PAUL SCHERRER INSTITUT

PSI


Romain Sacchi :: Scientist :: Energy Systems Analysis :: Paul Scherrer Institute

# Integrating Scenario projections into Life-Cycle Assessment databases

07.05.2024

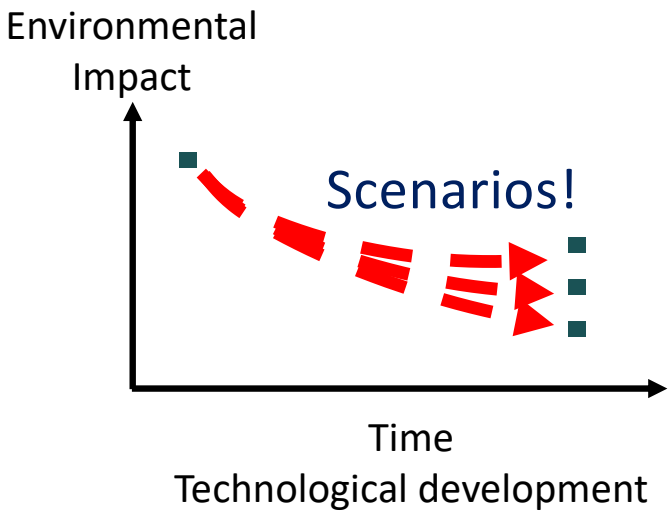
# Why prospective LCA and scenarios?

- We need to **transform our economies** to avoid catastrophic climate change and other environmental consequences
- This requires deploying **sustainable technologies.**
- **Prospective LCA** helps to **anticipate** the environmental impacts of technologies, products, and services and thus **guide** the development of sustainable technology
- **Prospective LCA** is **defined** here as *"LCA that models the product system at a future point in time relative to the time at which the study is conducted*" (Arvidsson 2023)
- pLCA is based on LCI data that tries to depict the future state of a product system. Such data is typically derived by developing **scenarios**.

# Prospective LCA builds on scenarios

1. The technologies under investigation (foreground system)
   - How will new technologies develop? (technology scenarios, upscaling, …)
   - How will respective markets develop?

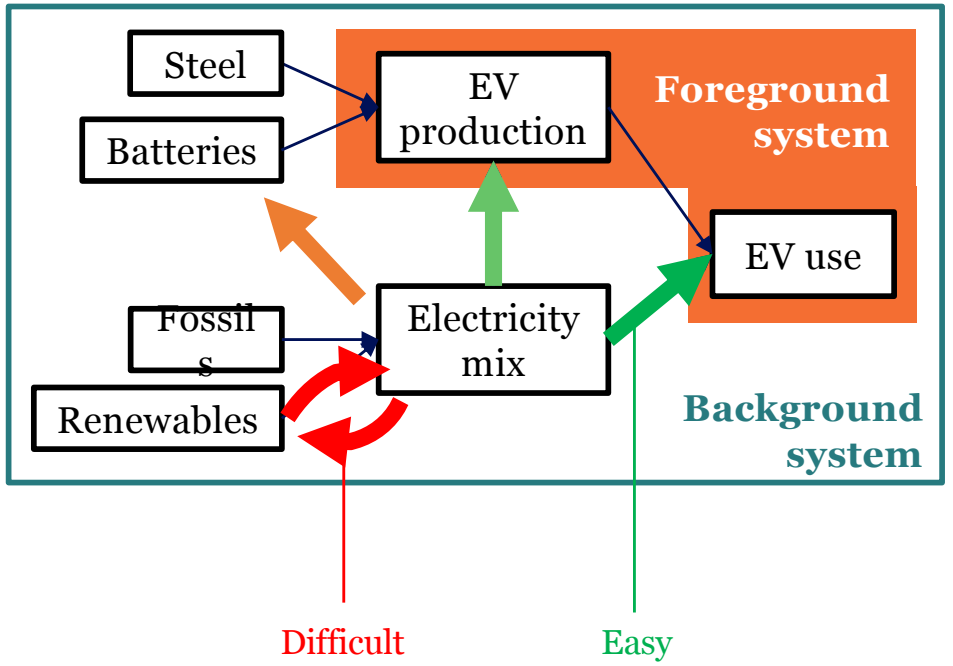
2. The surrounding technological systems (background system)
   - How will the wider economy develop? (e.g., the energy transition)



# Our economy is deeply interlinked!

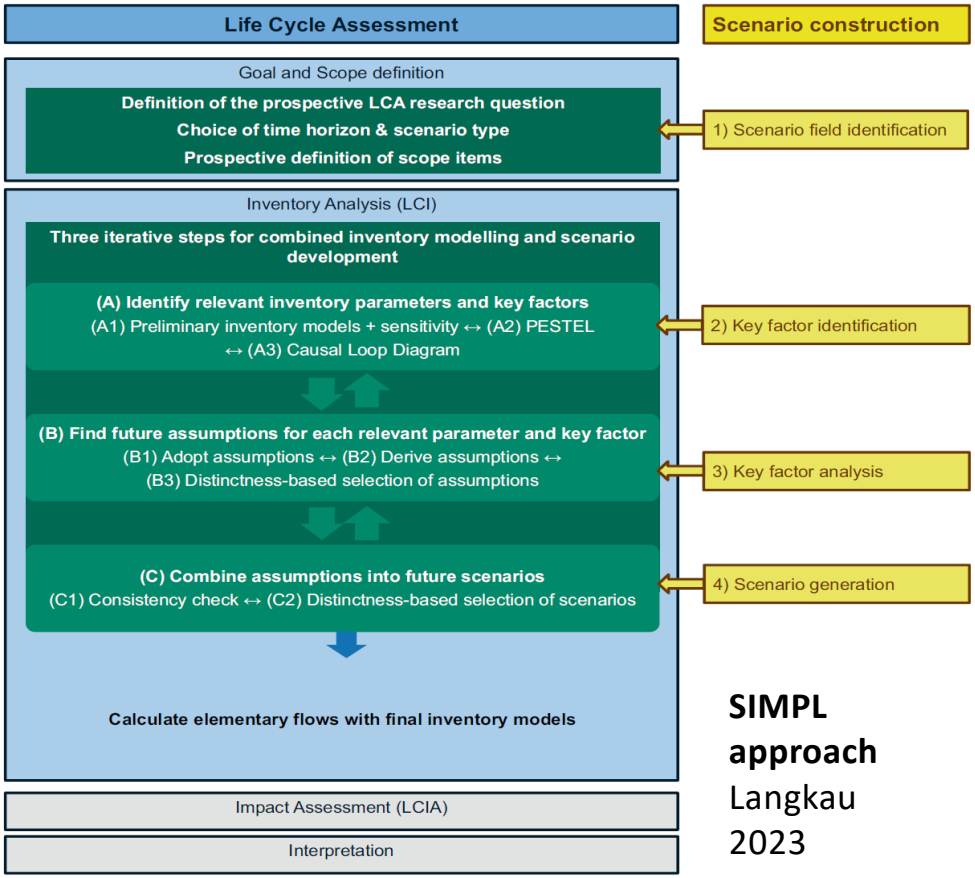
- E.g., Electricity mix affects:
  - EV use
  - EV production
  - Materials/components production
- But greener raw materials also improve the electricity mix *and most other products*!
  - Feedback loops

➔ Broad future (background) scenarios help LCA practitioners consider the combined effect of future changes (deep integration)



# Developing foreground scenarios

- Should be based on a good understanding of the investigated technology (→ collaboration with technology developers)
- Is still an art, but systematic approaches have been presented
- Good overview: Bisinella et al. 2022
- Scale up frameworks: Piccinno et al. 2016, vd Hulst 2020; Tsoy 2020
- SIMPL approach (Scenario-based Inventory Modelling for Prospective LCA): structured and practical guidance to constructing scenarios for prospective LCA




**SIMPL approach** Langkau 2023

Langkau S, Steubing B, Mutel C, Ajie MP, Erdmann L, Voglhuber-Slavinsky A, Janssen M (2023) A stepwise approach for Scenario-based Inventory Modelling for Prospective LCA (SIMPL) Int J Life Cycle Assess

# Developing background scenarios

Prospective LCA should consider developments in foreground *and* background systems to yield the right conclusions.

➔ *temporal consistency*, see e.g., Mendoza Beltran 2018


Mendoza Beltran A et al. (2018) When the Background Matters: Using Scenarios from Integrated Assessment Models in Prospective Life Cycle Assessment J Ind Ecol

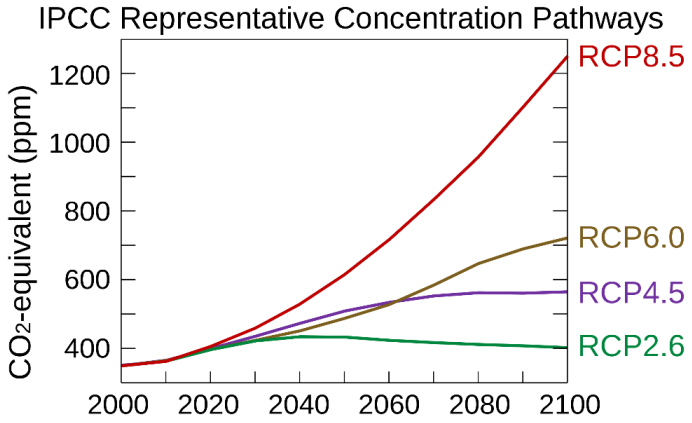
# A short and incomplete history of pLCA databases

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, fuels, …

# IAM/ESM world vs. LCA world

Current 2030 2050 2100

Current

# Integrated Assessment Model

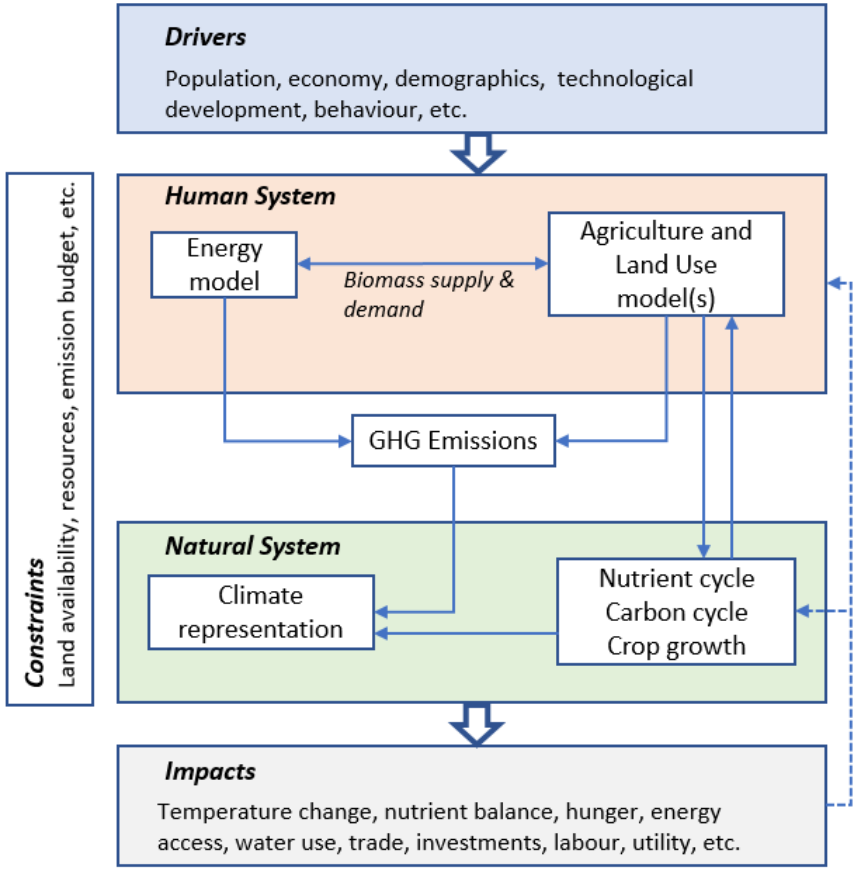
Integrated Assessment Models (IAMs) assess the interactions between **human** and **natural** systems

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?

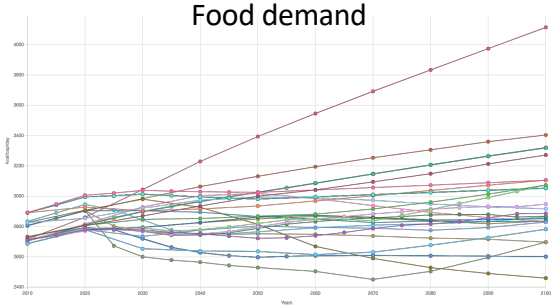


PAUL SCHERRER INSTITUT

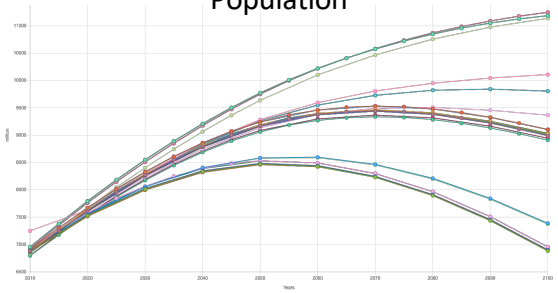
# The IAM world

## Socio-economic constraints (SSP)

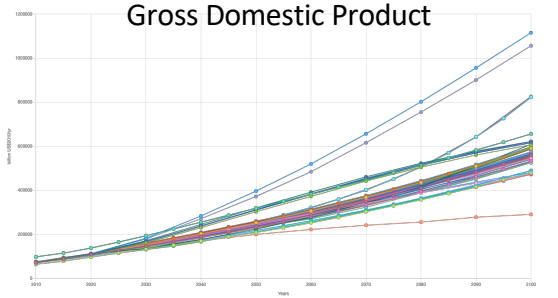
### Food demand



### Population

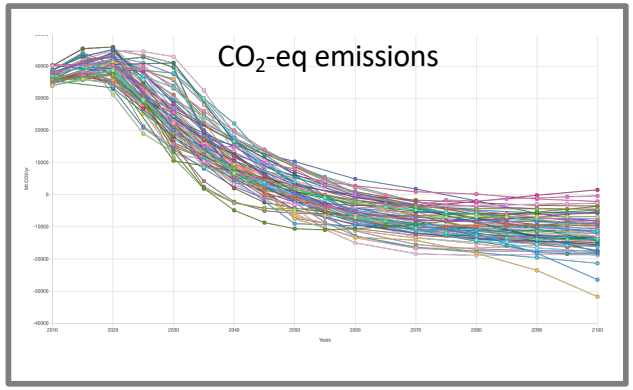


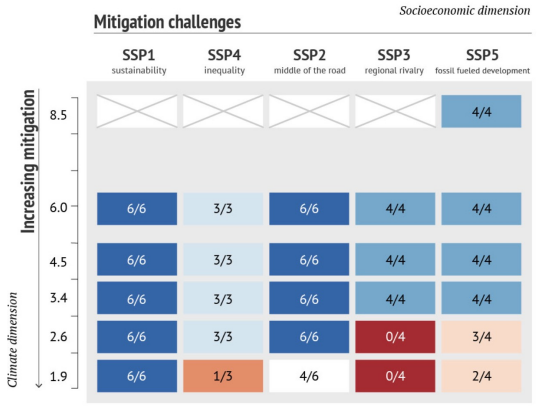
### Gross Domestic Product



## Climate constraints (RCP)

### $CO_2$-eq emissions

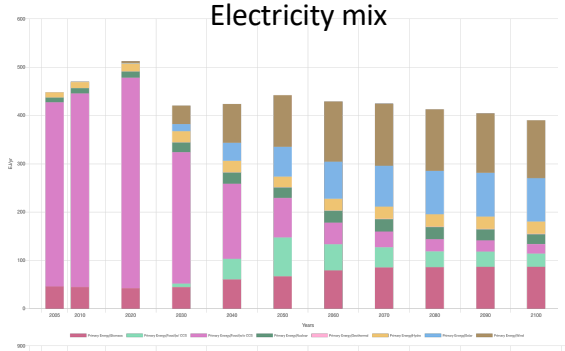




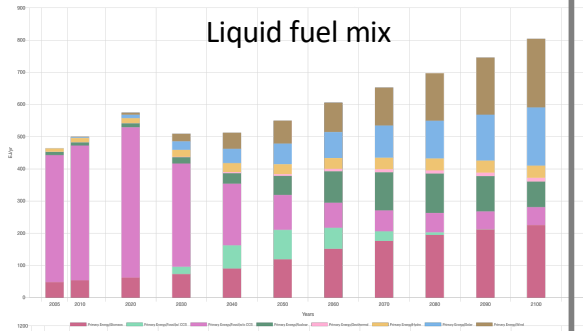

https://www.carbonbrief.org/explainer-how-shared-socioeconomic-pathways-explore-future-climate-change

## Techno-economic solutions

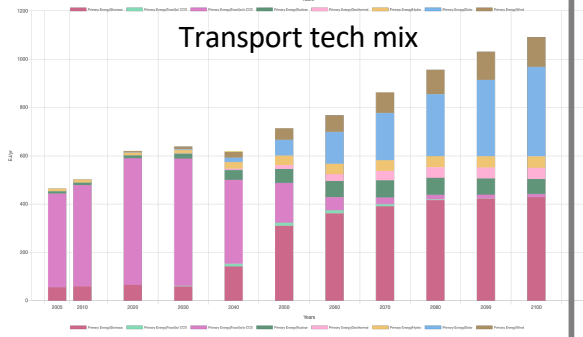
### Electricity mix



### Liquid fuel mix



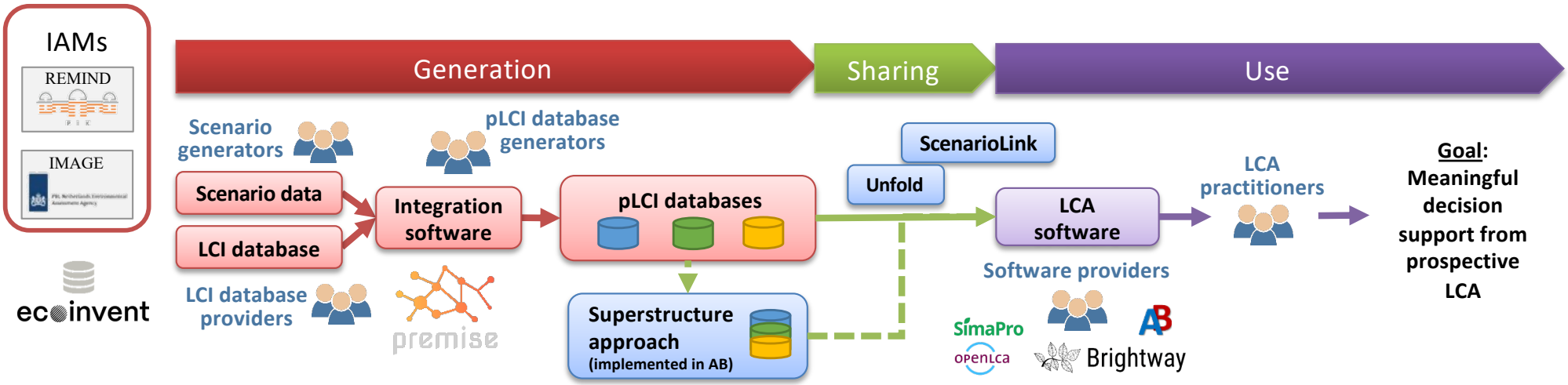
### Transport tech mix



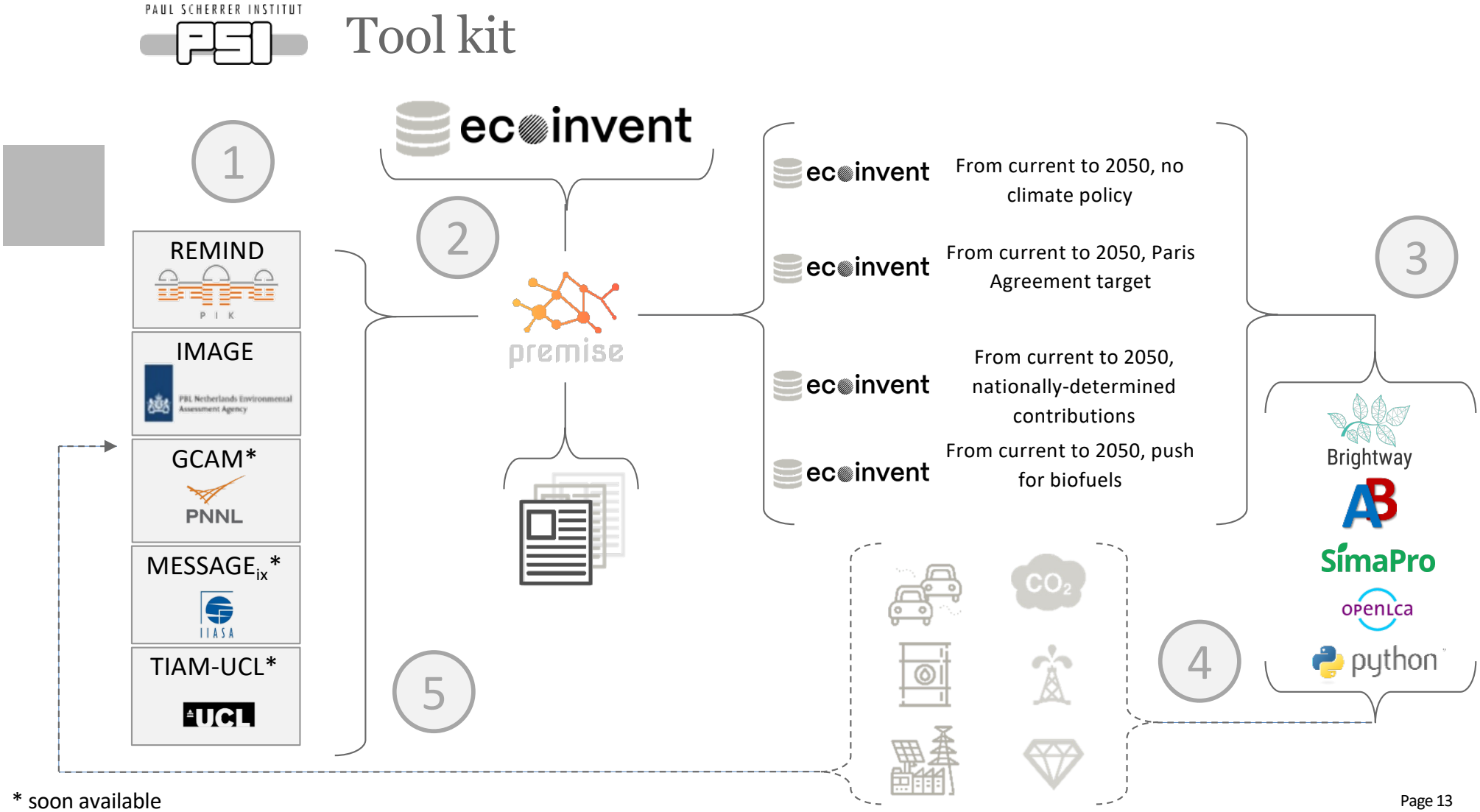
# Scenarios dashboard

Link

# Background scenarios tool chain



# Tool kit




* soon available

# Database manipulation

| | Product A | Product A | Product A | Product A | … | Fuel | Fuel | $CO_2$ | $NO_x$ |
|---|---|---|---|---|---|---|---|---|---|
| Global market for A | 1 | | | | | | -0.5 | | |
| Prod. of A from CZ | -0.5 | 1 | | | | | | | |
| Prod. of A from NO | -0.3 | | 1 | | | | | | |
| Prod. of A from DE | -0.2 | | | 1 | | | | | |
| … | | | | | … | | | | |
| Global market for conv. fuel | | -0.1 | -0.1 | -0.1 | | 1 | | | |
| Prod. of conv. fuel from Global | | | | | | -1 | 1 | | |
| $CO_2$ | | 0.3 | 0.3 | 0.3 | | | 1.2 | 1 | |
| $NO_x$ | | 0.02 | 0.02 | 0.02 | | | 0.05 | | 1 |

~ 19,000

| | Product A | Product A | Product A | … | Product A | Product A | Product A | Product A | … | Fuel | Fuel | Fuel | Fuel | Fuel | $CO_2$ | $NO_x$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Global market for A | 1 | | | | | | | | | | | | | | | |
| European market for A | -0.3 | 1 | | | | | | | | | | -0.5 | | | | |
| Indian market for A | -0.2 | | 1 | | | | | | | | | | -0.5 | | | |
| … | | | | … | | | | | | | | | | | | |
| Production of A from CZ | | -0.6 | | | 1 | | | | | | | | | | | |
| Production of A from NO | | -0.1 | | | | 1 | | | | | | | | | | |
| Production of A from DE | | -0.3 | | | | | 1 | | | | | | | | | |
| Production of A from IN | | | -1 | | | | | 1 | | | | | | | | |
| … | | | | | | | | | … | | | | | | | |
| European market for fuel | | | | | -0.15 | -0.08 | -0.11 | | | 1 | | | | | | |
| Indian market for fuel | | | | | | | | -0.12 | | | 1 | | | | | |
| Conv. fuel prod. from Europe | | | | | | | | | | -1 | | 1 | | | | |
| Conv. fuel prod. from India | | | | | | | | | | | -0.2 | | 1 | | | |
| Synth. fuel prod. from India | | | | | | | | | | | -0.8 | | | 1 | | |
| $CO_2$ | | | | | 0.47 | 0.25 | 0.35 | 0.38 | | | | 1.1 | 1.2 | 0.1 | 1 | |
| $NO_x$ | | | | | 0.01 | 0.02 | 0.01 | 0.03 | | | | 0.05 | 0.05 | 0.4 | | 1 |

> 19,000

Markets transformations | Regional production | Efficiency | Emerging technologies | Non-$CO_2$ emissions

# What does *premise* do?

Power

Create regional electricity markets
Adjust power plant efficiency

Fuels

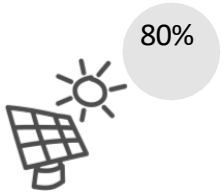
Create regional fuel markets
Add new production pathways (synthetic fuels)


Metals recycling

Adjust future recycled content

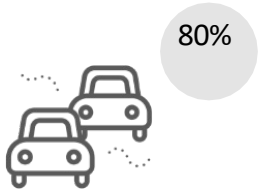
Hot pollutant emissions

Adjust hot pollutant emission from GAINS




Renewables

Adjust solar PV and wind turbines efficiency

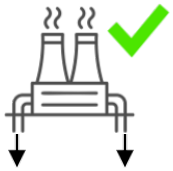



Transport

Create market for passenger and freight road transport

Industry

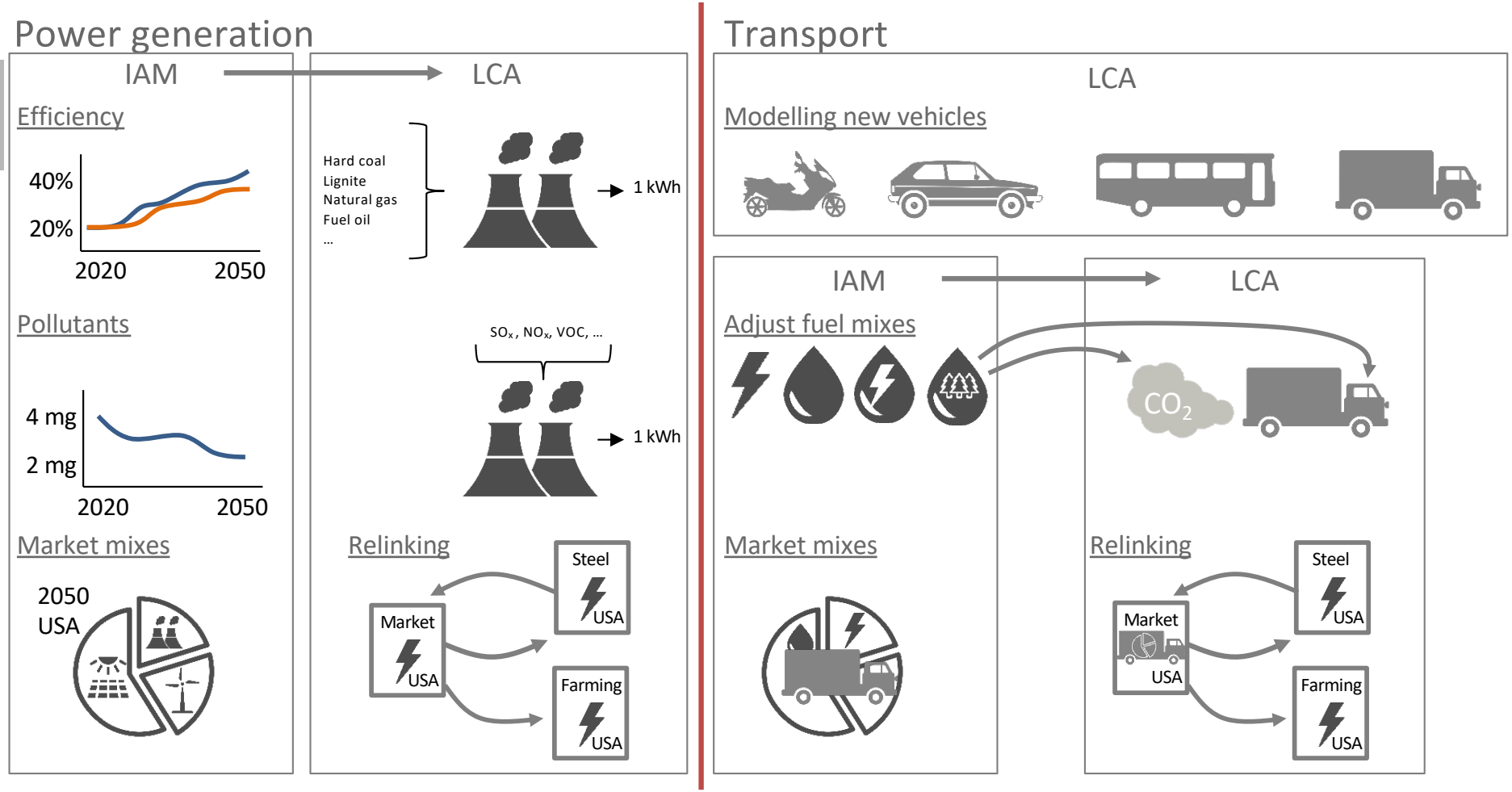
Adjust efficiency for cement and steel production (fuel mix, process efficiency, material composition, etc.)



Carbon capture and storage

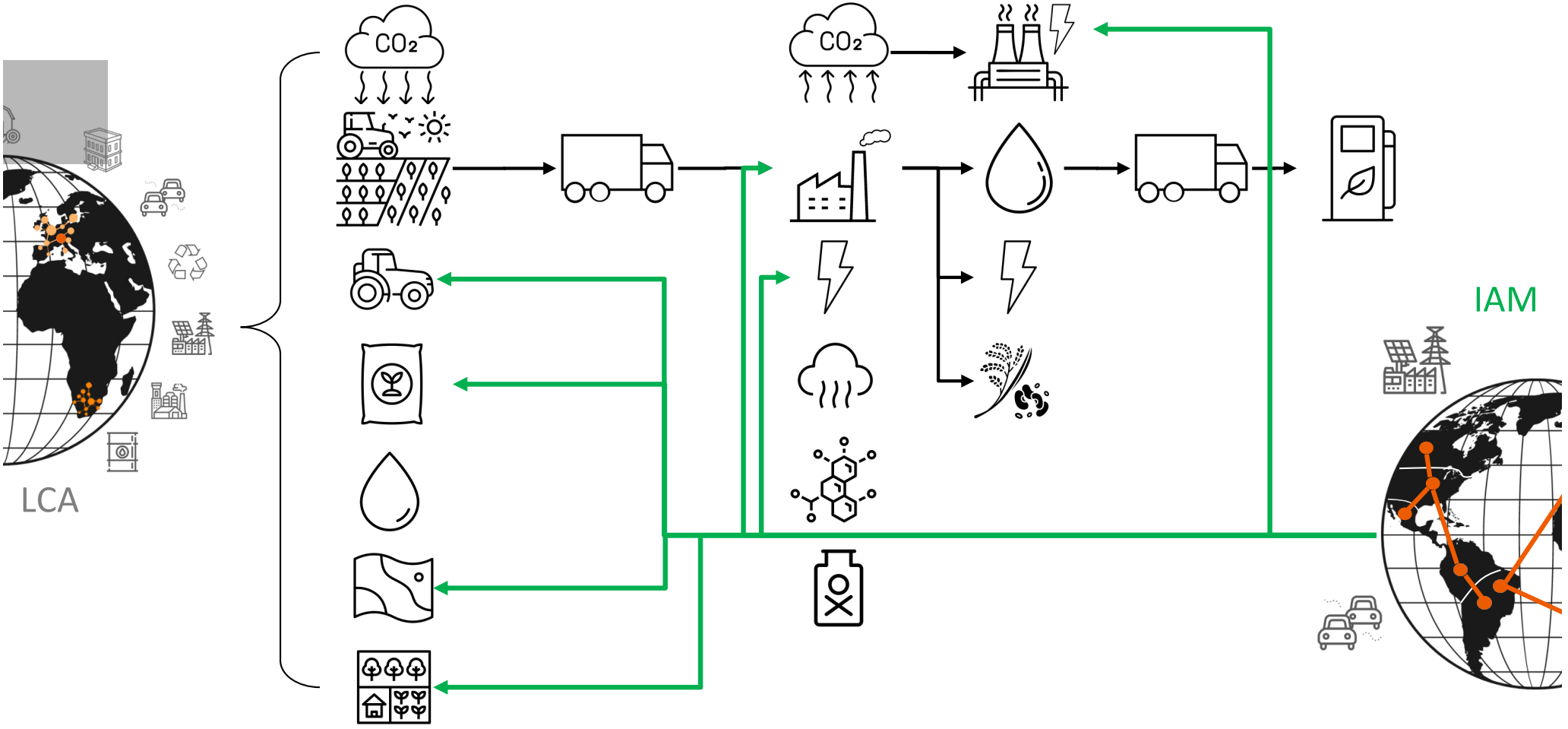
Add carbon capture and storage where needed

# Example of transformation



PAUL SCHERRER INSTITUT

# Biofuels



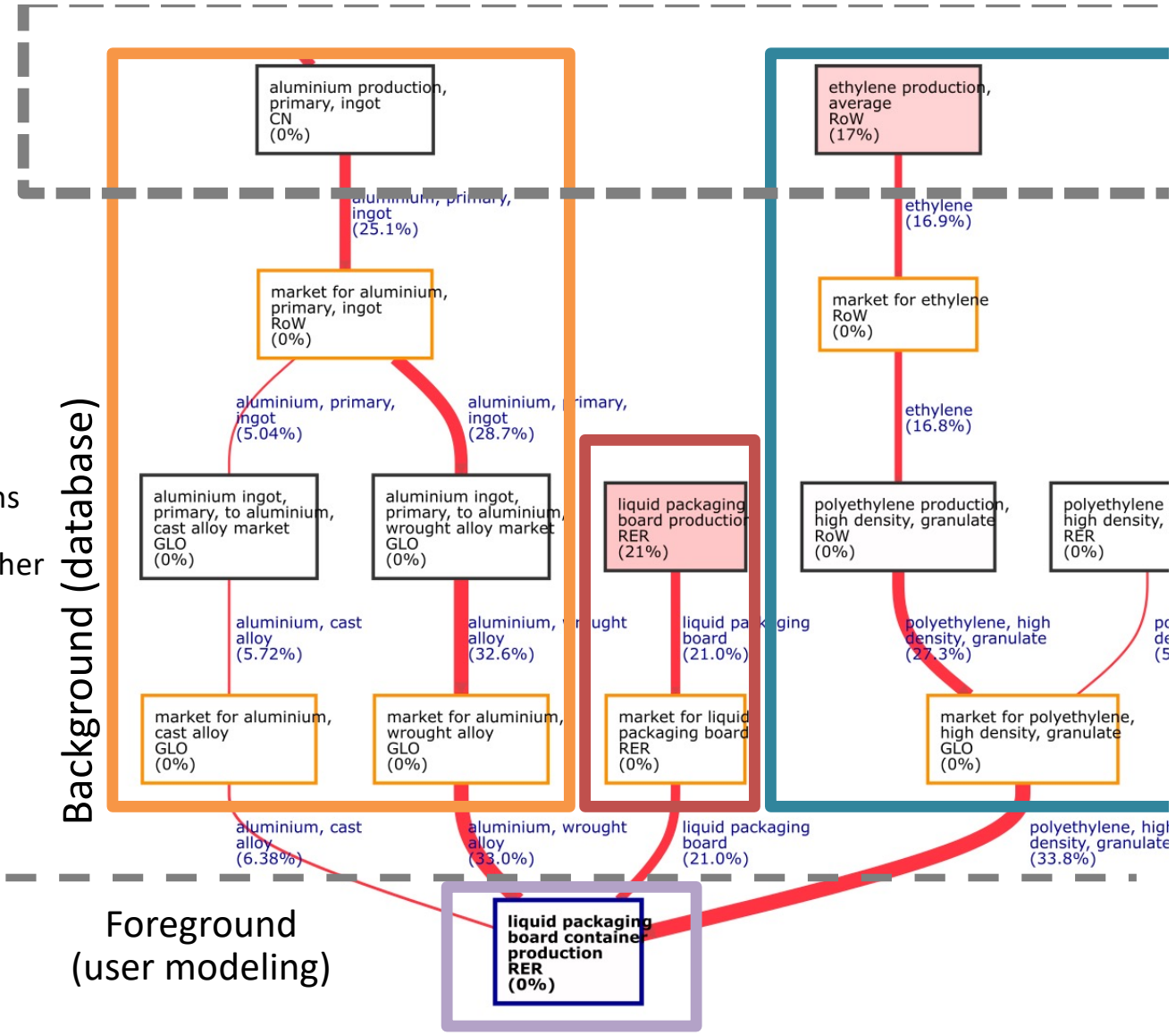
PAUL SCHERRER INSTITUT

# Expected results

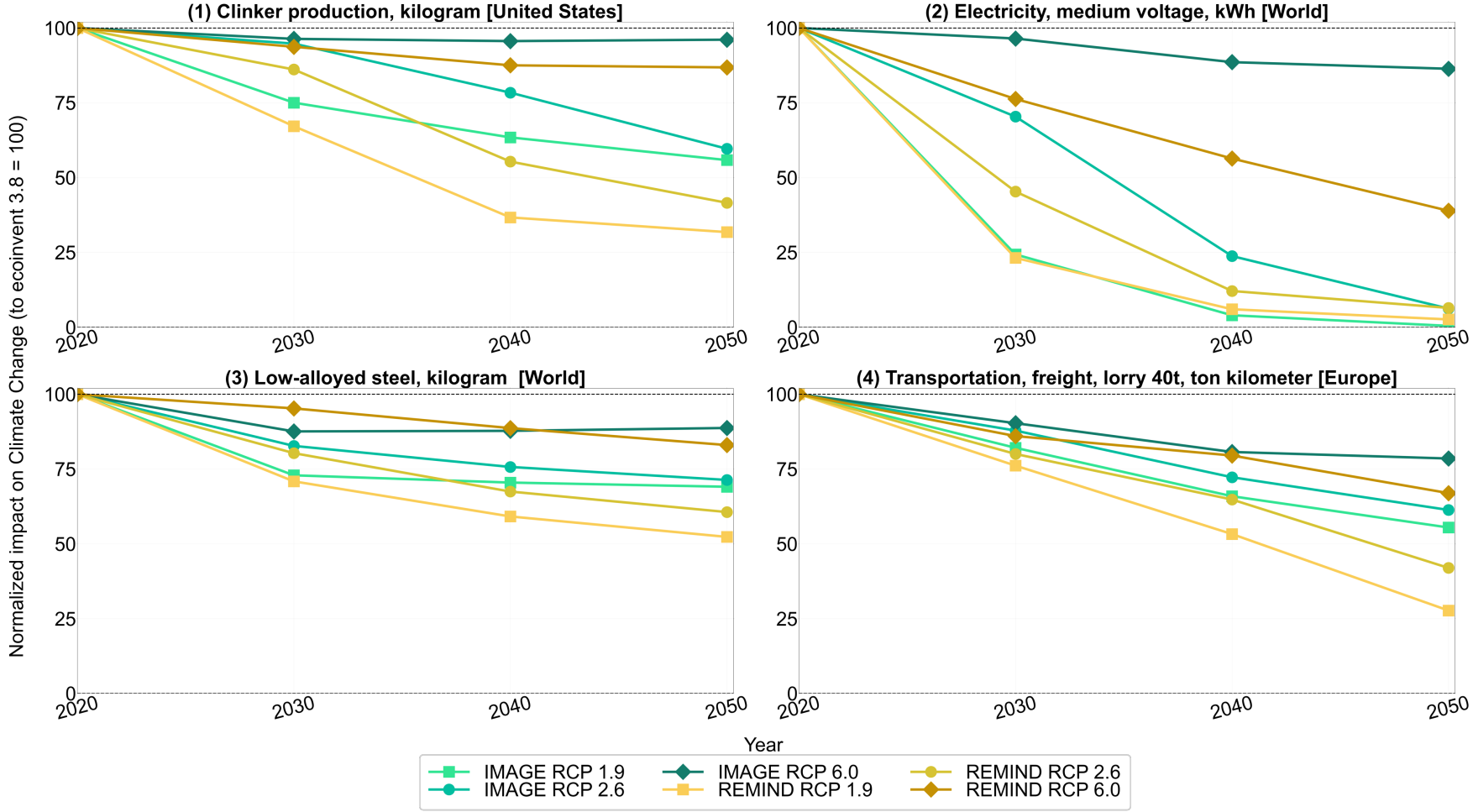
- Foreground modeling (new packaging design)
- Packaging-specific processes
- Plastics industry projections
- Aluminium industry projections
- Regional scenario (IAM) for other products (e.g., electricity, transport, etc.)

The whole system (foreground + background) becomes temporally-adjusted:

- Efficiencies change
- Market shares change
- Packaging designs change

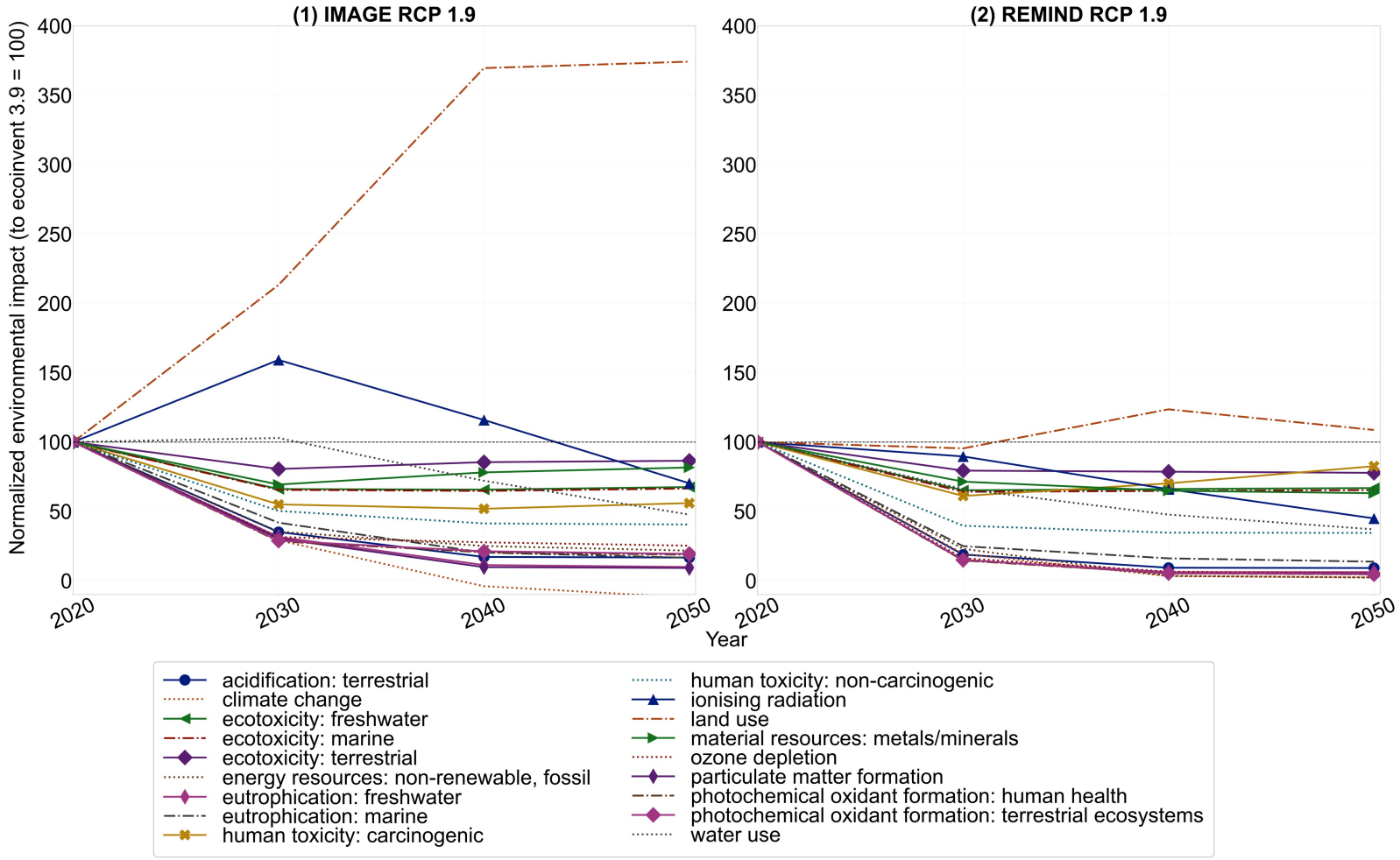


# Efficiency change across time and scenarios

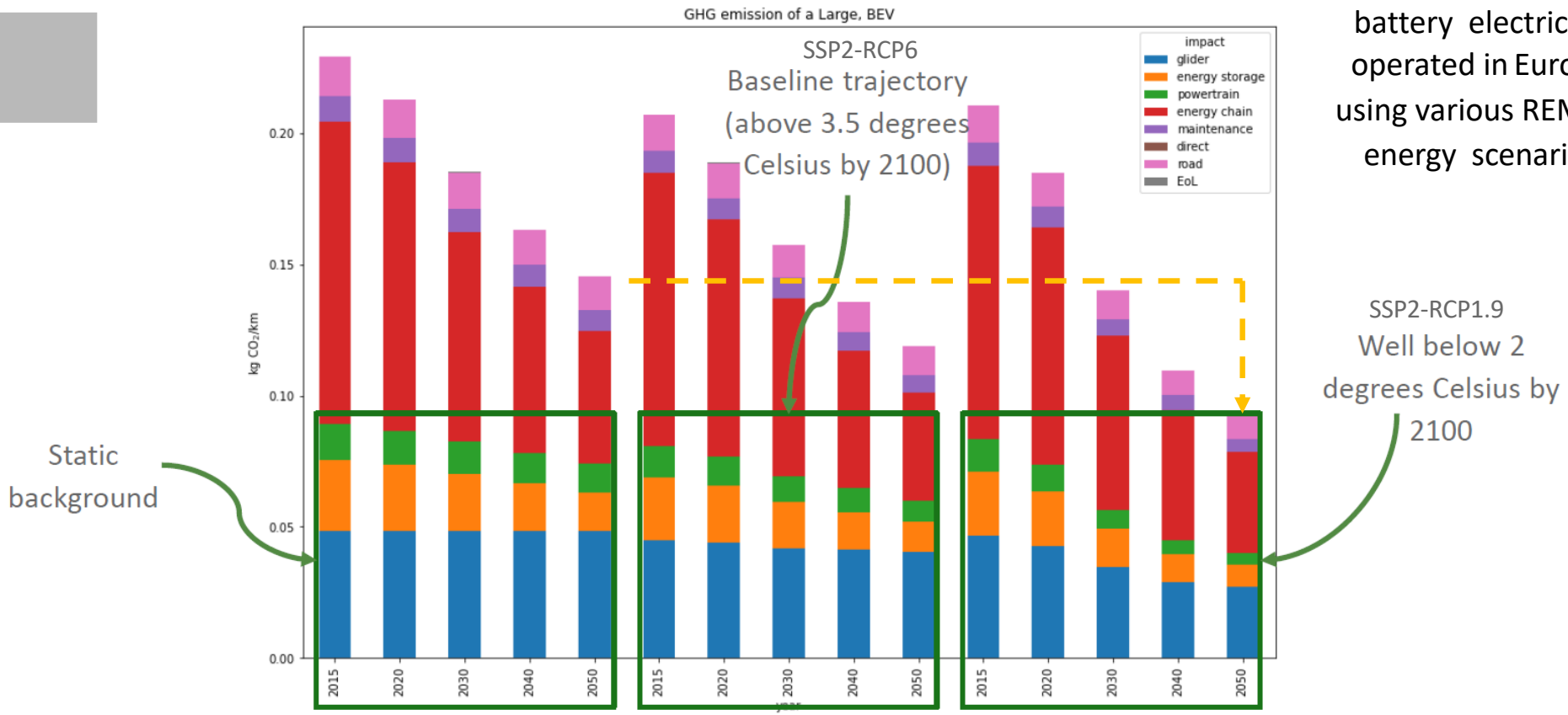


PAUL SCHERRER INSTITUT

# Indicators evolution across time and scenarios



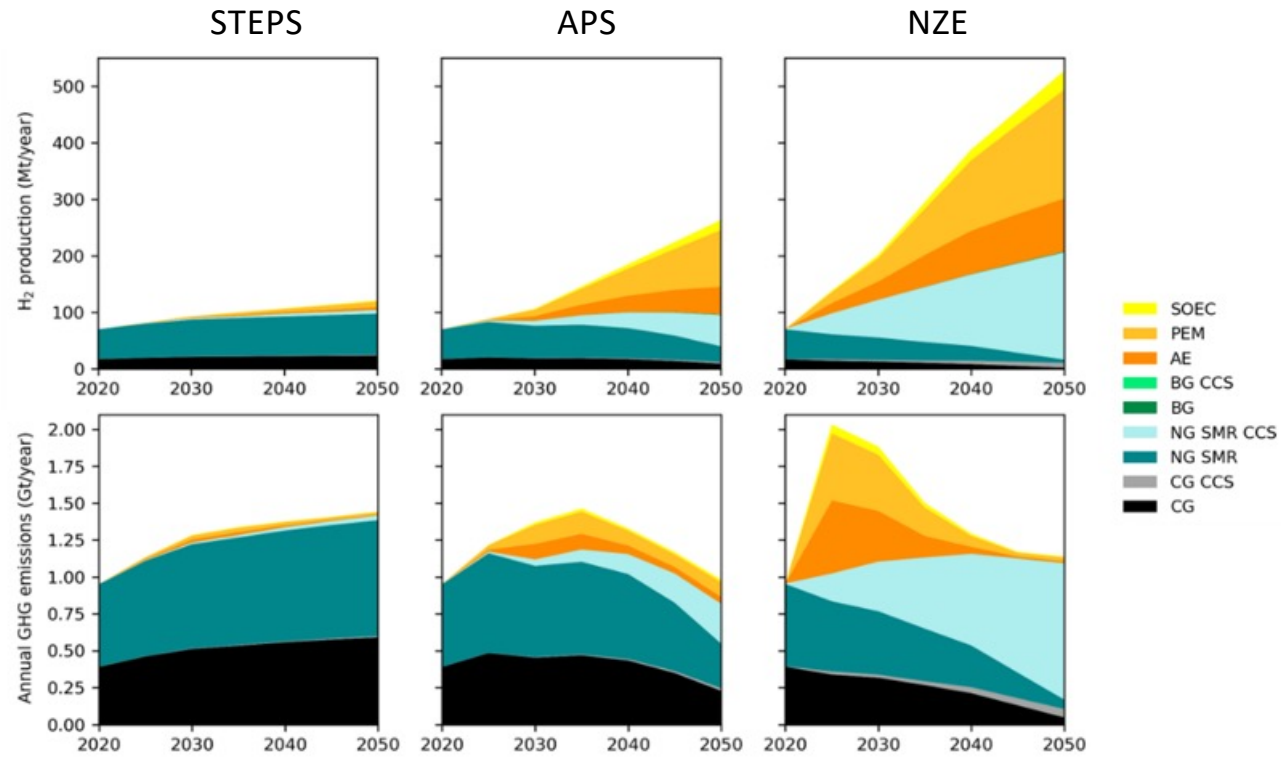
# Battery-electric cars




Example for a large size battery electric car operated in Europe, using various REMIND energy scenarios.

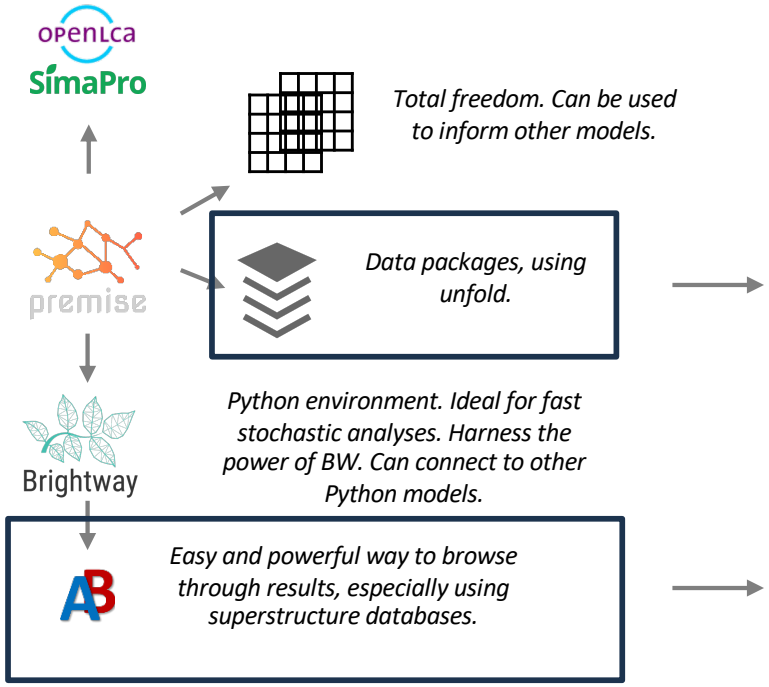
# Hydrogen (Wei et al. 2024) https://doi.org/10.1039/D3EE03875K

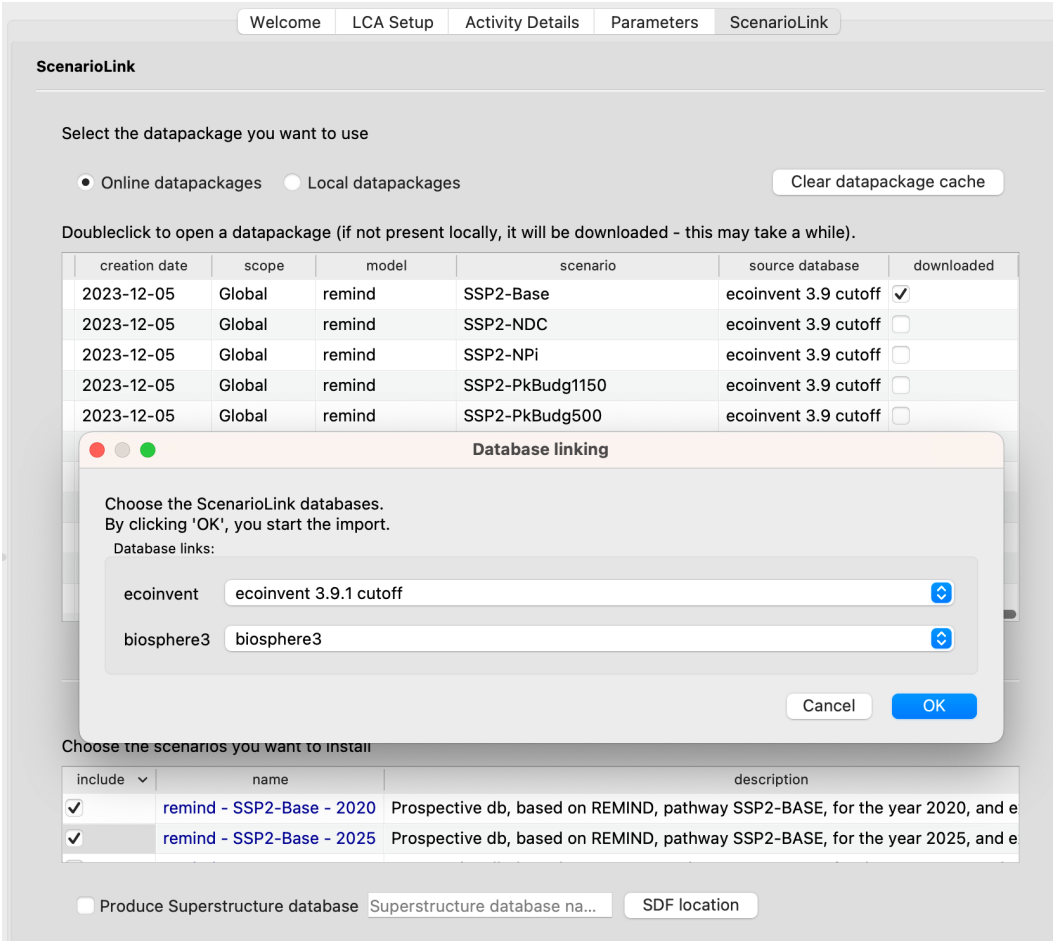
Hydrogen production alone may use up 12% of the remaining carbon budget for the 1.5 °C!
Strong decarbonization of future hydrogen production possible, but requires faster development of renewable electricity supply and electrolysis



# Integration in LCA software

*premise*'s outputs play nicely with *Activity Browser*, using *superstructure* databases




*Example of using premise with AB's superstructure databases.*

# What's coming?

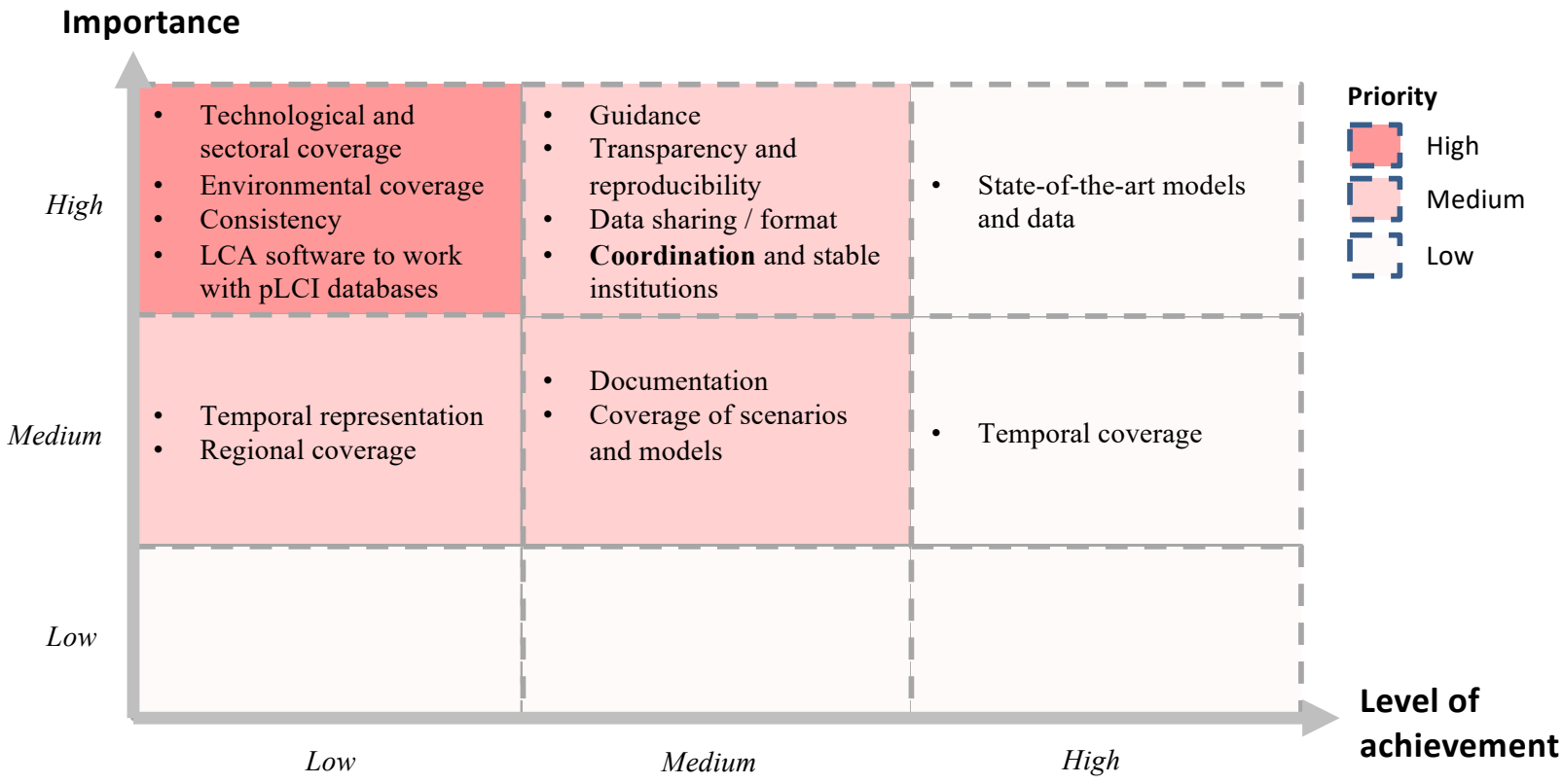
- Heat integration
  - Currently, only mobile heat generators decarbonize (via fuel blend modification)

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

- Scenarios from three additional IAMs
  - Message-ix, Ti-IAM, GCAM

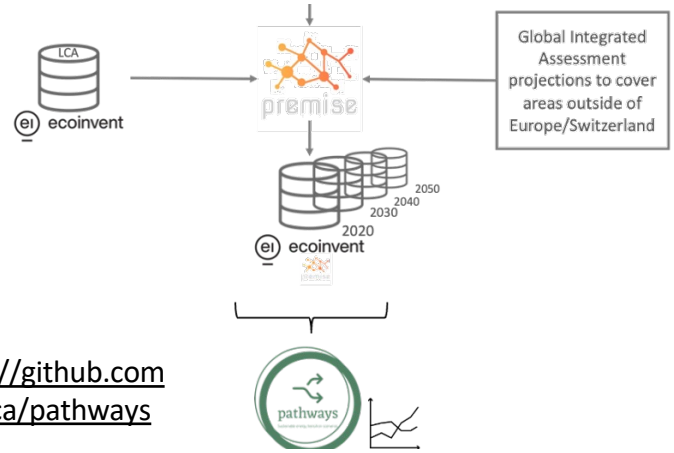
- *pathways*
  - A new library for scenario- or sector-wide LCA (next slide)

# Prioritizing future actions

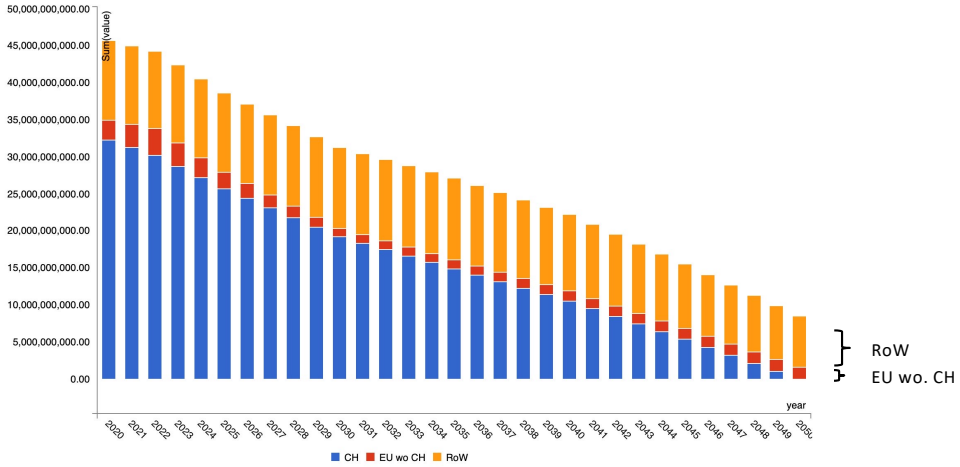



Steubing B, Mendoza Beltran A, Sacchi R (2023) Conditions for the broad application of prospective life cycle inventory databases Int J Life Cycle Assess doi:10.1007/s11367-023-02192-8

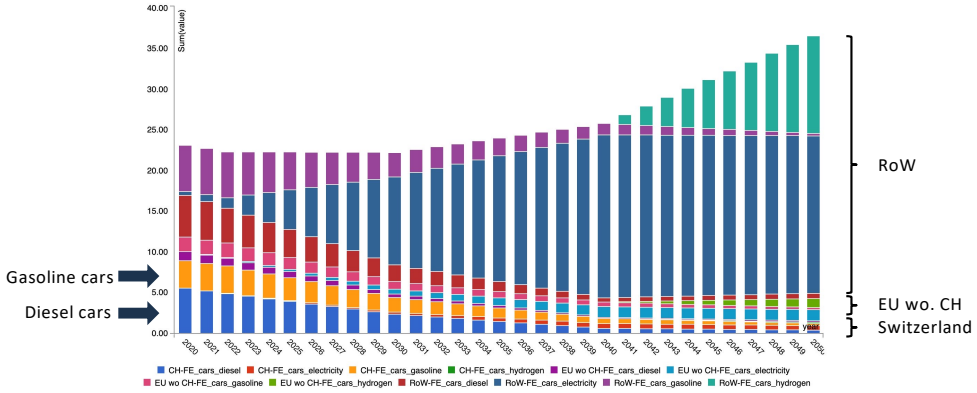
# Pathways: Prospective LCA of the whole system



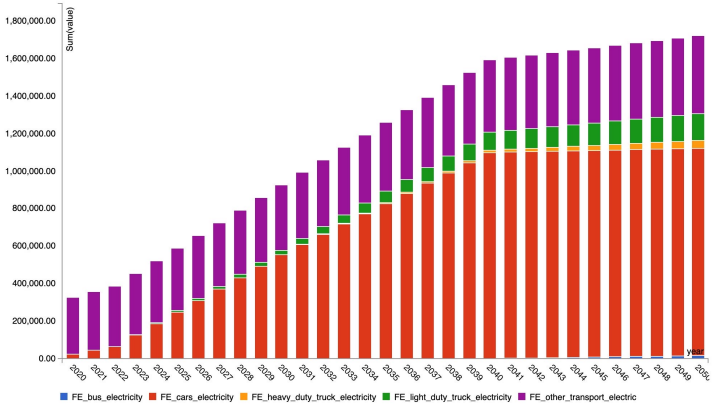

https://github.com/polca/pathways




Global Warming impacts, in kilograms of $CO_2$-eq., for the system-wide final energy supply in switzerland, by geographical origin (Switzerland, EU without Switzerland and Rest-of-World), for the SPS1 scenario. Preliminary results.




Ecosystem impacts (in species-year lost) for Swiss passenger cars fleet, per powertrain type, per impact origin (Swiss TIMES model). Electrification of transport leads to reduce ecosystem impacts in Switzerland but increased impacts abroad (notably because of the increased demand for cobalt, lithium,




Demand for lithium, in kilograms, across electric mobility options (Swiss TIMES model).

# 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 to:
     - Brightway/Activity Browser
     - Simapro CSV
     - OpenLCA CSV
     - Sparse matrices

2. I generate databases via Activity Browser:
   - From a local ecoinvent copy: ScenarioLink plugin

# Open source tools

- *Brightway2* (LCA framework): https://github.com/brightway-lca
- *Activity-Browser* (GUI for Brightway2): https://github.com/LCA-ActivityBrowser/activity-browser
- *Brightway-superstructure* (multiple-scenario database): https://github.com/LCA-ActivityBrowser/brightway-superstructure
- *premise* (IAM-LCA coupling): https://github.com/polca/premise
- *wurst* (fast handling of LCA databases): https://github.com/polca/wurst

# Wir schaffen Wissen – heute für morgen

Technology Assessment Group

**https://www.psi.ch/en/ta**

Questions?

Romain Sacchi

**romain.sacchi@psi.ch**