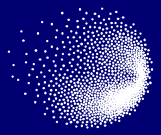


PSI Center for Nuclear Engineering and Sciences
Center for Energy and Environmental Sciences

Premise

An introduction to IAM-LCA coupling for prospective background databases

Romain Sacchi

Grenoble, 14th October 2025

Who am I?

Ph.D. on integration of energy-intensive industry in industrial symbiosis projects

Joined PSI in 2019 as PostDoc

Tenure-track scientist since September 2023

Research vision
Understanding and shaping the sustainability of net-zero futures beyond GHG emissions

My role
Develop the tools and methods for our research group

2'000 active users/month
40'000 registered users

carculator
Interactive tool for calculating the carbon footprint of cars

Released in 2022
Used in over 300 studies

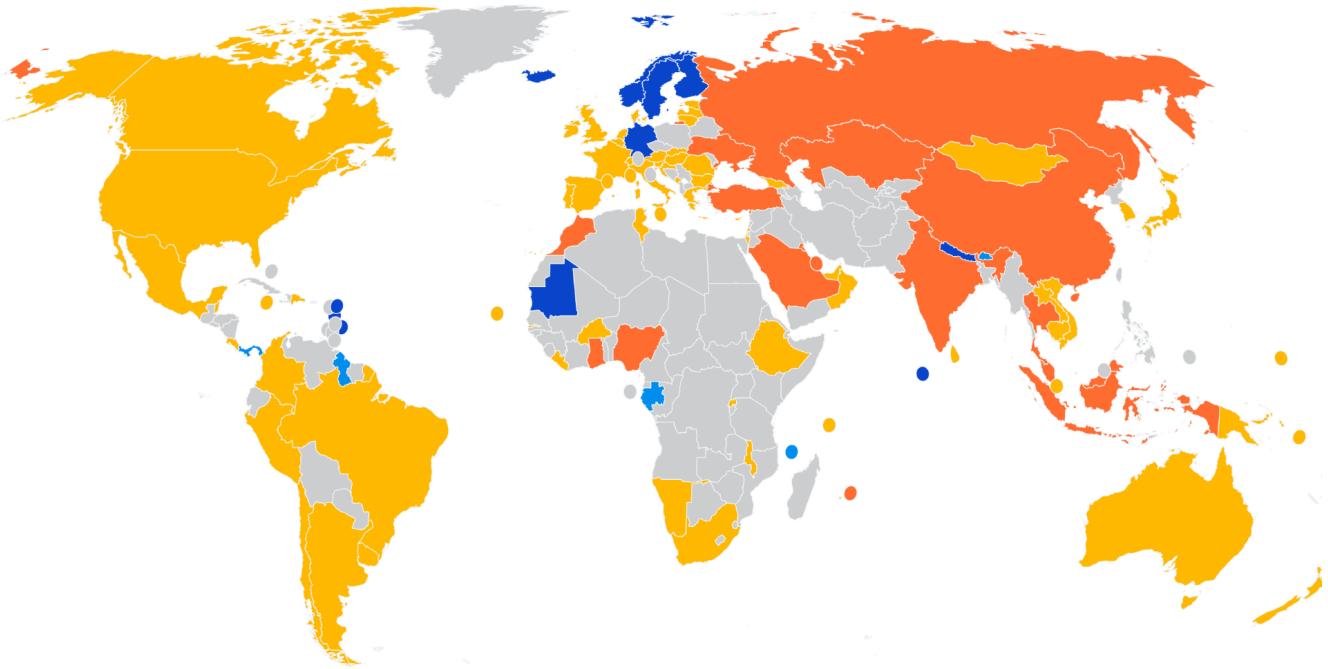
premise
Links future energy scenarios to Life Cycle Analysis

Just released.
But strong potential.

edges
Allows for regionalization and parametrization of impacts

pathways
Allows for calculating a system's impacts over time.

NET ZERO emission targets



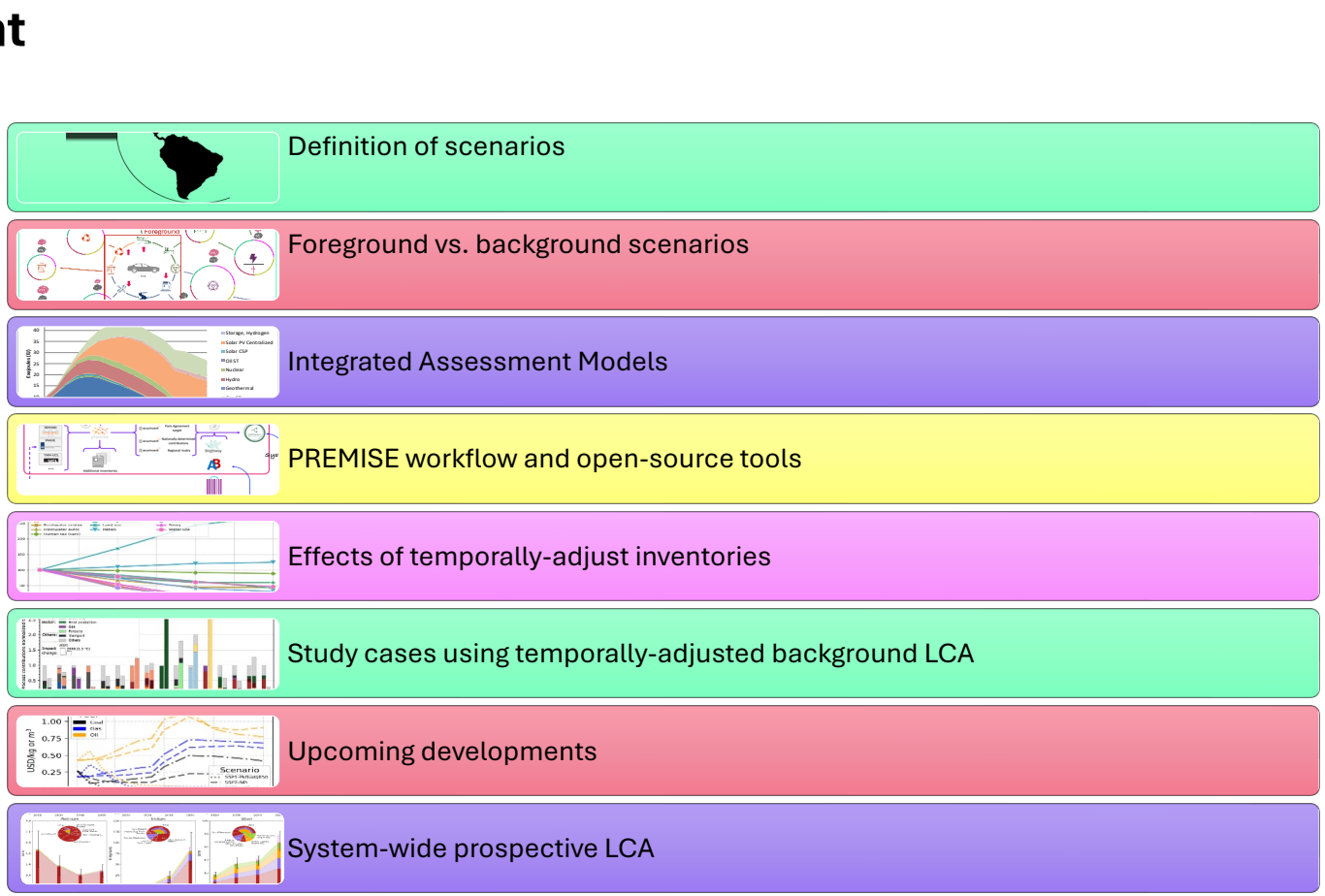
Graphic: Climate Watch – Net Zero Tracker

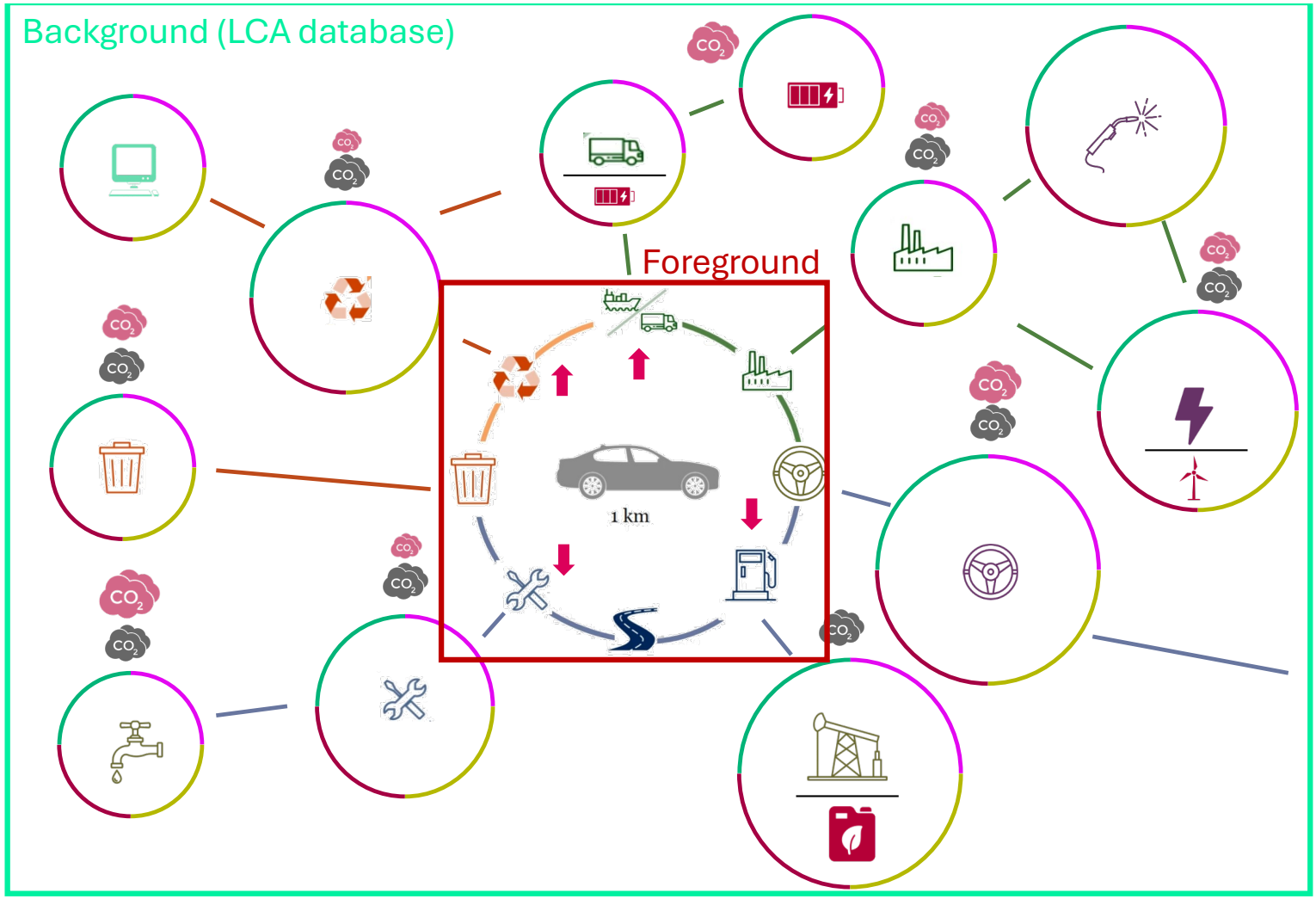
Switzerland, the EU, the UK and ~100 other countries pledged to net-zero GHG emissions

GHG mitigation is vital, but trade-offs must be anticipated

Need for holistic assessments beyond GHG emissions

Talk content





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

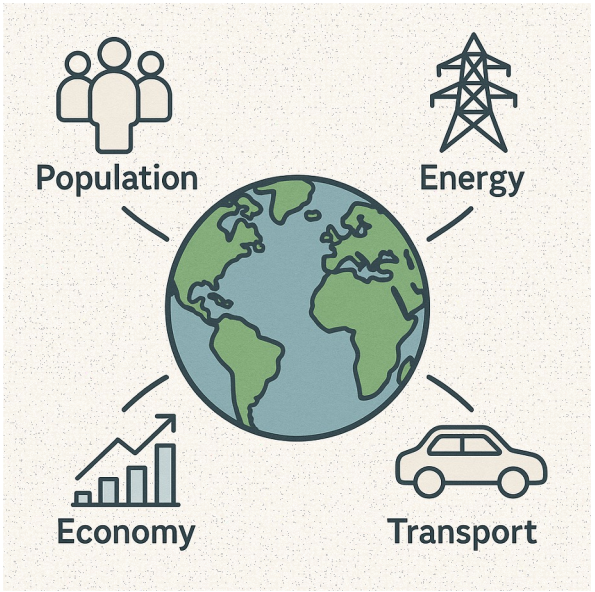
pLCA is about projecting changes in process efficiency and supply chain relations, both in foreground and background, following on a coherent storyline.

Different scenario scopes

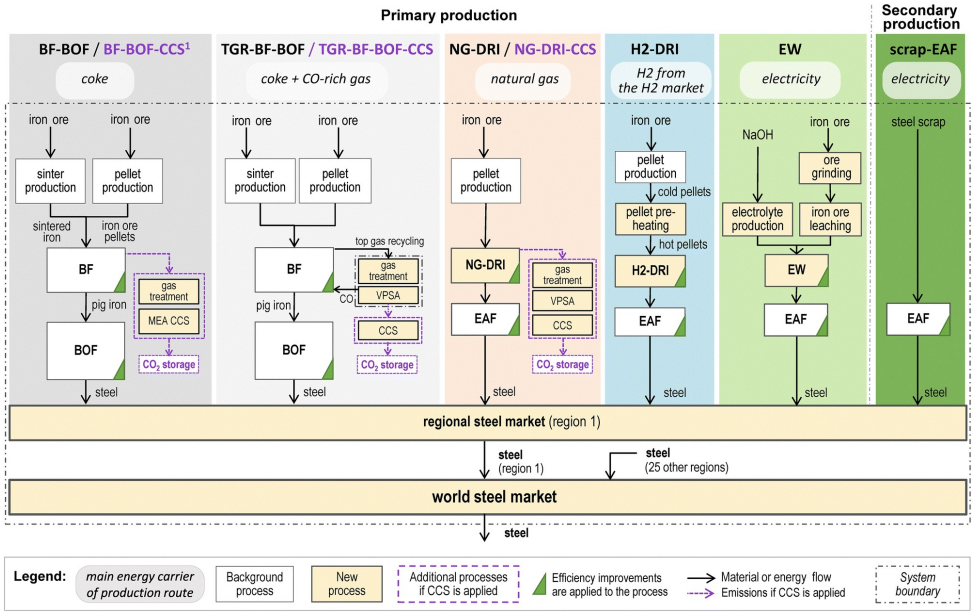
Broad (global) scenarios

-For the global economy (CGE models, IAM)

- Relevant for prospective LCAs in general



Technology-focused scenarios



Harpprecht C, Sacchi R, Naegler T, et al (2025) Future environmental impacts of global iron and steel production. Energy Environ Sci. https://doi.org/10.1039/D5EE01356A

What is a background scenario?

Term	IPCC-inspired definition	Key features	Example
Storyline / Narrative	Qualitative description of the main features, driving forces, and dynamics shaping a future, often used as a basis for quantification.	No numerical outputs by itself; sets the socio-economic, political, and technological context.	SSP2 storyline: Continuation of historical trends, moderate population growth, uneven development, slow technological change.
Scenario	Coherent description of a possible future, combining a qualitative narrative with quantitative projections of key variables.	Integrates narrative + quantification; explores "what-if" futures; not predictive.	SSP2-4.5: Middle-of-the-road socio-economic trends, moderate climate policy, ~4.5 W/m^2 forcing by 2100.
Pathway	Time-ordered evolution of quantitative indicators describing the transition from the present to a scenario's future state.	Focuses on trajectories of variables (e.g., emissions, energy use); multiple pathways can be consistent with one scenario narrative.	An emissions trajectory reducing CO_2 from 40 Gt in 2020 to net-zero by 2070 under an SSP2-4.5 scenario.

Integrated Assessment Models (IAM)

REMIND | IMAGE | GCAM | MESSAGE$_{ix}$ | TIAM-UCL

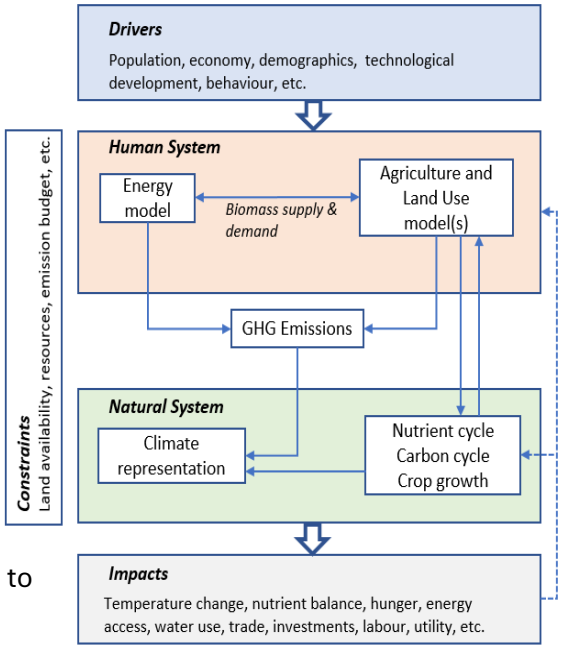
Integrated Assessment Models (IAMs) assess the interactions between **human** and **natural** systems

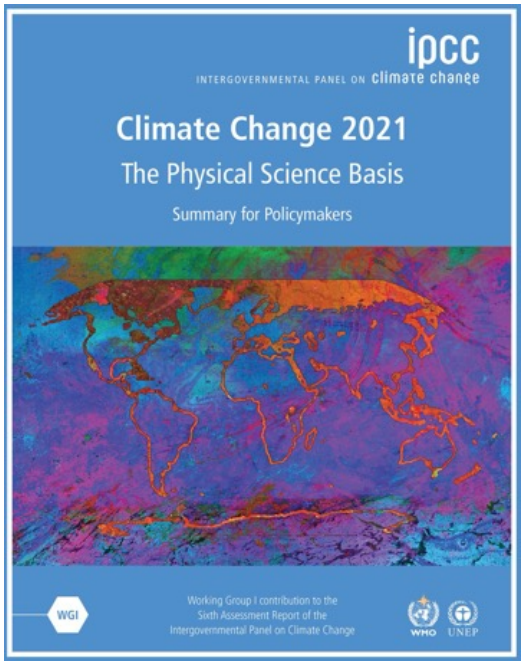
Contain stylized representations of

- 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?





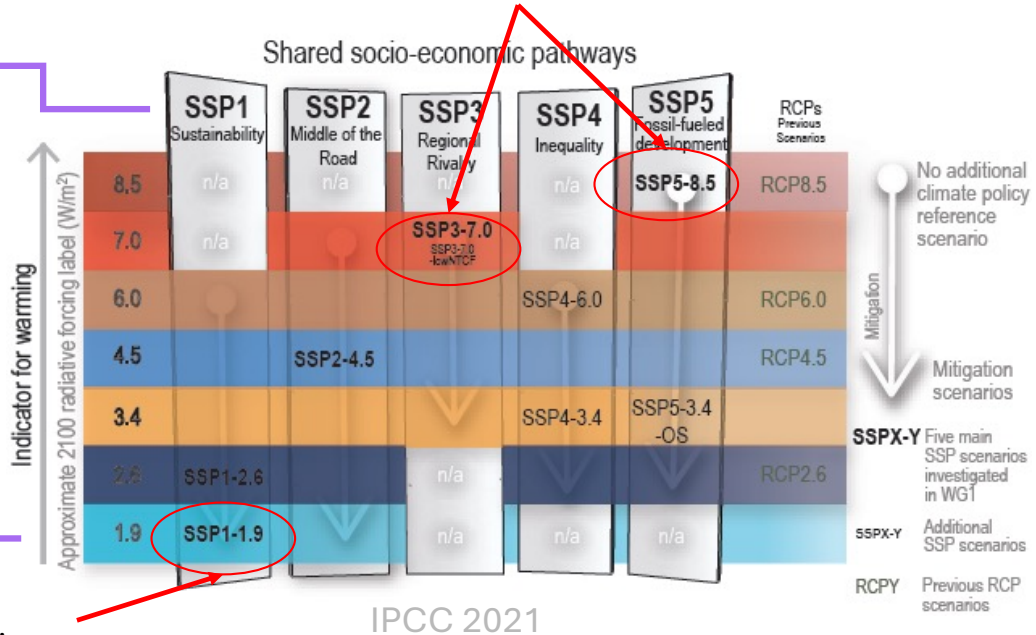
Integrated Assessment Models (IAM)

PSI

Shared-Socioeconomic Pathways (SSPs)

Representative Concentration Pathways (RCPs)

No additional climate policy
(~5 °C warming by 2100)

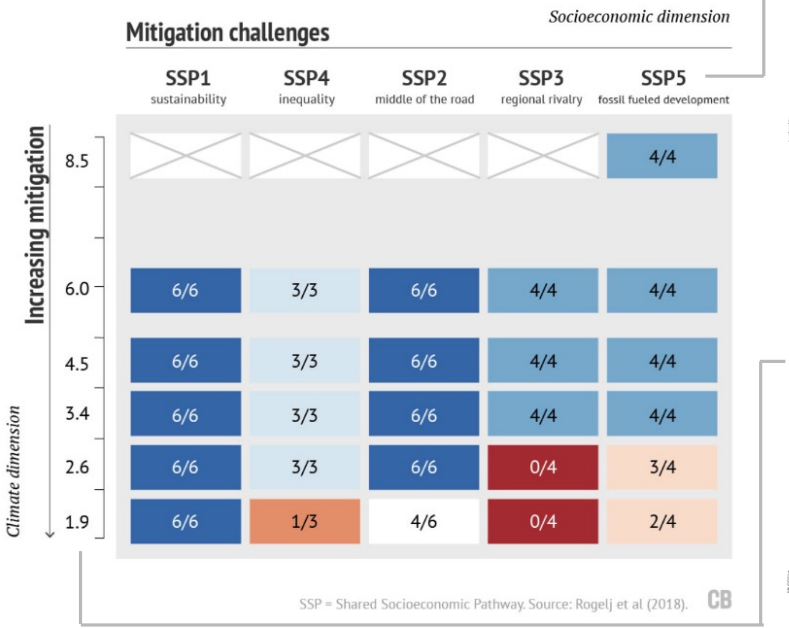


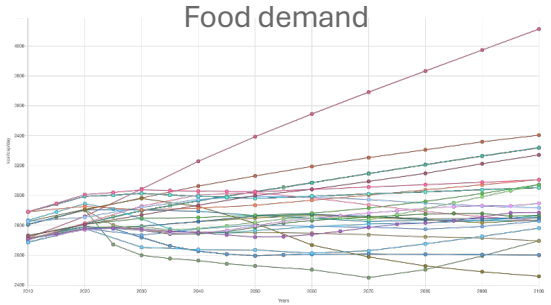
Paris agreement
(~1.5 °C warming by 2100)

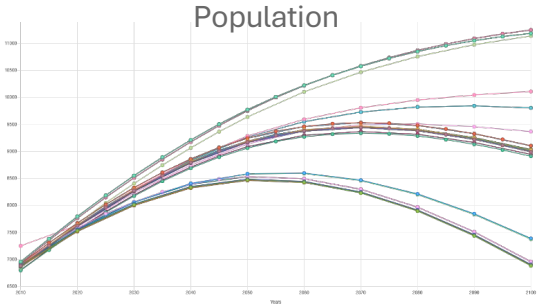
Socio-economic and climate constraints

PSI

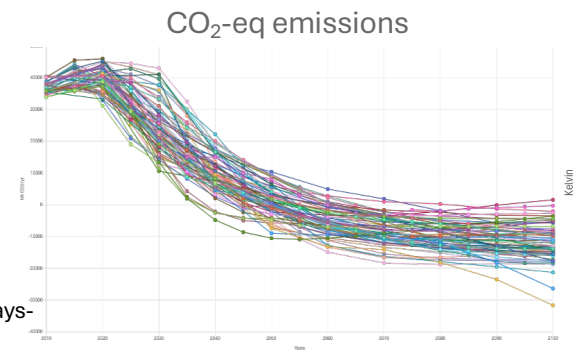
Socio-economic constraints (SSP)

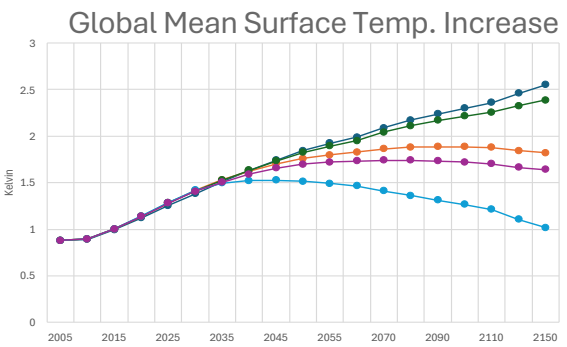






Climate constraints (RCP)





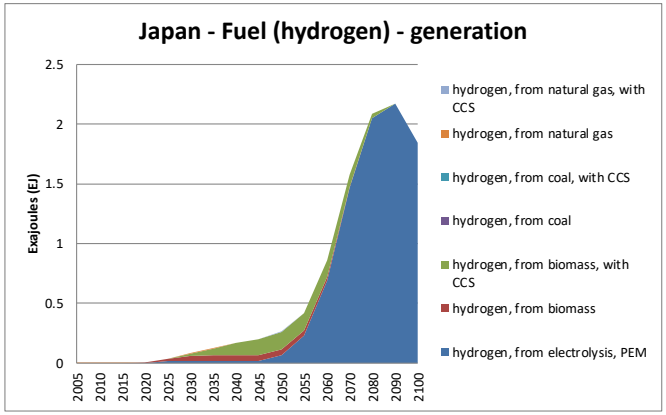
Credit: CarbonBrief, Zeke Hausfather, 2018.
https://www.carbonbrief.org/explainer-how-shared-socioeconomic-pathways-explore-future-climate-change

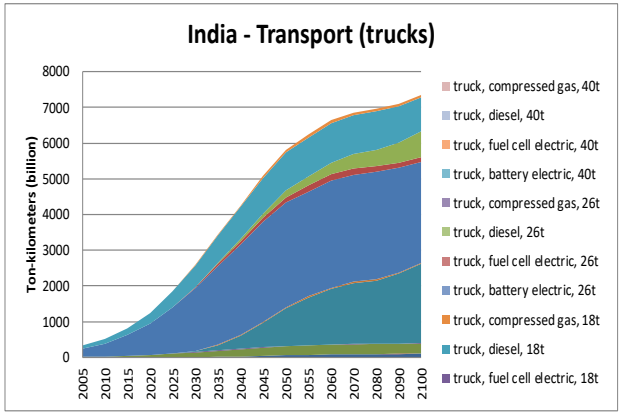
Projections on energy-intensive sectors

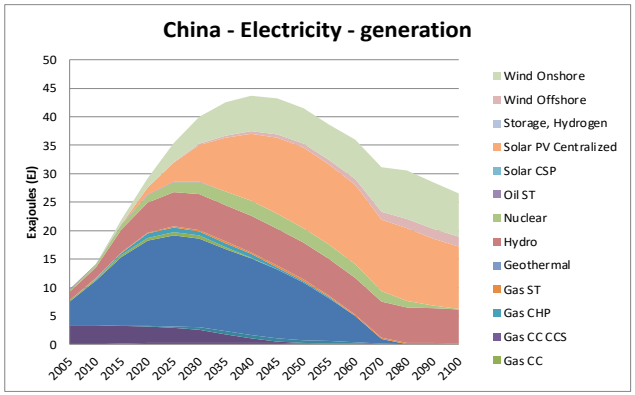
For each time step:

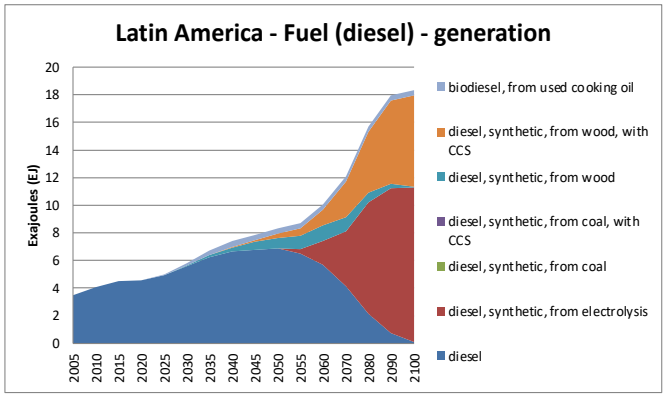
- Technology investments
- Capacity build-up
- Generation
- Efficiency change

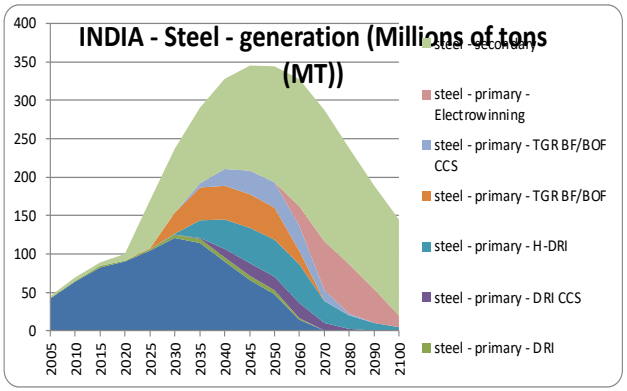
- Link to dashboard



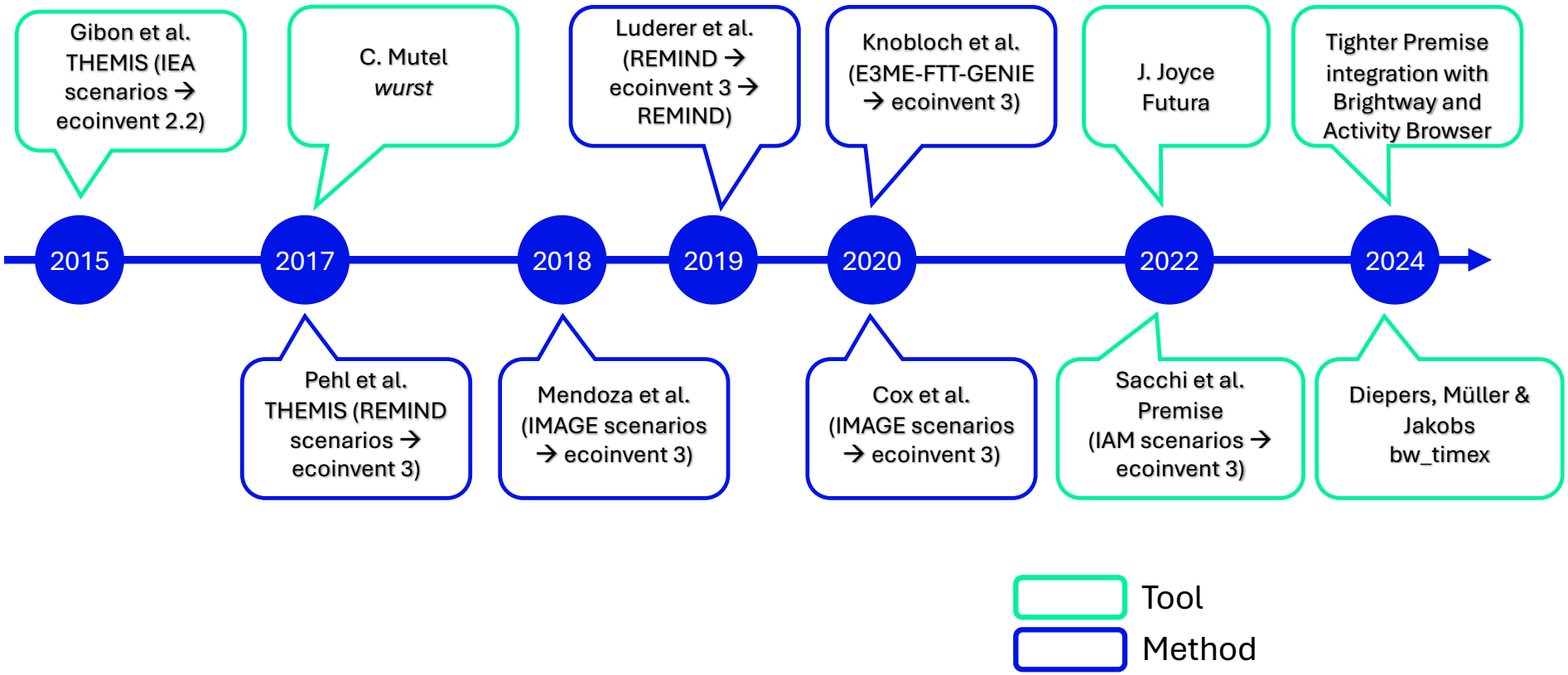




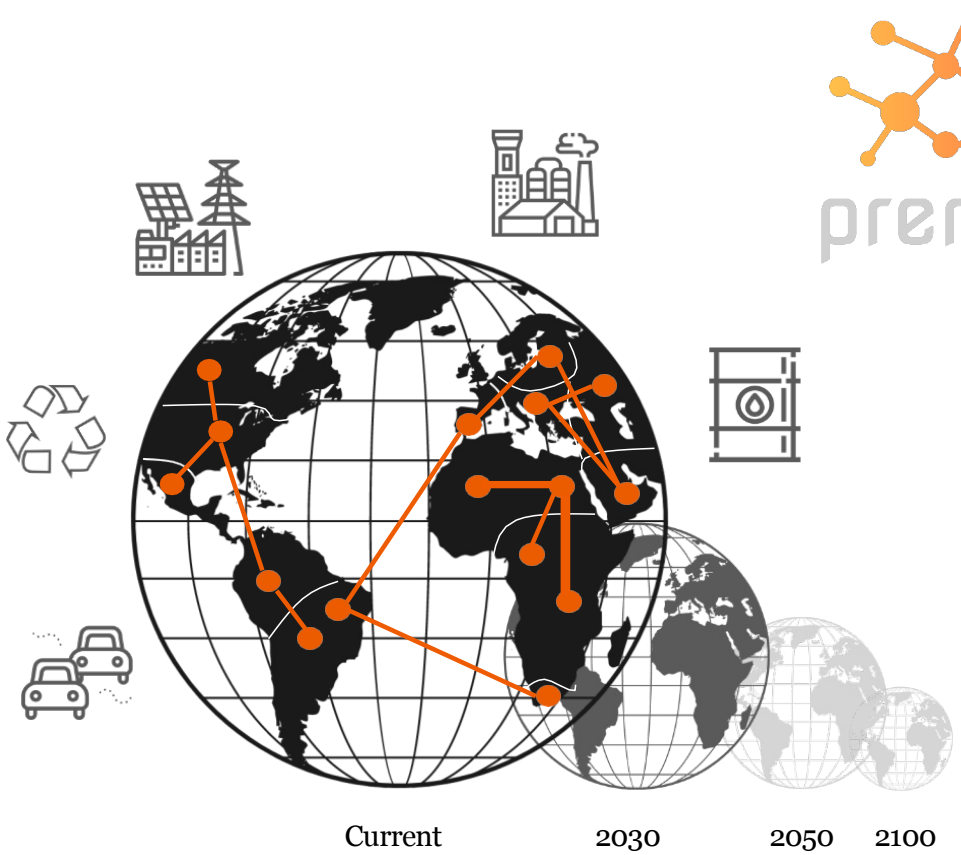




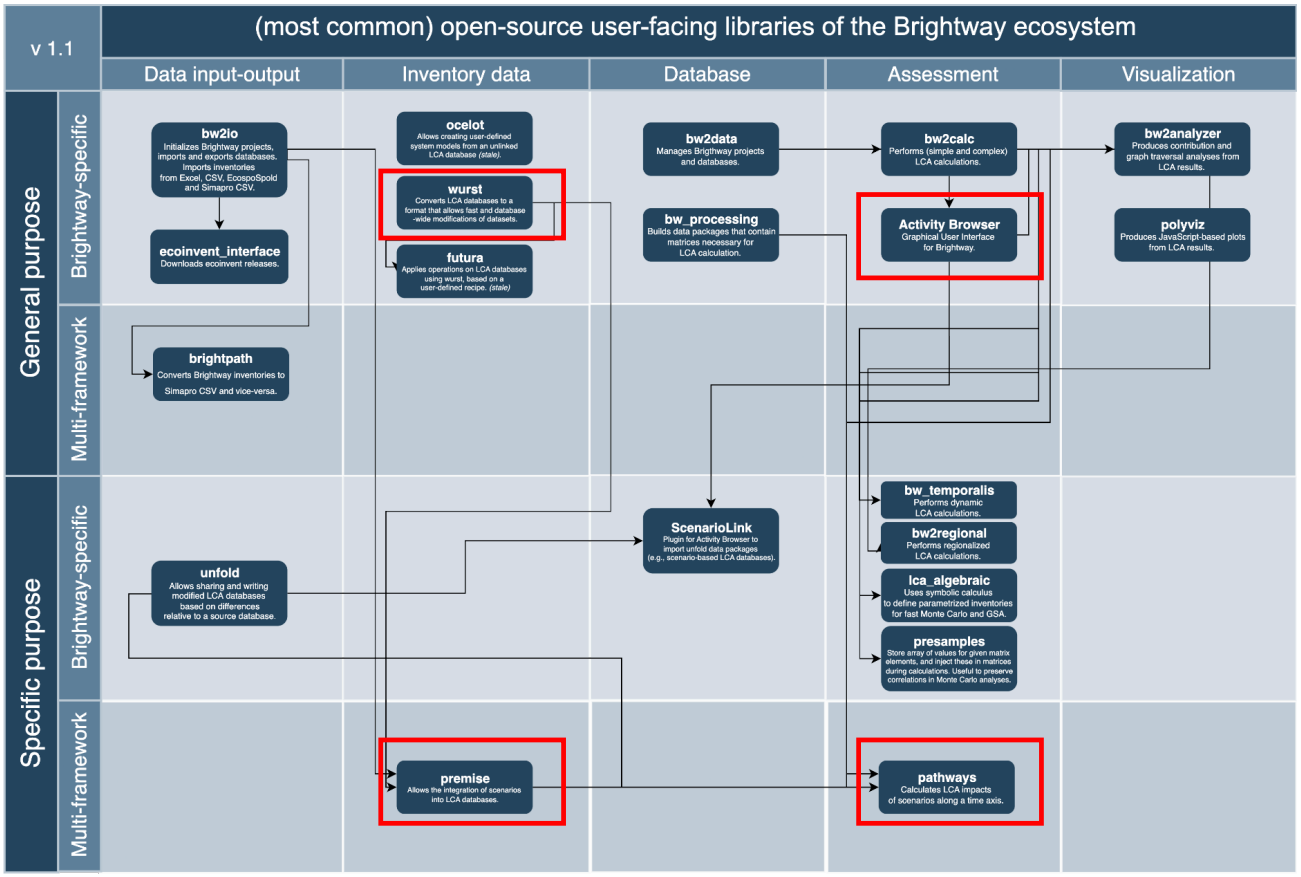
The history of scenario-based prospective LCA



IAM and LCA



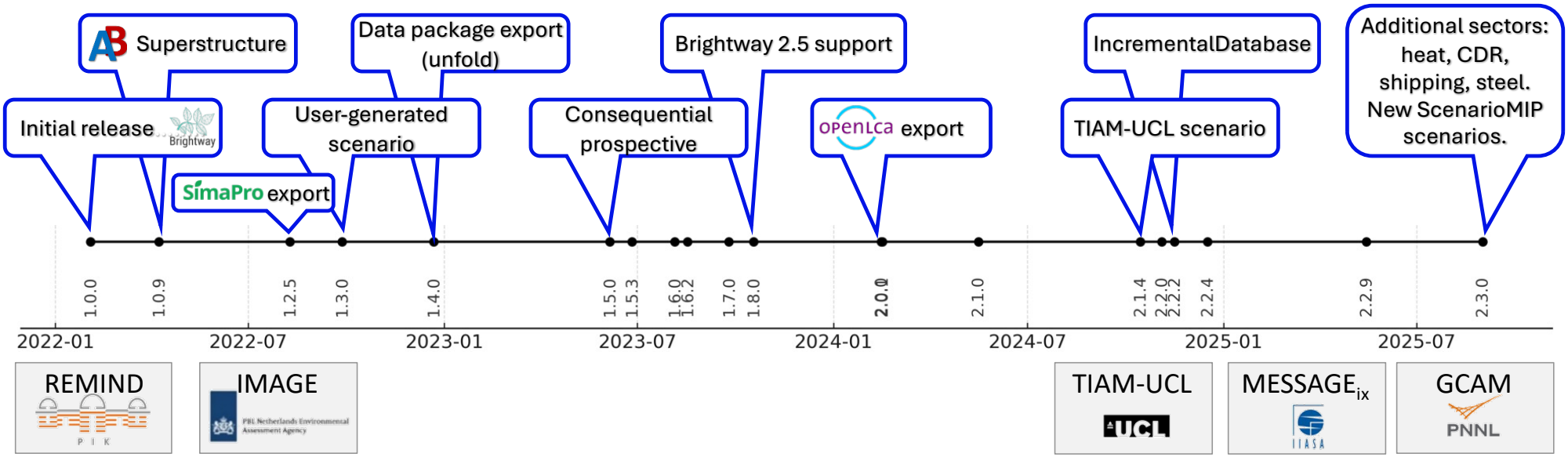
Overview of open-source tools in the Brightway ecosystem



Statistics on Premise

- Links to 6 IAM models
- ~30 IAM scenarios
  - Covering all SSPs (socio-economic scenarios) and climate scenarios
  - Dashboard

- Mostly used with Brightway, and more specifically, the «Superstructure» feature of Activity Browser



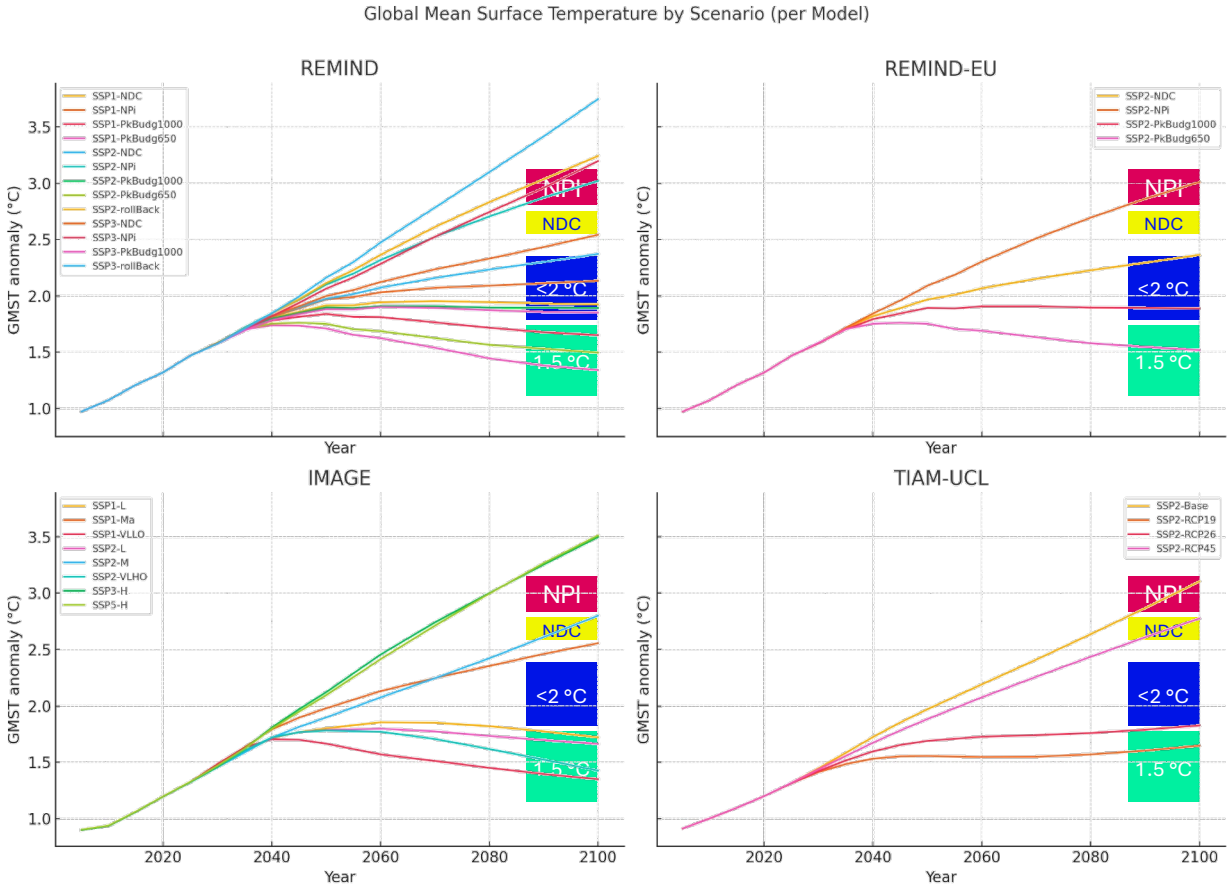
Scenarios in Premise: how to choose?

The choice of model and scenario is usually a weighted trade-off between:

- the characteristics of the model (e.g., regionalization, technology detail, land-use modeling, myopic vs. perfect foresight, etc.),
- the climate target (e.g., 1.5°C, 2.0°C, etc.),
- the extent of sectoral integration (e.g., how many sectors are mapped in premise), and
- the availability of scenarios (e.g., some models have more scenarios than others).

	REMIND	REMIND-EU	IMAGE	TIAM-UCL
Model Type	CGE + Energy	CGE + Energy	IAM (PEM)	Bottom-up
Foresight	✓ Perfect	✓ Perfect	✗ Myopic	✓ Perfect
Energy System	✓ Detailed	✓ Detailed	✓ Moderate	✓ Very detailed
Land Use	✓ (MAGPIE)	✓ (MAGPIE)	✓ Integrated	✗
Regional Focus	Global	EU + Global	Global	Global
Key Strength	Energy-economy	EU policies	Land & climate	Tech pathways

Scenarios in Premise: GMST range coverage

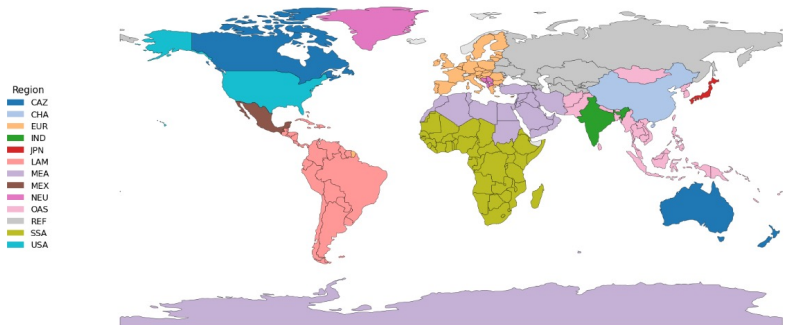


Scenario / Policy case	Description	Best estimate (°C)
+1.5 °C pathway (SSP1-1.9)	Stringent mitigation, net-zero ~2050, minimal overshoot	~1.4
<2 °C pathway (SSP1-2.6)	Strong mitigation, net-zero ~2070	~1.8
NDCs (2030 pledges)	Full implementation of 2030 targets, incl. conditional	2.6 – 2.8
NPi / Current policies	Implemented policies only (no extra action)	2.7 – 3.1
All long-term pledges	NDCs + full delivery of announced net-zero	2.1 – 2.3
Worst case (SSP5-6.0)	Very high emissions, no climate policy	~4.0

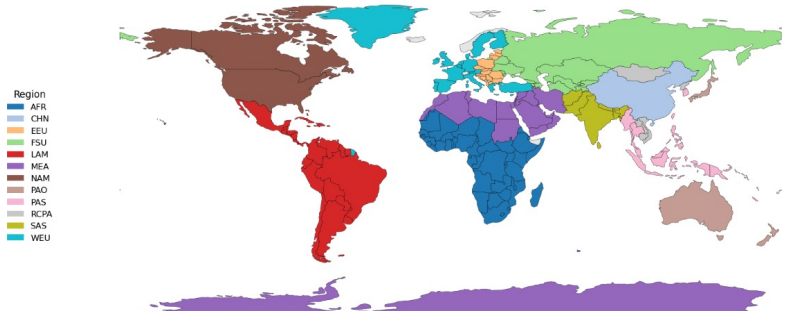
Scenarios in Premise: geographical coverage

PSI

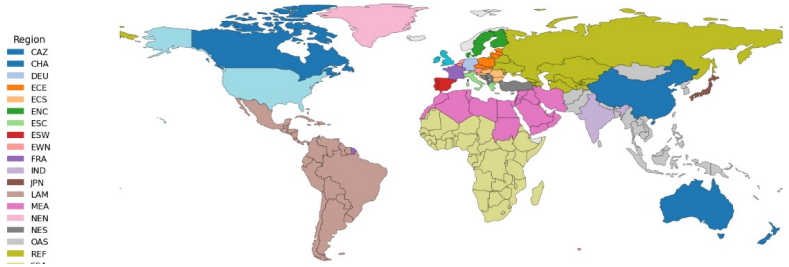
Regions in REMIND



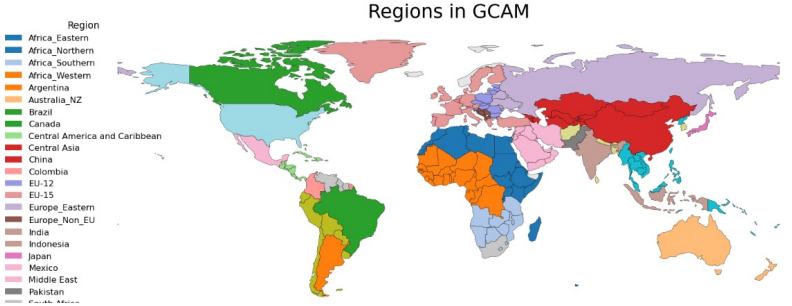
Regions in MESSAGE



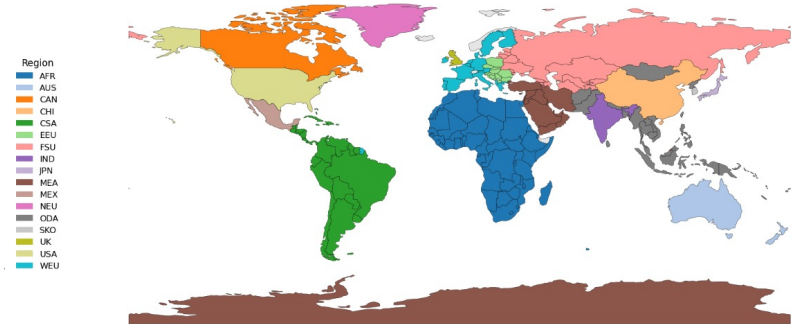
Regions in REMIND-EU



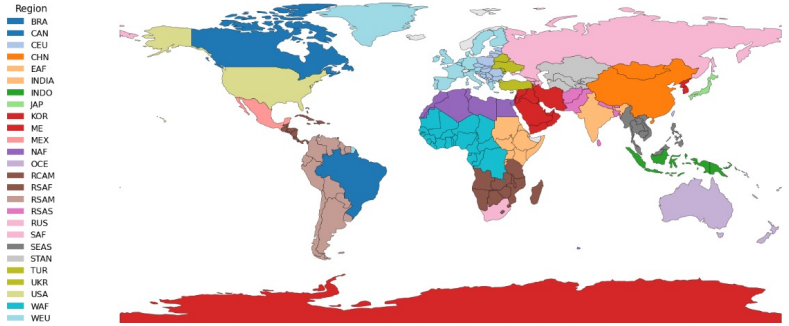
Regions in GCAM



Regions in TIAM-UCL



Regions in IMAGE



Scenarios in Premise: sectoral coverage

	image	remind	remind-eu	tiam-ucl
Biomass	3	2	2	2
Carbon Dioxide Removal	2	7	7	2
Cement	10	4	4	2
Crops	5	0	0	1
Electricity	51	34	34	61
Fuels	53	42	42	55
Heat	14	24	24	2
Other	4	4	4	4
Steel	22	12	12	12
Transport Bus	8	8	8	12
Transport Passenger Cars	8	60	60	20
Transport Rail Freight	6	6	6	4
Transport Road Freight	14	40	40	50
Transport Sea Freight	8	12	12	13
Transport Two Wheelers	0	12	12	0

General observations:

REMIND and **REMIND-EU** have the broadest coverage, with strong mappings in electricity (34 variables), fuels (42 variables), and transport, especially passenger cars (60 variables) and road freight (40 variables).

IMAGE offers extensive integration, particularly in electricity (51 variables), fuels (53 variables), and industrial sectors like cement (10 variables) and steel (22 variables). However, two-wheelers are not covered by IMAGE.

TIAM-UCL is highly detailed in electricity (61 variables), fuels (55 variables), and road freight (50 variables) but has lower coverage in cement and heat compared to **REMIND** and **IMAGE**.

Sectoral observations:

Electricity and fuels remain the most consistently mapped sectors across all models.

Transport sub-sectors (bus, passenger cars, rail, road, and sea freight) are well represented in **REMIND(-EU)** and **TIAM-UCL**, with **IMAGE** covering all except two-wheelers.

Industrial sectors, particularly steel and cement, are better represented in IMAGE and REMIND(-EU) than in TIAM-UCL.

Scenarios in Premise: strengths and weaknesses

- REMIND is best suited for global energy–economy transition analyses where the interplay between macroeconomic growth, energy markets, and climate policies is key.
- REMIND-EU is ideal for EU-focused studies, particularly those assessing the European Green Deal or country-level decarbonization strategies within the EU.
- IMAGE is the preferred choice when land-use change, agriculture, biodiversity, or climate–ecosystem interactions are central to the analysis. Its biophysical and environmental modules complement energy-focused IAMs.
- TIAM-UCL is most appropriate for exploring detailed technology pathways, resource allocation, and cost-optimal energy system designs, particularly for Paris Agreement-compatible scenarios.

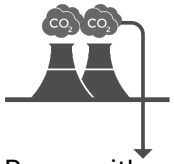
Our recommendation is to assess the sensitivity of your results across different IAMs for a given climate target. IAMs will deploy different technologies and resources to achieve the same climate target, which will lead to different life cycle inventories.

Datasets

GaAs, Perovskite, ...

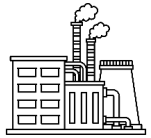
FT fuels

Biofuels



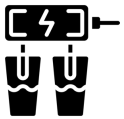
Power with CCS

Geothermal, wave, ...



Cement: CCS via MEA, oxyfuel, direct separation

Fuel cell: PEM, AEFC, SOFC, DMFC



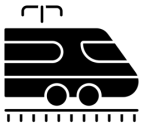
Electrolyzer: PEM, AE, SOE

Batteries: LiB, SiB

Trucks/buses: EV, FC

Cars/motorcycles: EV, FC

Steel: BF/BOF, NG-DRI, H2-DRI, TGR, EW

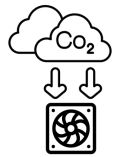


Trains: PEM, D, EV, FC

Shipping

Chemicals: MeOH, NH3

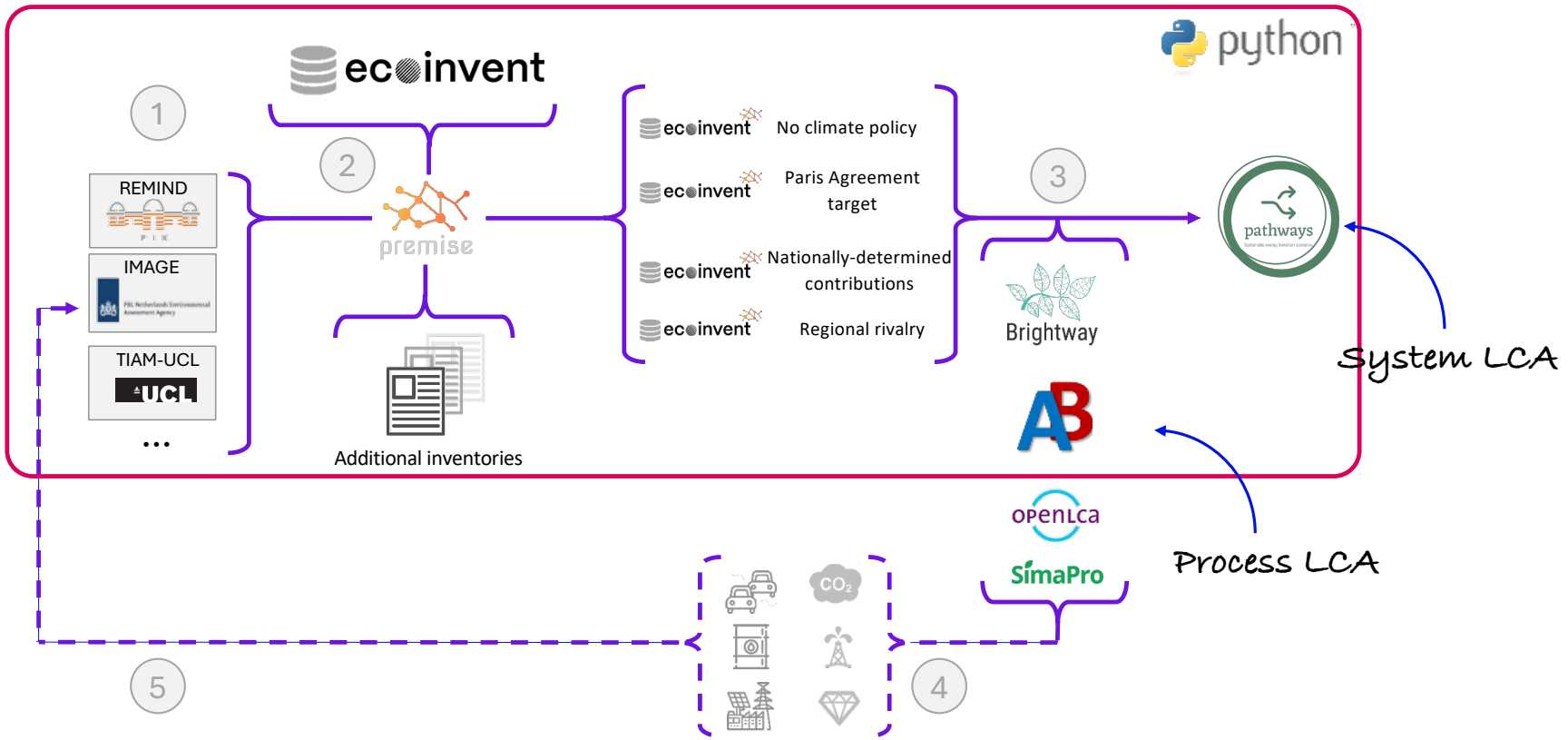
Metals: PGM, Li, Co



CDR: DACCS, BECCS, EWR, OAE, biochar

- +2’300 datasets
- Peer-reviewed
- Documented
- EI 3.6-3.11

Workflow

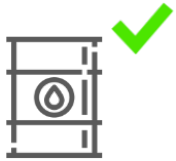

python
ecoinvent
1
2
REMIND
IMAGE
TIAM-UCL
...
premise
Additional inventories
ecoinvent No climate policy
ecoinvent Paris Agreement target
ecoinvent Nationally-determined contributions
ecoinvent Regional rivalry
3
Brightway
pathways
System LCA
OPENLCA
SimaPro
Process LCA
4
5

Which IAM sectors does premise integrate?

PSI

Power

Create regional electricity markets
Adjust power plant efficiency



Fuels

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

ongoing

Metals recycling

Adjust critical raw materials use
Adjust future recycled content (MFA)

Hot pollutant emissions

Adjust hot pollutant emission from GAINS

70%

Heating

Heating mix for industrial, residential and other purposes.

80%

Renewables

Adjust solar PV and wind turbines efficiency

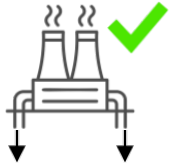
70%

Transport

Create market for passenger and freight transport

Industry

New production routes for cement and steel



Carbon capture and storage

Add carbon capture and storage where needed

ongoing

Carbon dioxide removal

Region-specific CDR mixes

0%

Chemicals

Ammonia, ethene, ethylene

0%

Agriculture

Fertilizer, pesticide, land and water use

ongoing

Data centers

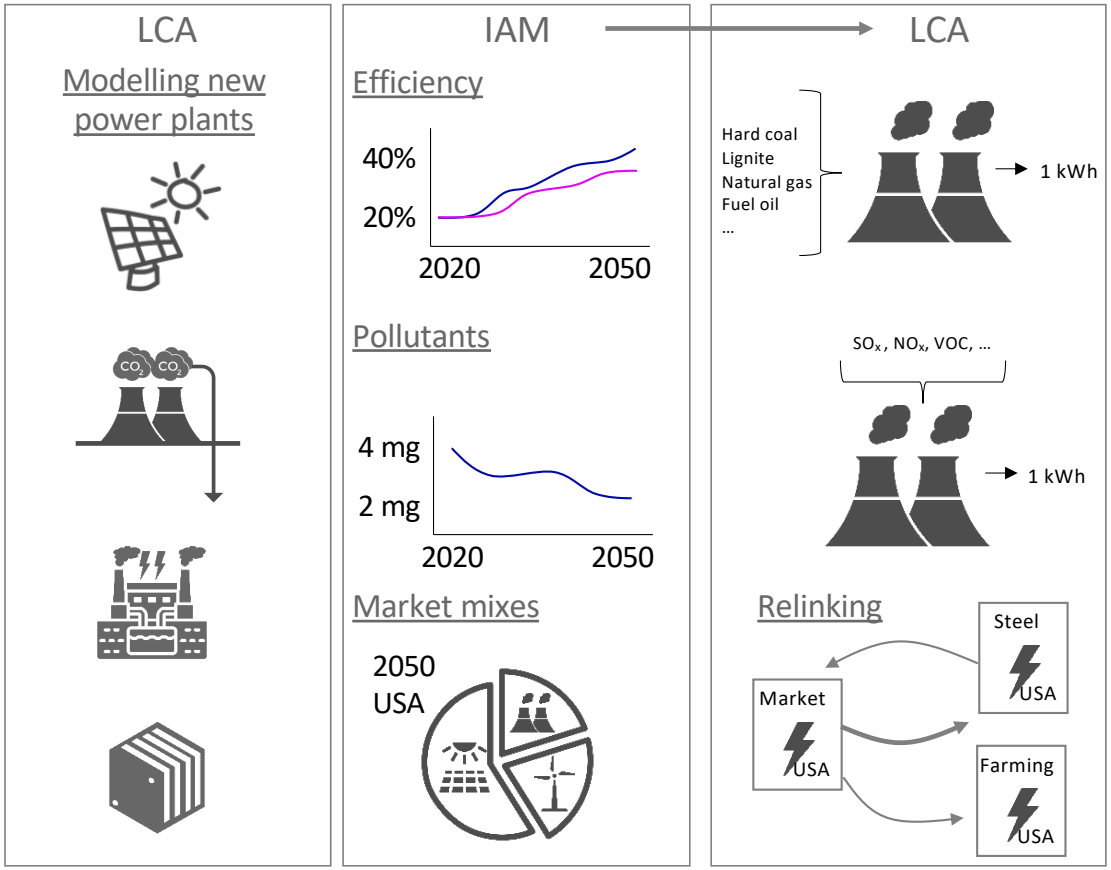
Cloud computing, gen-AI

ongoing

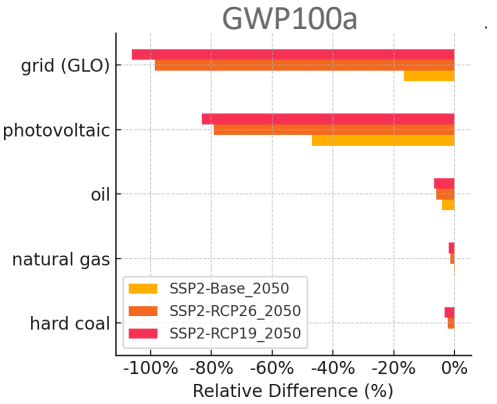
Mining

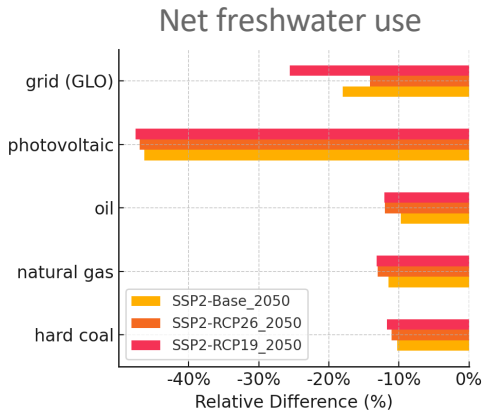
Waste management practices, biodiversity impacts

Example of SECTOR-SPECIFIC transformation: power generation

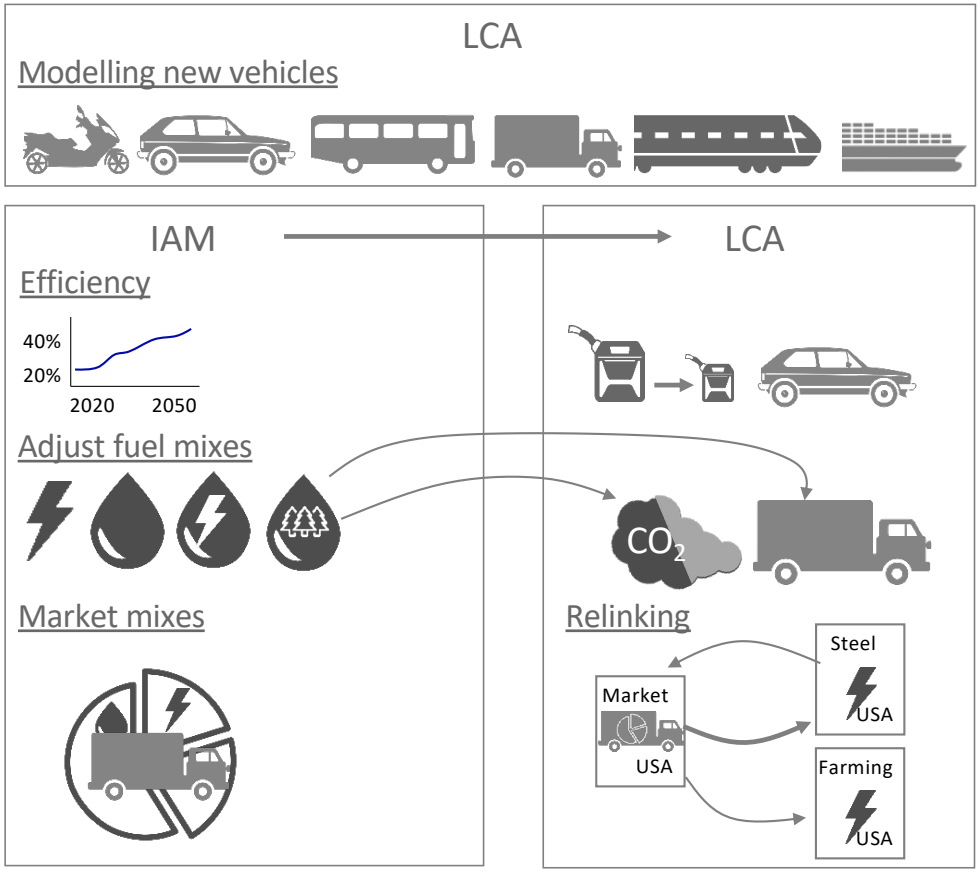


Scores relative to original Ecoinvent values

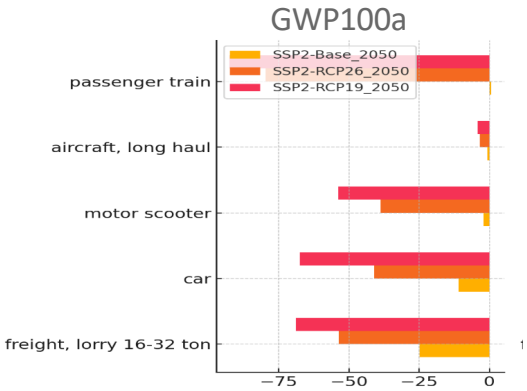


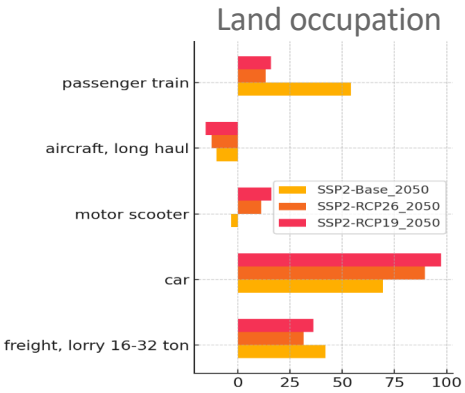


Example of SECTOR-SPECIFIC transformation: TRANSPORT

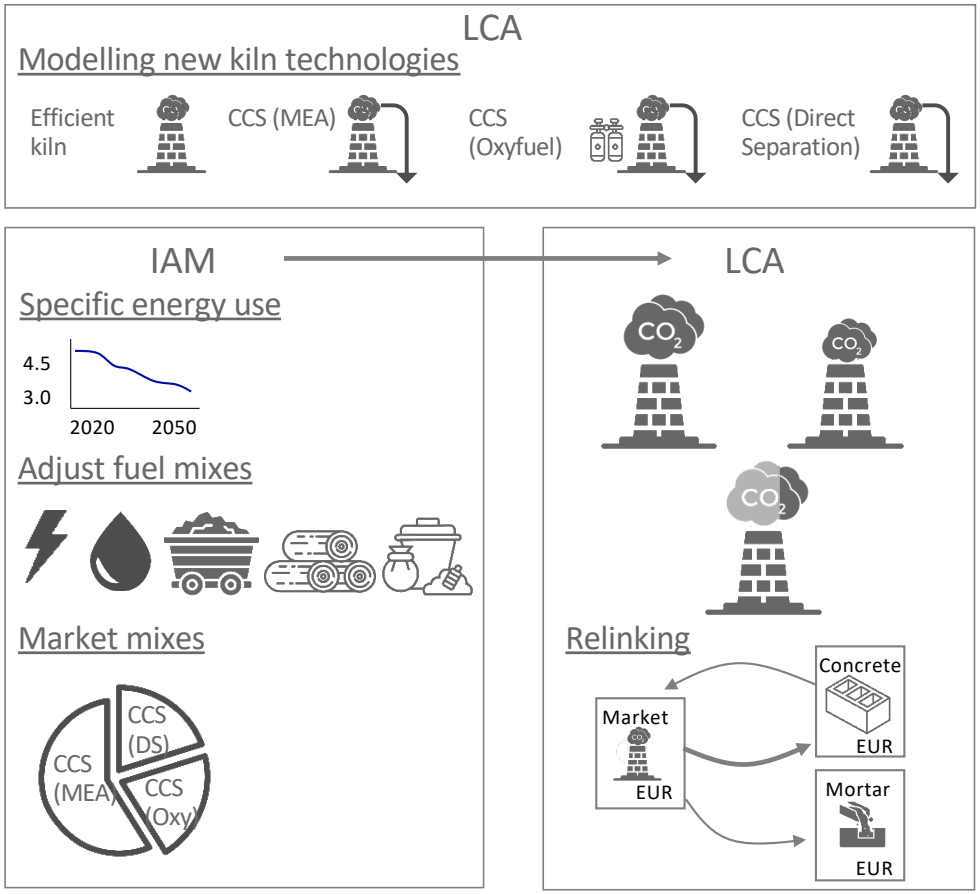


Scores relative to original Ecoinvent values

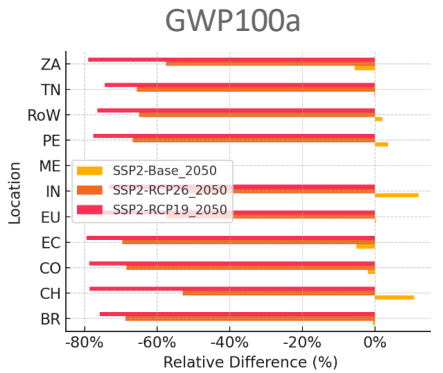


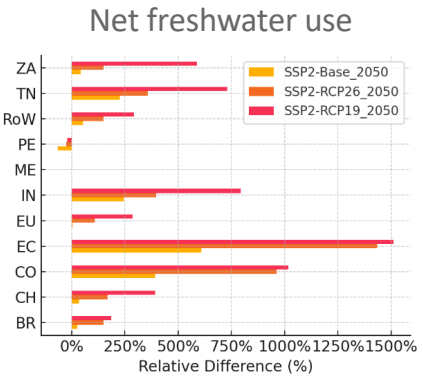


Example of SECTOR-SPECIFIC transformation: CEMENT



Scores relative to original Ecoinvent values





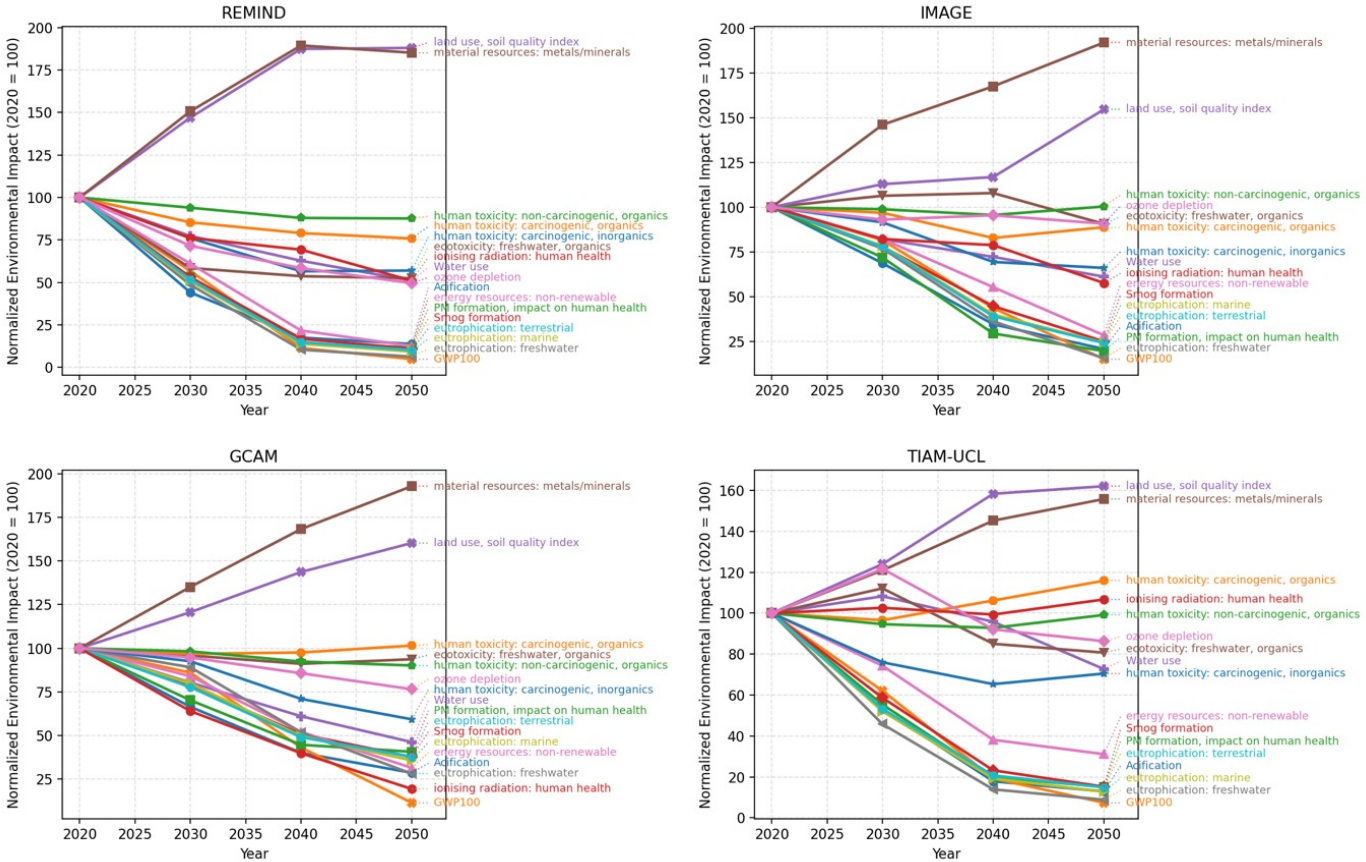
Indicators evolution across IAM models for <2 °C scenarios

Impacts of 1 kWh of global electricity, relative to 2020

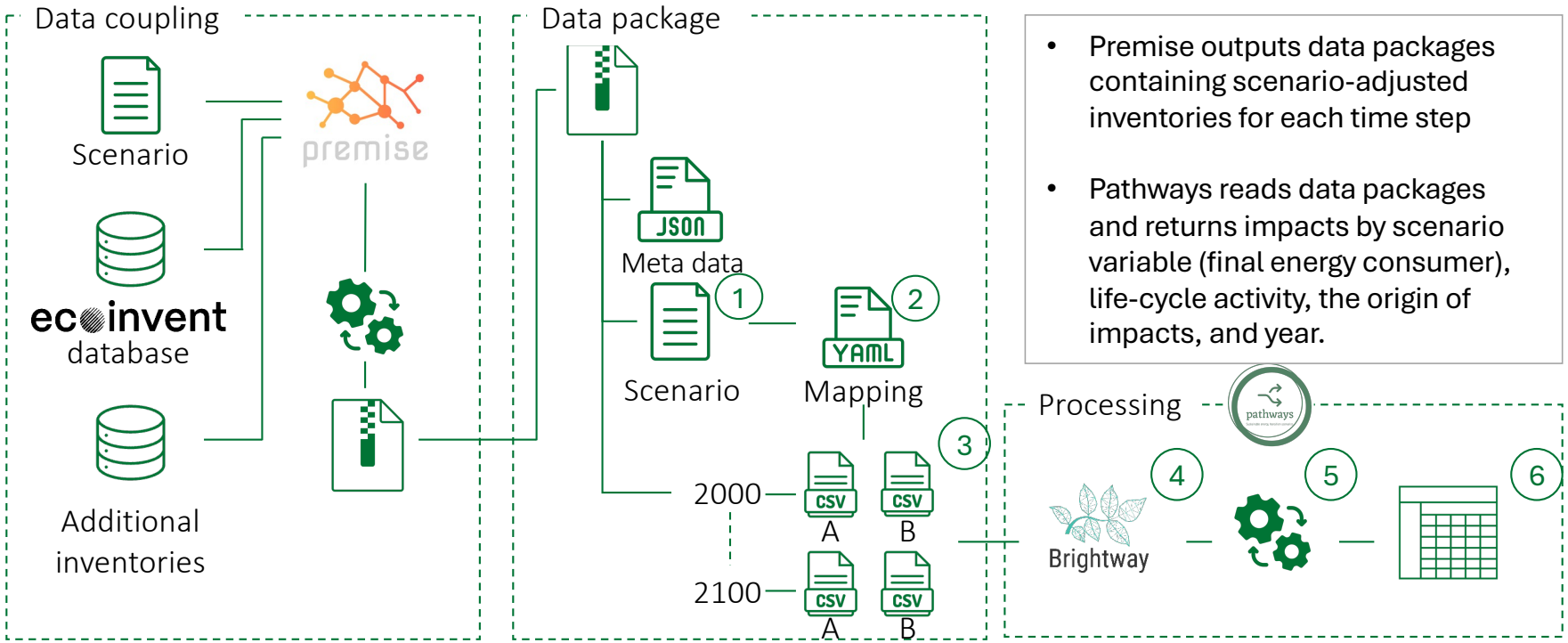
GHG emissions decrease, but some resource use indicators increase.

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?).

Even decreasing trends can be an issue if electricity use is ten fold what we have today. System-level perspective is important.



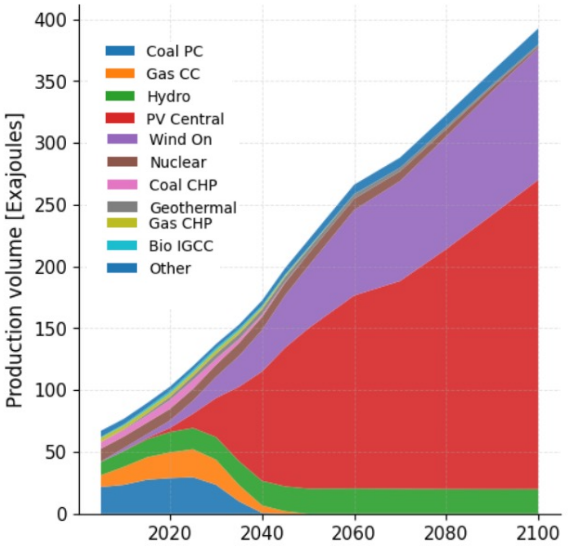
PATHWAYS: System-wide prospective LCA



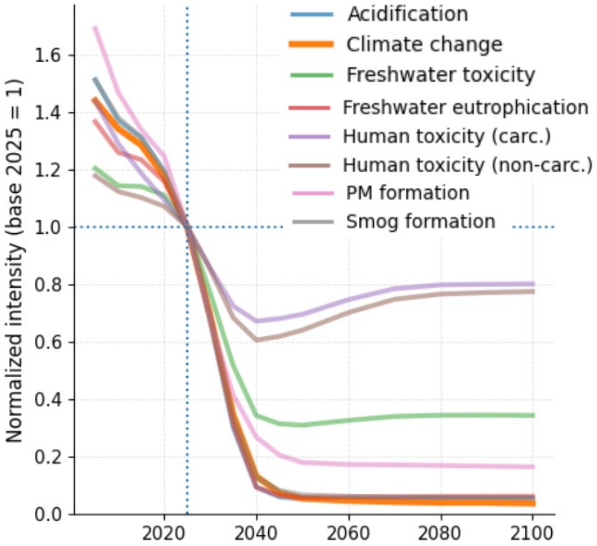
- Premise outputs data packages containing scenario-adjusted inventories for each time step
- Pathways reads data packages and returns impacts by scenario variable (final energy consumer), life-cycle activity, the origin of impacts, and year.

Environmental trade-offs in a <2 °C scenario

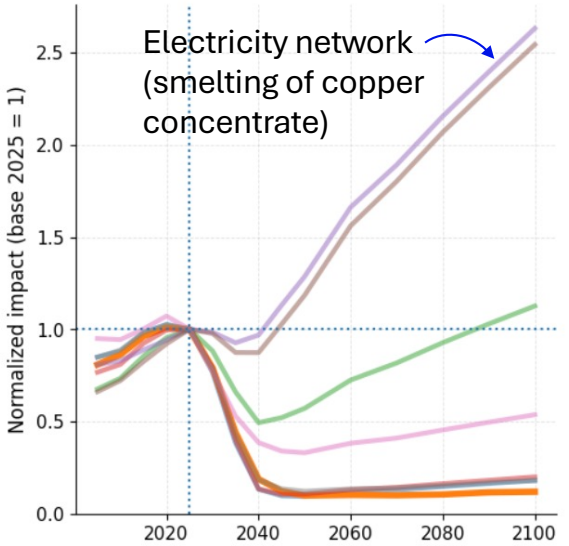
Global **electricity** production



Global **electricity production** (EJ), REMIND, SSP2-1000 GtC Carbon budget



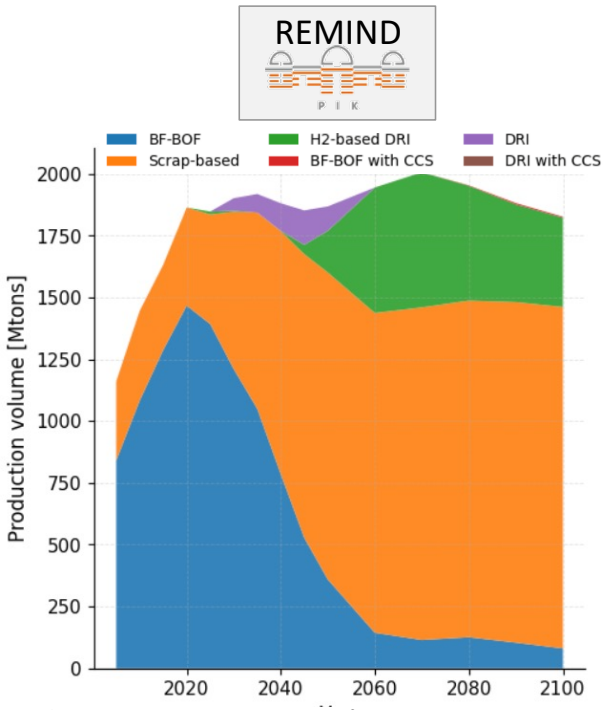
Per unit environmental scores (EF 3.1), relative to 2025



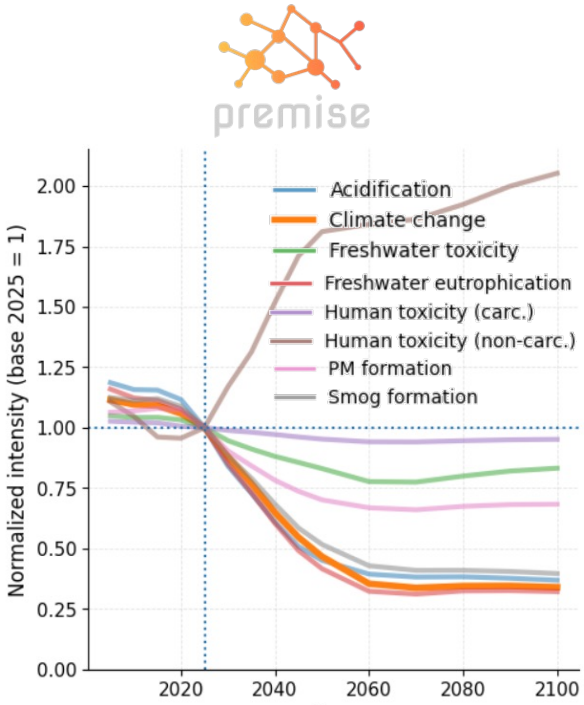
Scaled environmental scores, relative to 2025

Environmental trade-offs in a <2 °C scenario

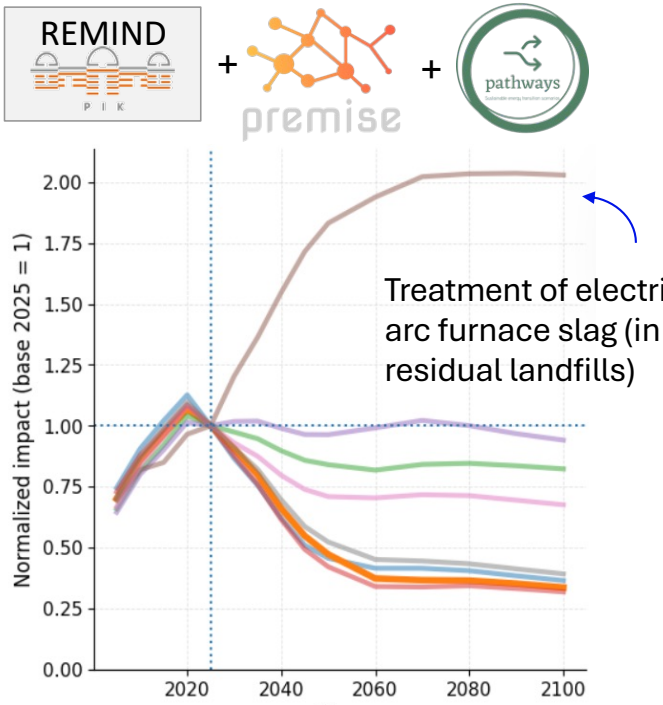
Global **steel** production



Global **steel production** (EJ), REMIND, SSP2-1000 GtC Carbon budget



Per unit environmental scores (EF 3.1), relative to 2025



Treatment of electric arc furnace slag (in residual landfills)

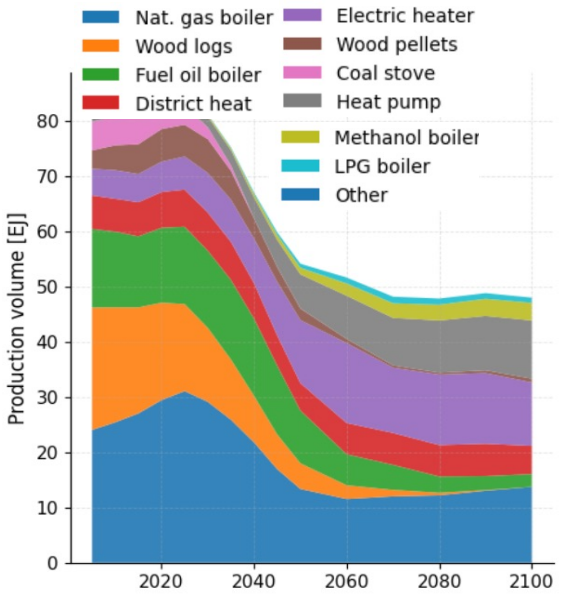
Scaled environmental scores, relative to 2025

Environmental trade-offs in a <2 °C scenario

PSI

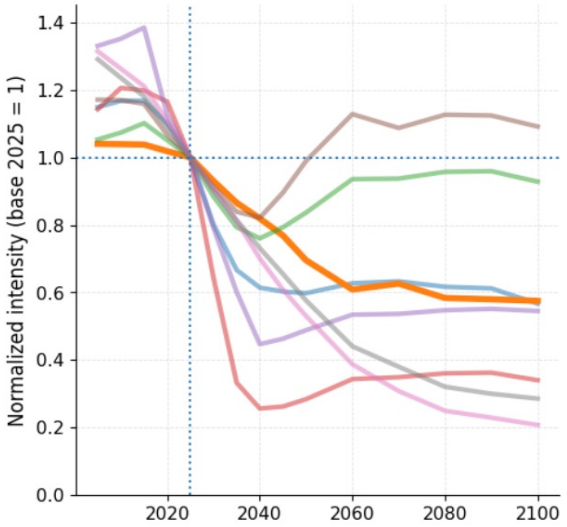
Global **residential heat** supply

REMIND



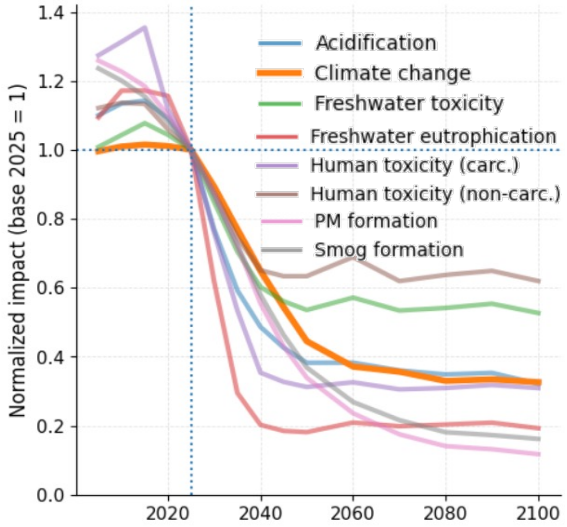
Global **residential heat** (EJ), REMIND, SSP2-1000 GtC Carbon budget

premise



Per unit environmental scores (EF 3.1), relative to 2025

REMIND + premise + pathways



Scaled environmental scores, relative to 2025

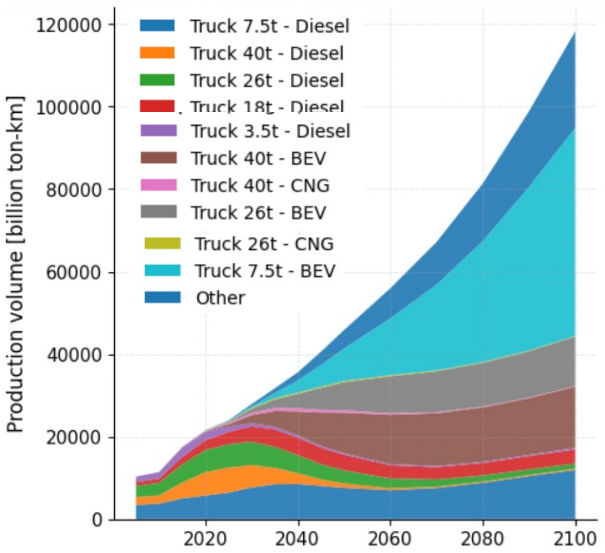
Environmental trade-offs in a <2 °C scenario

Global **freight transport (road)**

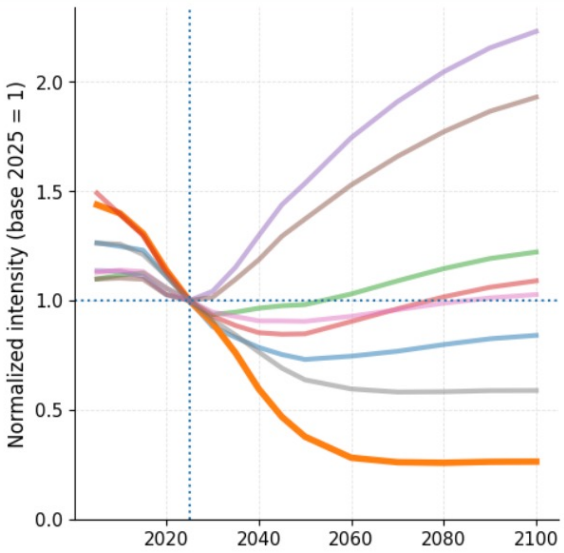
REMIND

premise

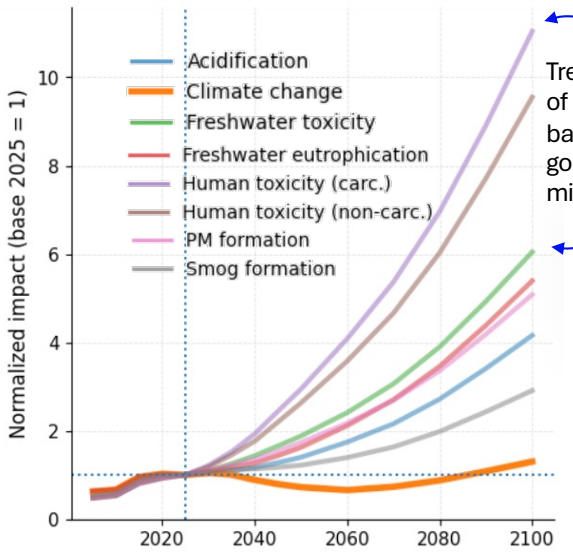
REMIND + premise + pathways



Global **road transport (freight)** (EJ), REMIND, SSP2-1000 GtC Carbon budget



Per unit environmental scores (EF 3.1), relative to 2025



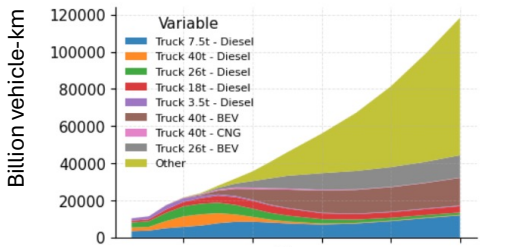
Treatment of used batteries, gold mining, ...

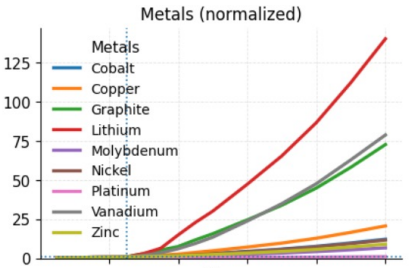
Scaled environmental scores, relative to 2025

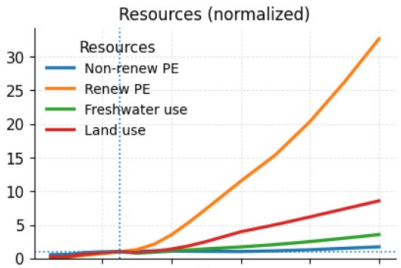
Pressure on resources in a <2 °C scenario

PSI

Global **freight transport (road)**

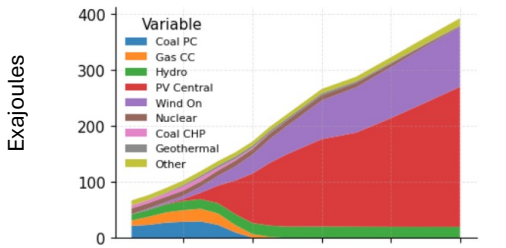


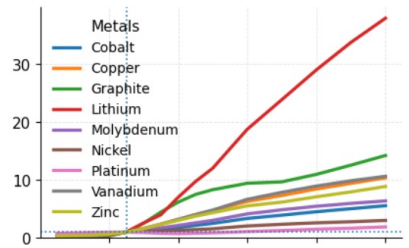


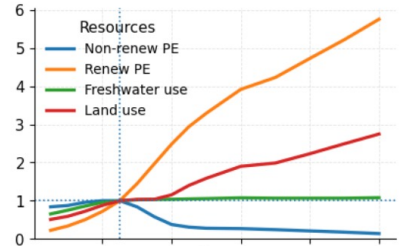


Lans use: road + forest biomass for biofuel

Global **electricity**

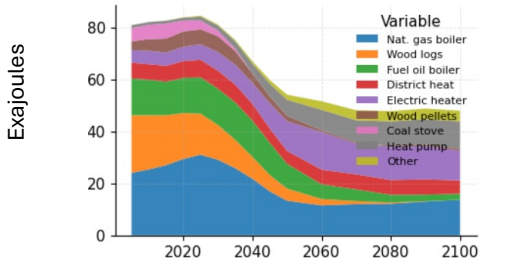


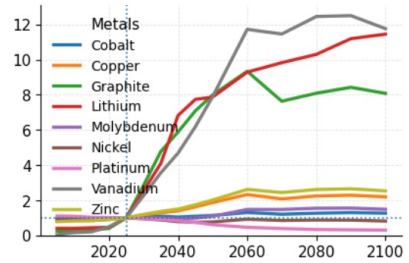


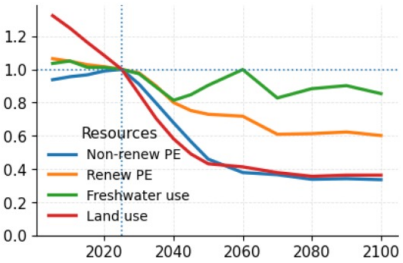


Land use: open ground solar PV

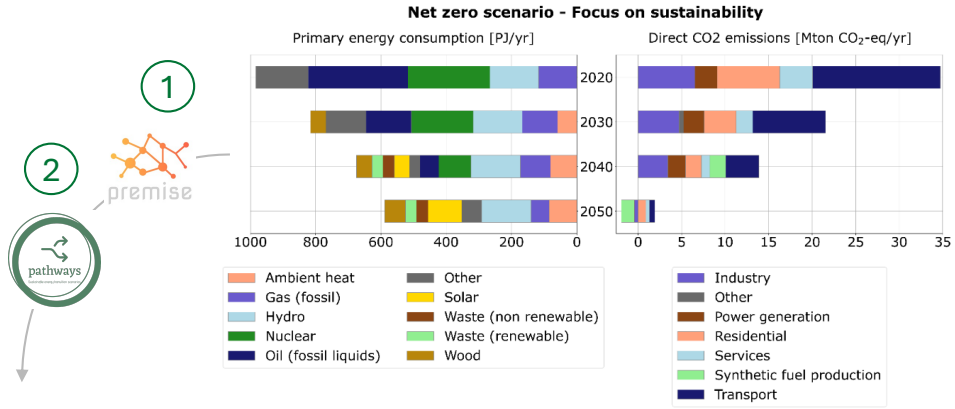
Global **residential heat**

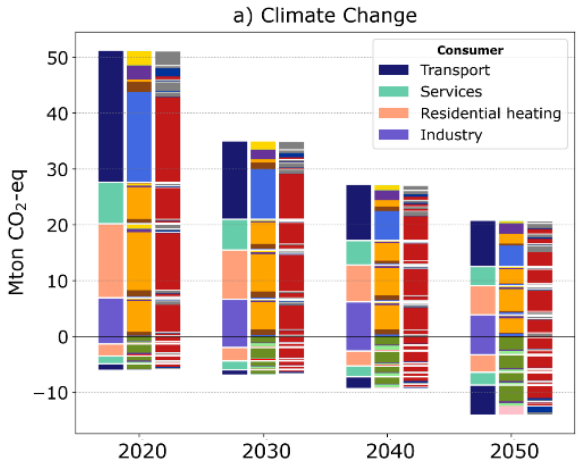


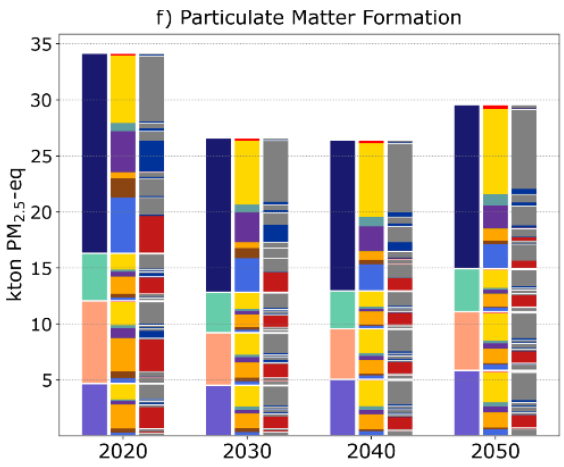


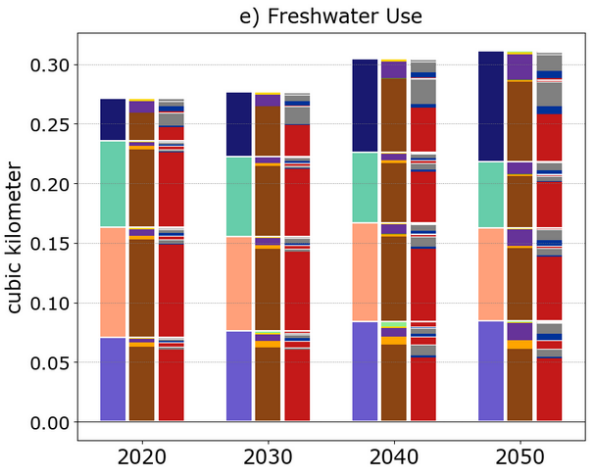


Swiss net-zero scenarios





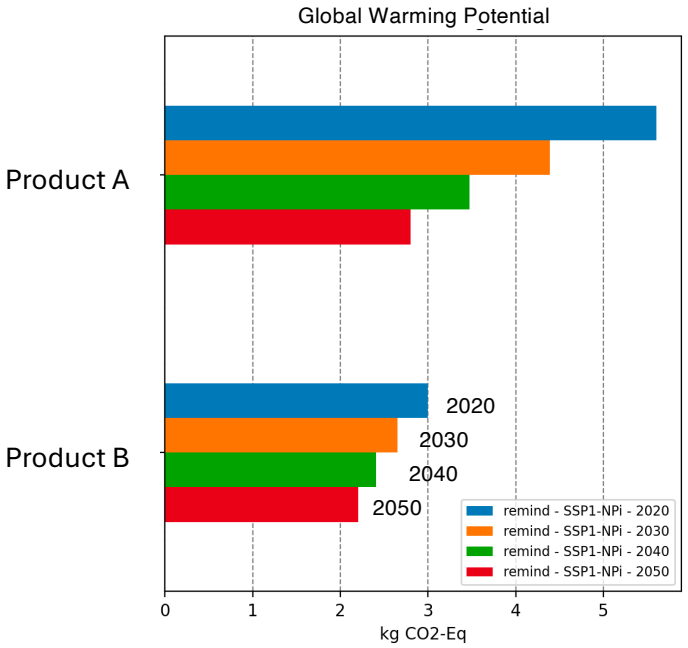




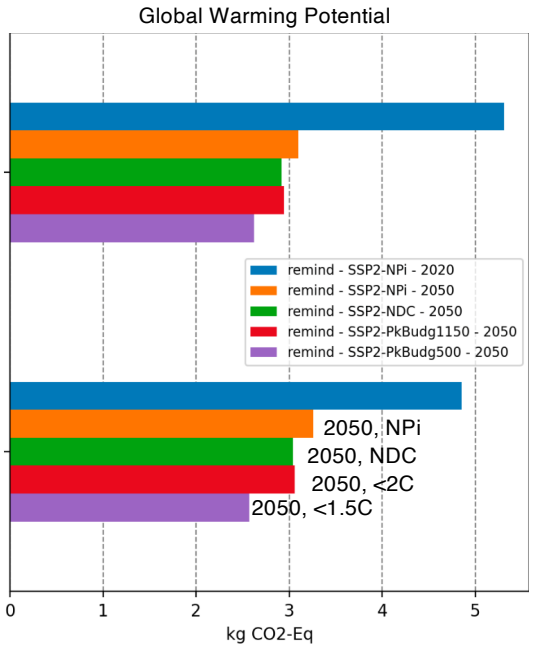
At the process level

Scenario analysis (Superstructure database)

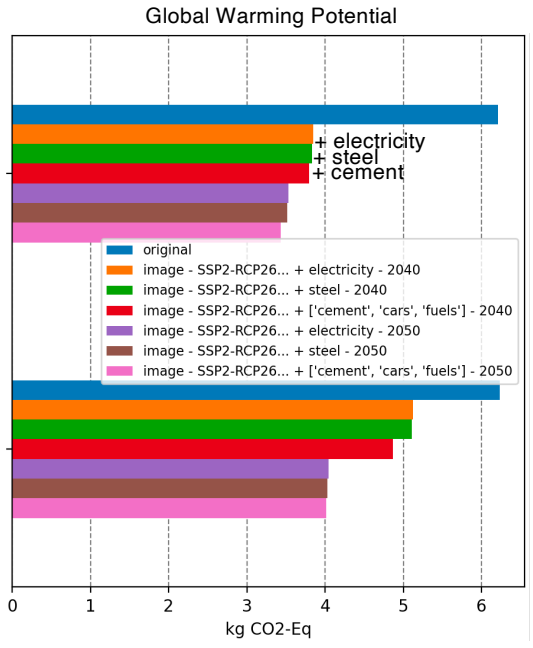
Today, vs. 2030 vs. 2040 vs. 2050



Today, vs. 2050 across scenarios



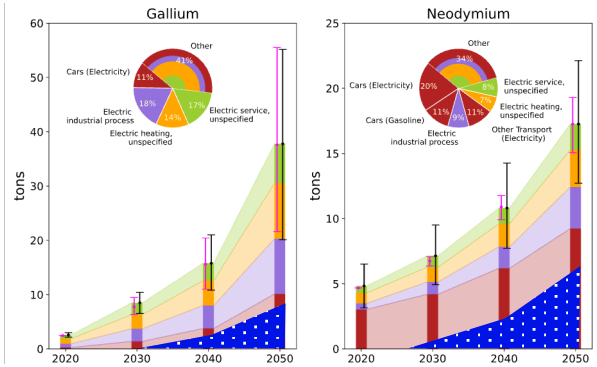
Today, vs. 2050, sector contributions



What we're Building Toward

premise + pathways

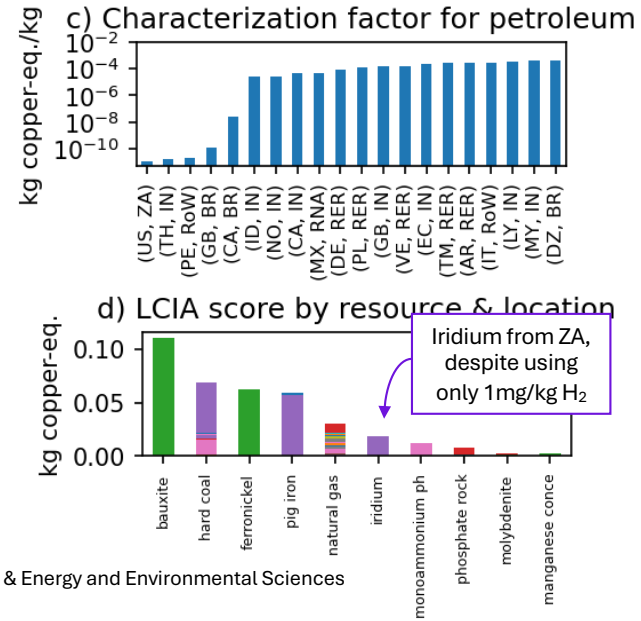
Stronger assessment of future resource at system-level (e.g. water, land, critical raw materials)



What is the recycling potential? Which policy leads to the highest share of recycled content?

edges

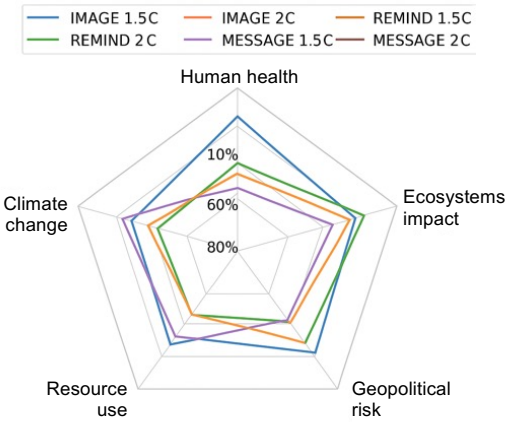
Integration of geopolitical risk and supply-chain vulnerability in net zero scenarios



premise + pathways + edges

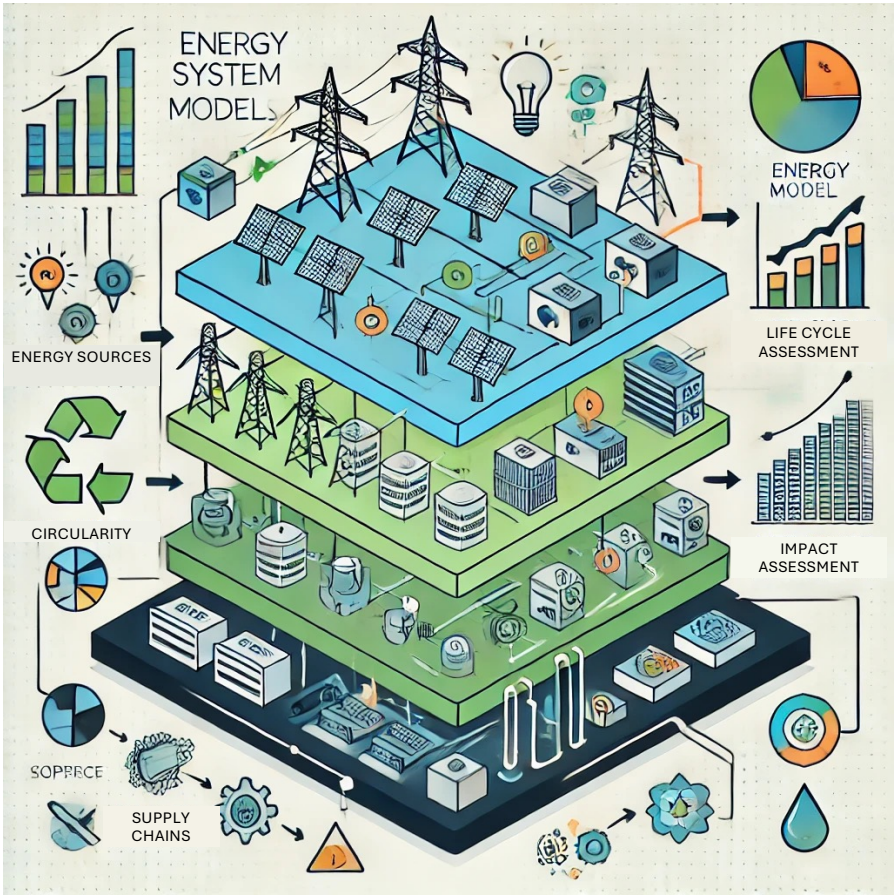
All net-zero scenarios are equal, but some are more equal than others

Comparing global net zero scenarios across LCA indicators



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
- *Edges: https://github.com/Laboratory-for-Energy-Systems-Analysis/edges*

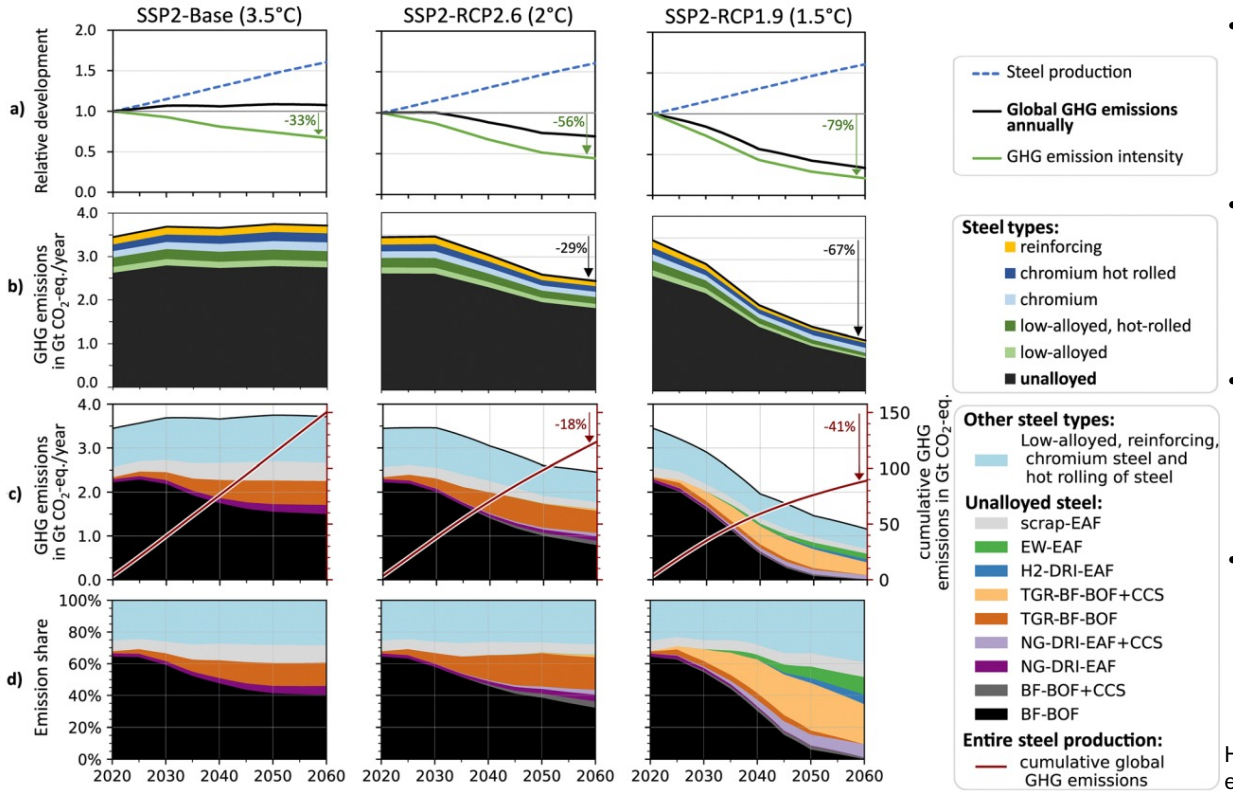
Thank you for your attention.

Learn more about PSI-LEA at https://www.psi.ch/en/lea.

Looking for a Ph.D. or PostDoc?

romain.sacchi@psi.ch

CASE USING pLCA DATABASE: STEEL



- Approach – Prospective LCA of global steel production to 2060, combining nine production routes with IMAGE model scenarios (3.5 °C baseline, <2 °C, 1.5 °C).
- Climate Impact – Even with electrification and CCS, net-zero is unlikely by 2060; steel could consume up to 30% of the 1.5 °C carbon budget.
- Technology Outlook – Electrified routes (EW, scrap-EAF) with clean power offer ~95% GHG cuts, outperforming CCS; H_2-DRI depends on green hydrogen supply.
- Trade-offs – Decarbonization cuts air-pollution impacts but raises others (ionising radiation, land use, metal depletion) due to higher electricity and material needs.

Harpprecht C, Sacchi R, Naegler T, et al (2025) Future environmental impacts of global iron and steel production. Energy Environ Sci. https://doi.org/10.1039/D5EE01356A

CASE USING pLCA DATABASE: ammonia production

(Boyce et al., 2024)

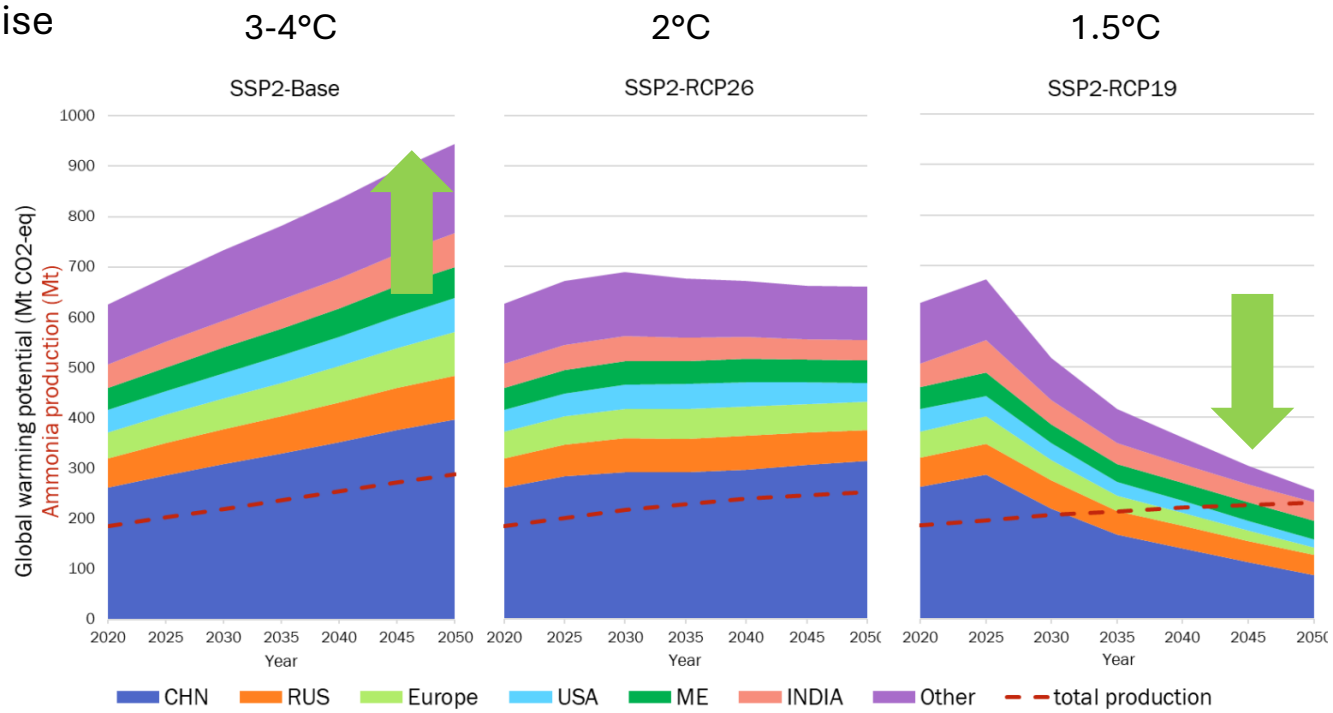
- IEA ammonia scenarios + premise
- GHG emissions from global ammonia production can be substantially lowered

Key factors:

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

Key limitation:

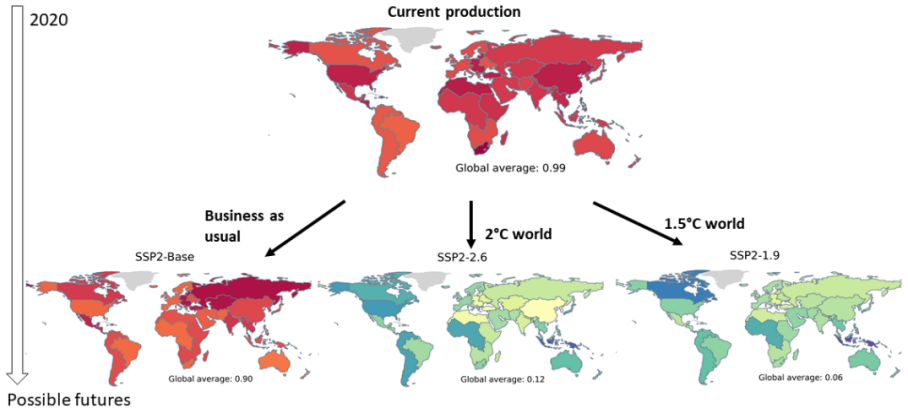
- Need for urea delays H2-based options

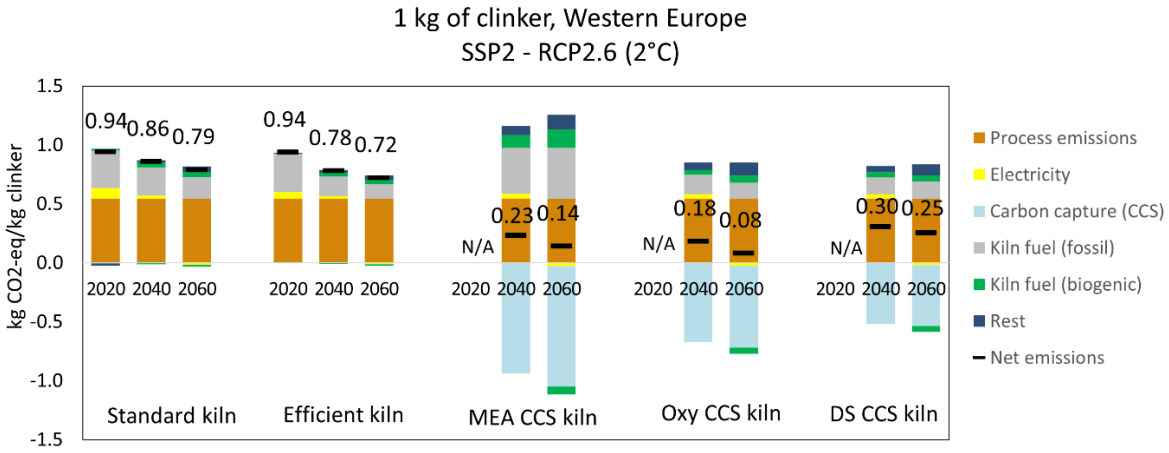


CASE USING pLCA DATABASE: cement production

(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 H_2 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