

PSI

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

Future background scenarios in LCA

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Grosshöchstetten, 12 November 2024

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

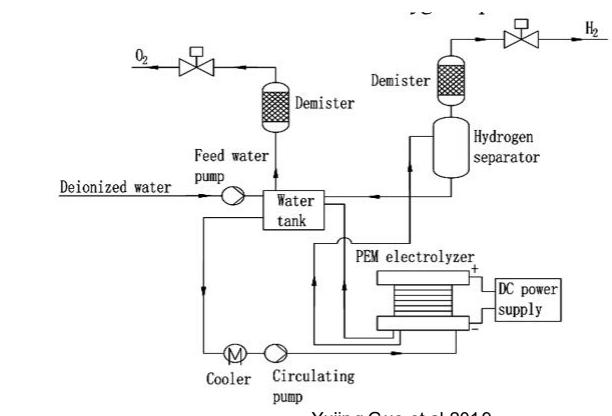
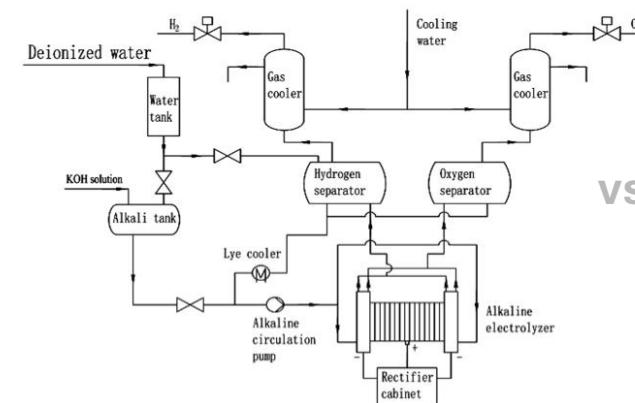
Broad (global) scenarios

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



Narrow (local) scenarios

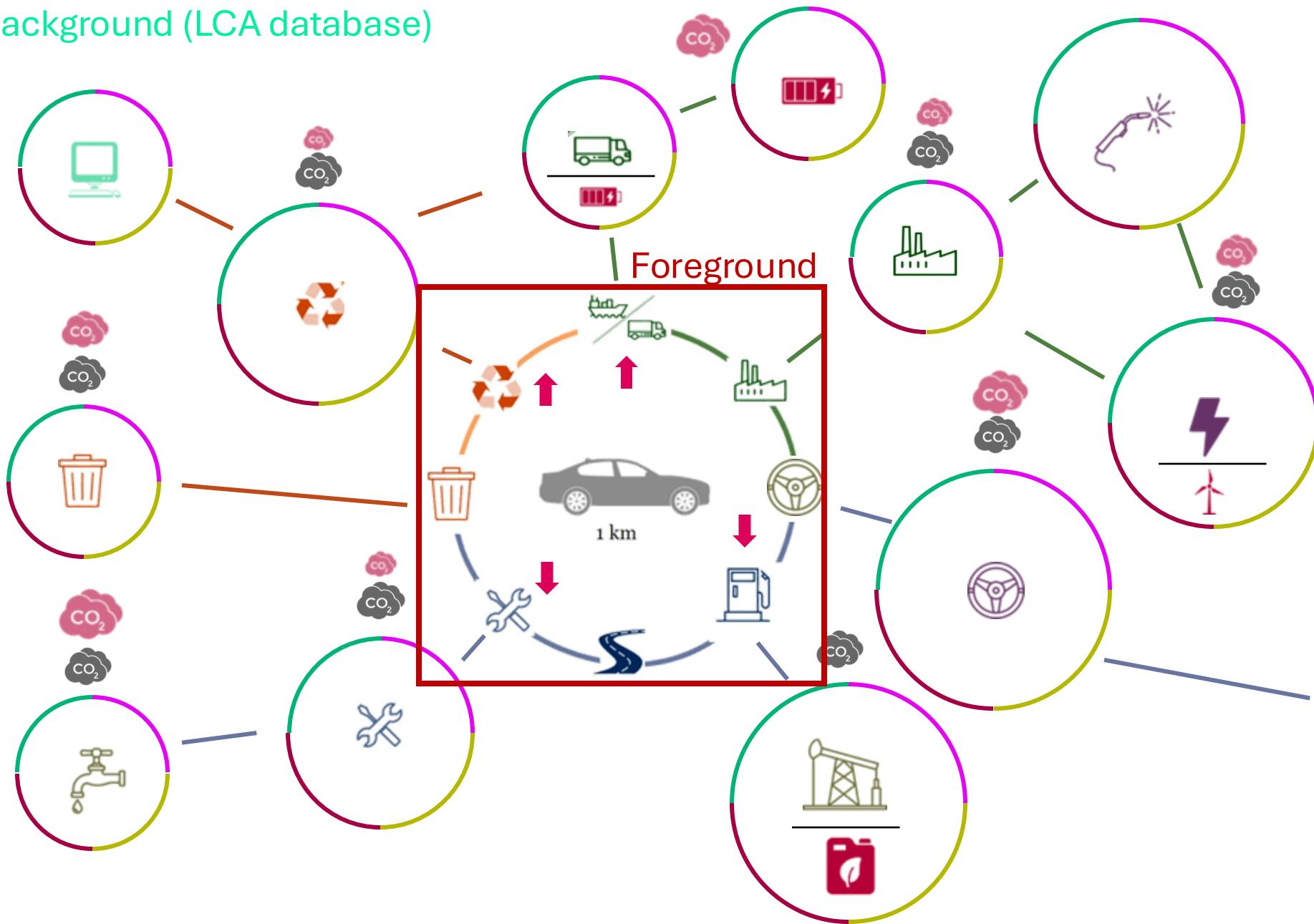
- For specific technologies (hydrogen)
- Limited to a specific prospective LCA
 - **Foreground scenarios**



vs

Yujing Guo et al 2019

Background (LCA database)



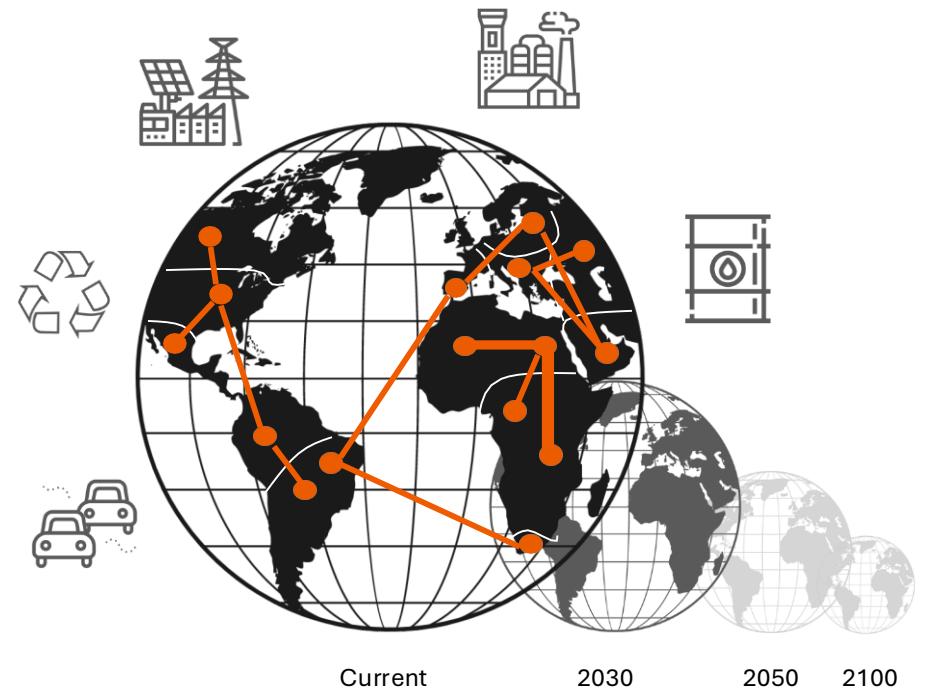
LCA is about PSI
systematically accounting for environmental impacts associated with a service, considering supply chain relations between processes.

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

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

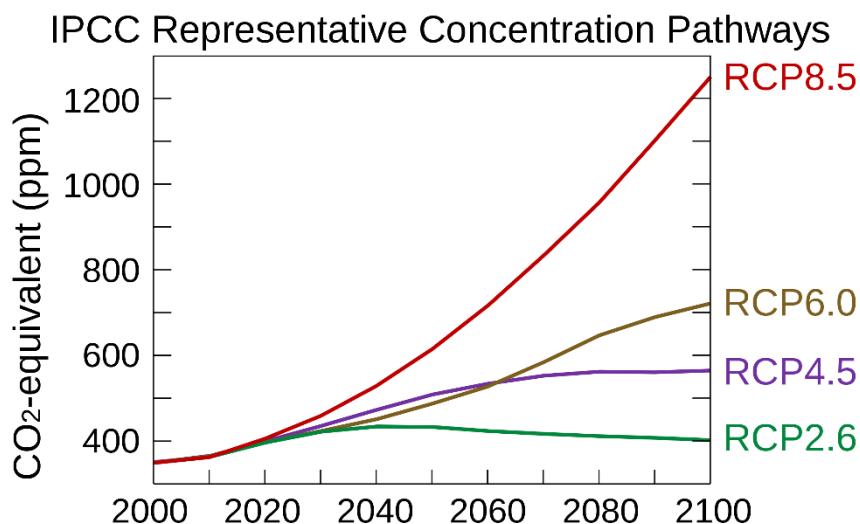
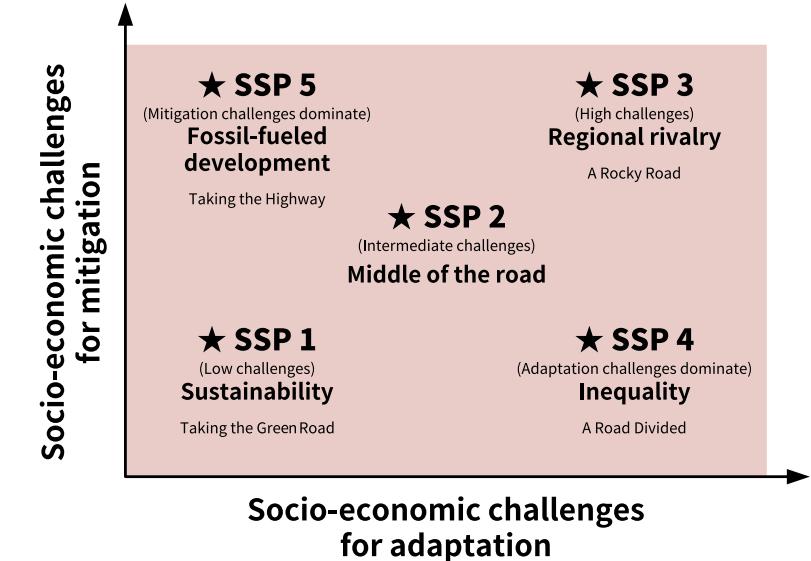
“When background matters” (Mendoza and Cox 2018)

- 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)

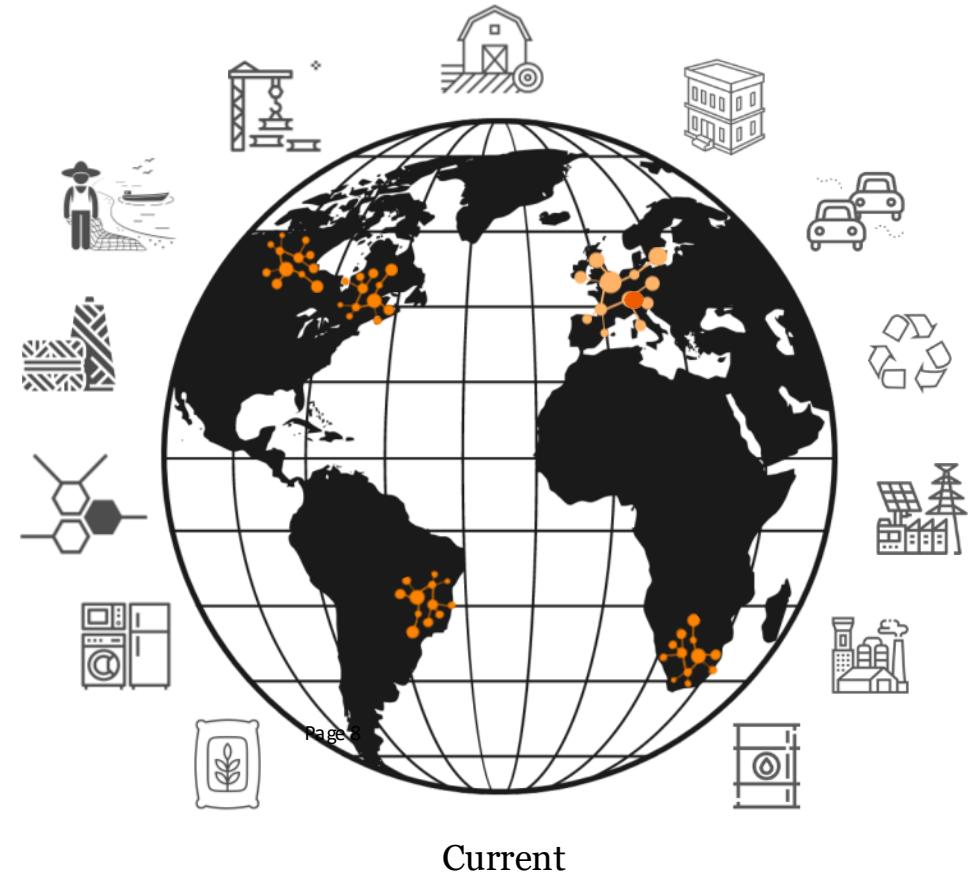
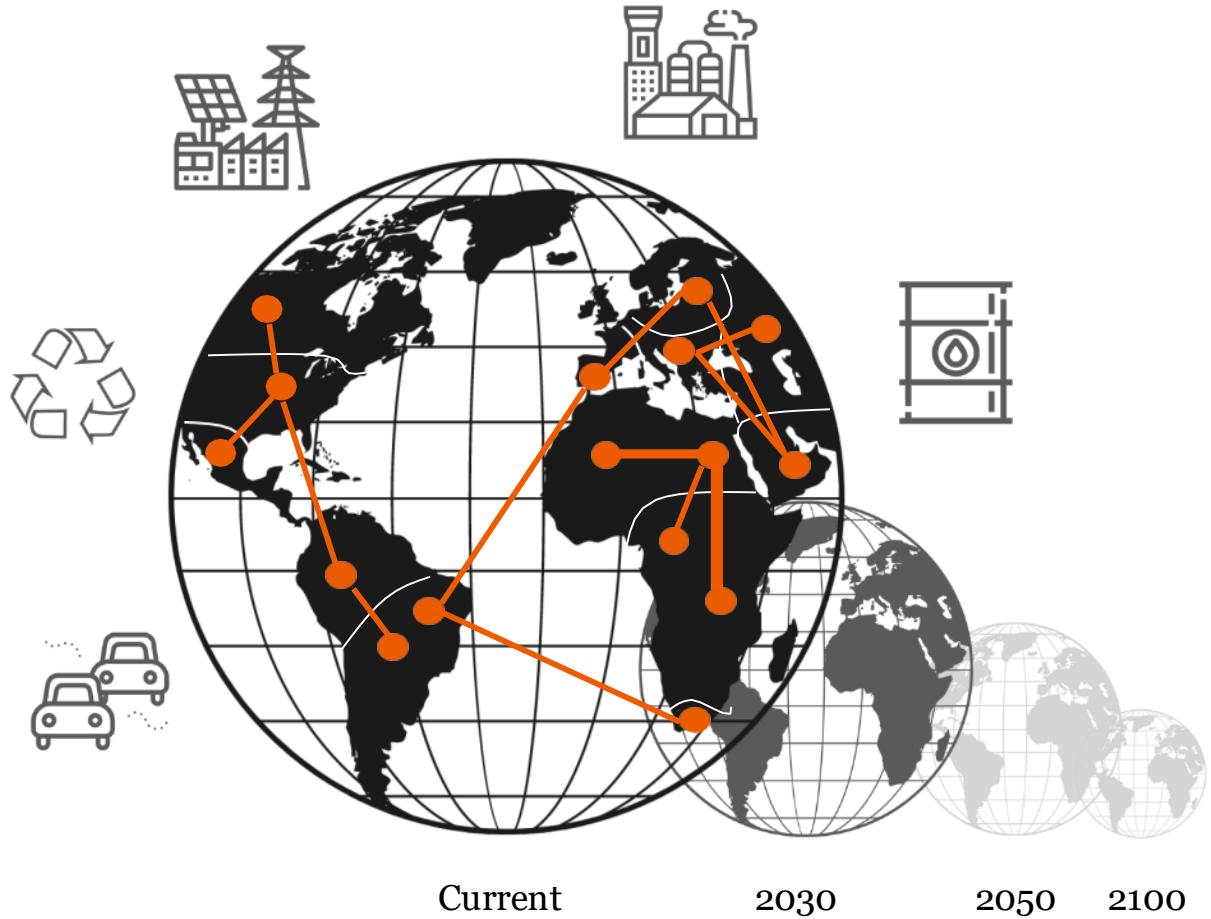
wurst: python package for systematic modifications of LCI databases (Mutel, 2017)

premise (Sacchi 2022)

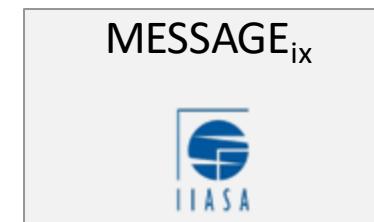
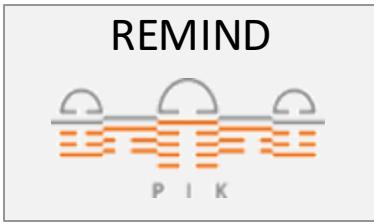
- python package for generating pLCI databases
- Strongly based on IAM data (IMAGE, REMIND)
- Electricity, steel, cement, transport, fuel



INTEGRATED ASSESSMENT MODELS (IAM) VS. LCA



INTEGRATED ASSESSMENT MODELS (IAM)



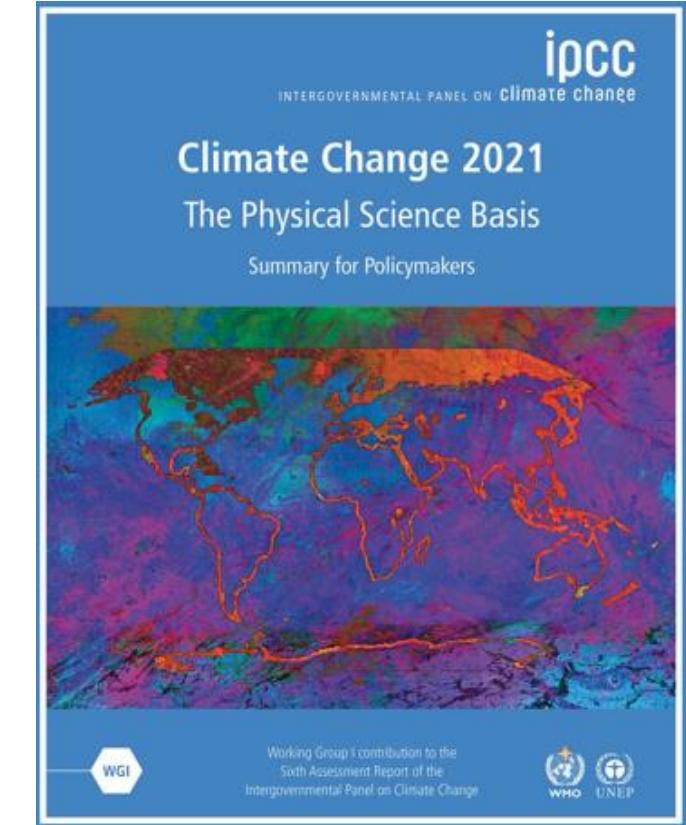
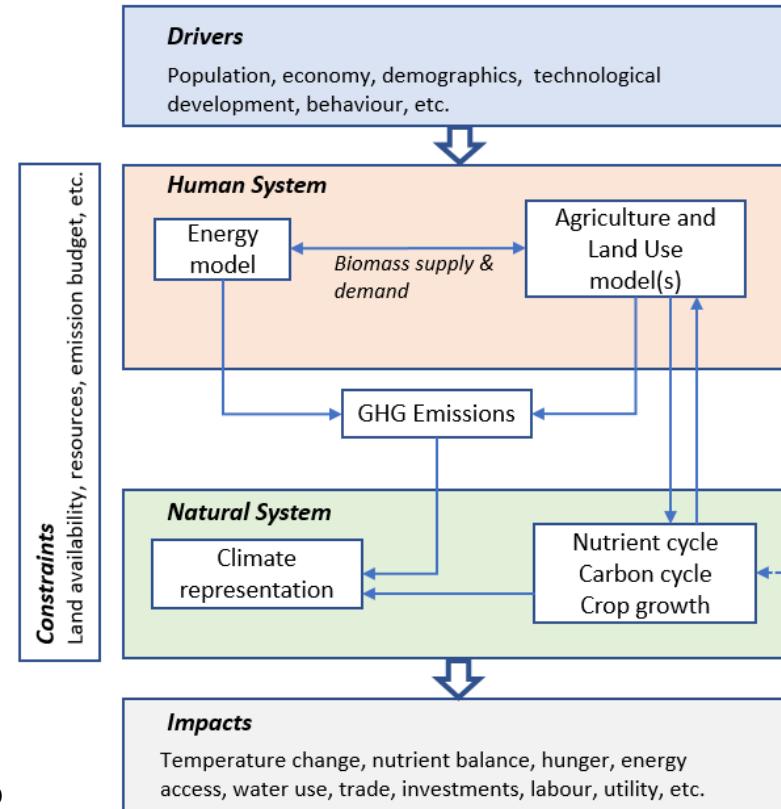
Integrated Assessment Models (IAMs) assess the interactions between **human** and **natural** systems

Contain stylized representations of

- Energy system
- Agricultural economy
- Climate
- Land system

Bridge the Science/Policy interface

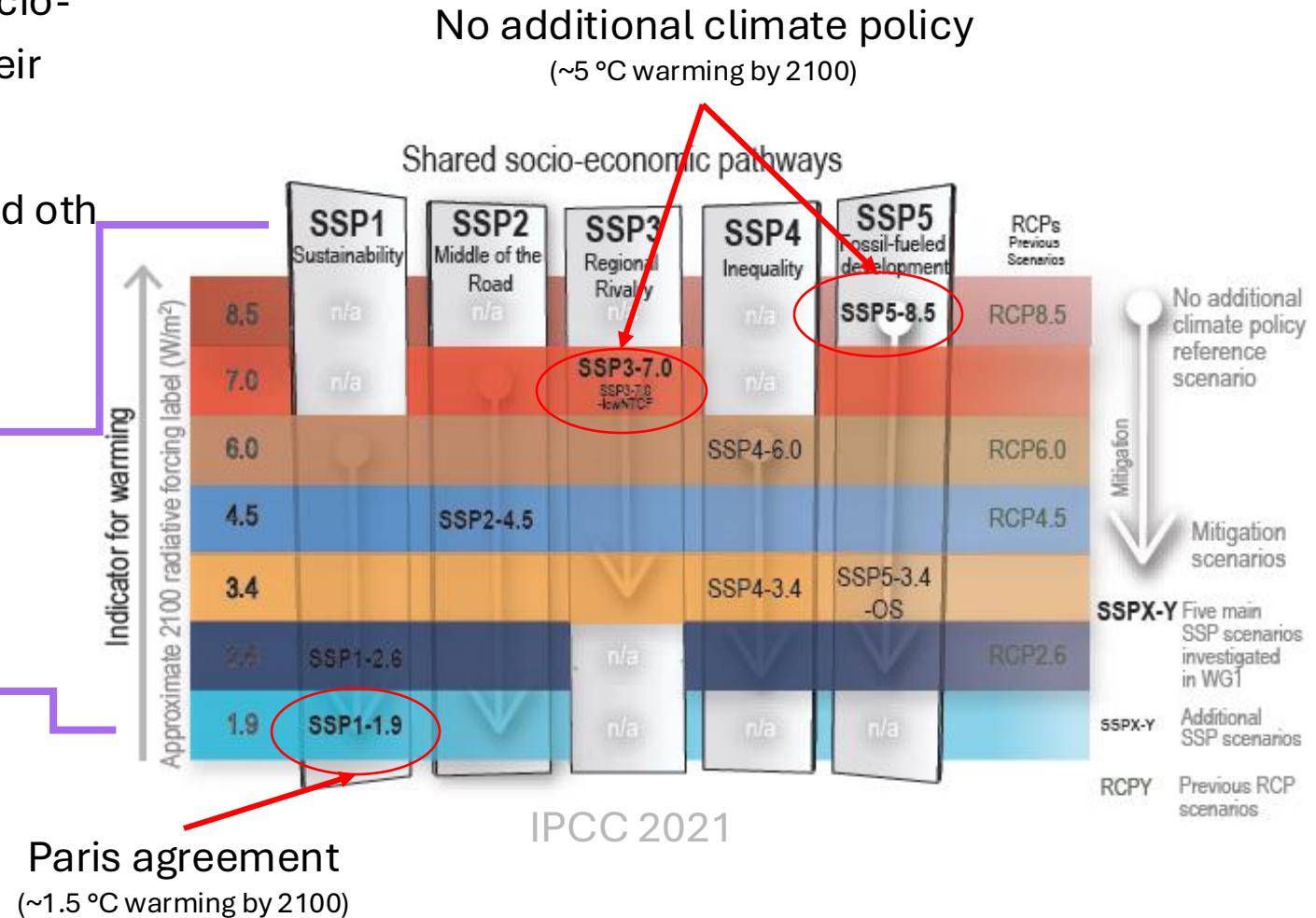
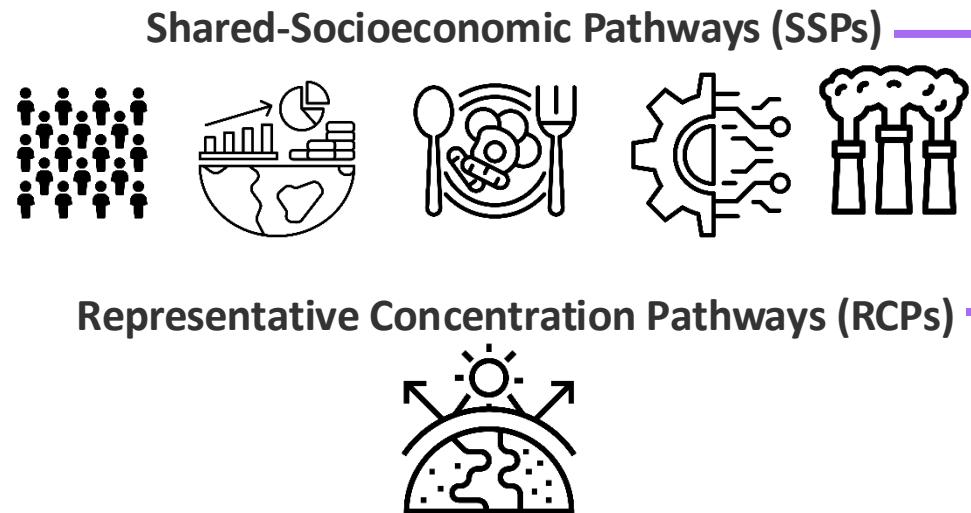
- Scenario Analysis: *What if?*
- What are the drivers or constraints of change?
- How do technology and policy choices lead to different outcomes?
- 9 • Uncertainties? Sensitivities?



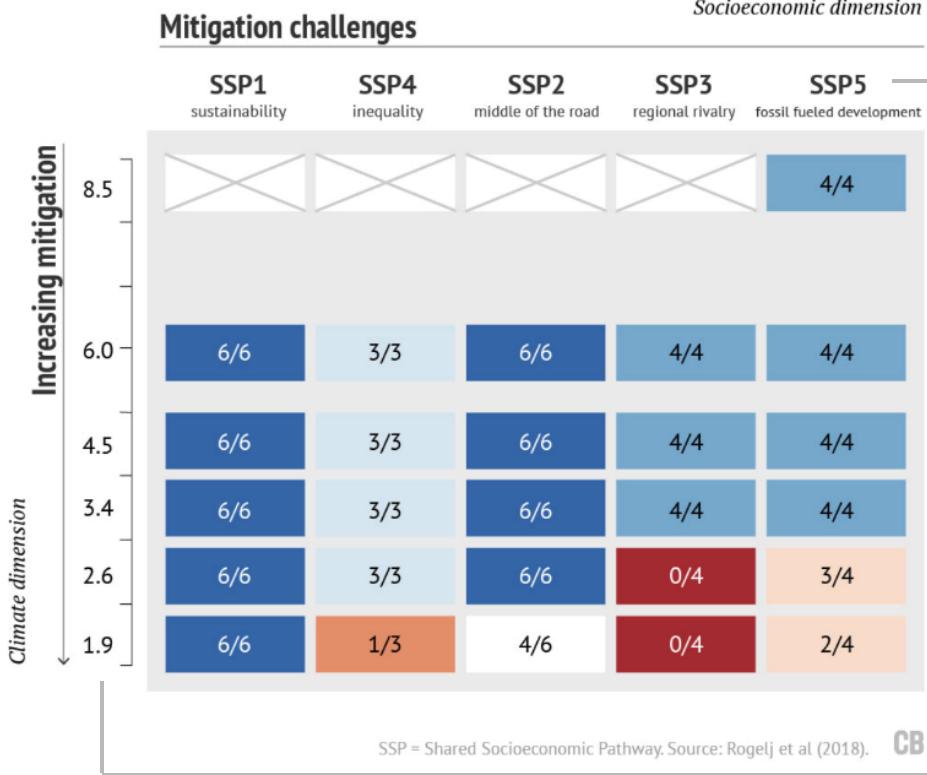
INTEGRATED ASSESSMENT MODELS (IAM)

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.



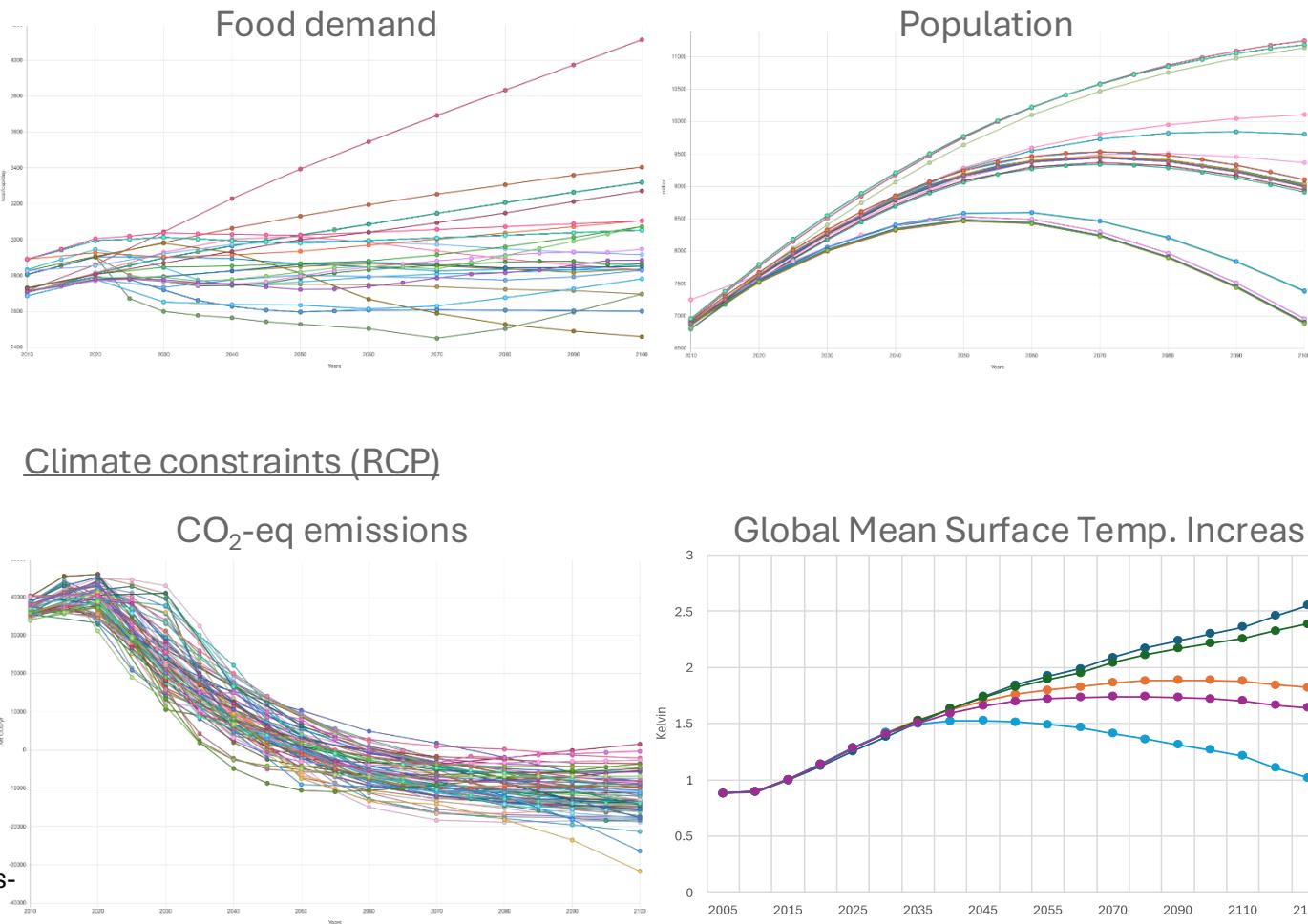
Socio-economic and climate constraints



Credit: CarbonBrief, Zeke Hausfather, 2018.

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

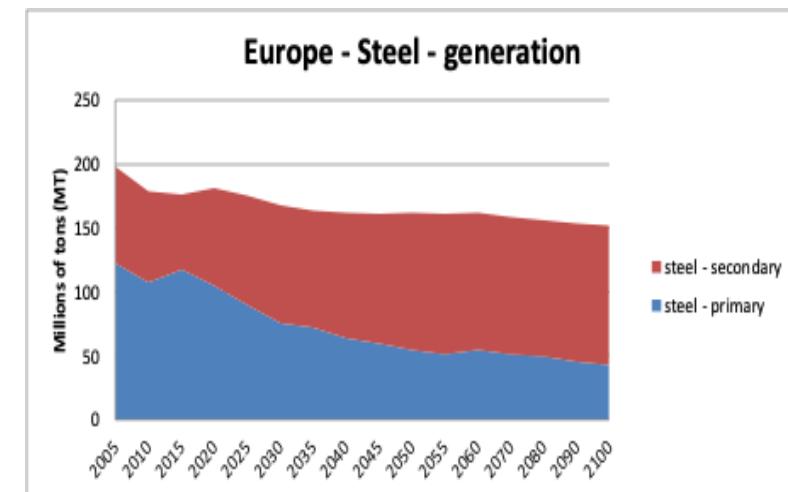
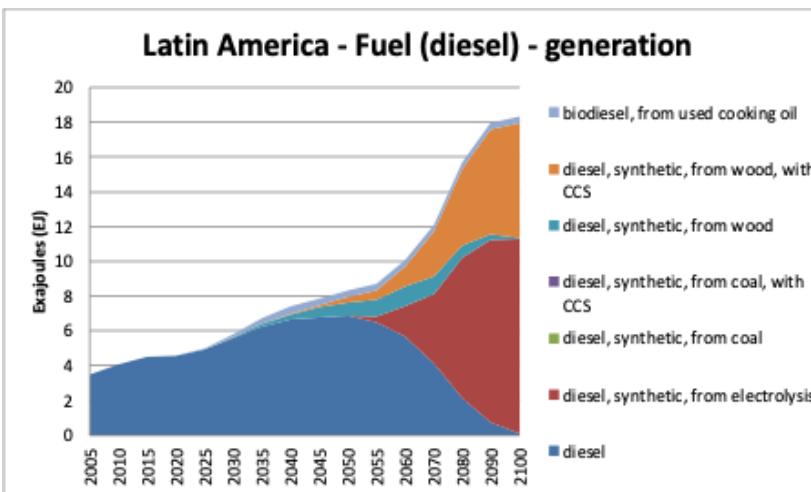
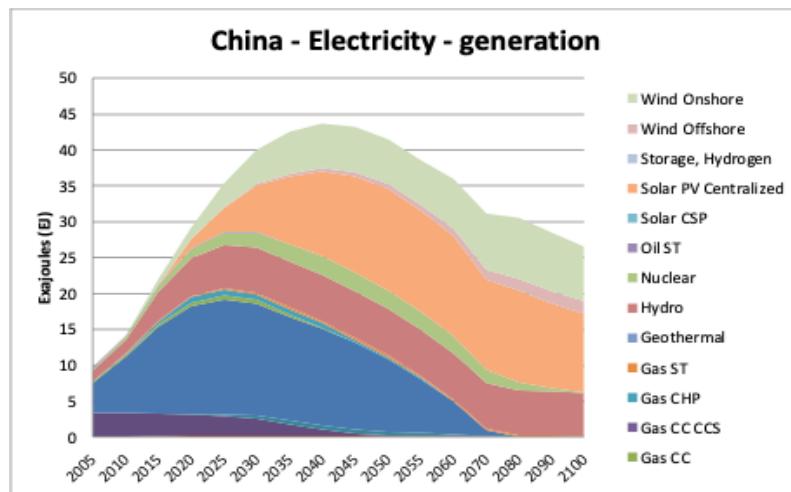
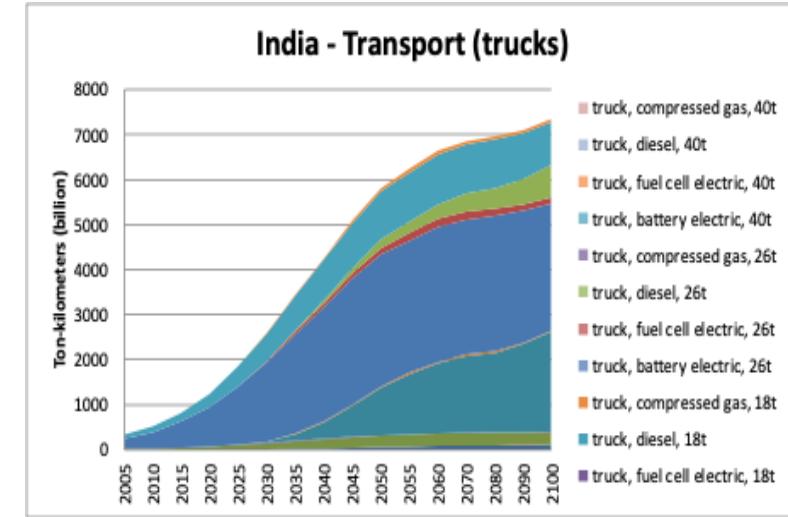
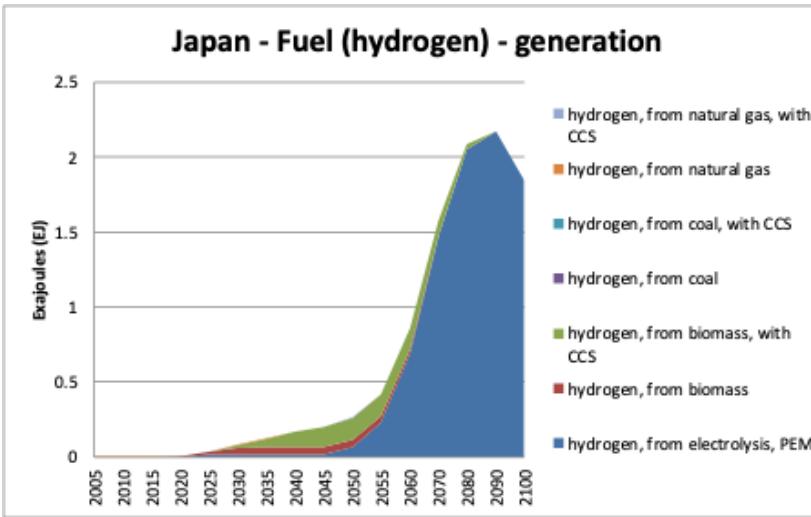
Socio-economic constraints (SSP)



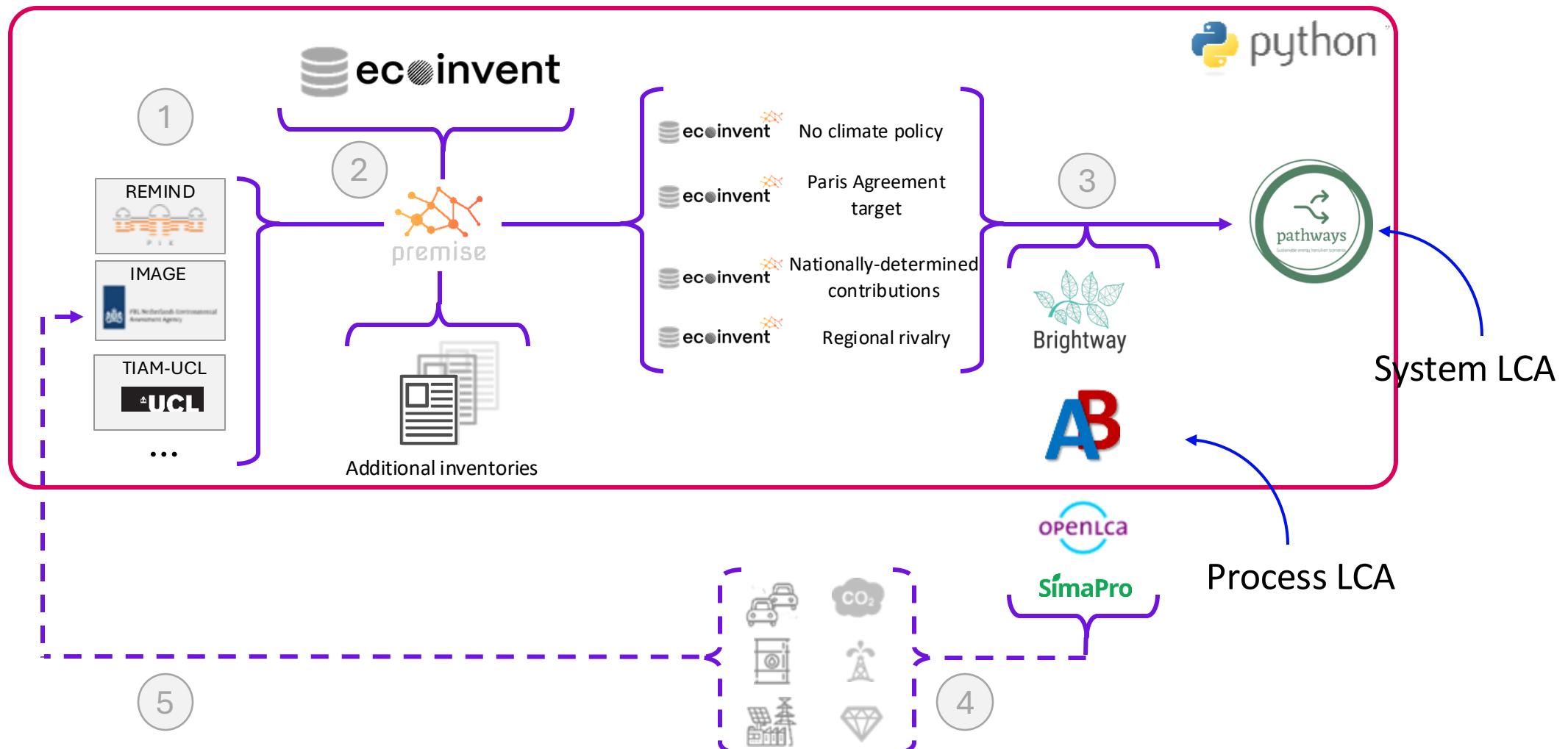
Projections on energy-intensive sectors

For each time step:

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



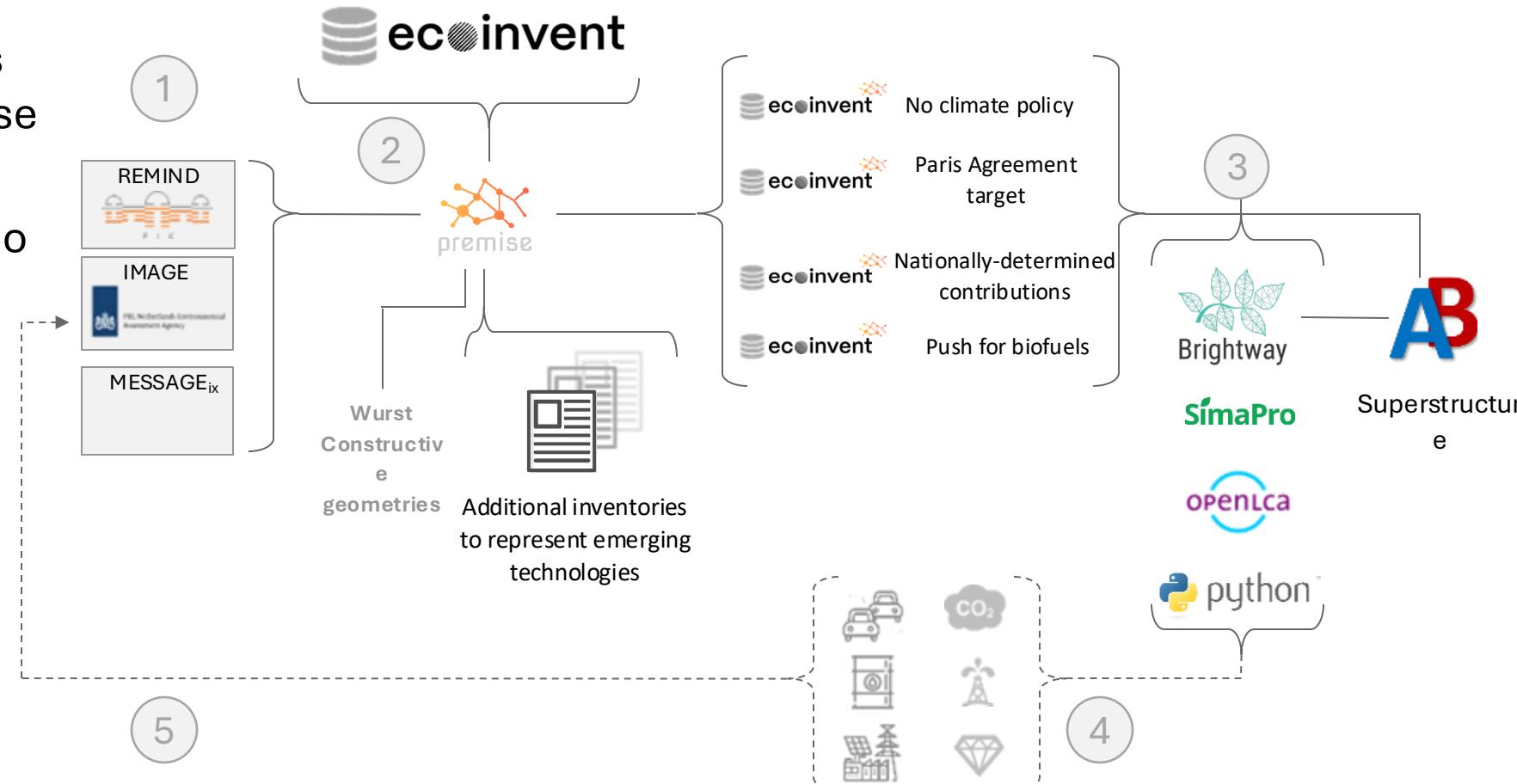
Premise: the workflow



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

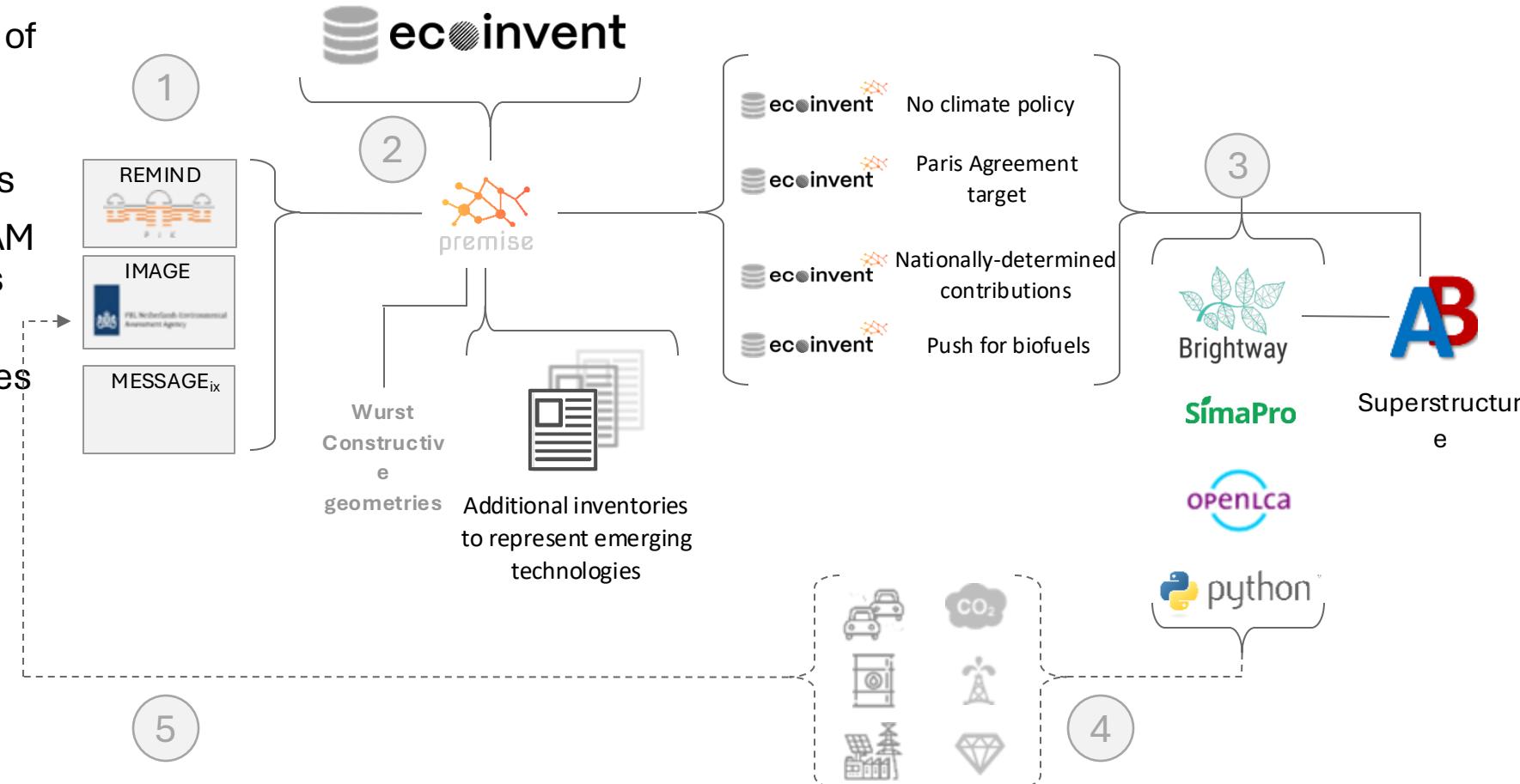
Wurst: systematic transformations of LCI datasets

Constructive geometries: handling of ecoinvent geographies

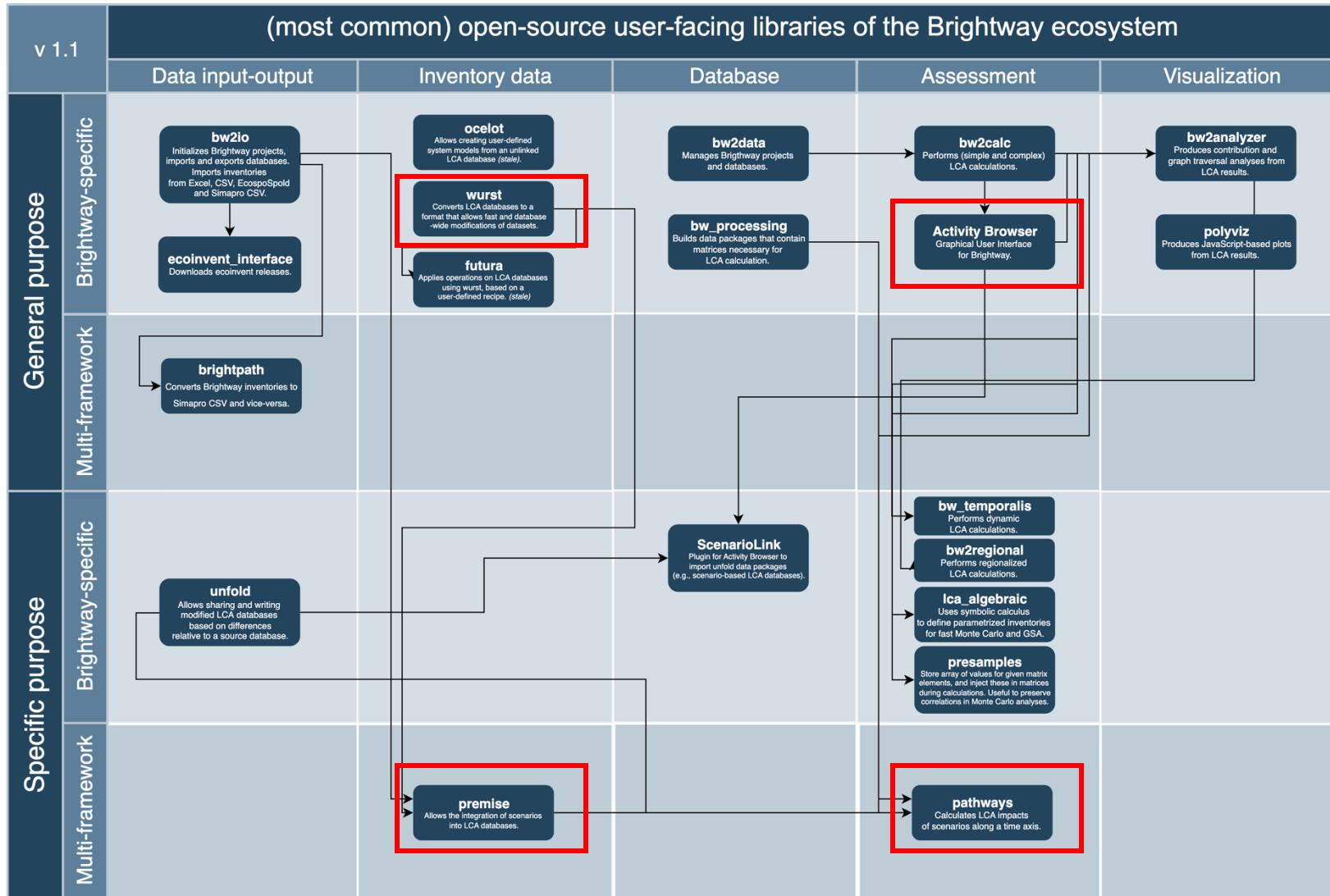
Premise: integration software for IAM (and other) data with LCI databases

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?



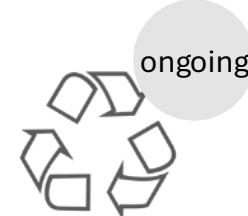
Power

Create regional electricity markets
Adjust power plant efficiency



Fuels

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



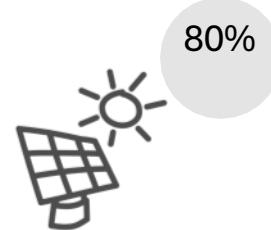
Metals recycling

Adjust critical raw materials use
Adjust future recycled content



Hot pollutant emissions

Adjust hot pollutant emission
from GAINS



Renewables

Adjust solar PV and windturbines
efficiency



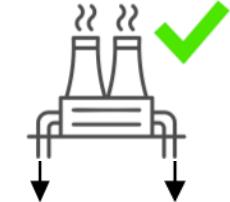
Transport

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

Statistics on premise



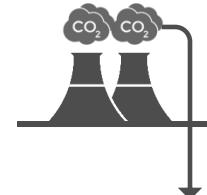
GaAs,
Perovskite, ...



FT fuels



Biofuels



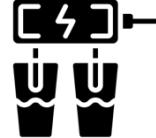
Power with
CCS



Geothermal,
wave, ...



Fuel cell:
PEM, AEFC,
SOFC, DMFC



Electrolyzer:
PEM, AE, SOE



Batteries: LiB,
SiB



Trucks: EV, FC



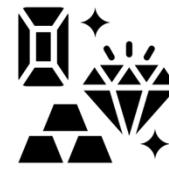
Cars: EV, FC



Trains: PEM,
D, EV, FC



Chemicals:
MeOH, NH3



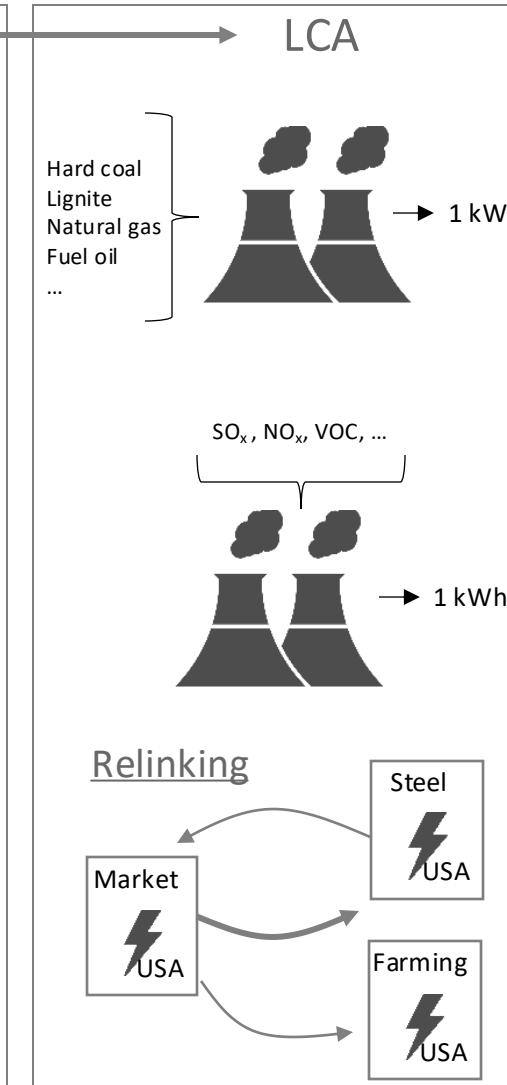
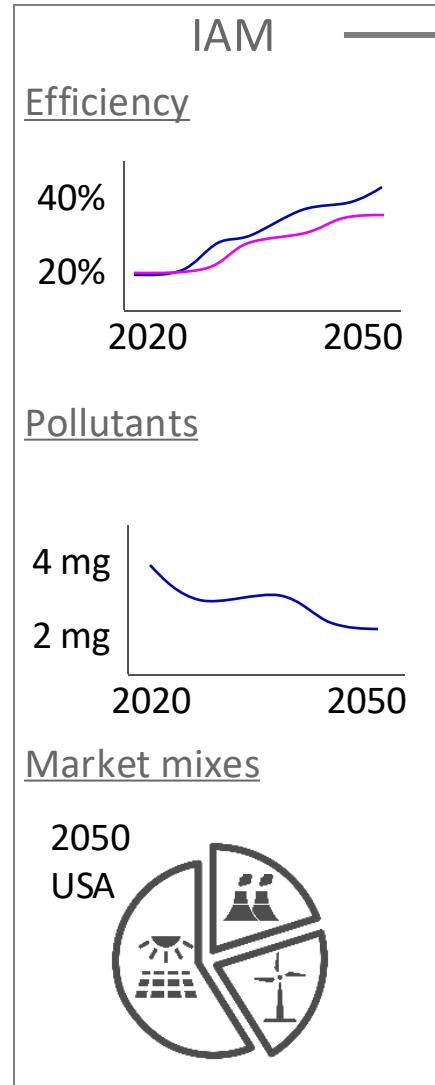
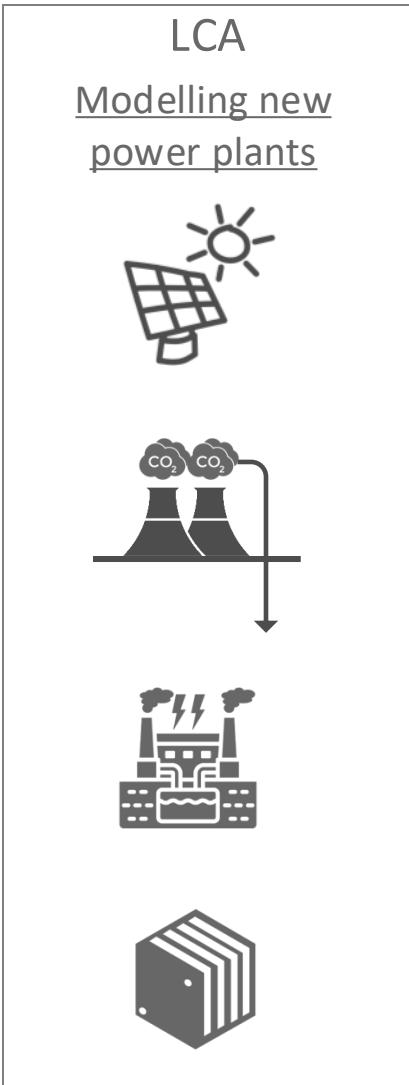
Metals: PGM,
Li, Co



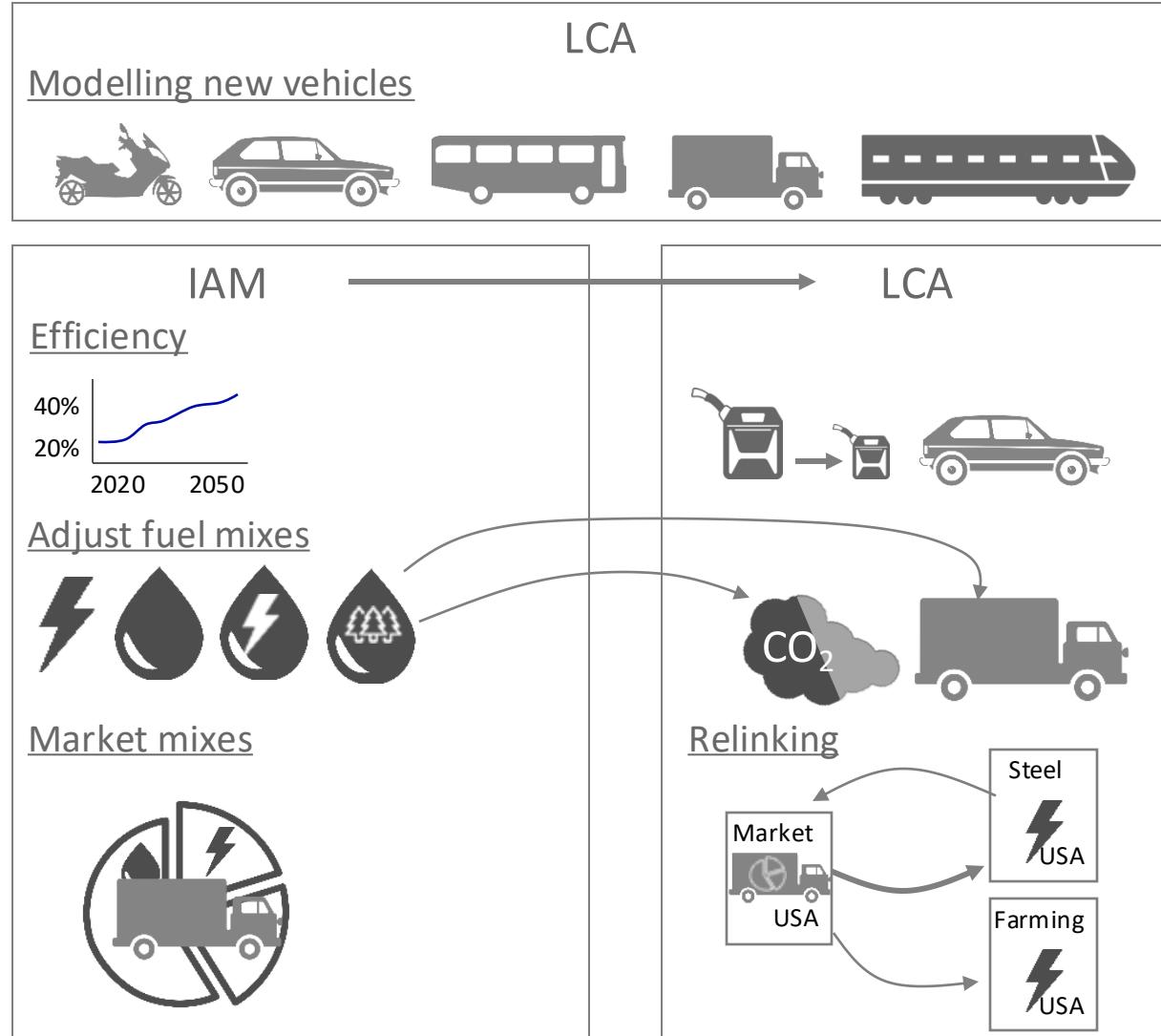
CDR: DACCS,
BECCS

- +2'300 datasets
- Peer-reviewed
- Documented
- EI 3.6-3.10

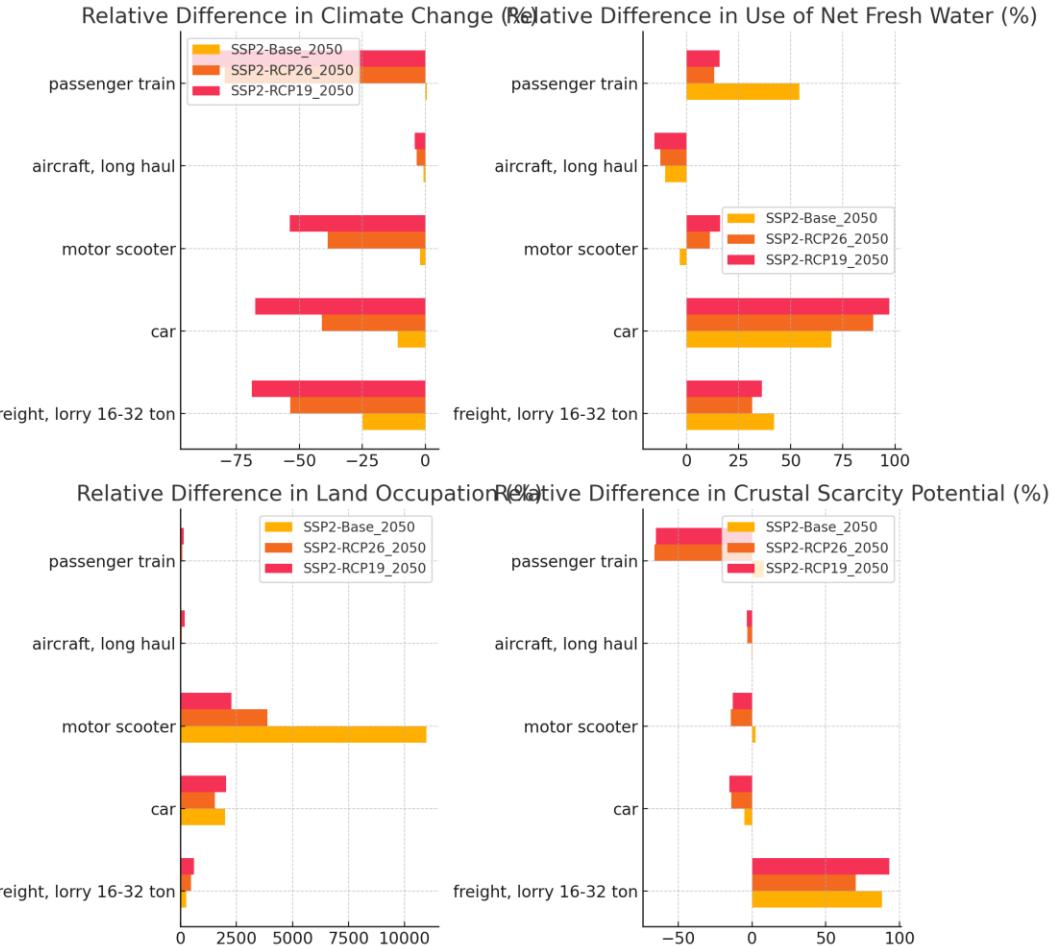
Example of SECTOR-SPECIFIC transformation: power generation



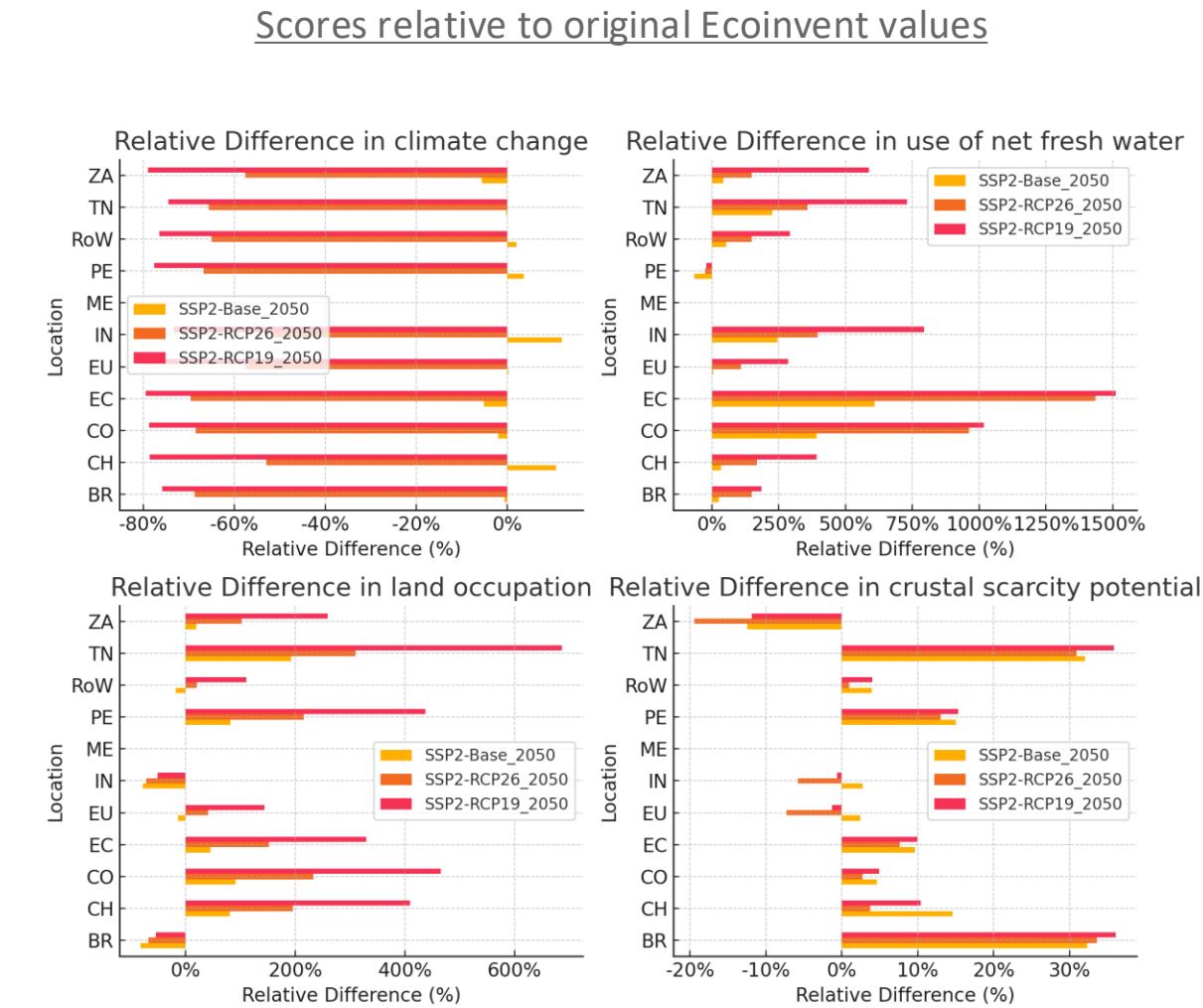
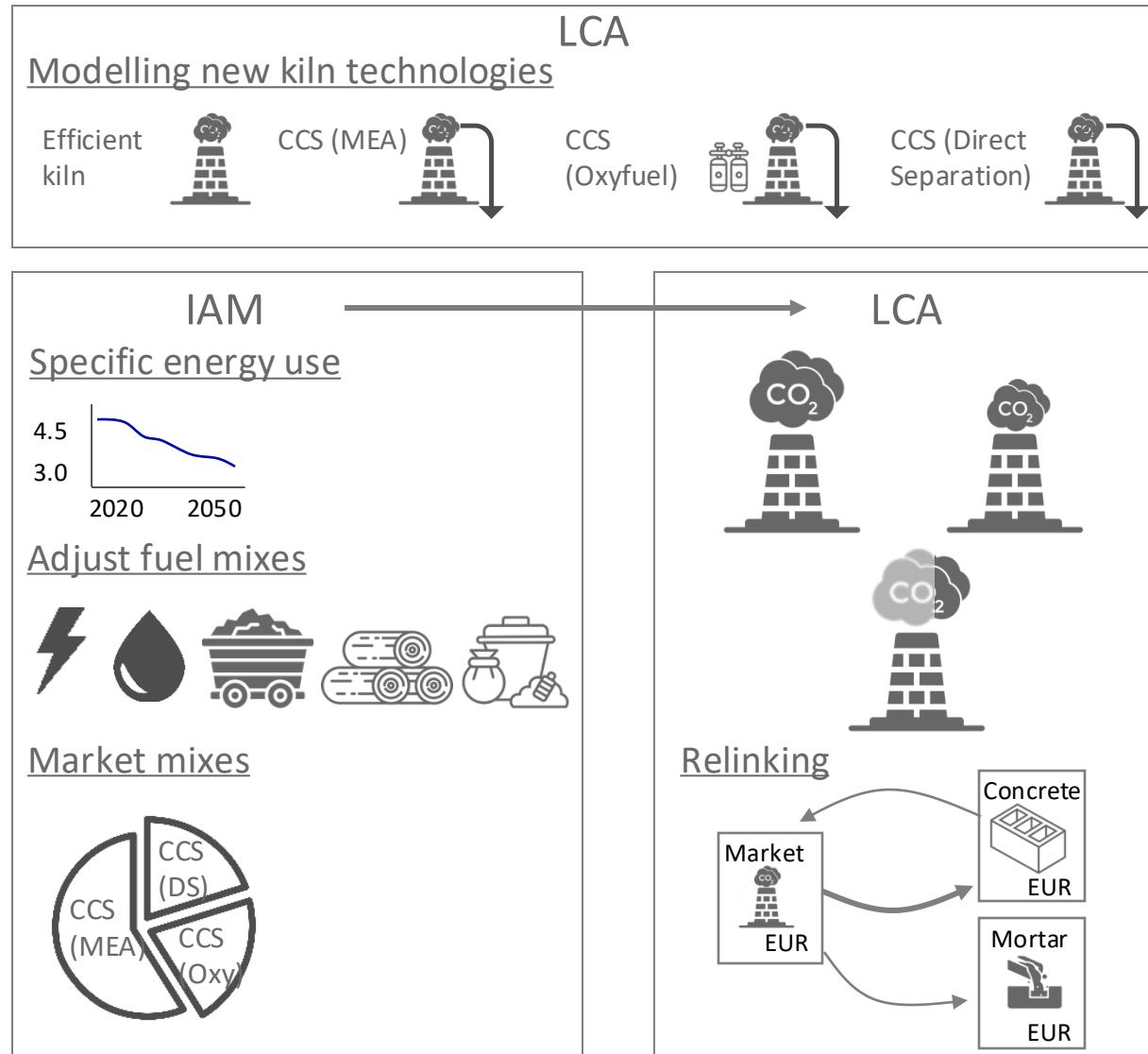
Example of SECTOR-SPECIFIC transformation: TRANSPORT



Scores relative to original Ecoinvent values



Example of SECTOR-SPECIFIC transformation: CEMENT

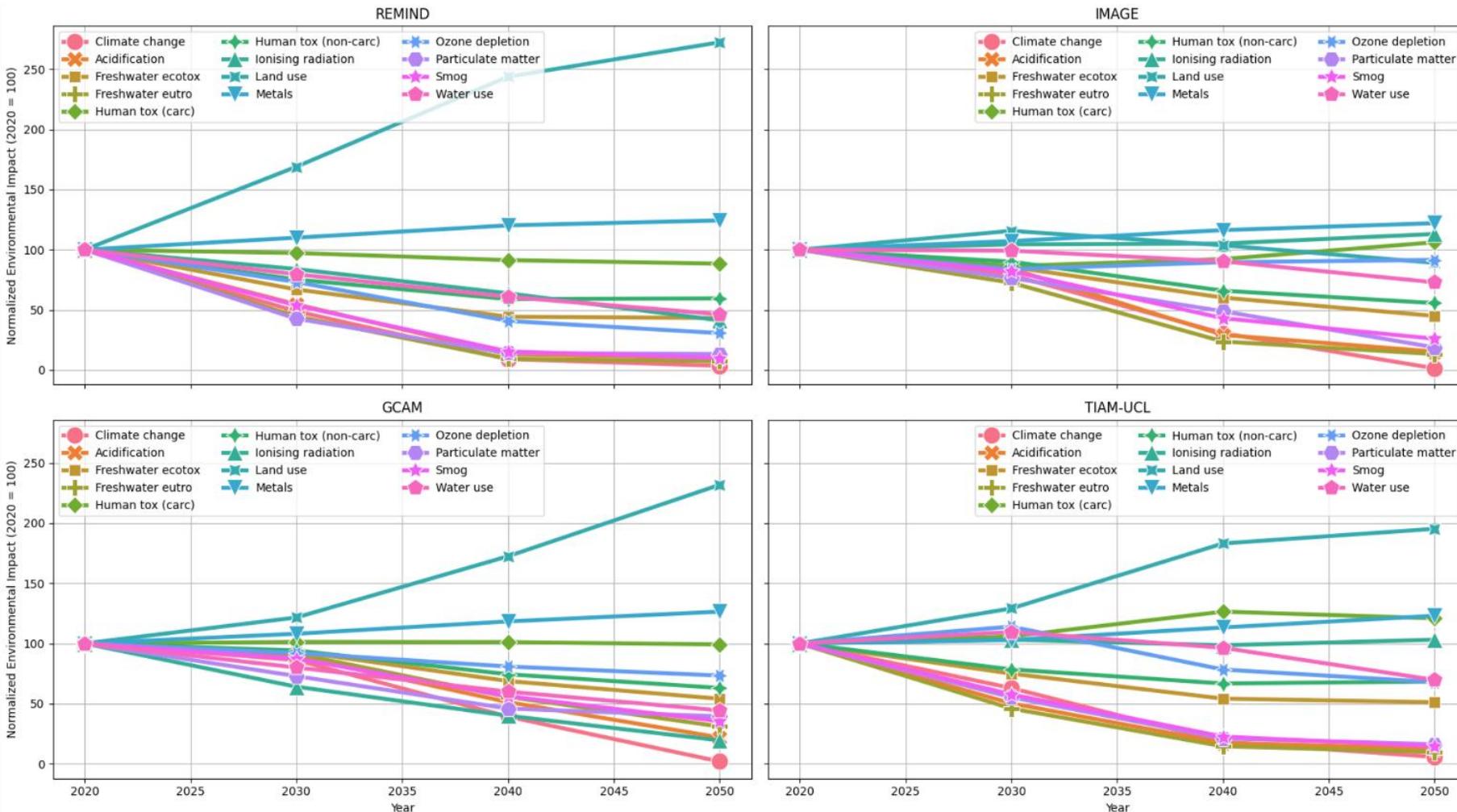


Indicators evolution across IAM models for <2 °C scenarios

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?).

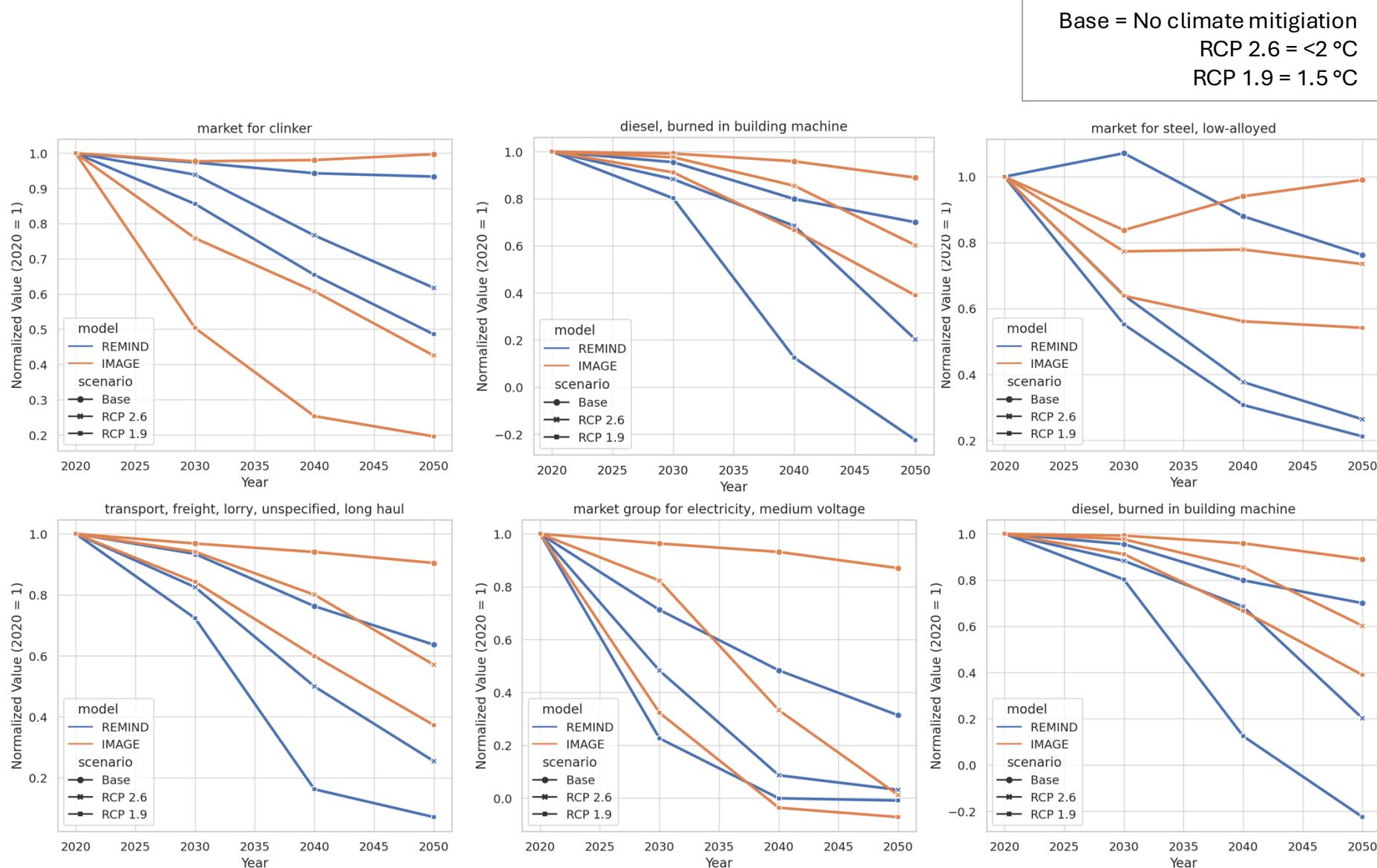


Climate change impacts across time and scenarios

Substantial impact reductions across sectors

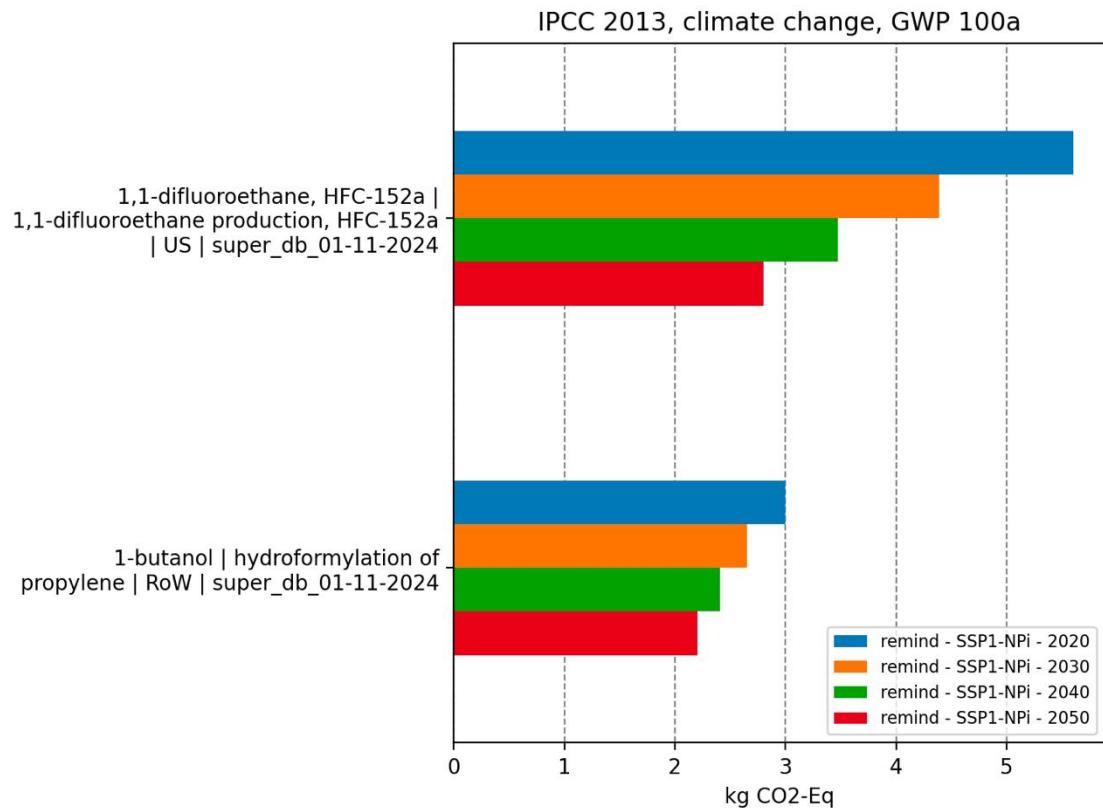
Much is due to lower GHG per kWh of electricity and electrification

Results strongly depend on the scenario and the IAM

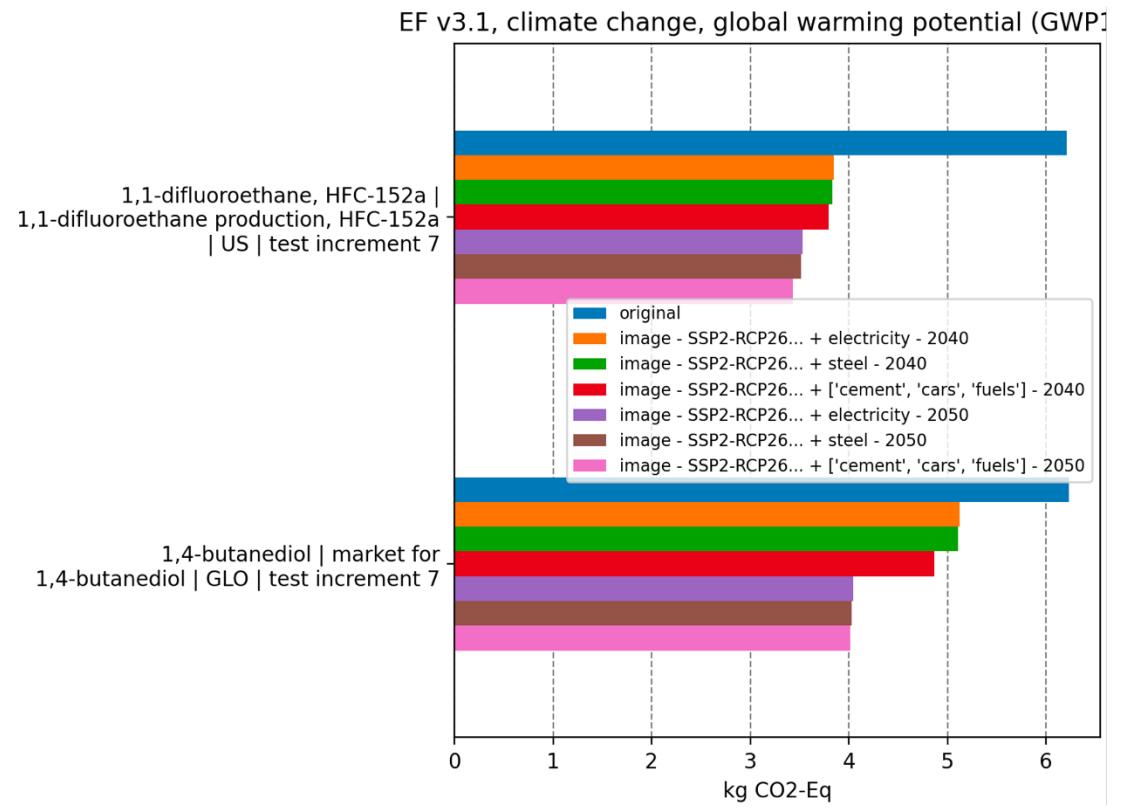


Premise in action

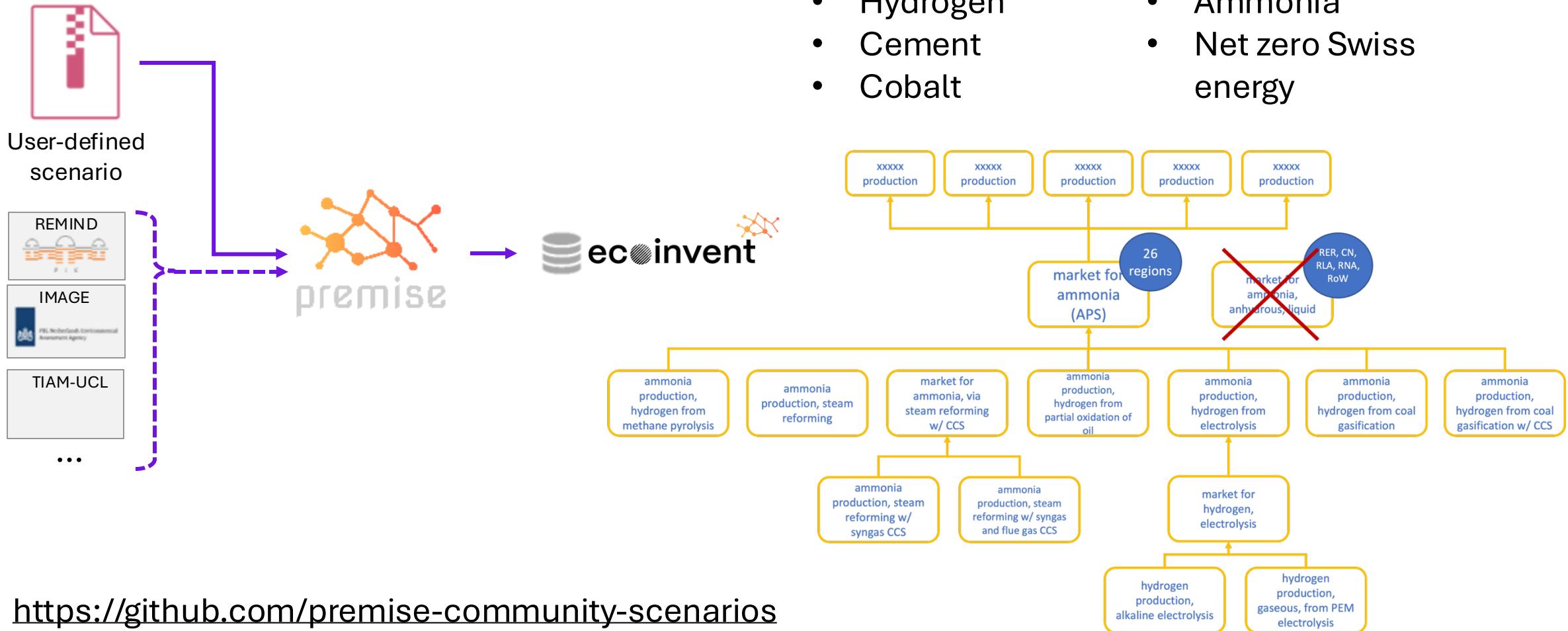
Scenario analysis (Superstructure database)



Sector analysis (Incremental database)



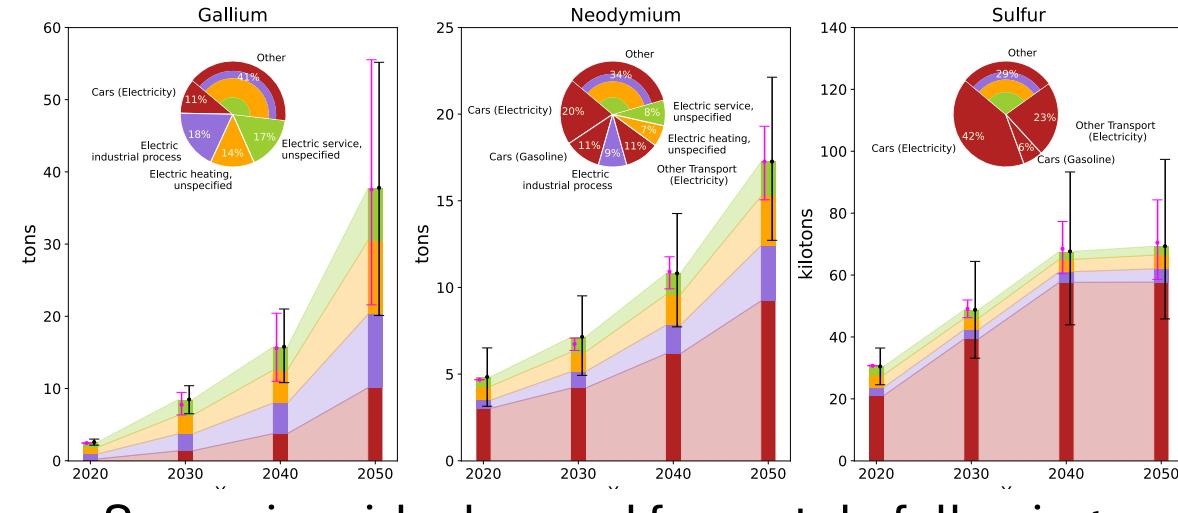
Community scenarios



<https://github.com/premise-community-scenarios>

Outlook

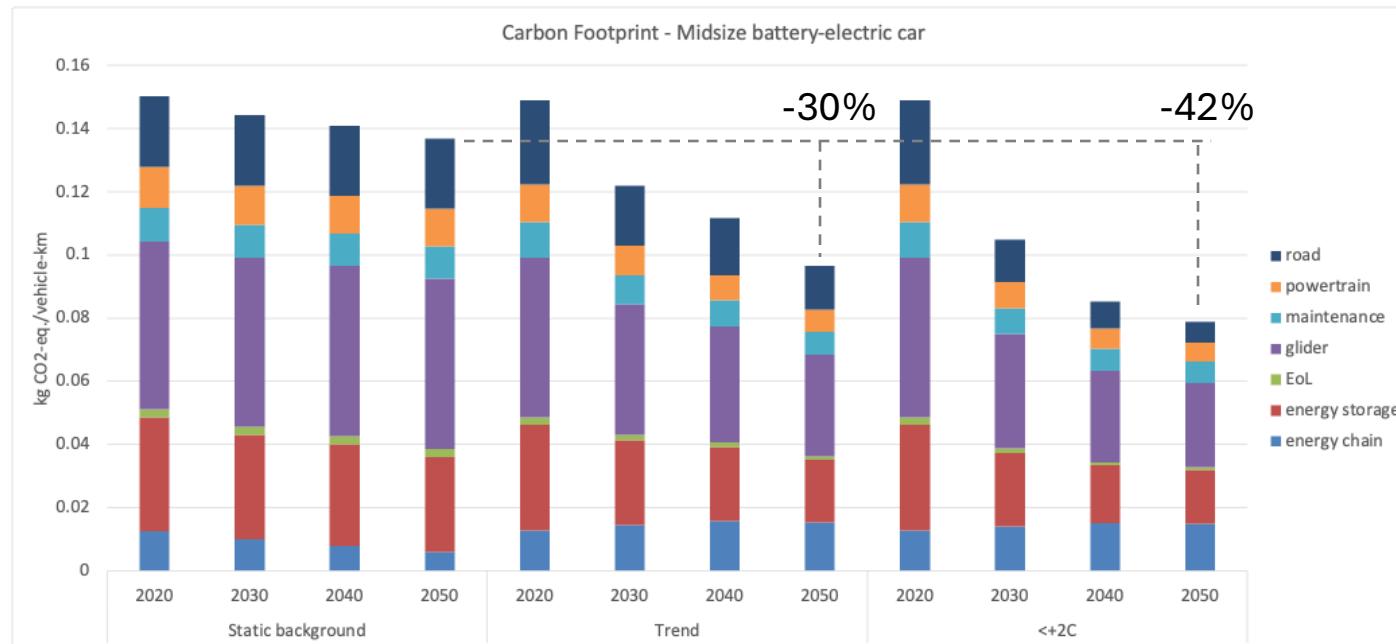
- Better representation of critical raw materials stock and flows in scenarios (MFA)
- Regionalized impact assessment (GIS)
- Tighter integration between Premise and IAM/Energy System Models
- Further development of scenario-wide LCA (Pathways) 



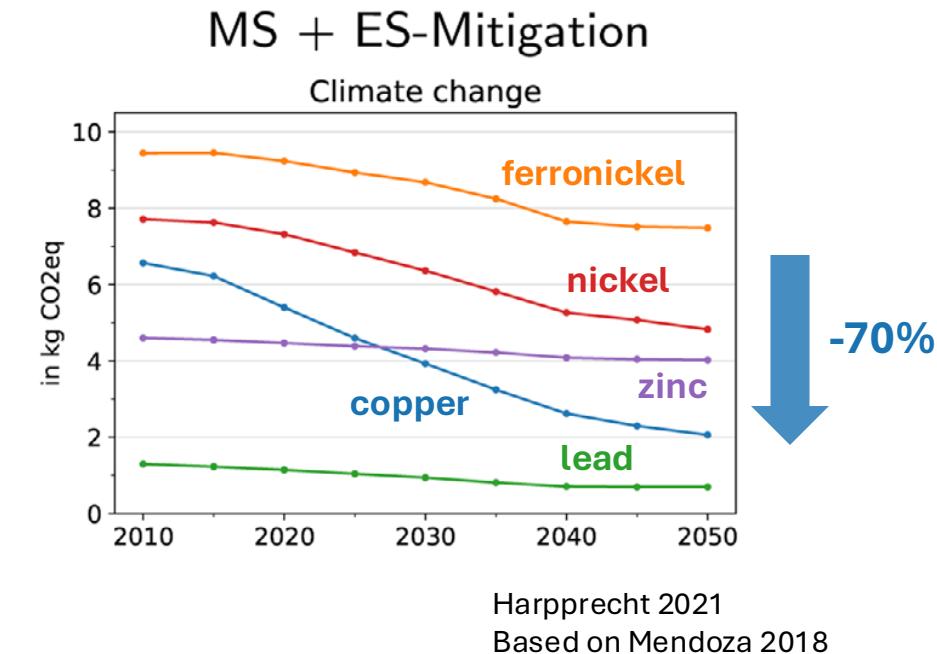
Scenario-wide demand for metals following Switzerland's Net Zero scenario between 2020 and 2050.
Menacho, A., Sacchi, R., Bauer, C., Moretti, C., Panos, E. and Burgherr, P. Switzerland's net zero objective: quantifying impacts beyond borders.
<https://doi.org/10.21203/rs.3.rs-4915252/v1>

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.



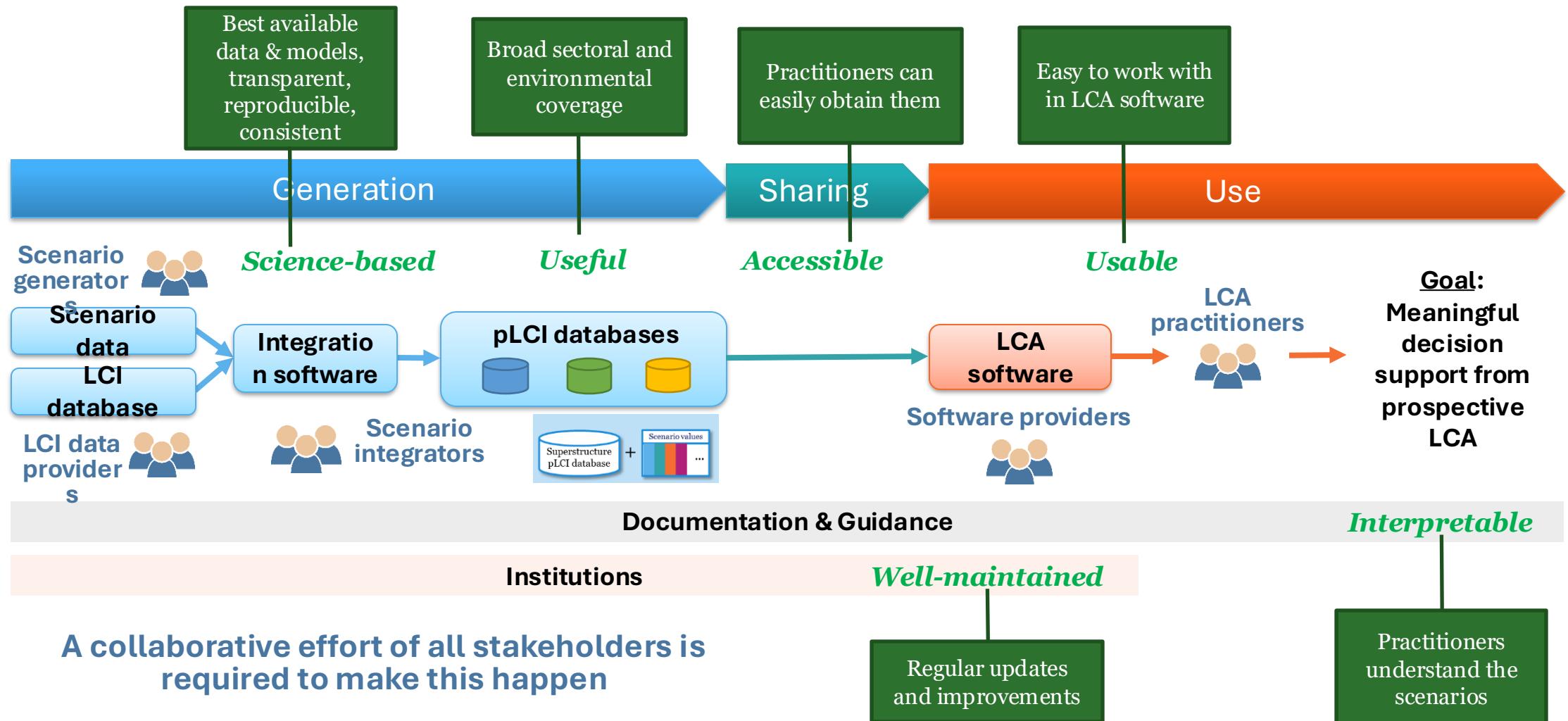
Climate change results for metals, including electricity change, ore degradation, technology mix, and recycling



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

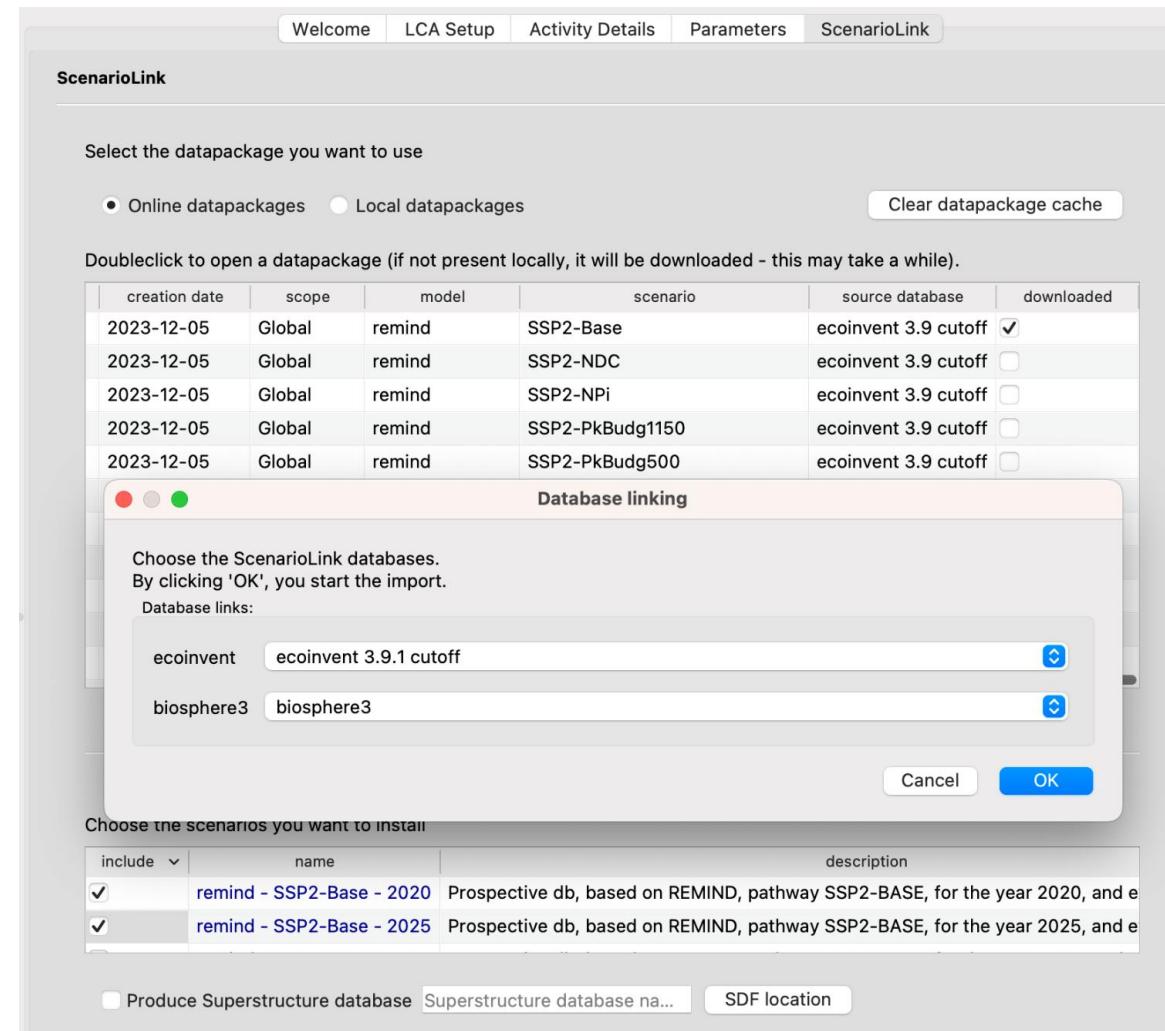


2) I import databases via Activity Browser:

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



ScenarioLink Plugin, Activity Browser



The screenshot shows the ScenarioLink Plugin interface within 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 sub-section "Select the datapackage you want to use" with a radio button for "Online datapackages" (which is selected) and "Local datapackages". There's also a "Clear datapackage cache" button. A note says "Doubleclick to open a datapackage (if not present locally, it will be downloaded - this may take a while)". Below this is a table showing five datapackages:

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"/>

Below the table is a section titled "Database linking" with the instruction "Choose the ScenarioLink databases. By clicking 'OK', you start the import." It shows two pairs of dropdown menus: "ecoinvent" and "ecoinvent 3.9.1 cutoff", and "biosphere3" and "biosphere3". At the bottom right are "Cancel" and "OK" buttons.

At the very bottom, there's a section titled "Choose the scenarios you want to install" with a table:

include	name	description
<input checked="" type="checkbox"/>	remind - SSP2-Base - 2020	Prospective db, based on REMIND, pathway SSP2-BASE, for the year 2020, and e
<input checked="" type="checkbox"/>	remind - SSP2-Base - 2025	Prospective db, based on REMIND, pathway SSP2-BASE, for the year 2025, and e

At the bottom of the window, there are checkboxes for "Produce Superstructure database" (with a "Superstructure database na..." field), and "SDF location".

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

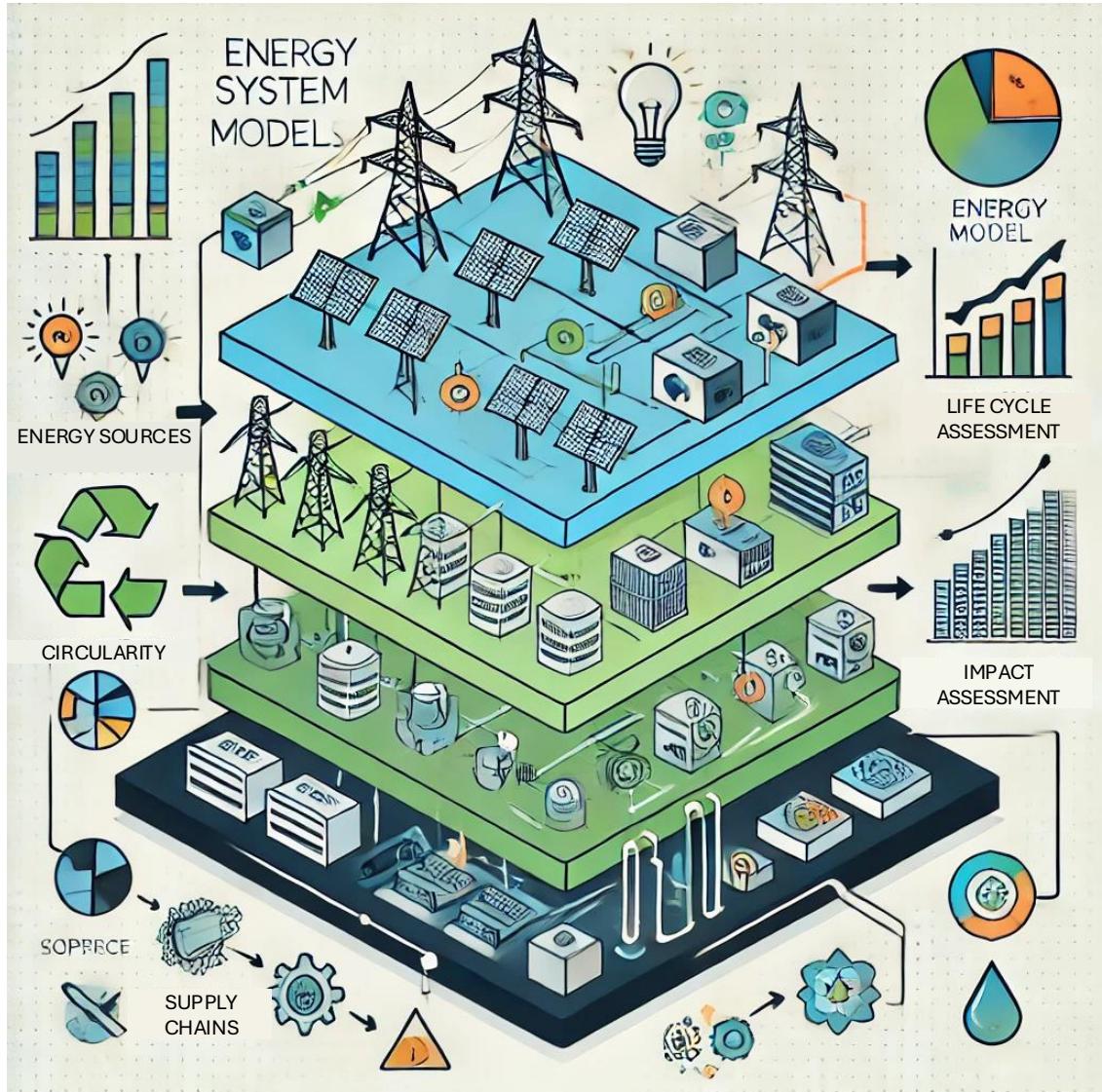


pathways

A new library for scenario- or sector-wide pLCA

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>

Selected references

Methodology

Sacchi R, Terlouw T, Siala K, Dirnachner A, Bauer C, Cox B, Mutel C, Daioglou V, Luderer G (2022) PRospective EnvironMental Impact asSEment (premise): A streamlined approach to producing databases for prospective life cycle assessment using integrated assessment models *Renewable Sustainable Energy Rev* 160:112311 doi:<https://doi.org/10.1016/j.rser.2022.112311>

Mendoza Beltran A, Cox B, Mutel C, van Vuuren DP, Font Vivanco D, Deetman S, Edelenbosch OY, Guinée J, Tukker A (2018) When the Background Matters: Using Scenarios from Integrated Assessment Models in Prospective Life Cycle Assessment *J Ind Ecol* doi:10.1111/jiec.12825

Steubing B, de Koning D (2021) Making the use of scenarios in LCA easier: the superstructure approach *Int J Life Cycle Assess* 26:2248-2262 doi:10.1007/s11367-021-01974-2

Use of broad future scenarios (list not comprehensive)

Cox B, Mutel CL, Bauer C, Mendoza Beltran A, van Vuuren DP (2018) Uncertain Environmental Footprint of Current and Future Battery Electric Vehicles *Environ Sci Technol* 52:4989-4995 doi:10.1021/acs.est.8b00261

Cox B, Bauer C, Mendoza Beltran A, van Vuuren DP, Mutel CL (2020) Life cycle environmental and cost comparison of current and future passenger cars under different energy scenarios *Applied Energy* 269:115021 doi:<https://doi.org/10.1016/j.apenergy.2020.115021>

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