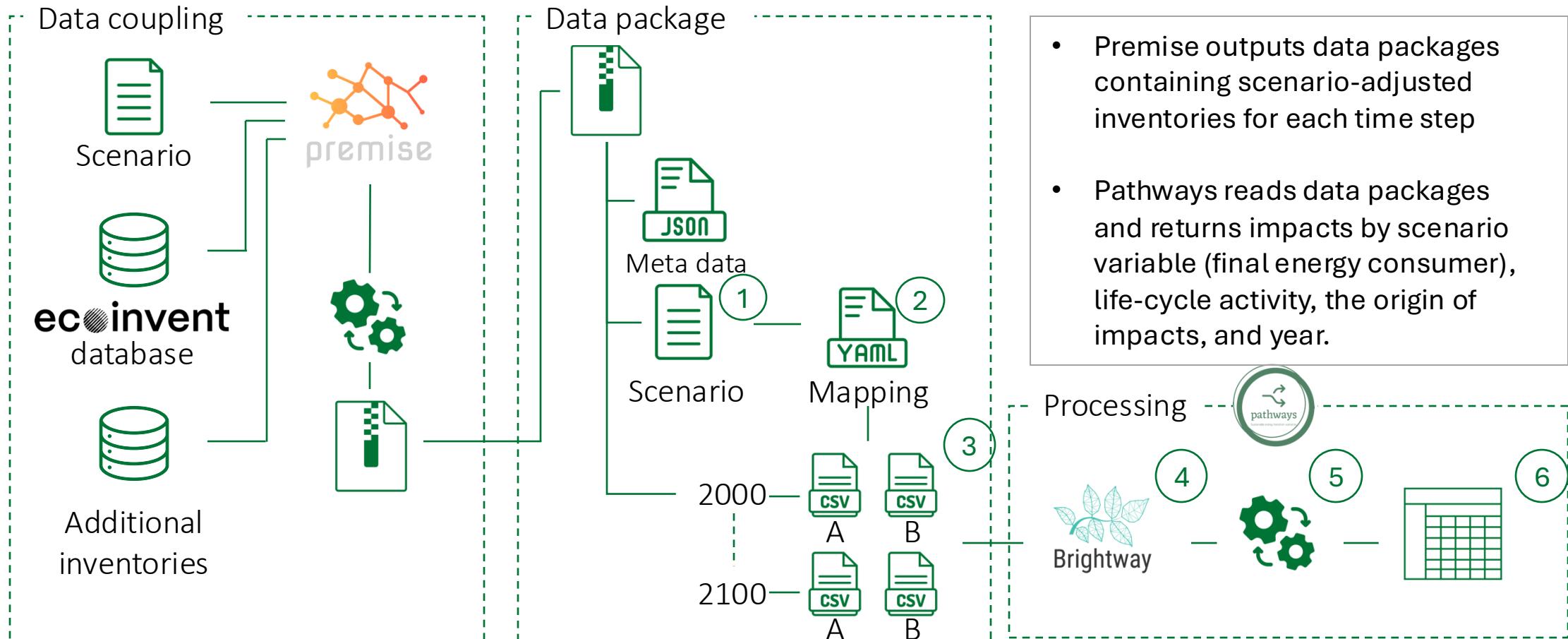
Message-ix, Ti-IAM, GCAM



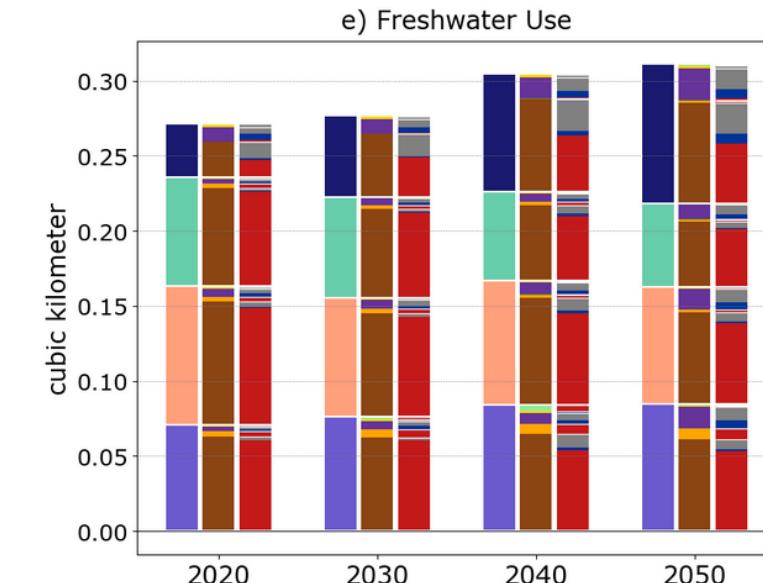
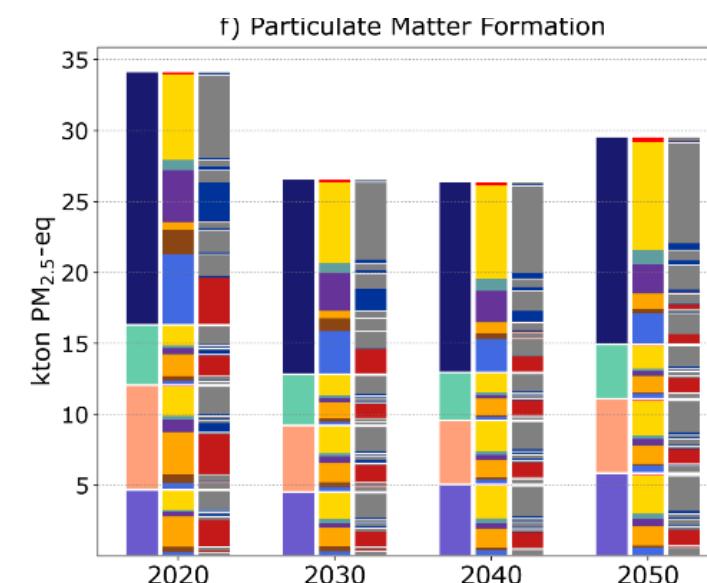
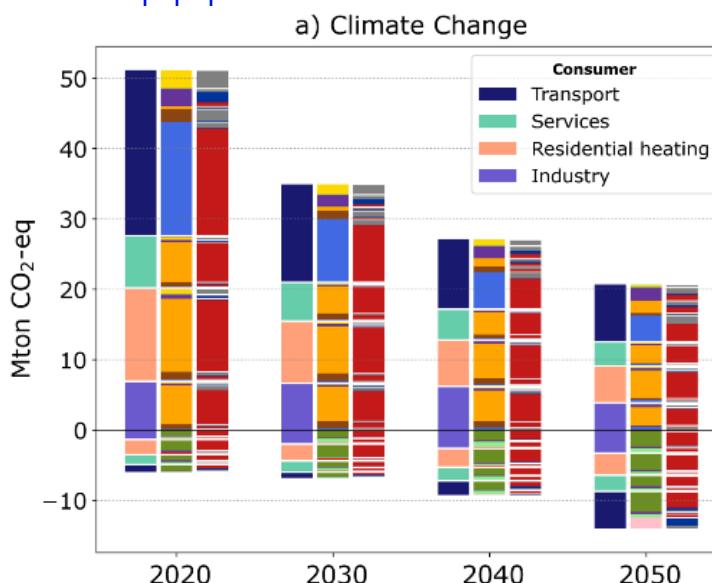
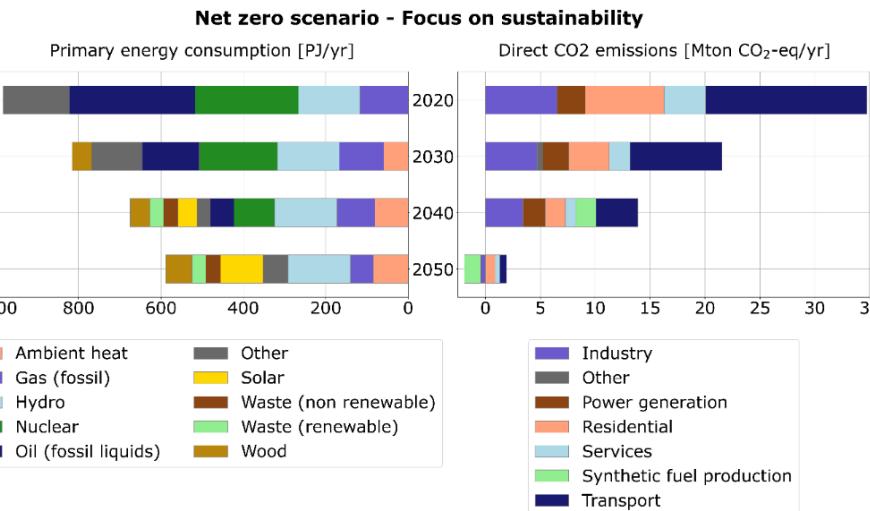
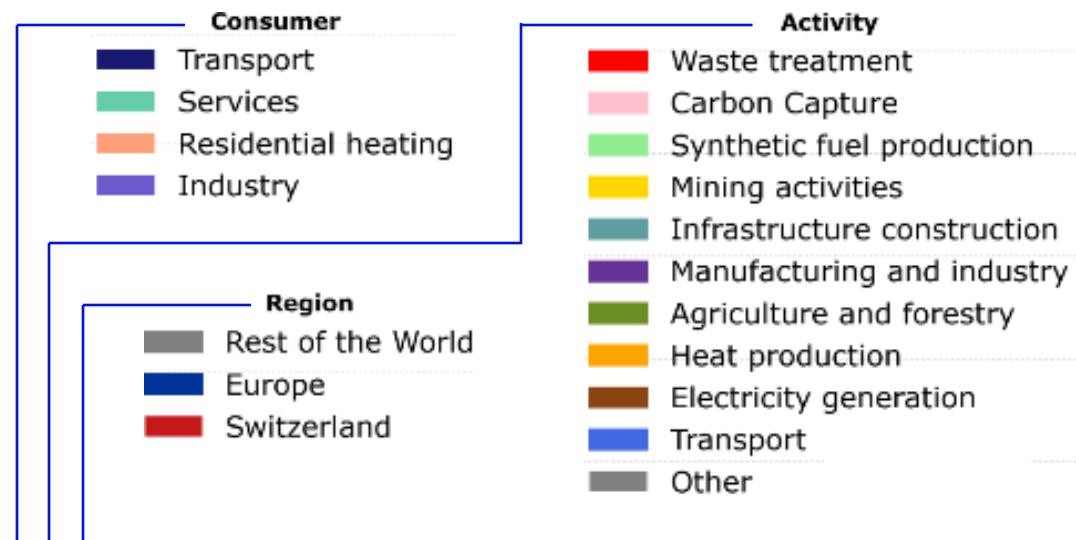
pathways

A new library for scenario- or sector-wide pLCA

PATHWAYS: System-wide prospective LCA

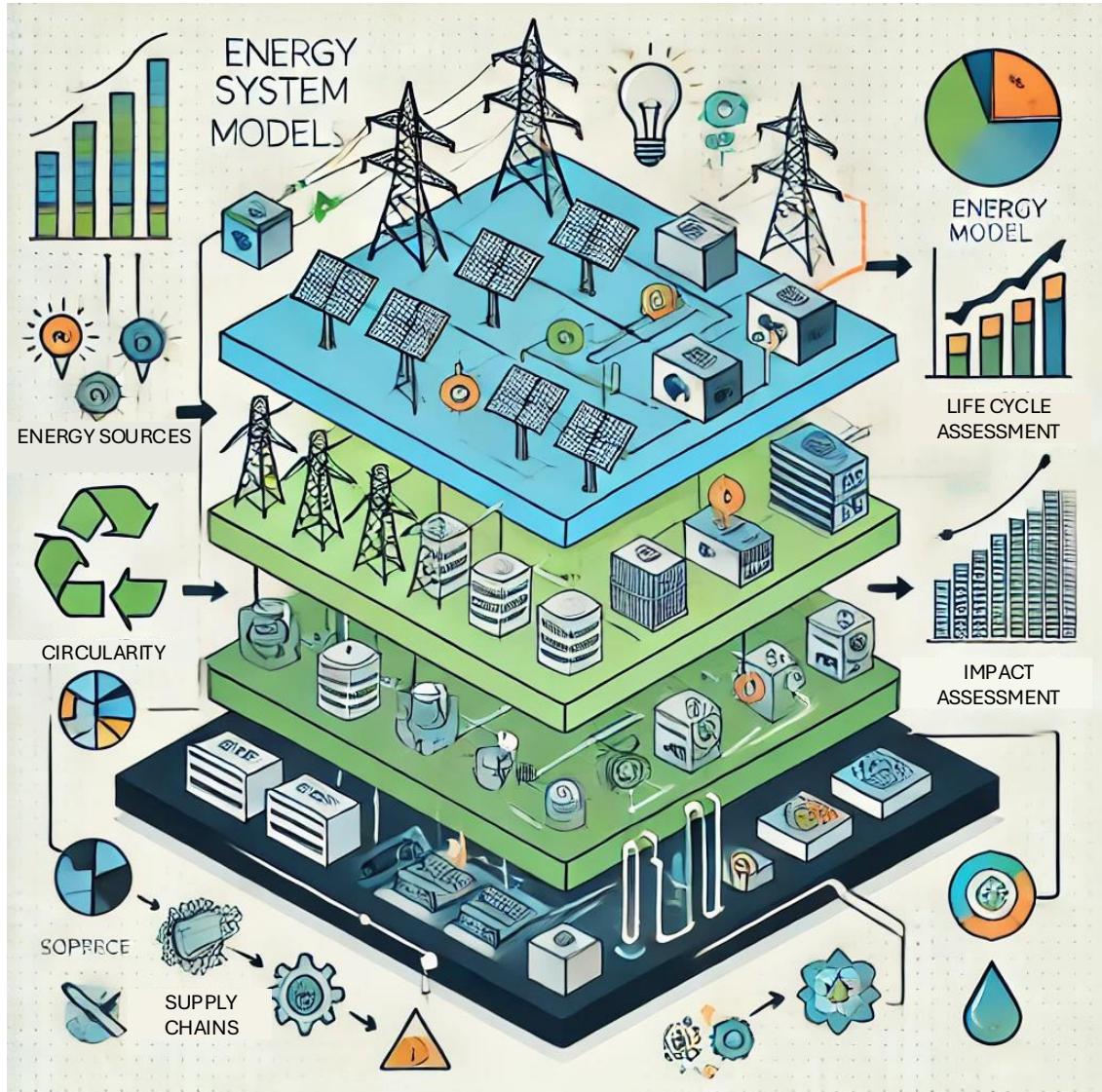


PATHWAYS: Swiss Final Energy supply



Conclusions

- Good scenarios matter! For LCA results, for stakeholder opinions, and for decision-making. Important to get this right!
- The systematic generation of pLCA databases is an exciting and important development for prospective LCA.
- pLCA databases are increasingly being used (at least in academia).
- Much work remains to improve these databases and prepare them for wider use in LCA practice – collaborative effort is needed!



Links to open-source tools

- *Brightway2* (LCA framework): <https://github.com/brightway-lca>
- *Activity-Browser* (GUI for Brightway): <https://github.com/LCA-ActivityBrowser/activity-browser>
- *Brightway-superstructure* (superstructure approach): <https://github.com/LCA-ActivityBrowser/brightway-superstructure>
- *wurst* (systematic transformation of LCA databases): <https://github.com/polca/wurst>
- *premise* (IAM-LCA coupling): <https://github.com/polca/premise>
- *Pathways* (system-wide pLCA): <https://github.com/polca/pathways>

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