Including broad future scenarios in prospective LCA

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PSI

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Imperial Life Cycle Network

Today's talk

1. Prospective LCA and scenarios (Bernhard, 7 min)
2. IAMs and Premise (Romain, 20 min)
3. Tools in practice (Bernhard, 10 min)

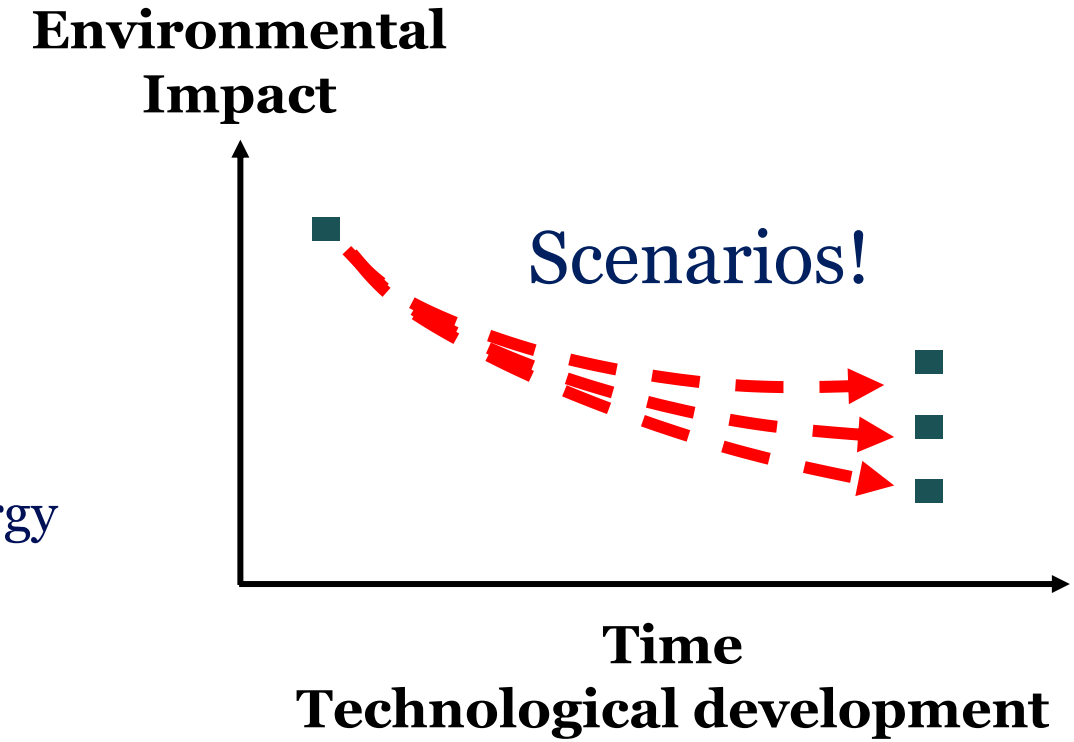
Part I
Prospective LCA and scenarios

Why prospective LCA and scenarios?

- We need to **transform our economies** to avoid catastrophic climate change and other environmental consequences
- This requires **sustainable technology**
- **Prospective LCA** helps to **anticipate** environmental impacts of **early-stage** 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**.

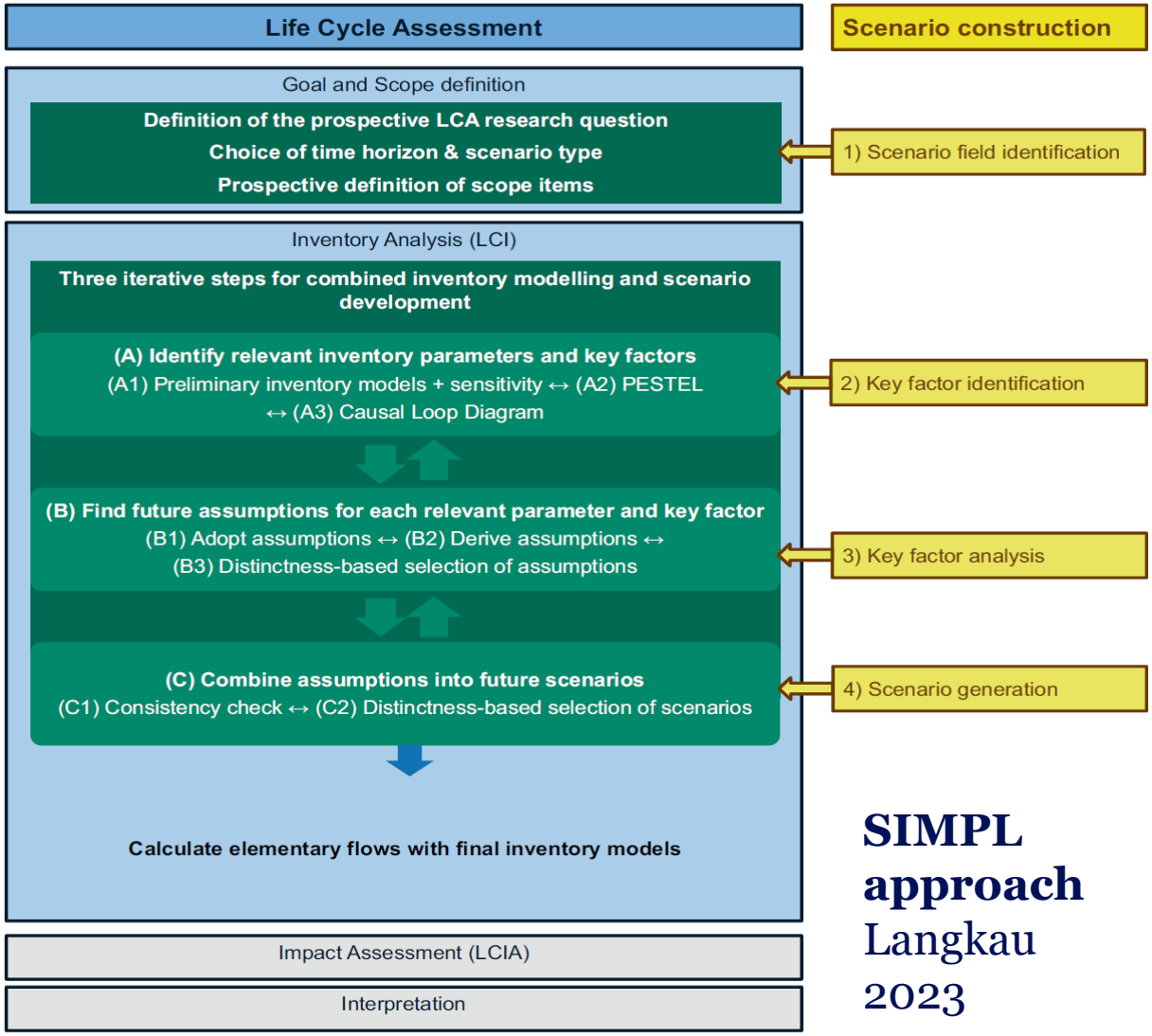
pLCA builds on scenarios

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)



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 2022
- Scale up frameworks: Piccinno 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



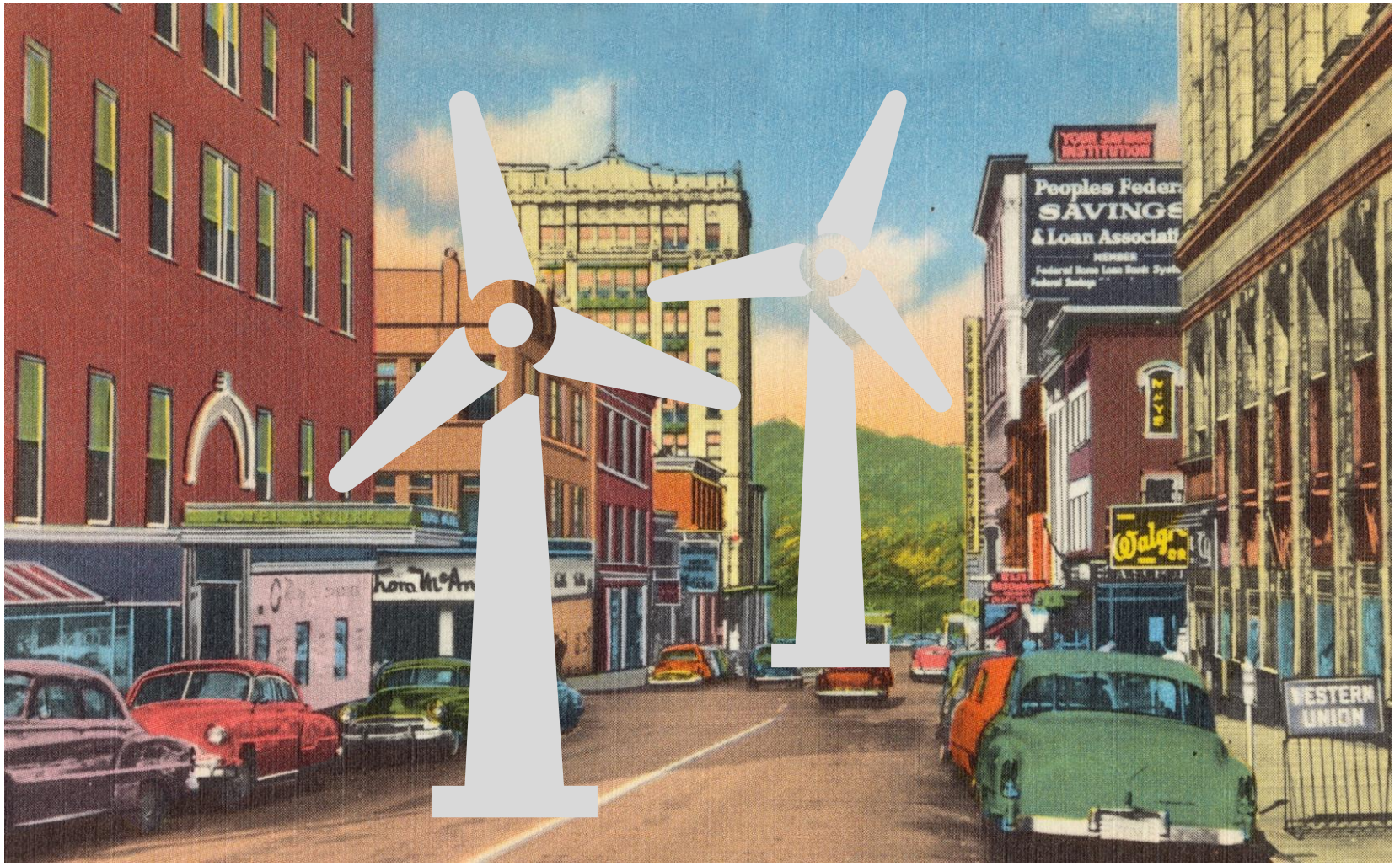
SIMPL approach Langkau 2023

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

Background scenarios

prospective LCA should consider developments in foreground *and* background systems in order to yield the right conclusions

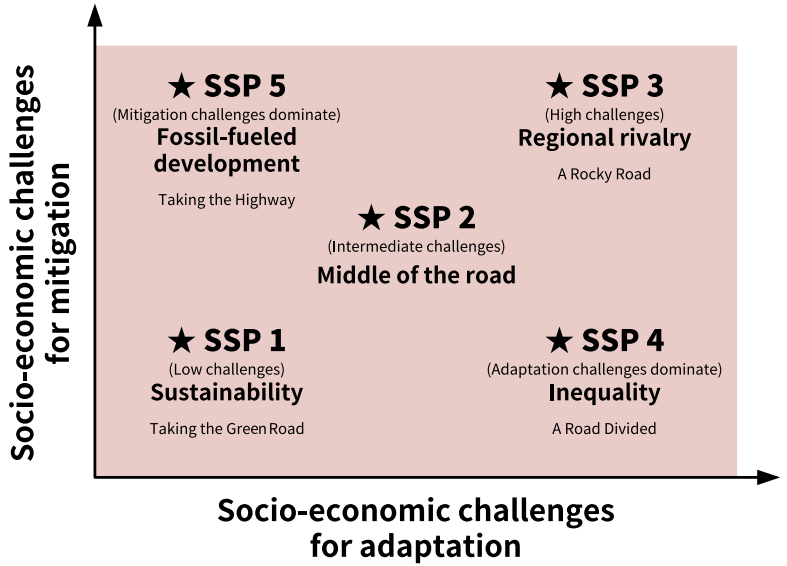
➔ *temporal consistency*, see e.g. Mendoza Beltran 2018

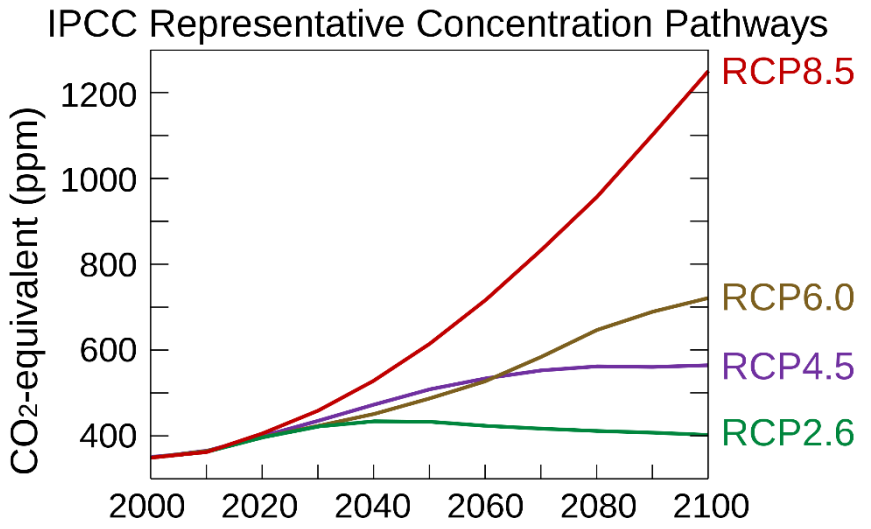


Mendoza Beltran A et al. (2018) When the Background Matters: Using Scenarios from Integrated Assessment Models in Prospective Life Cycle Assessment J Ind Ecol
"Temporal mismatch" by Brenda Miranda Xicotencatl, 2022

Developing background scenarios / prospective LCI databases: milestones

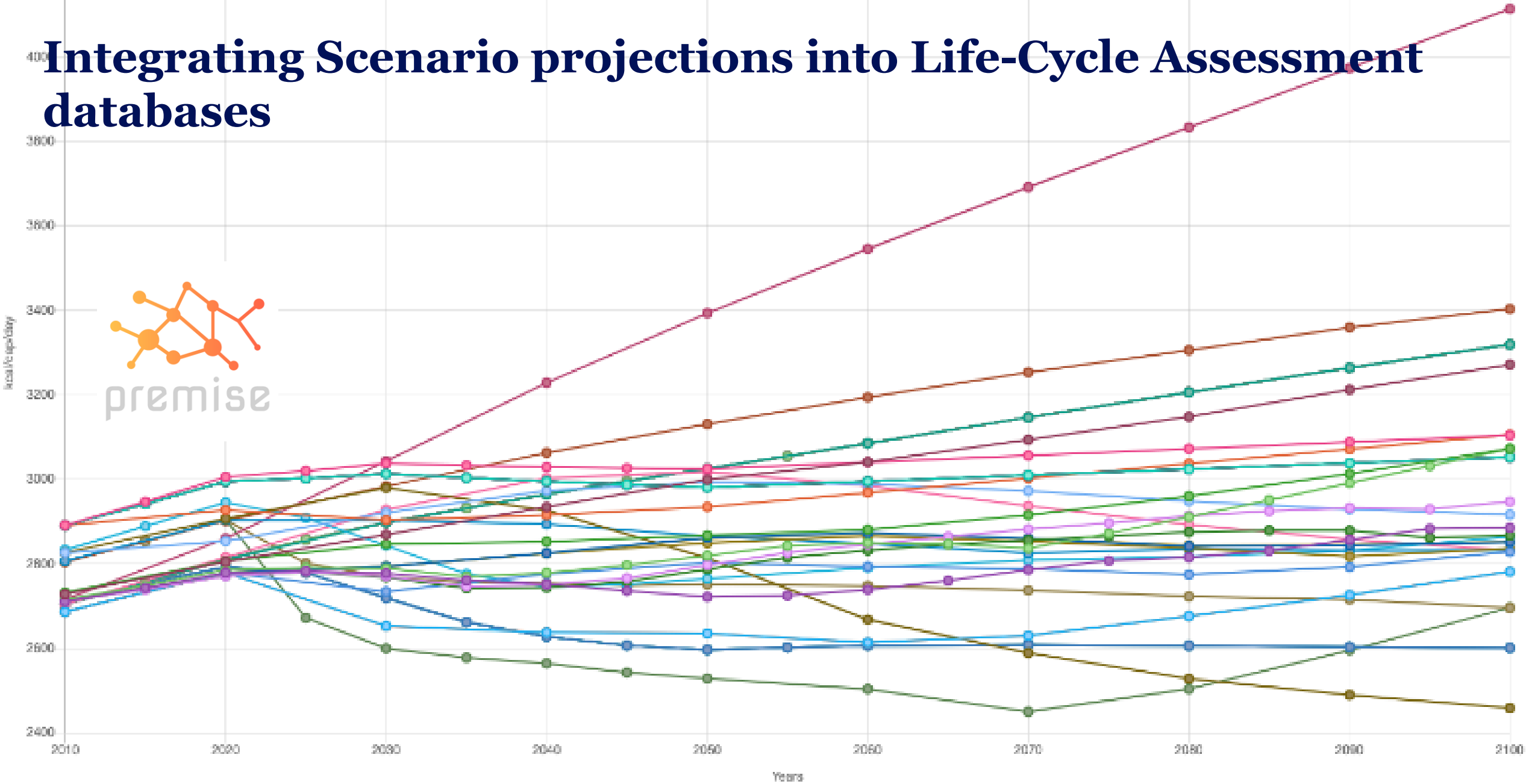
- NEEDS project (2004-2009)
  - First systematic approach to generate future scenarios of the ecoinvent database (electricity supply and other sectors)
- THEMIS model (Gibon 2015; Hertwich 2015)
  - Hybrid (MRIO-LCA) model including IEA energy and NEEDS scenarios
- "When background matters" (Mendoza 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, …

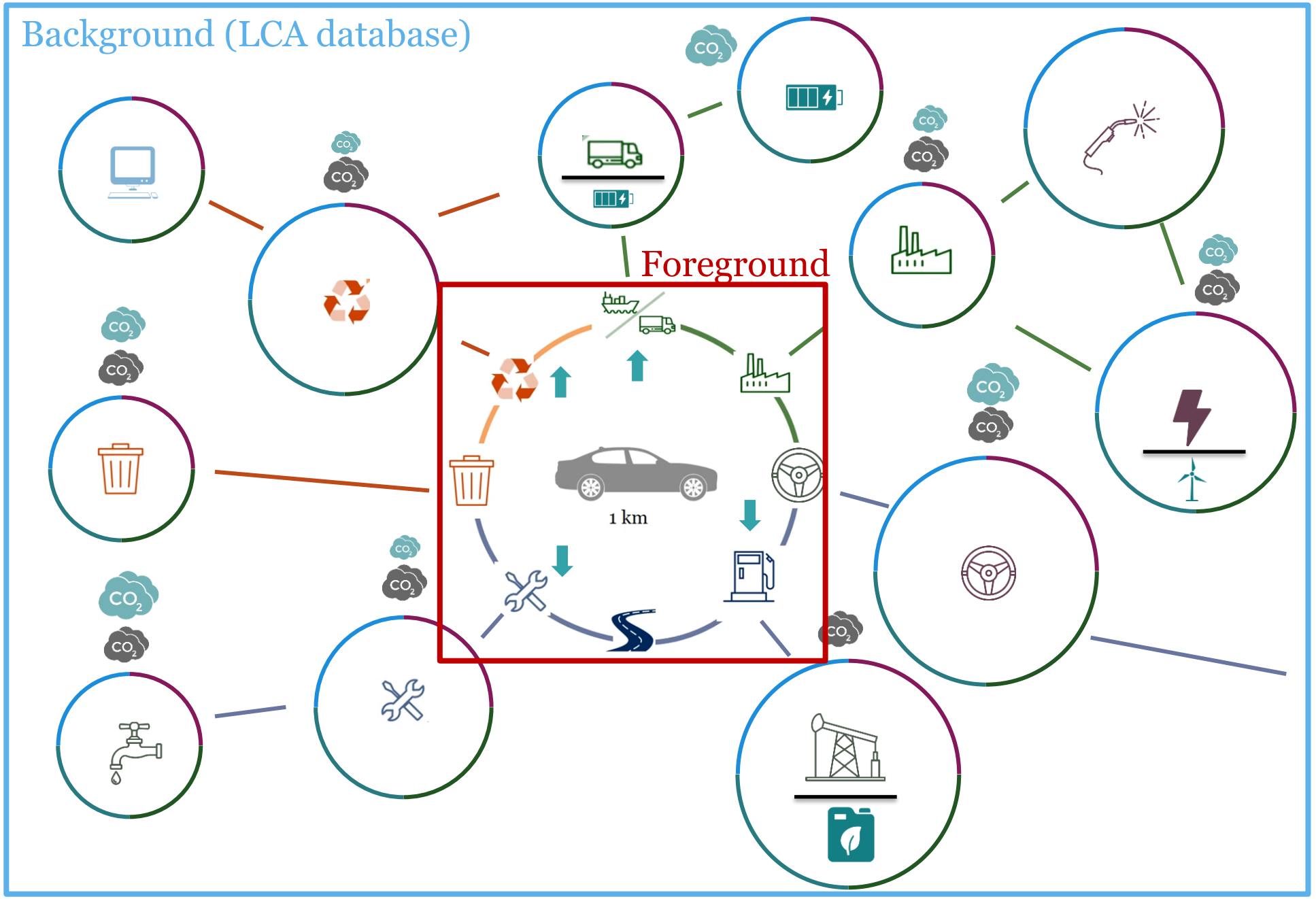




Part II
IAMs and Premise

Integrating Scenario projections into Life-Cycle Assessment databases





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.

IAM/ESM world vs. LCA world

Current 2030 2050 2100

Current

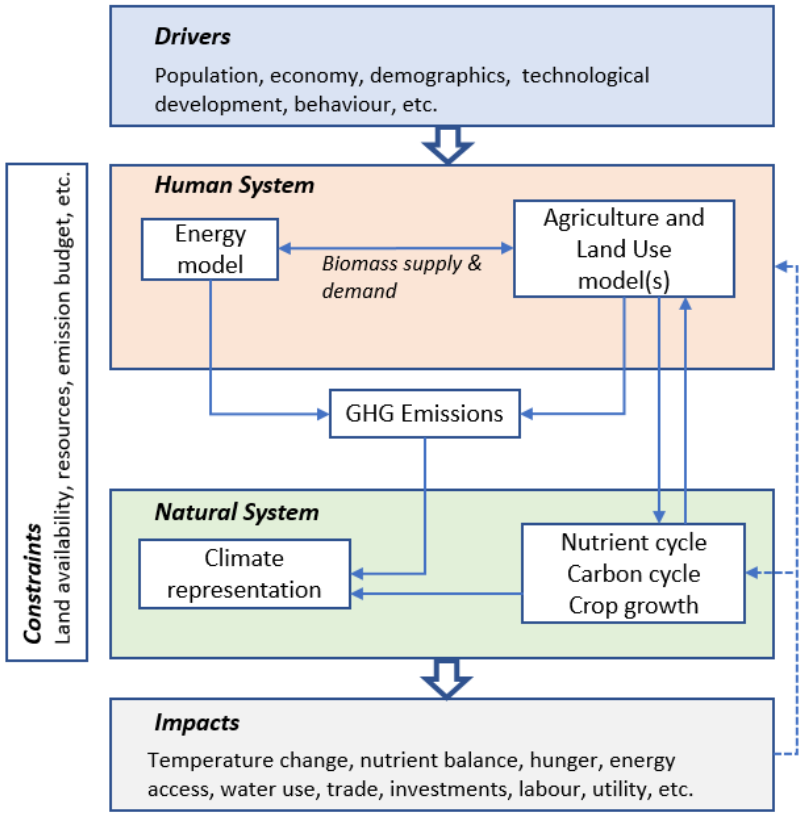
Integrated Assessment Models (IAM)

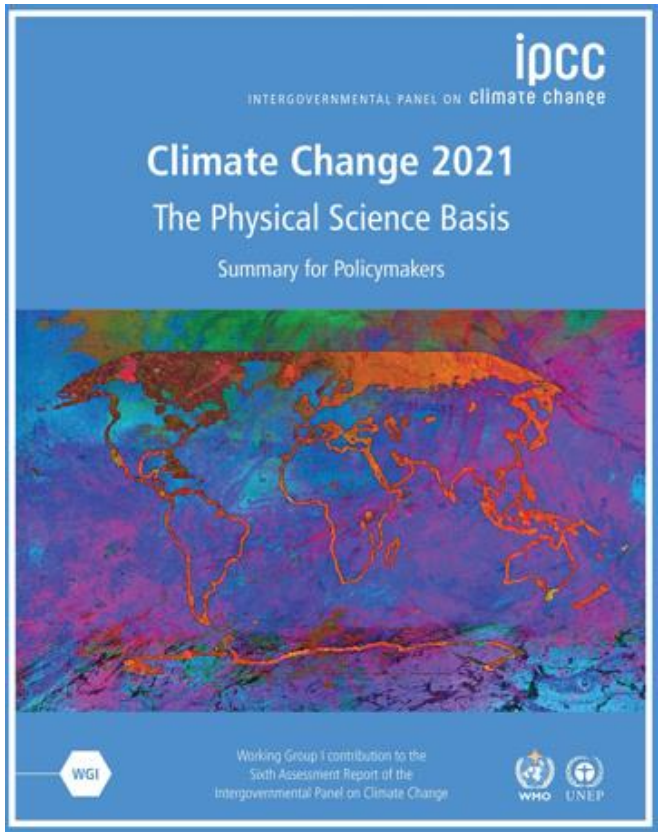
REMIND | IMAGE | GCAM | MESSAGE$_{ix}$ | TIAM-UCL

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

Contain stylized representations of
- Energy system
- Agricultural economy
- Climate
- Land system

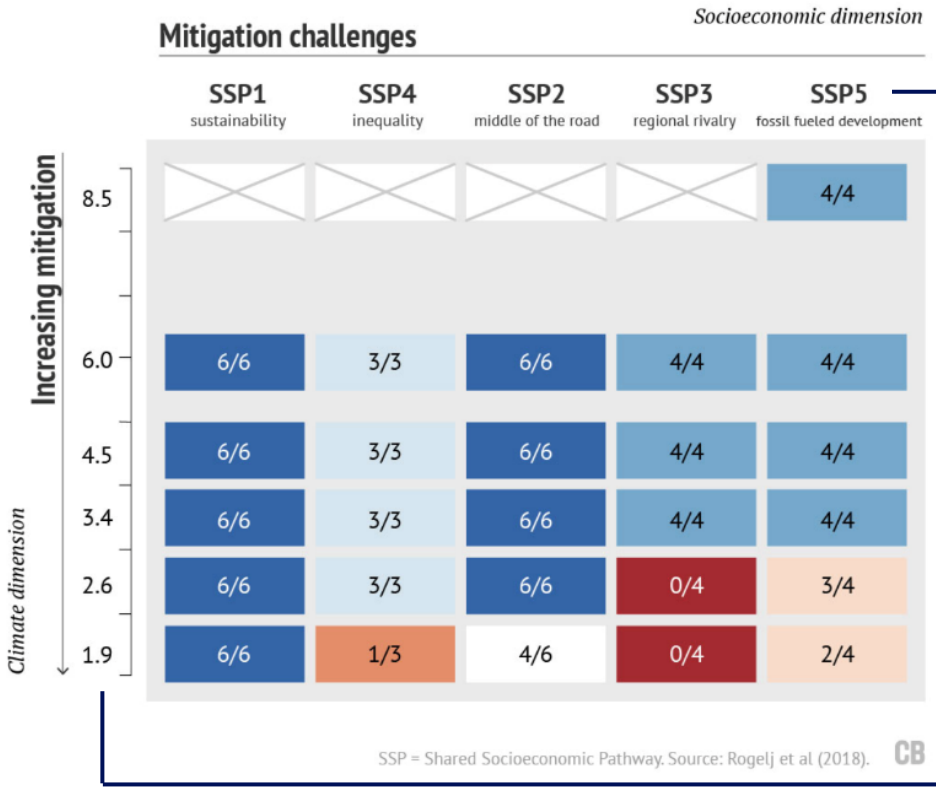
Bridge the Science/Policy interface
- Scenario Analysis: *What if?*
- What are the drivers or constraints of change?
- How do technology and policy choices lead to different outcomes?
- Uncertainties? Sensitivities?



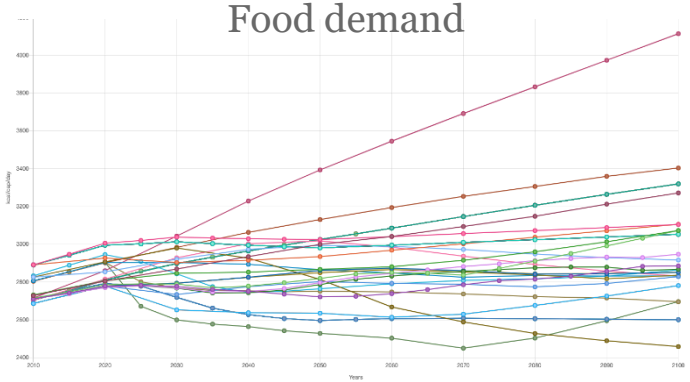


Socio-economic and climate constraints

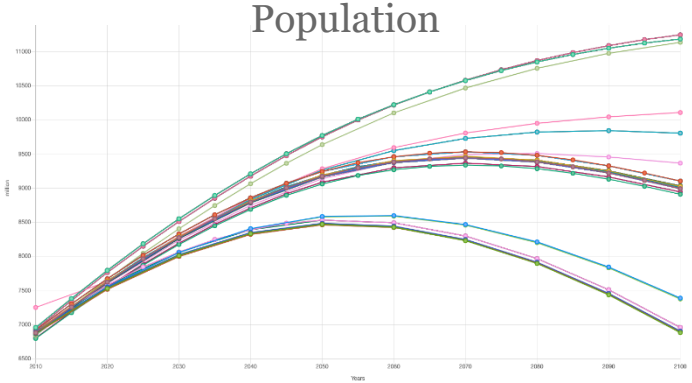
Socio-economic constraints (SSP)



Food demand

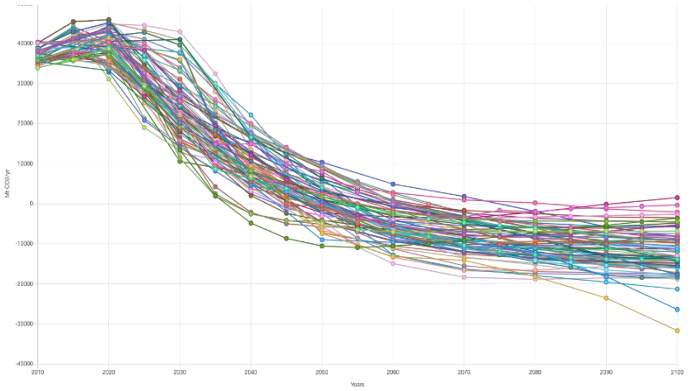


Population

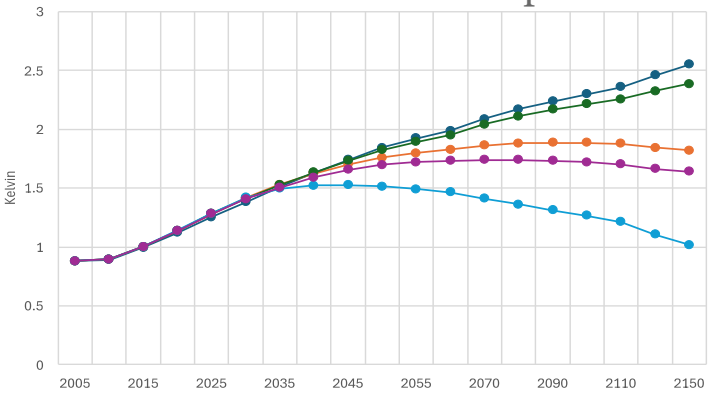


Climate constraints (RCP)

CO_2-eq emissions



Global Mean Surface Temp. Increase

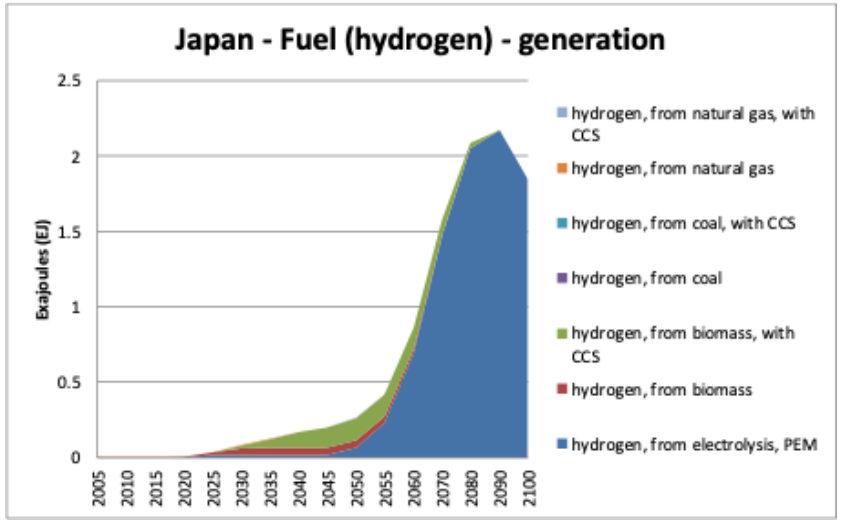


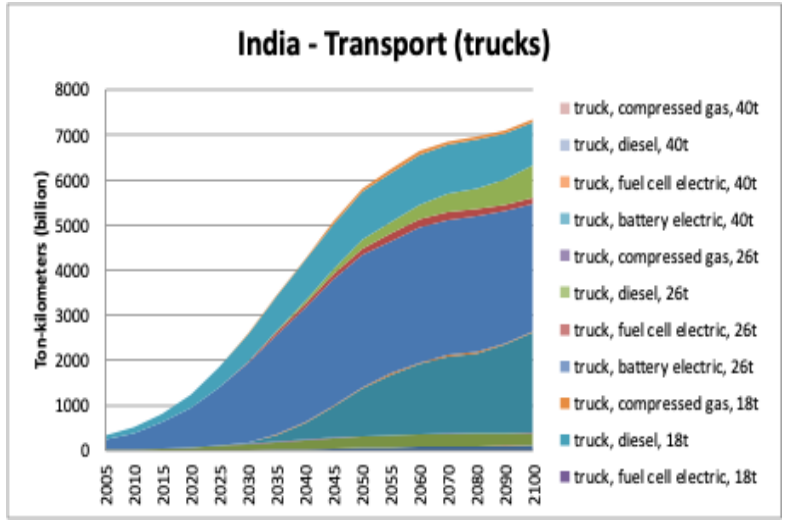
Credit: CarbonBrief, Zeke Hausfather, 2018.
https://www.carbonbrief.org/explainer-how-shared-socioeconomic-pathways-explore-future-climate-change

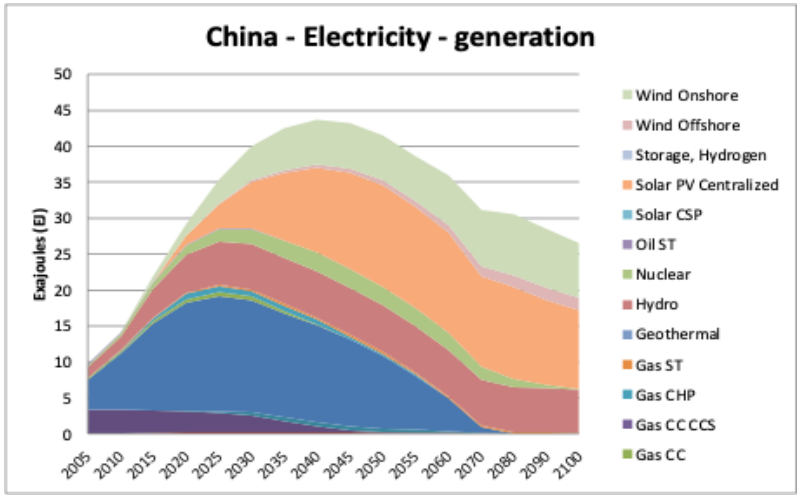
Projections on energy-intensive sectors

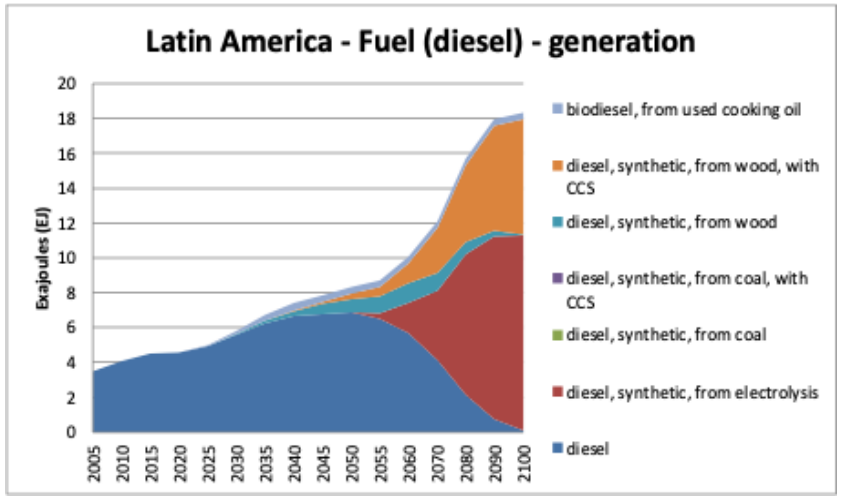
For each time step:

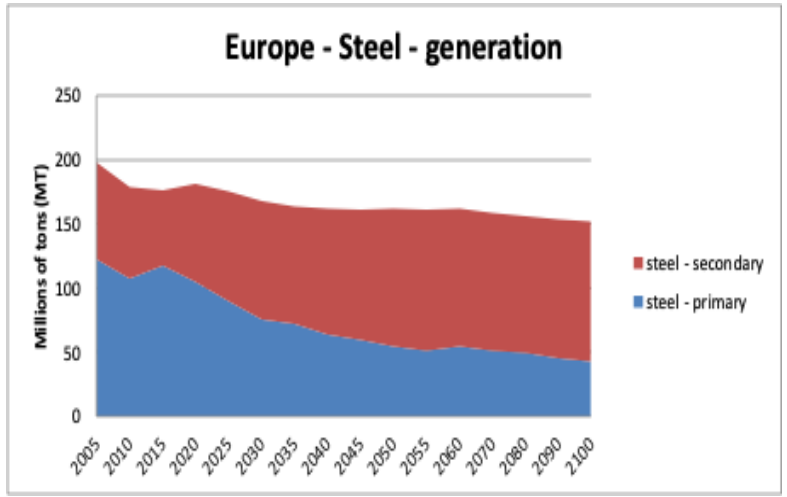
- Technology investments
- Capacity build-up
- Generation



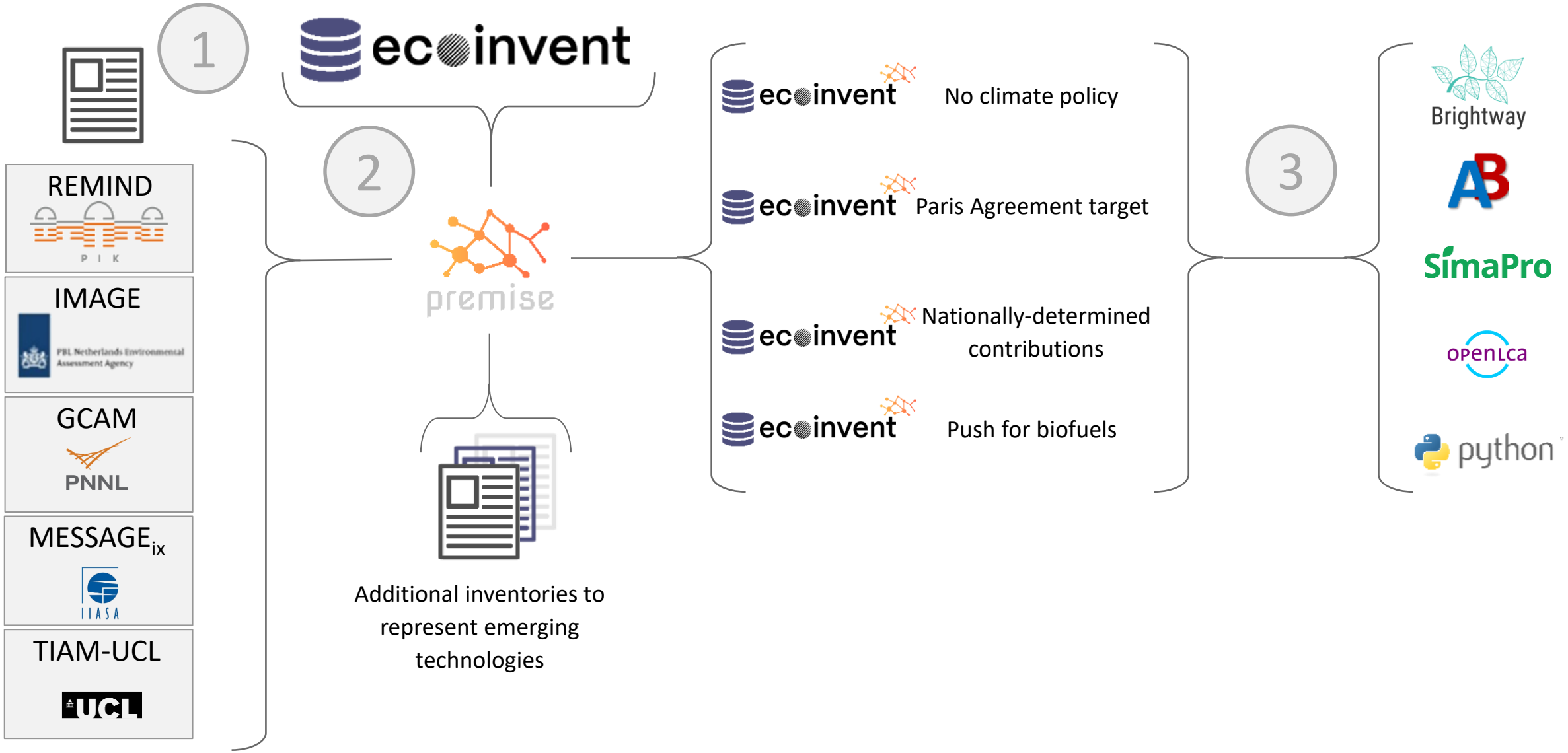






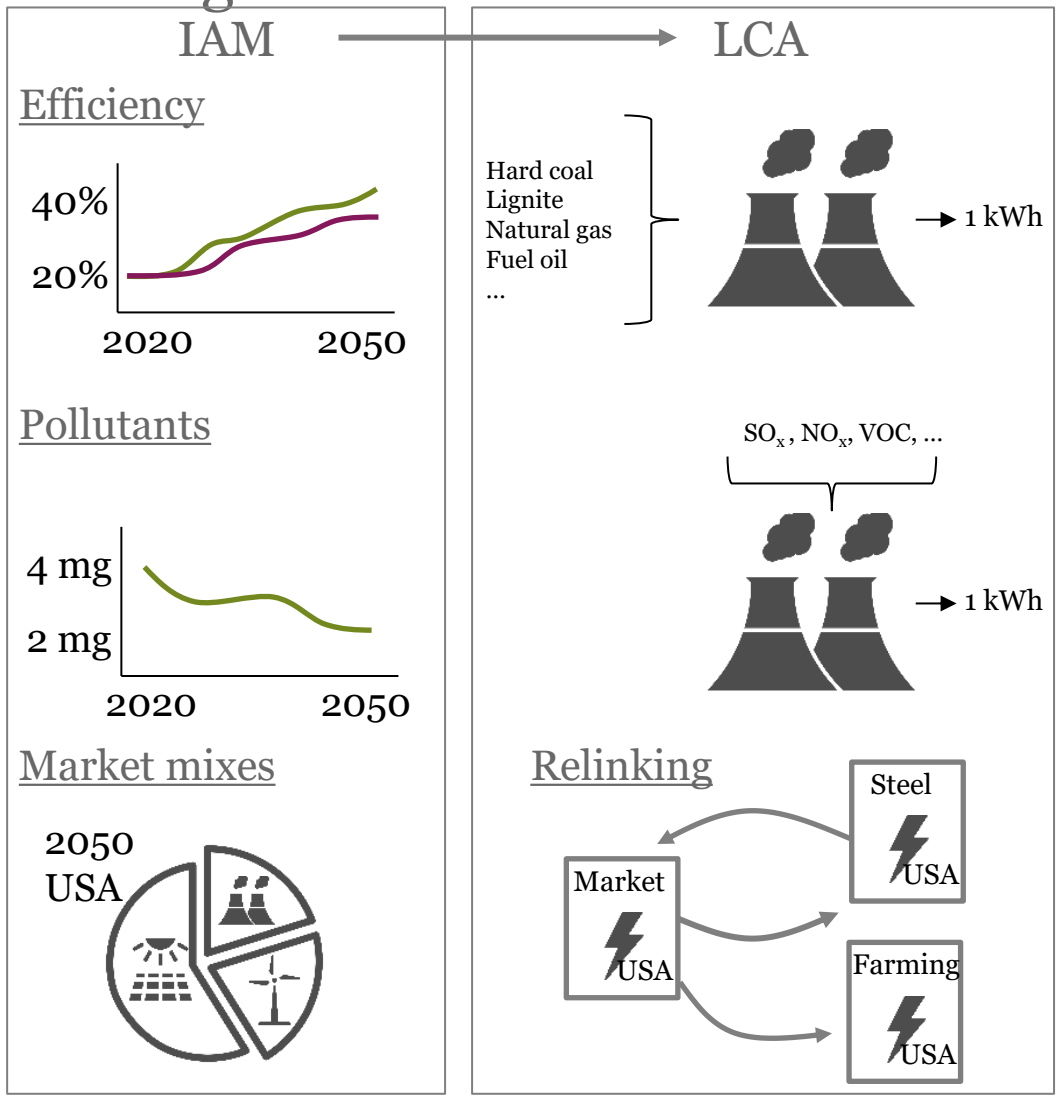


IAM ←→ LCA integration workflow

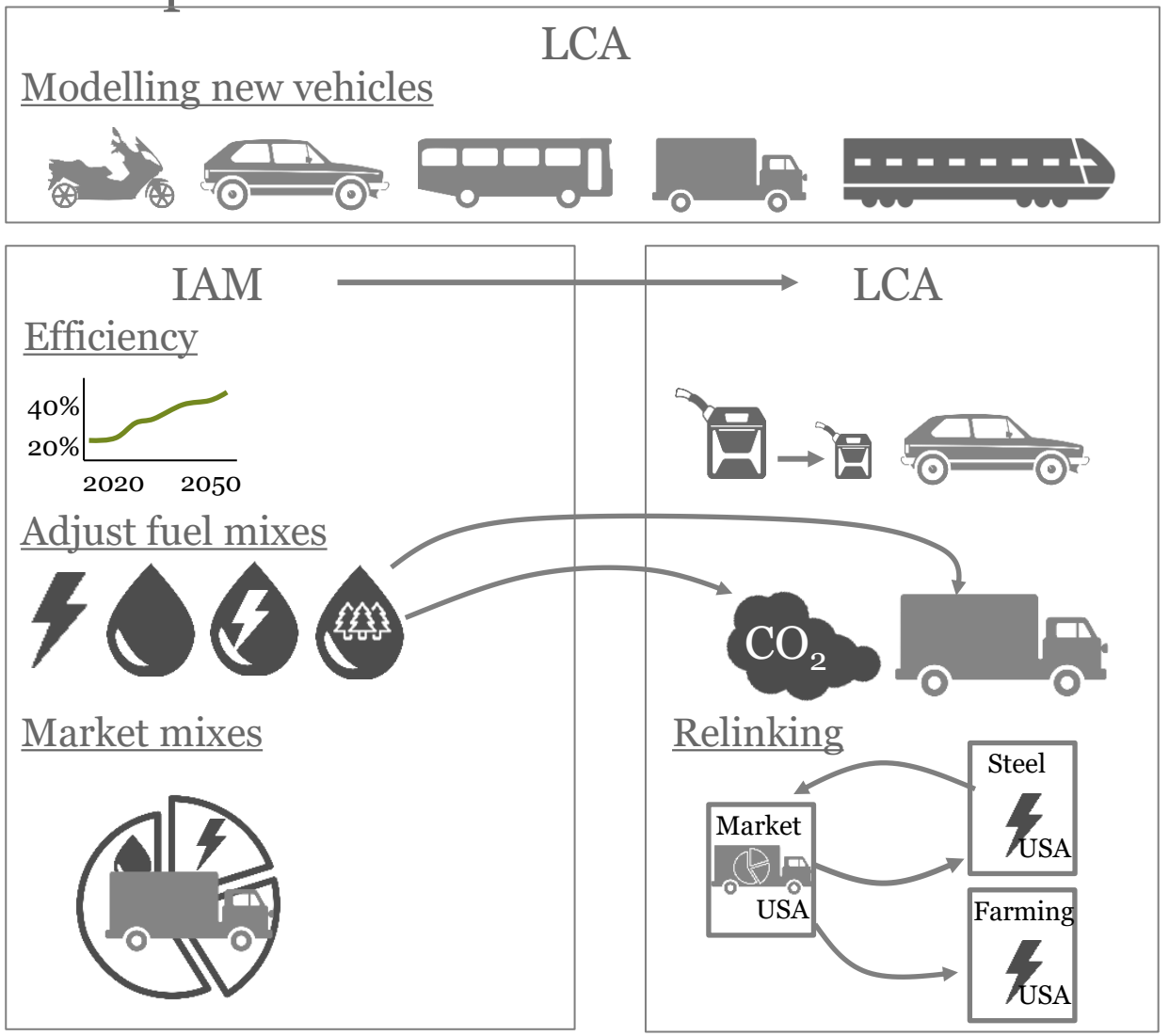


Example of transformation

Power generation



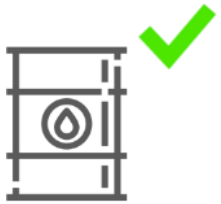
Transport



What does *premise* do?

Power

Create regional electricity markets
Adjust power plant efficiency



Fuels

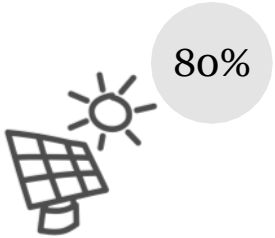
Create regional fuel markets
Add new production pathways (synthetic fuels)

Metals

Adjust critical raw materials use
Adjust future recycled content

Hot pollutant emissions

Adjust hot pollutant emission from GAINS



Renewables

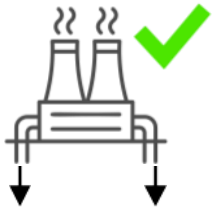
Adjust solar PV and wind turbines efficiency

Transport

Create market for passenger and freight road transport

Industry

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



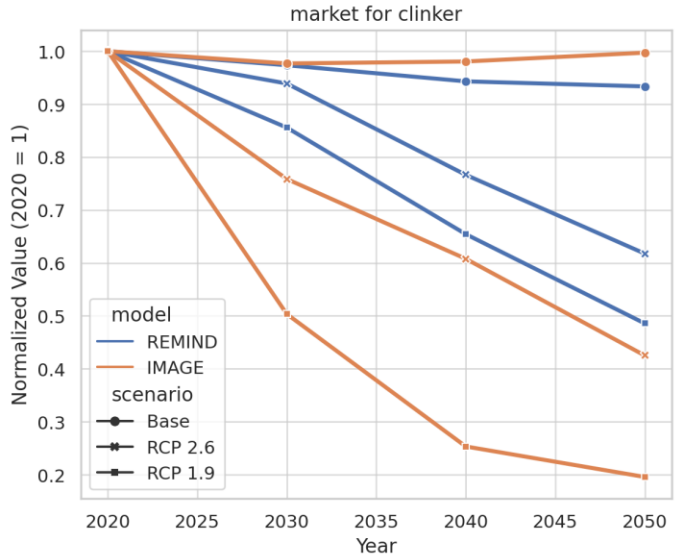
Carbon capture and storage

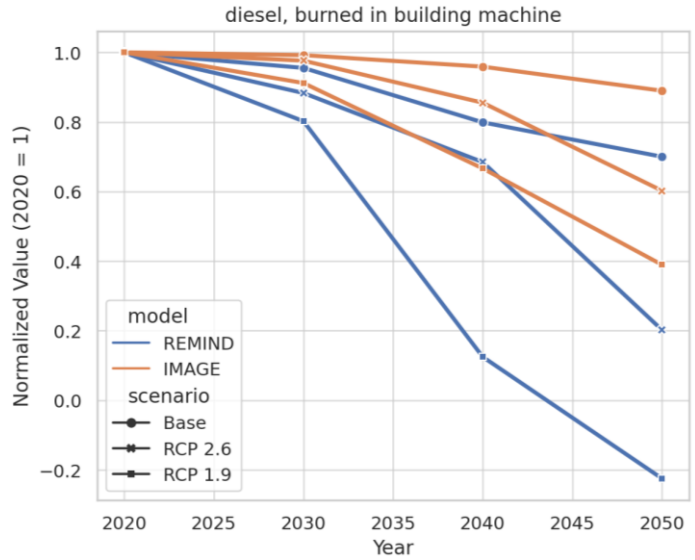
Add carbon capture and storage where needed

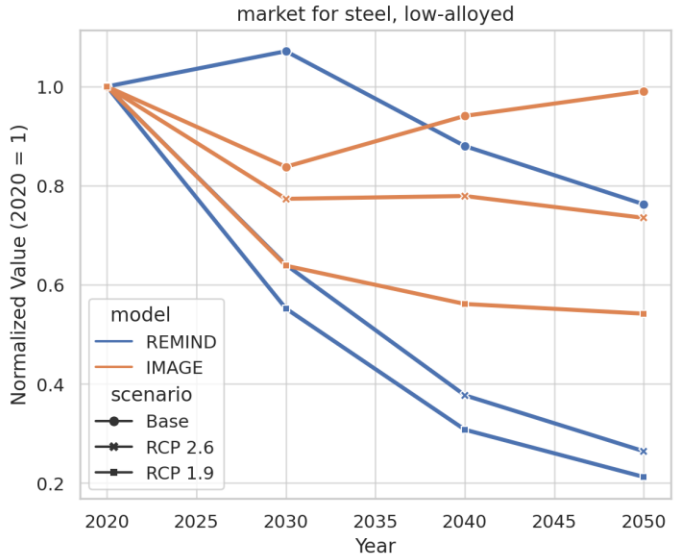
Climate change impacts across time and scenarios

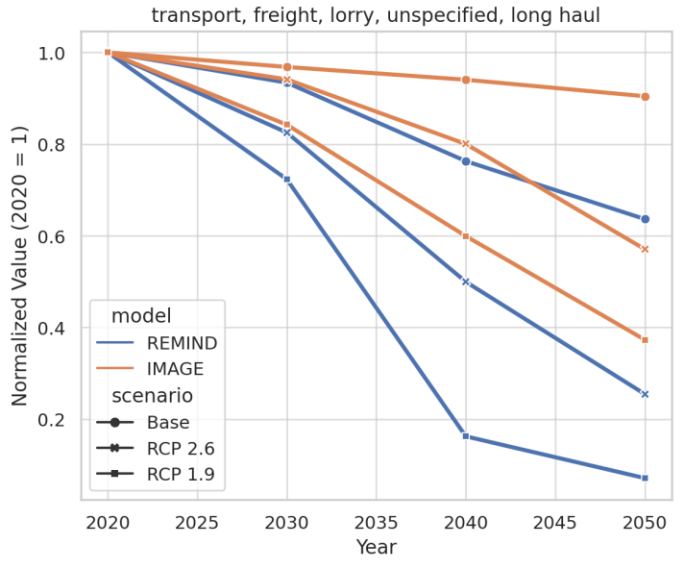
Base = No climate mitigiation
RCP 2.6 = <2 °C
RCP 1.9 = 1.5 °C

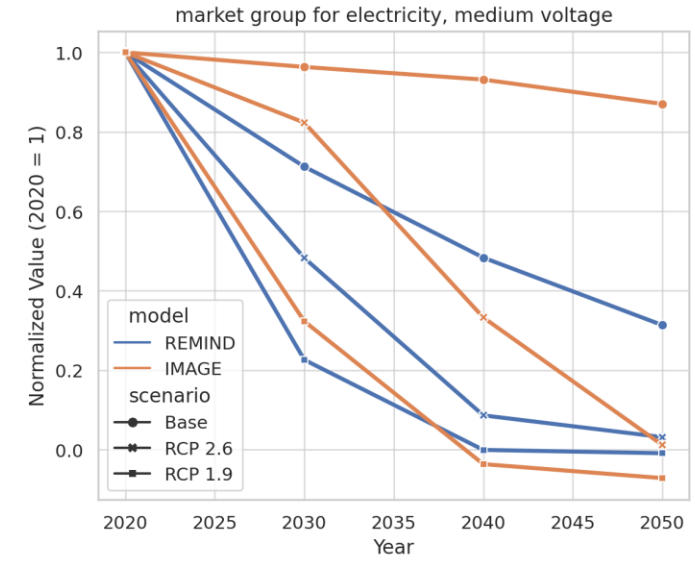
- Sectors decarbonize to a different extent across models and scenarios
- RCP 2.6 and 1.9 reach the same level of decarbonization, but RCP 1.9 reaches it earlier

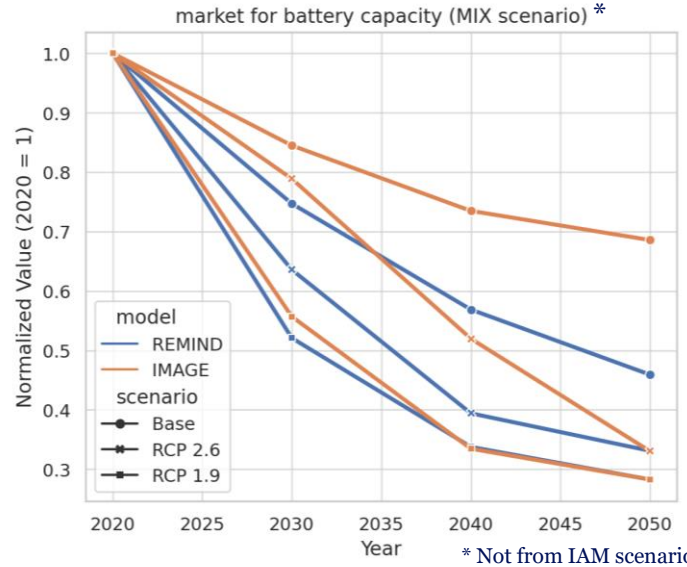






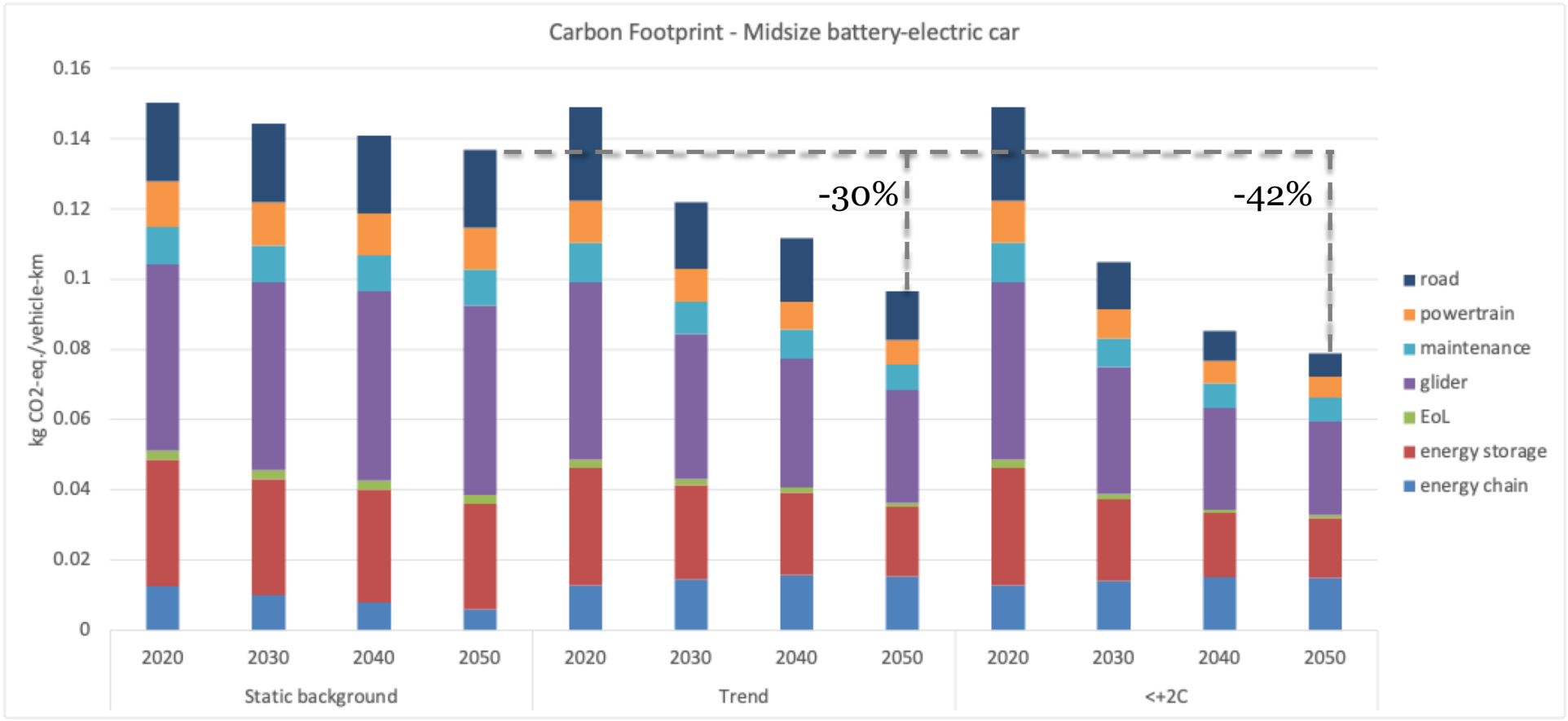






* Not from IAM scenario

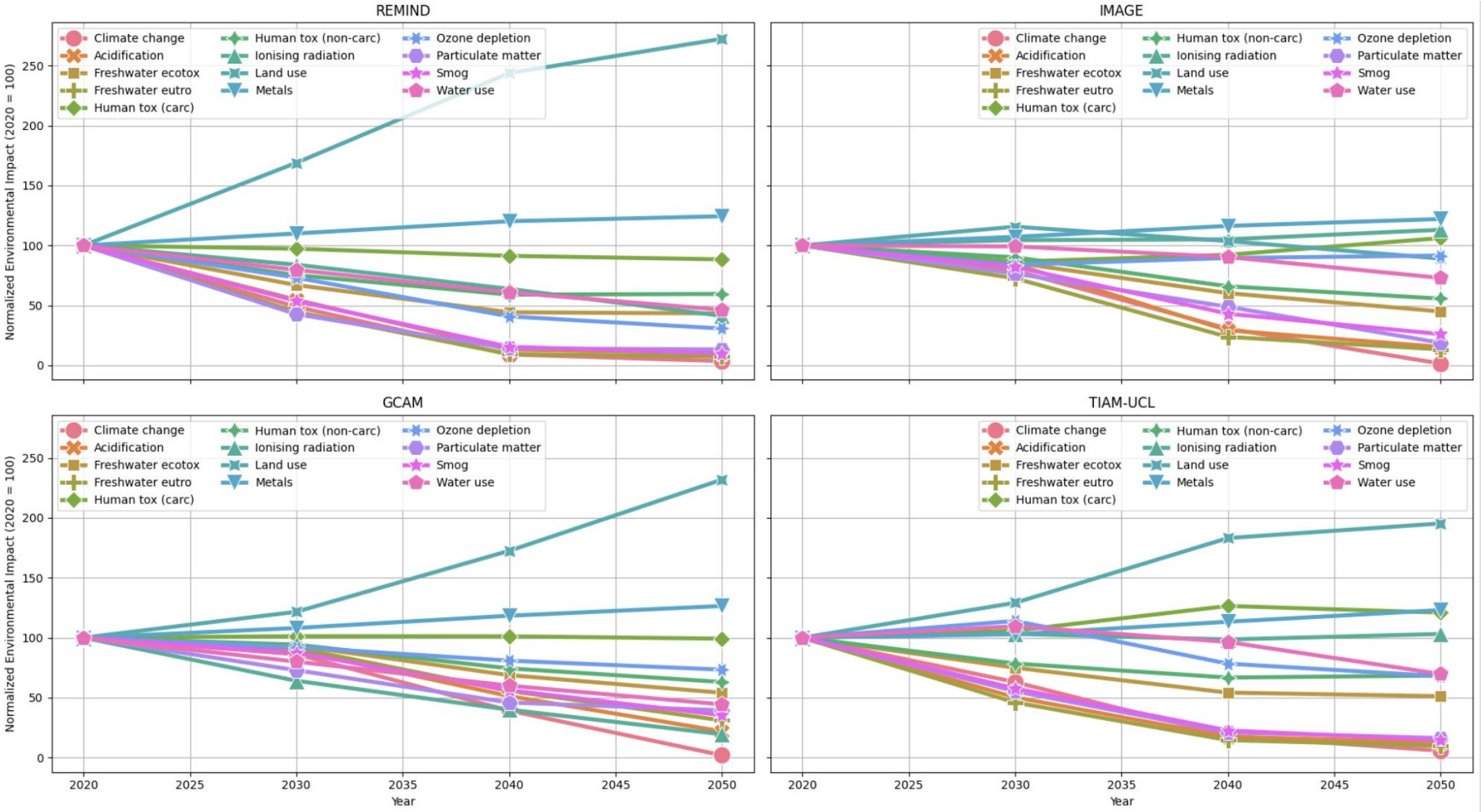
Carbon footprint of a battery-electric passenger car



Neglecting transformations in sectors that indirectly support the life cycle of BEV misses almost half of the expected GHG emissions reduction.

Indicators evolution across models for RCP 2.6 scenarios (< 2 °C)

- 1 kWh of global low-voltage electricity to user
- Most indicators show lower scores relative to 2020
- Exceptions for land and metal use and human toxicity



What's coming?

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

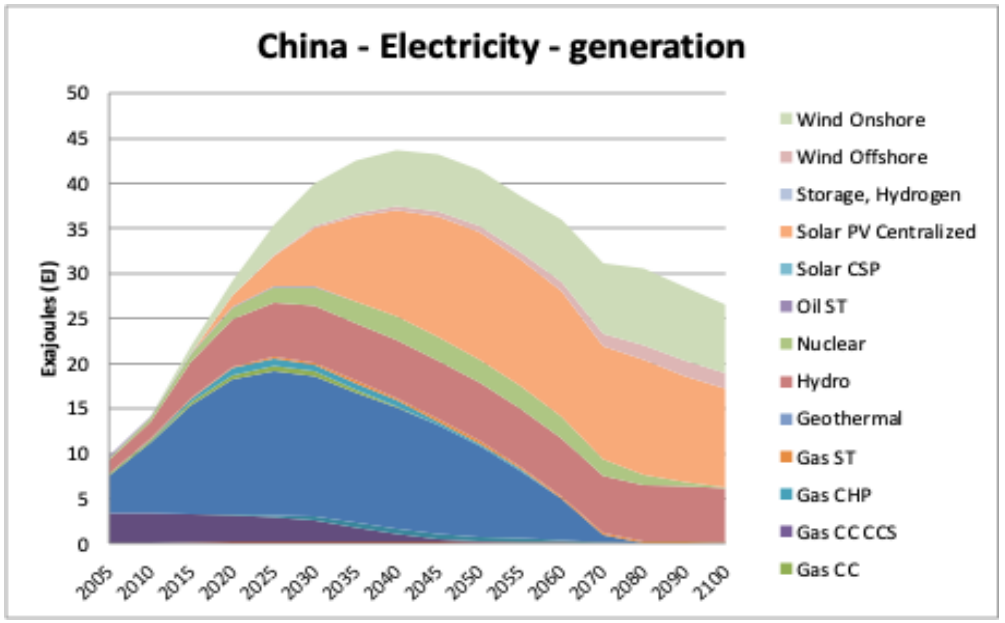
Message-ix, Ti-IAM, GCAM

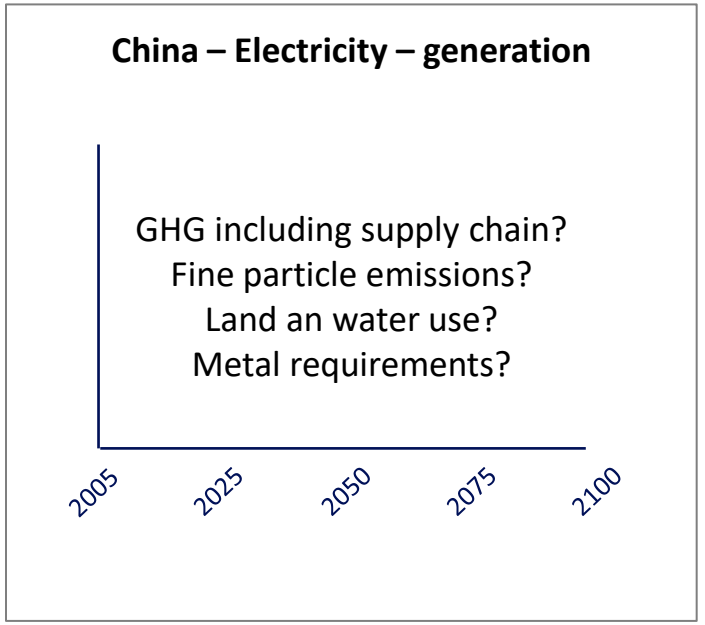
pathways

A new library for scenario- or sector-wide LCA

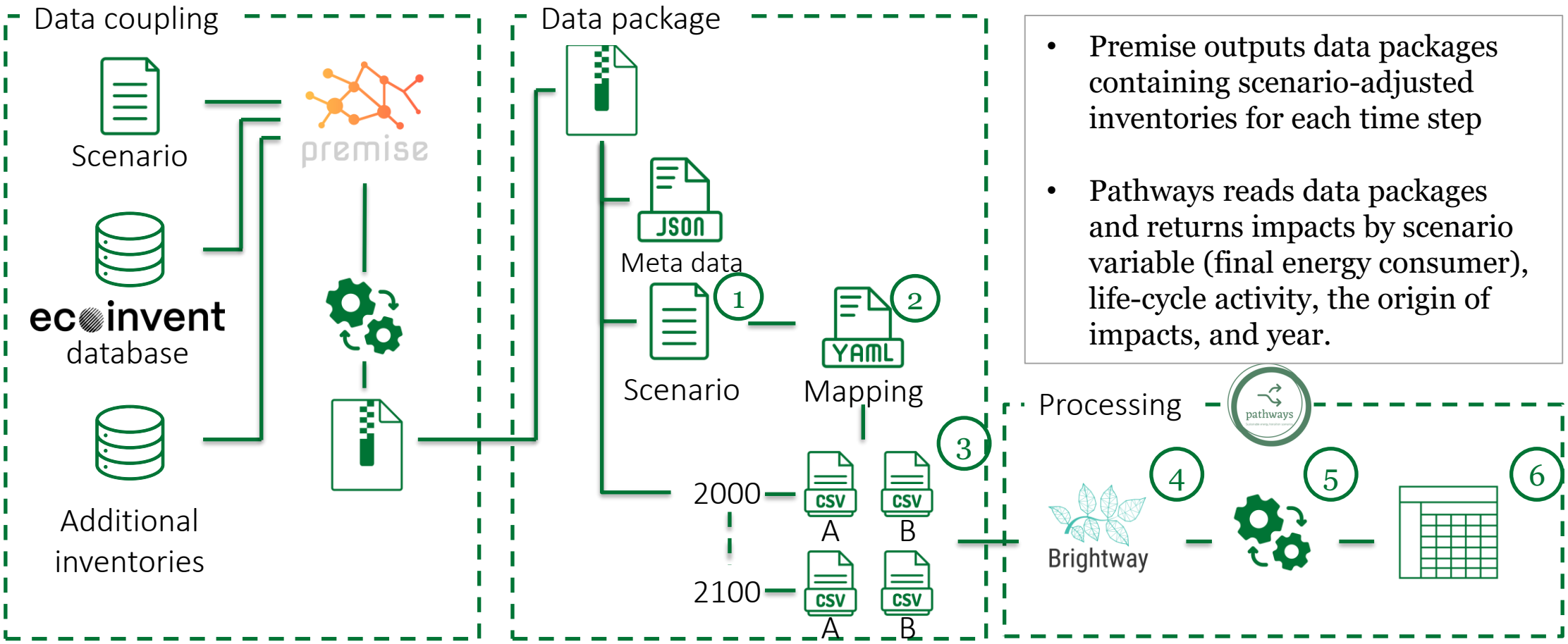
System-wide prospective LCA with Pathways

- Pathways characterizes entire prospective scenario
- Scenario variables mapped to LCA datasets
- Assess scenarios base don multiple environmental and resource criteria



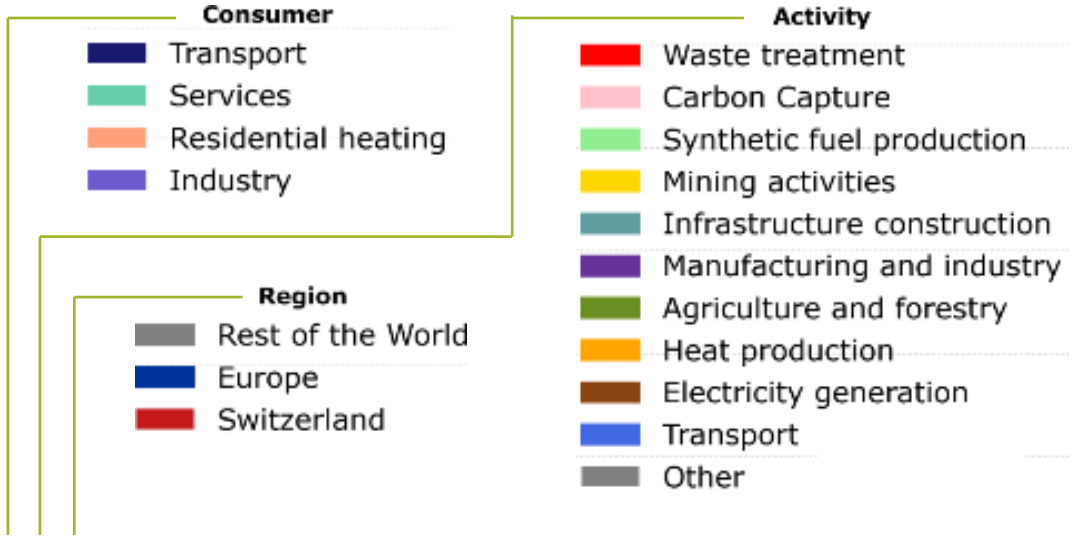


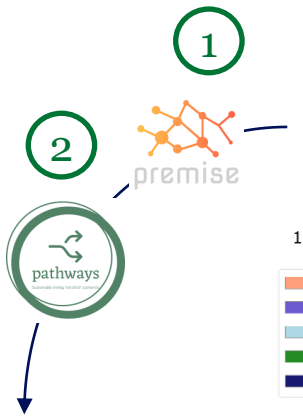
System-wide prospective LCA with Pathways

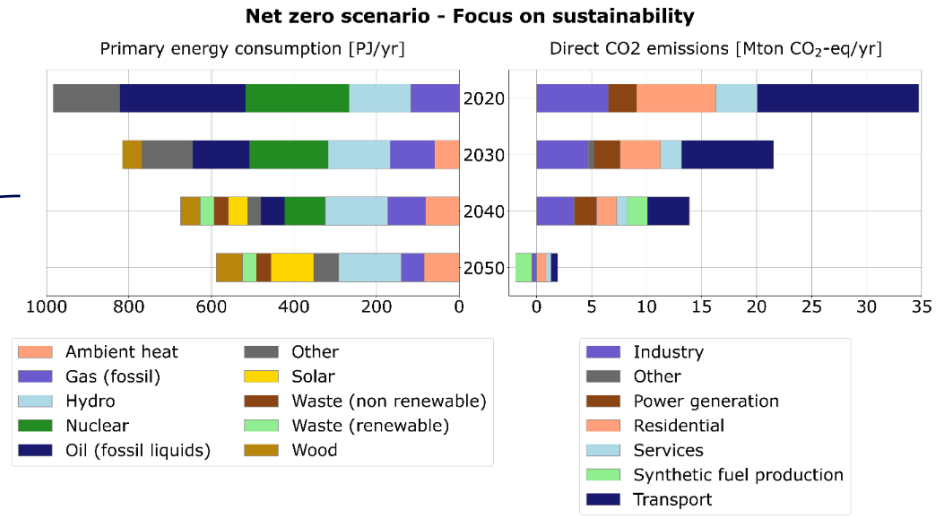


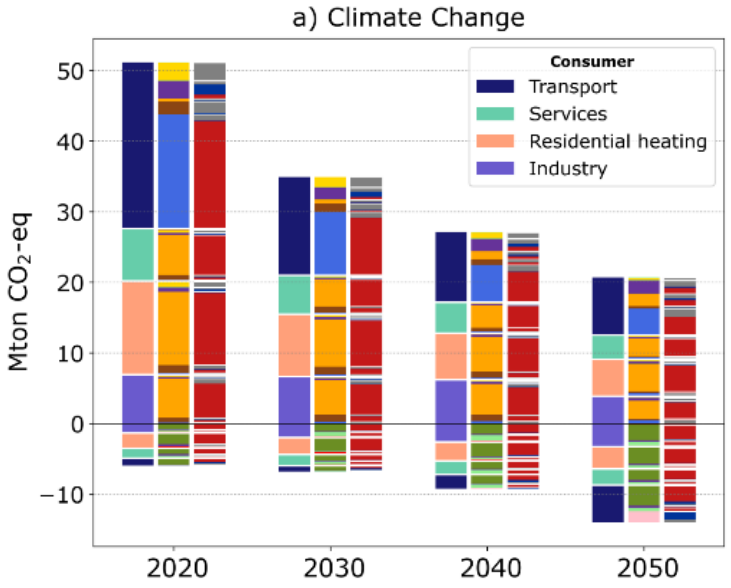
- Premise outputs data packages containing scenario-adjusted inventories for each time step
- Pathways reads data packages and returns impacts by scenario variable (final energy consumer), life-cycle activity, the origin of impacts, and year.

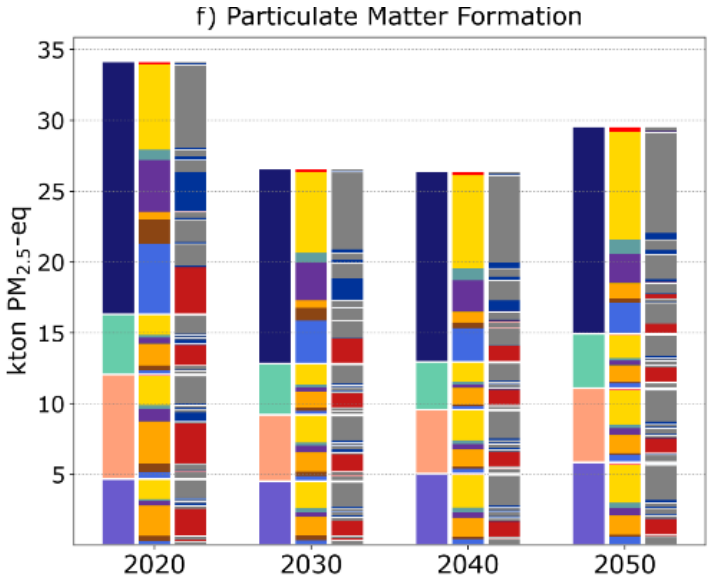
Prospective LCA of Swiss Final Energy supply

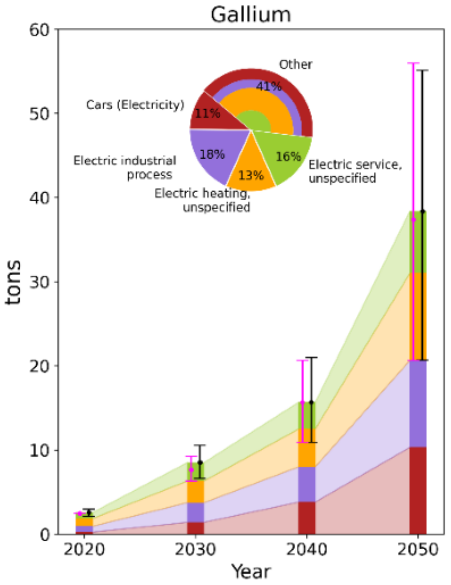


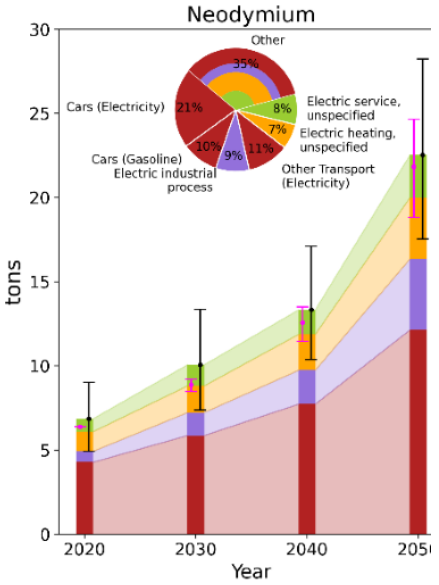












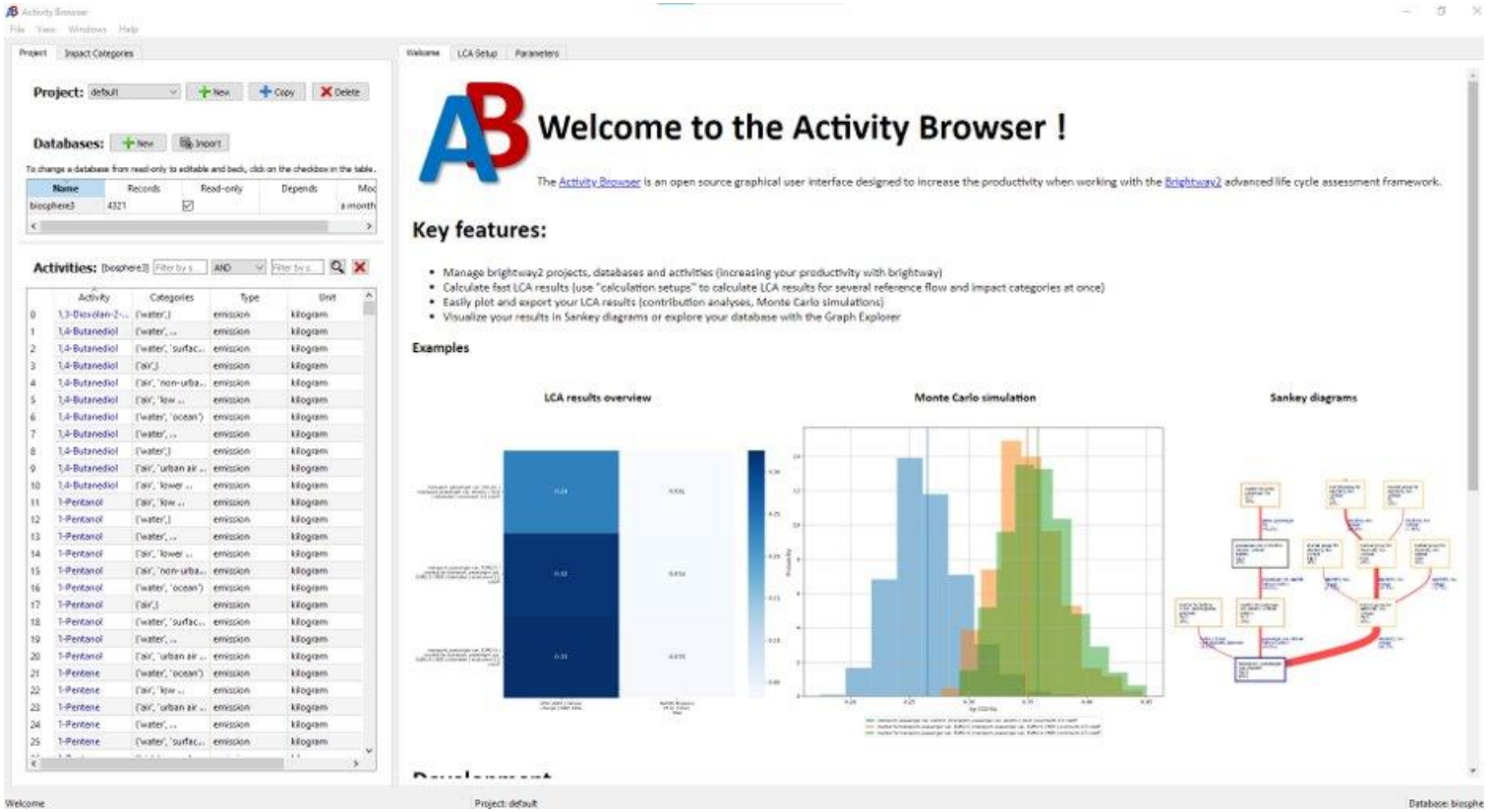
Part III
Practical tools

Brightway2

- Open source LCA framework (python)
- Good for:
  - Many LCA calculations (fast)
  - Advanced models, e.g. Regionalization / Dynamic LCA
  - Systematic modifications of your background system (e.g. future electricity systems)
  - **prospective LCA (scenario-LCA)**
  - …

Activity Browser LCA software

- Open source LCA software extending brightway
- Graphical user interface
- Fast LCA calculations and advanced analysis options
- **Advanced scenario modeling for prospective LCA (superstructure approach)**

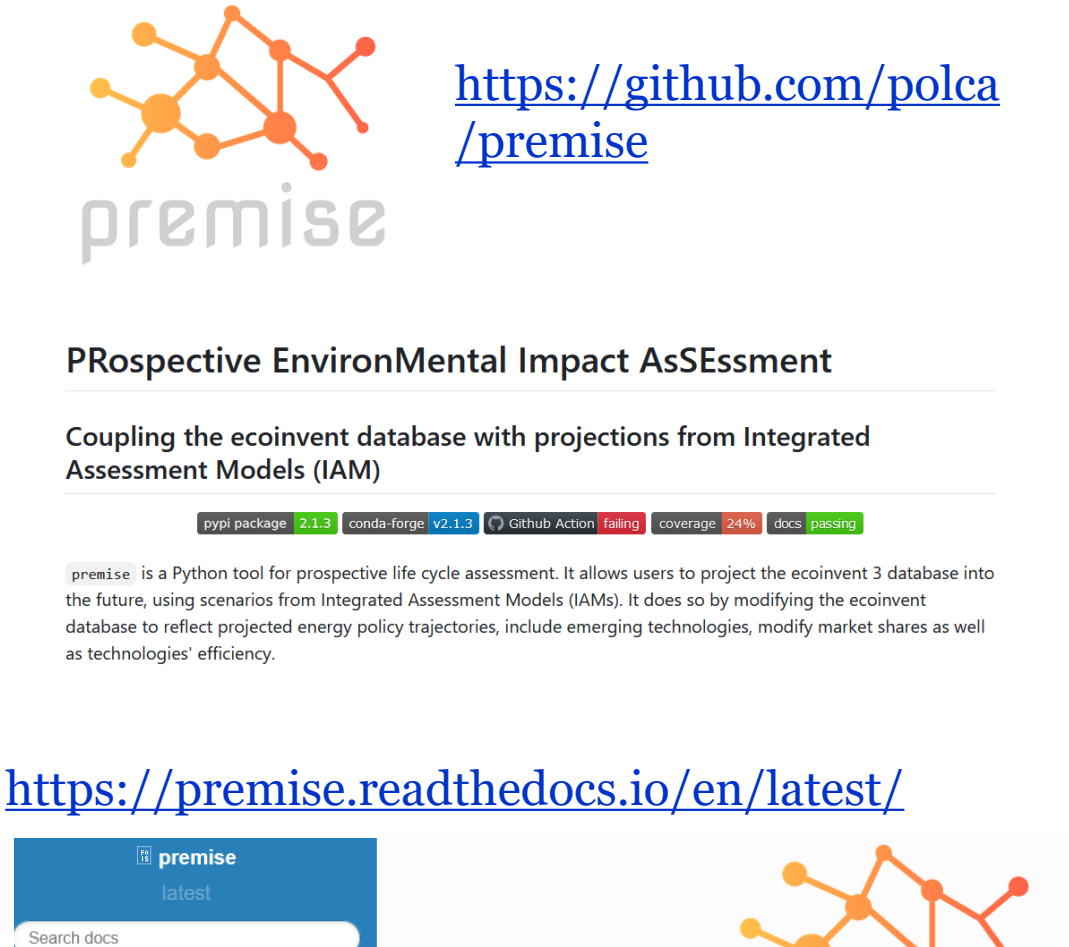


https://github.com/LCA-ActivityBrowser/activity-browser

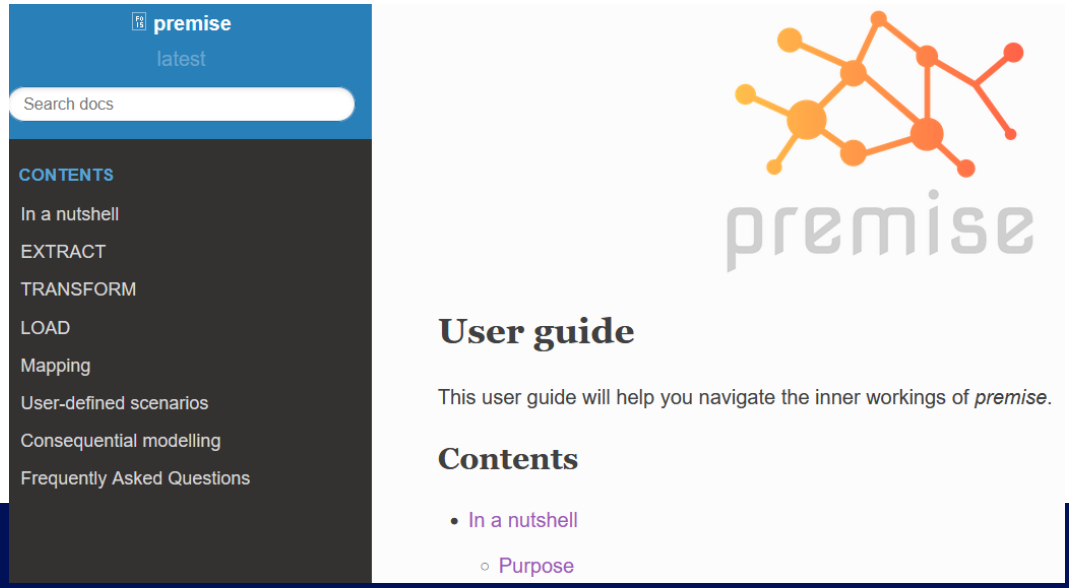
The premise framework

- Purpose: generate pLCI databases using the ecoinvent database, IAM and other data
- Python, open source, builds on brightway
- Code on GitHub
- Well documented “User Guide”

https://github.com/polca/premise



https://premise.readthedocs.io/en/latest/



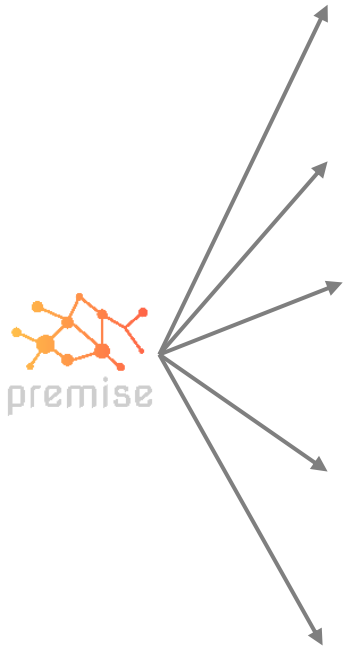
Generating pLCI databases with premise

General workflow

- Install python and premise
- Then in a script:
  - Select ecoinvent version*
  - Select IAM(s)
  - Select scenarios
  - Select sectors
  - Select years
  - Select output format: single databases or superstructure format
  - Run premise to generate the pLCI databases

*You need to have ecoinvent installed in brightway for this to work due to licensing reasons

Premise databases can be exported...



... in formats used in **common LCA software**

... for the **Activity Browser**. Here, the **superstructure approach** can be used, making LCA calculations with different background scenarios very easy.

... in **brightway format**. Almost anything is possible here, but it requires python knowledge.

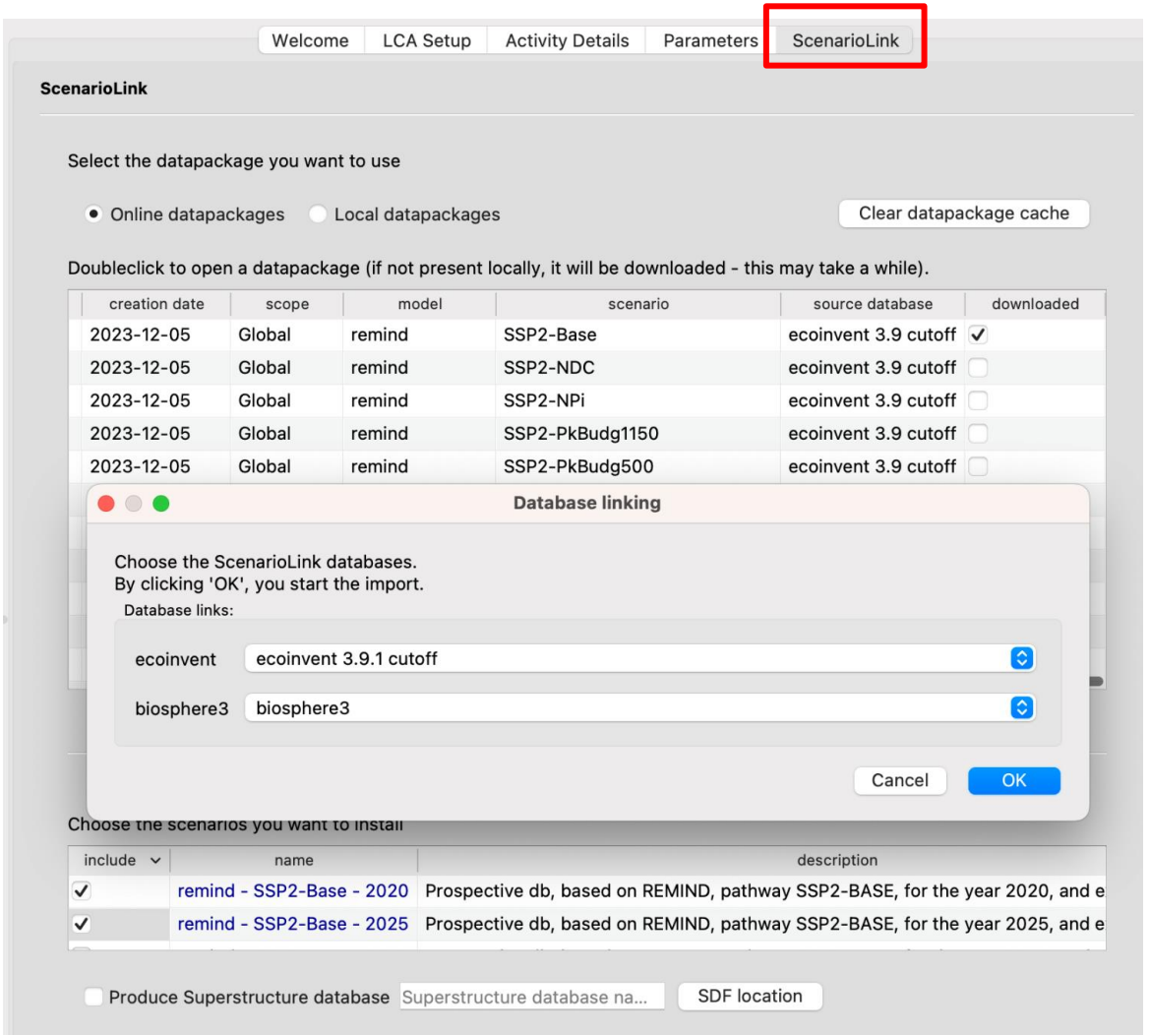
... as ***fold / unfold* data packages**. These can be imported in python and Activity Browser (via ScenarioLink). Good for sharing pLCI databases as no ecoinvent data is revealed.

... as **raw matrices**. This provides total freedom of using them as input for other models.

Alternative: ScenarioLink Plugin of Activity Browser

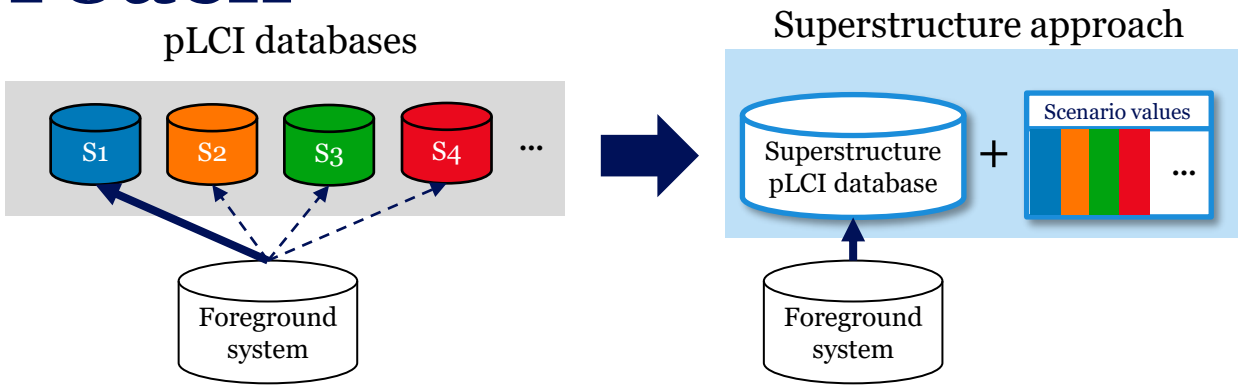
Import databases in the Activity Browser via the *ScenarioLink* plugin

- you need a locally installed version of the ecoinvent database
- It uses the fold/unfold library under the hood with databases pre-generated and uploaded to Zenodo
- Drawback: currently only generates superstructure for 1 scenario at a time (i.e. for different years, but not across different scenarios)



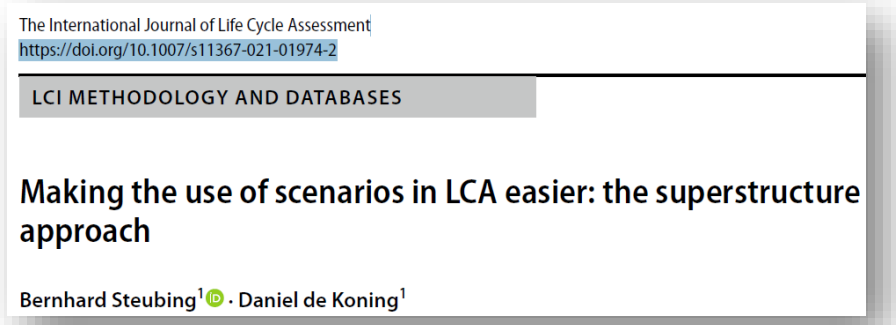
How to deal with multiple background systems? → Superstructure approach

- Practical obstacle: dealing with multiple background systems (representing different scenarios and years)
- Solution: «switching» background scenario during LCA calculations → **Superstructure approach** (Steubing and Koning 2021)



one click!

Implemention in the Activity Browser

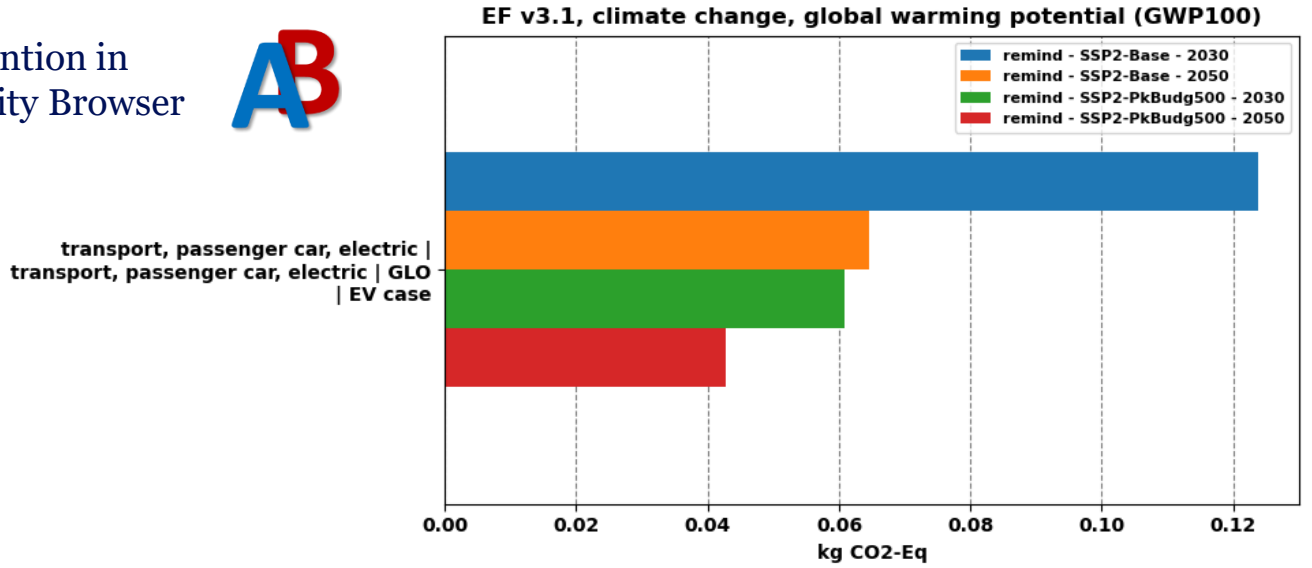

The International Journal of Life Cycle Assessment
https://doi.org/10.1007/s11367-021-01974-2

LCI METHODOLOGY AND DATABASES

Making the use of scenarios in LCA easier: the superstructure approach

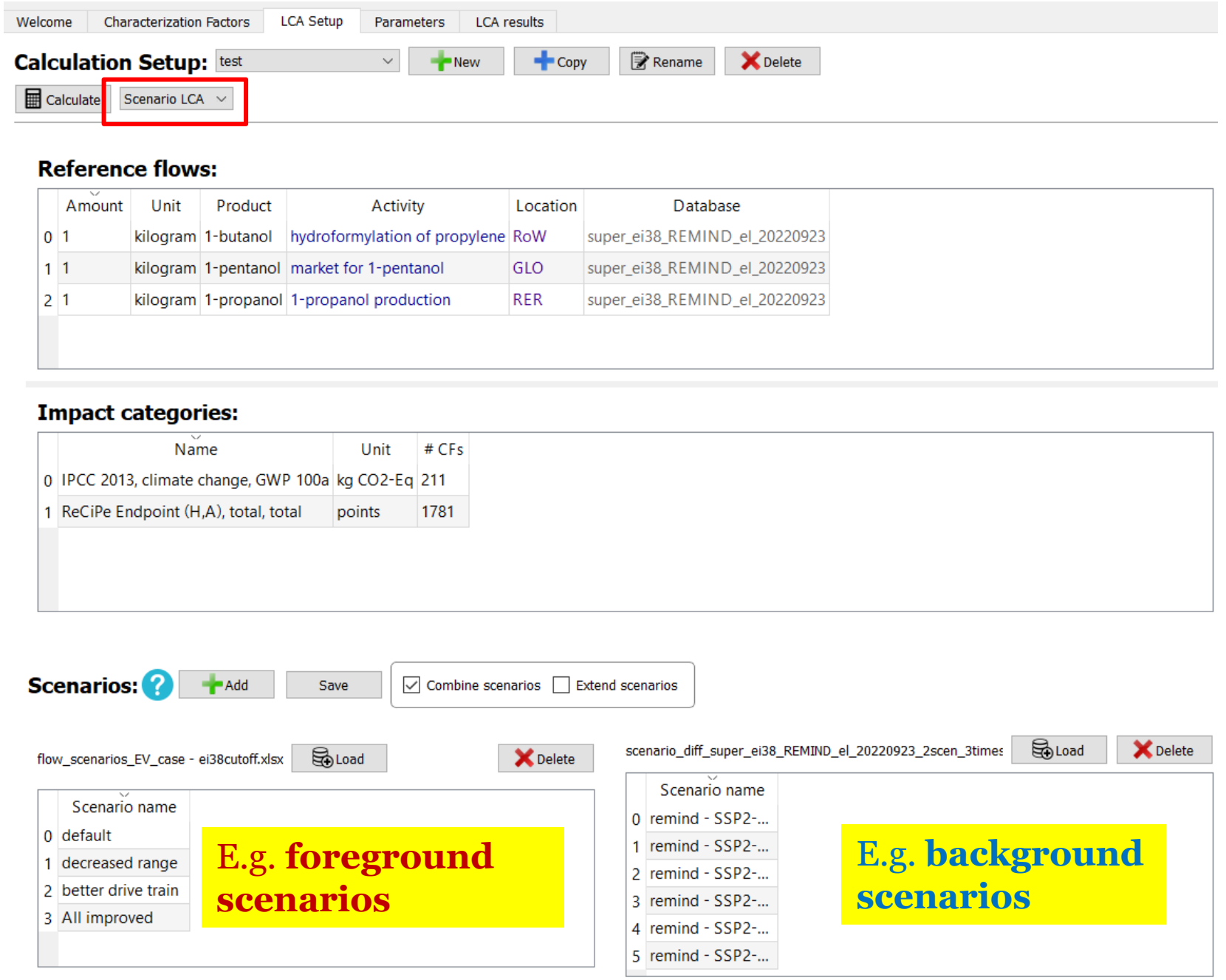
Bernhard Steubing[1] · Daniel de Koning[1]

https://link.springer.com/article/10.1007/s11367-021-01974-2



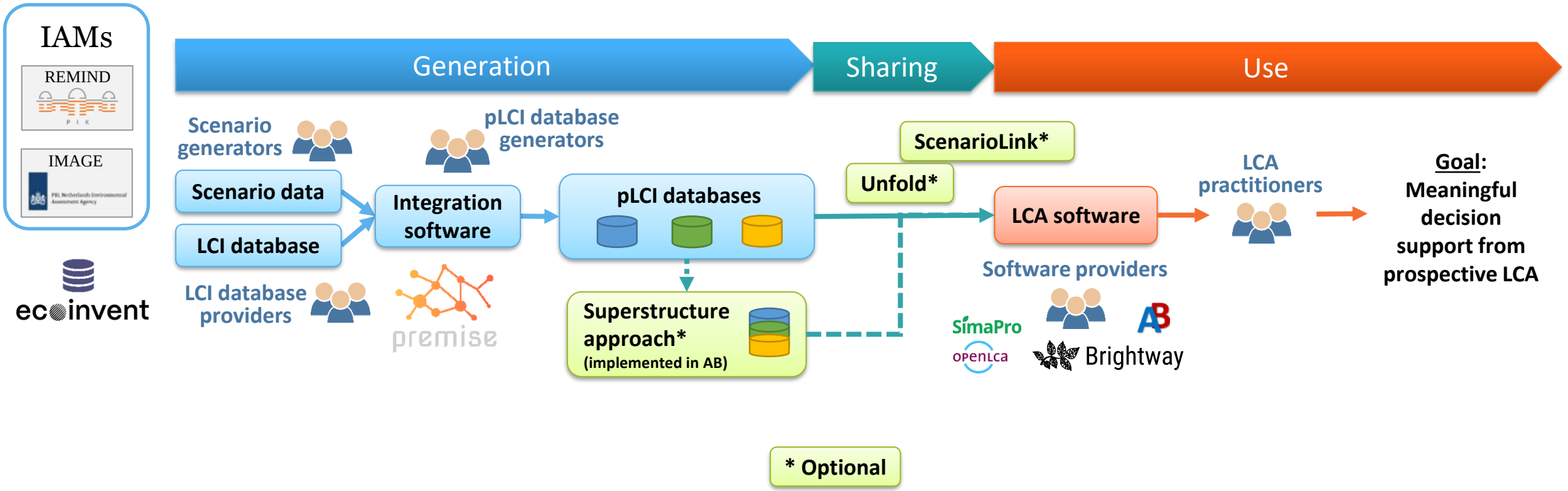
Scenario modelling in AB

- Superstructure approach
- Foreground scenarios
- Prospective LCI databases (future backgrounds e.g. from premise)
- **Combination of FG and BG scenarios**



Summary: the pLCI databases tool chain

How it all works together…



Conclusions

Great progress in recent years in prospective LCA!

Remaining challenges

1. Coverage
   - Sectoral, geographical, environmental
   - Circular systems (e.g. CCU)
   - Is being constantly increased
2. Harmonization
   - Consistency vs. quality
   - Many IAMs and other data sources
3. Sharing
   - Local generation, direct sharing, but easier system needed
4. Use in LCA software
   - Still difficult in most LCA software

Thank you!

Questions?

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Related

- Prospective LCA courses (contact us for more information)

https://www.youtube.com/@activity-browser

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Open source tools that specifically support prospective/scenario LCA

- *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