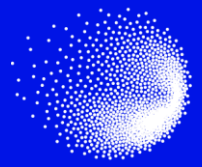


PSI Center for Nuclear Engineering and Sciences
Center for Energy and Environmental Sciences

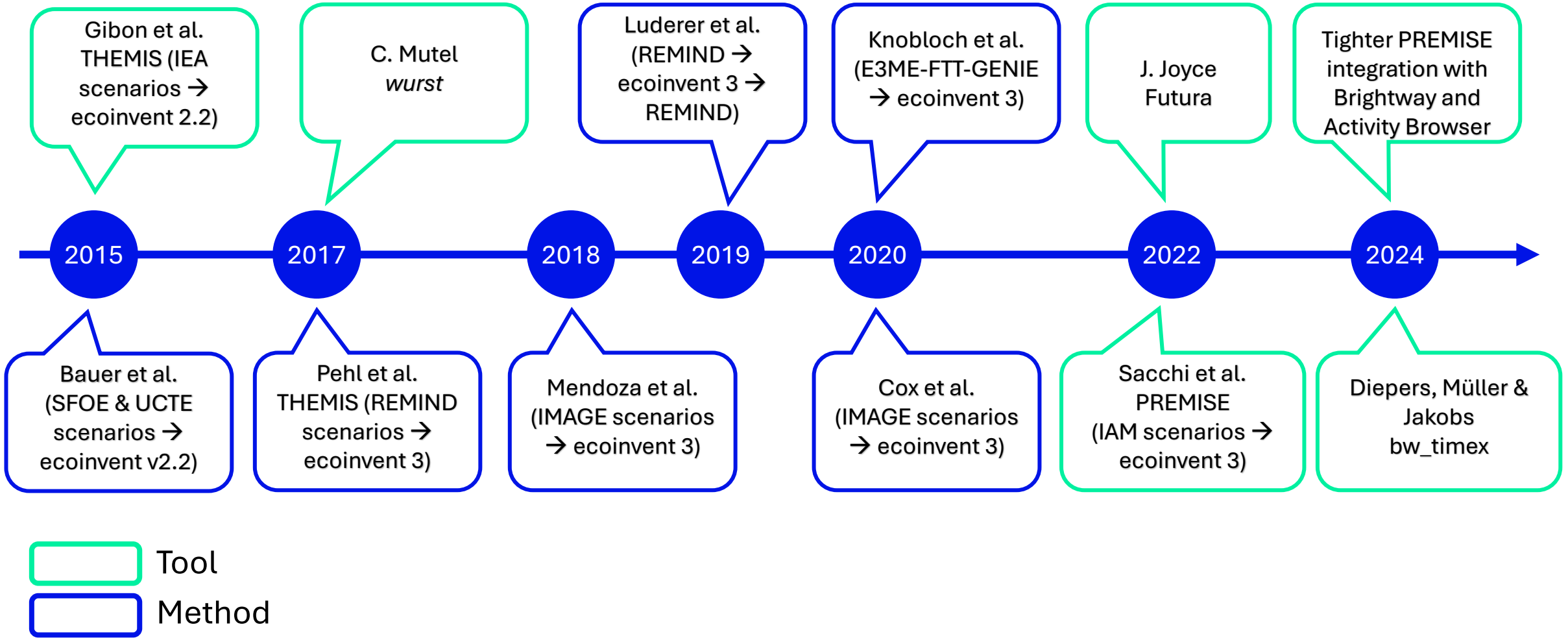
Prospective LCA – Does the background matter?

Current trends and future opportunities

Christian Bauer, Laboratory for Energy Systems Analysis | Technology Assessment

LCA DF89, Zurich, Feb 5th, 2025

Some history of scenario-based prospective LCA

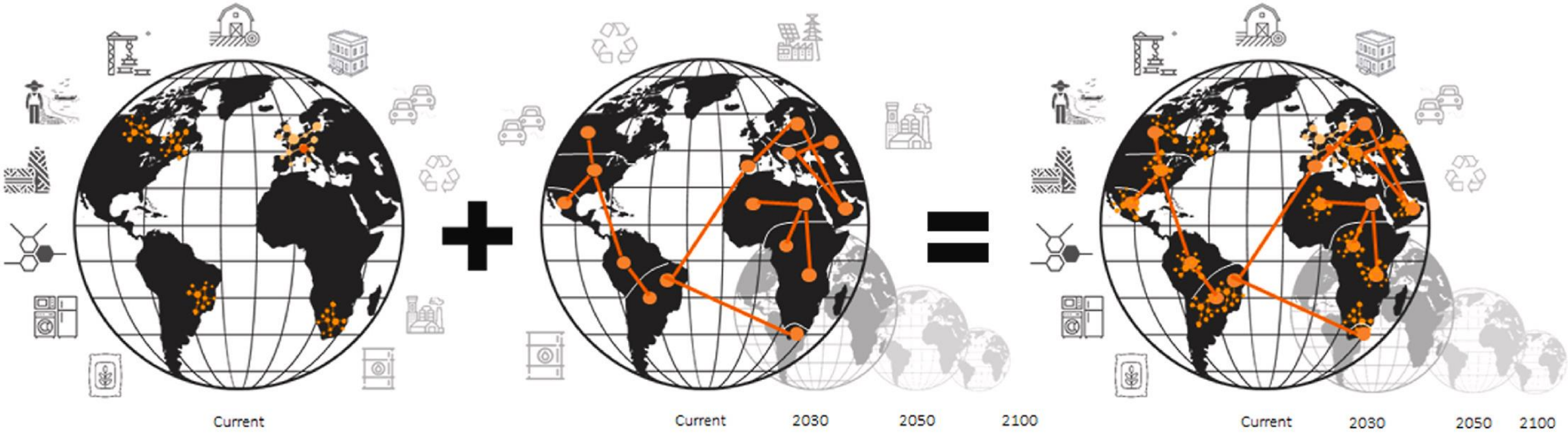


State-of-the-art: prospective background LCI databases

LCI database (ecoinvent)
+ additional LCI

Integrated Assessment Model (IAM)
scenarios

Prospective LCI
databases



+ technological granularity
+ env. burdens beyond GHG
- static
- geographically focused

+ consistent future scenarios
+ consistent global coverage
- limited env. burdens
- low technological granularity

+ combination of advantages of "both worlds"
- associated uncertainties

Integrated Assessment Models (IAM)

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

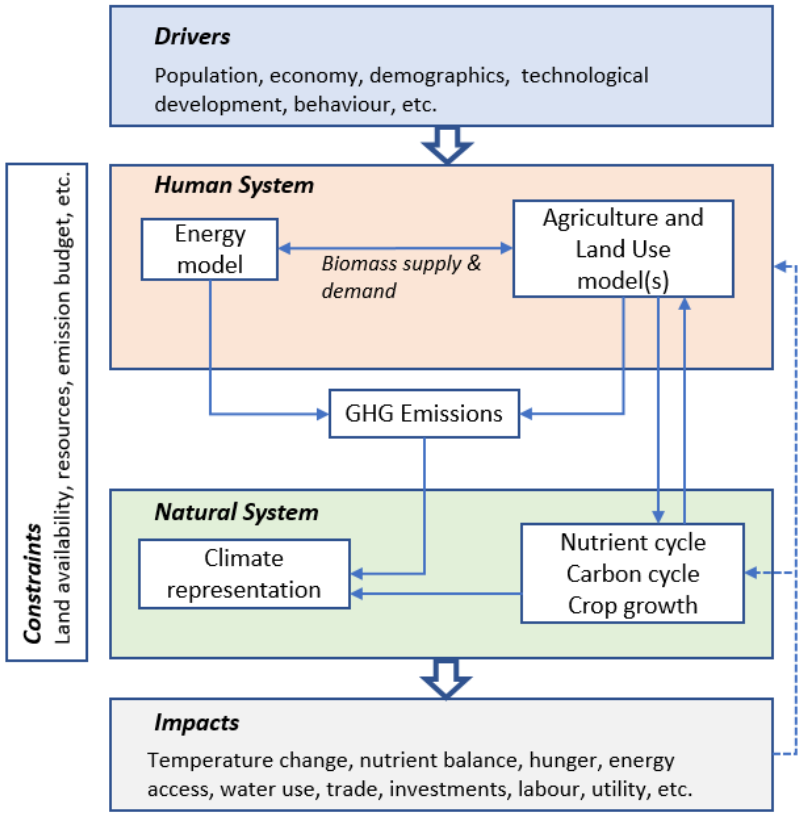
IAM assess the interactions between **human** and **natural** systems in **future scenarios**

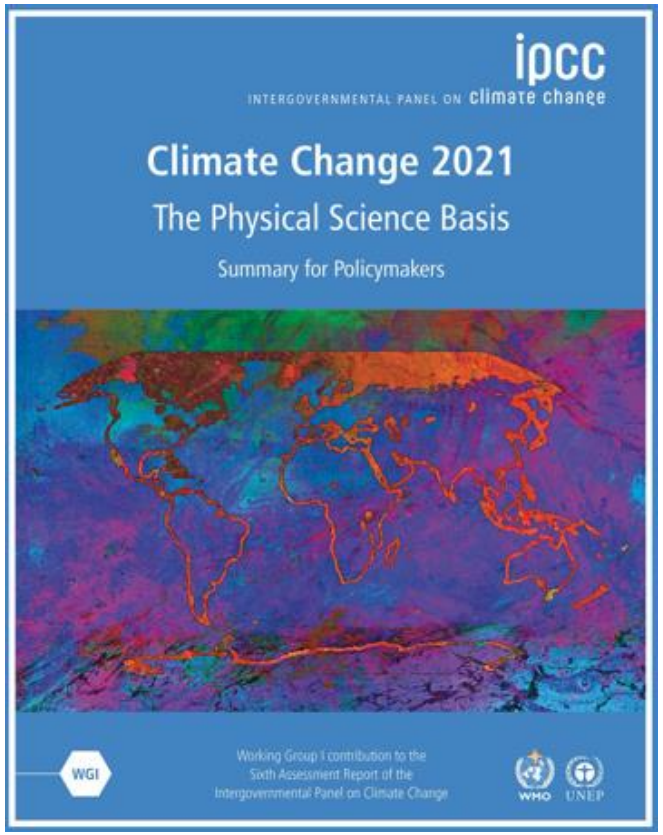
IAM contain stylized representations of:

- Energy system
- Agricultural system
- Climate and land systems

IAM 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?





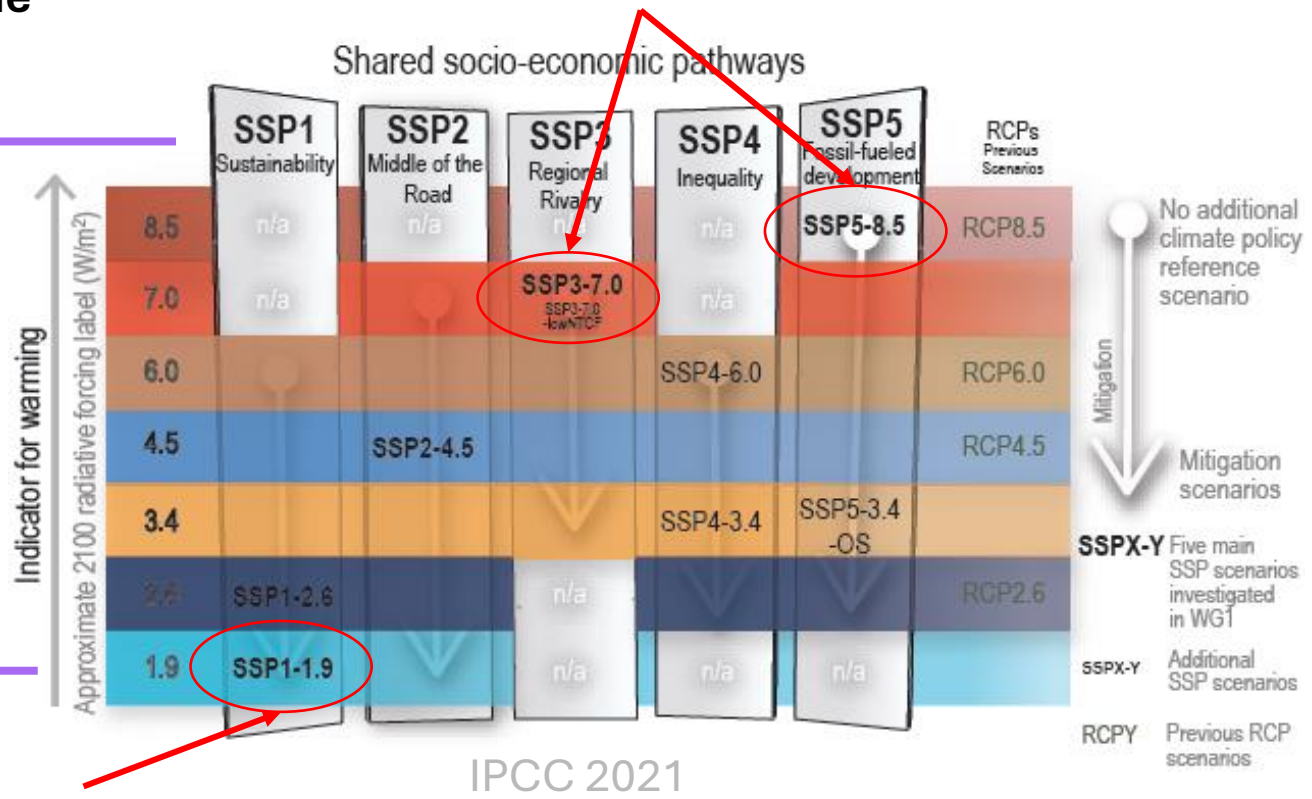
Integrated Assessment Models (IAM)

- **Global regionalized models** that consider broad **socio-economic and technological developments** and their consequences **over time**
- Used to **inform policymakers** on the **interdependencies** between future **economic**, **technological** and **social** developments and **climate change**

Shared-Socioeconomic Pathways (SSPs)

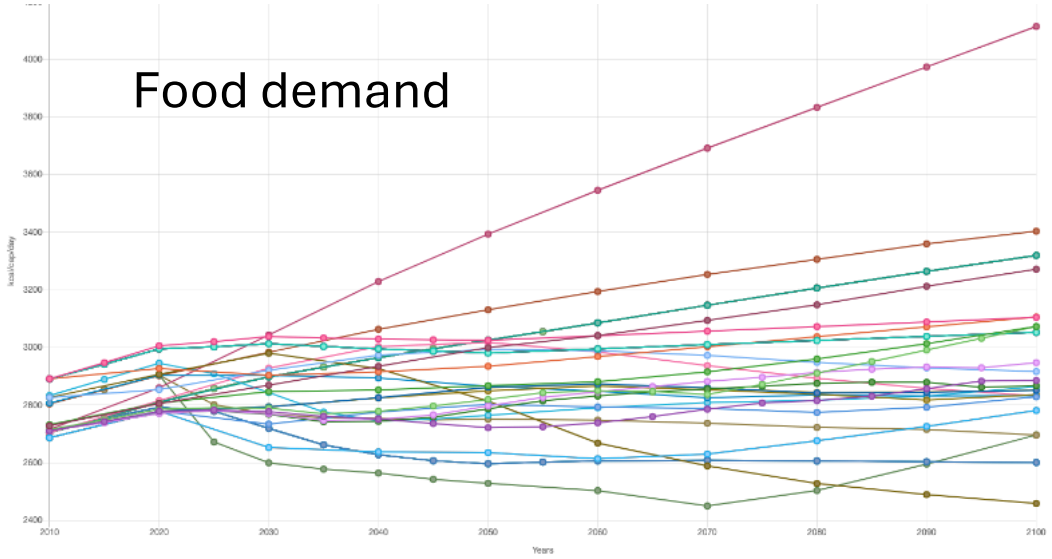
Representative Concentration Pathways (RCPs)

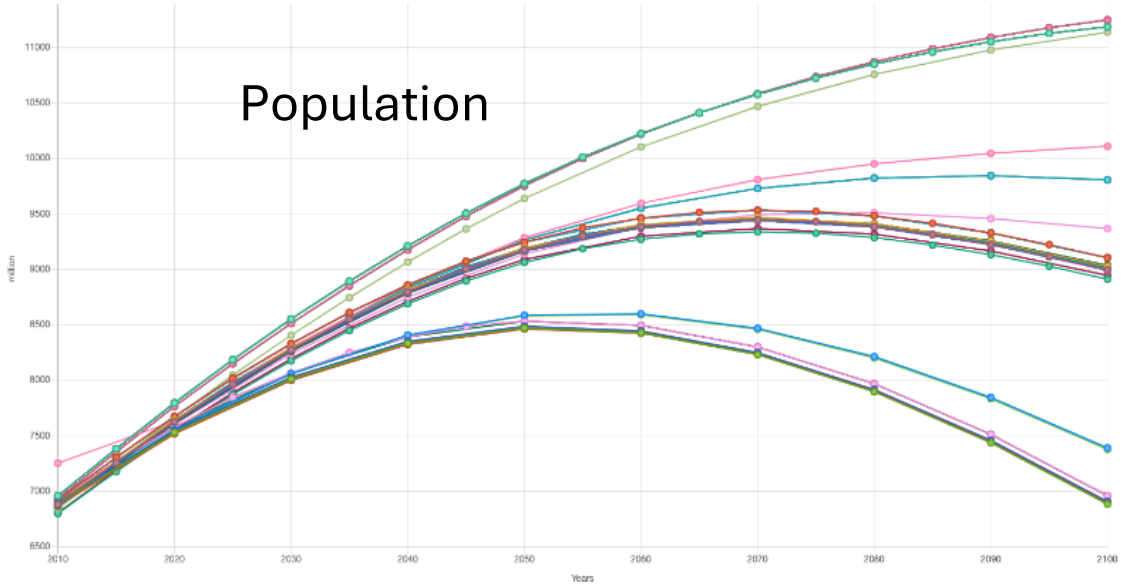
No additional climate policy
(~5 °C warming by 2100)

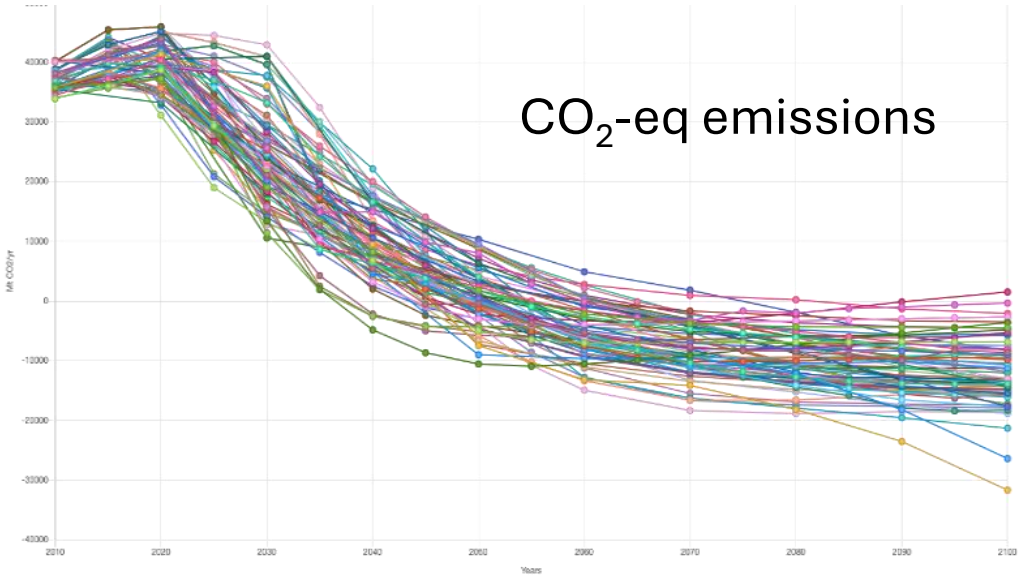


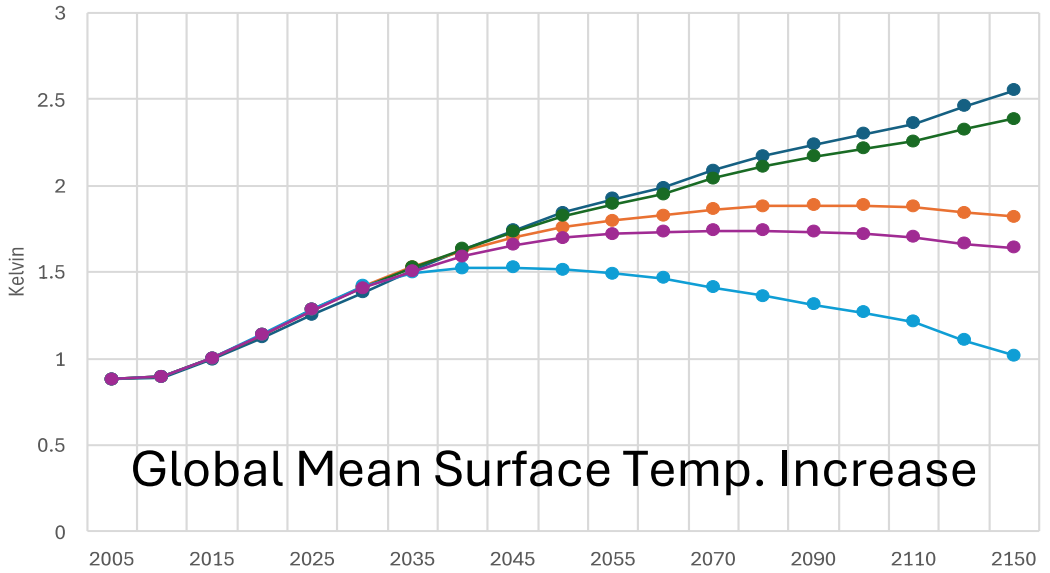
Paris agreement
(~1.5 °C warming by 2100)

IAM: Socio-economic and climate constraints (examples)





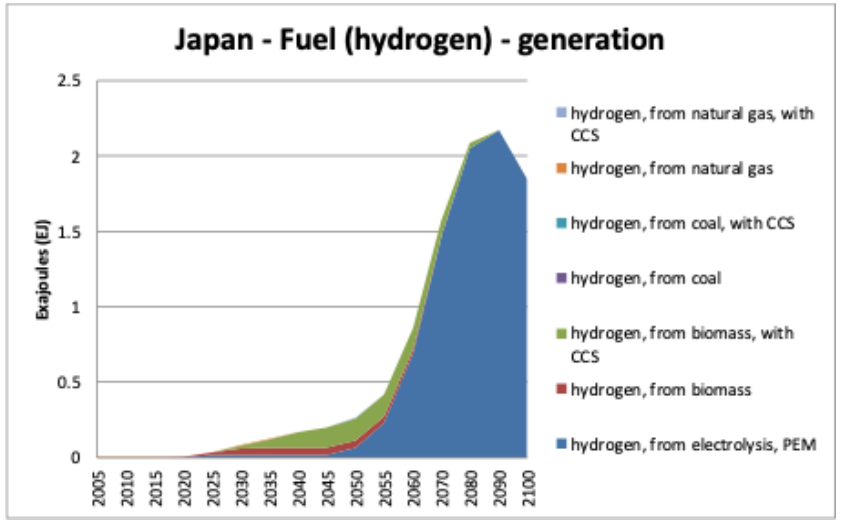


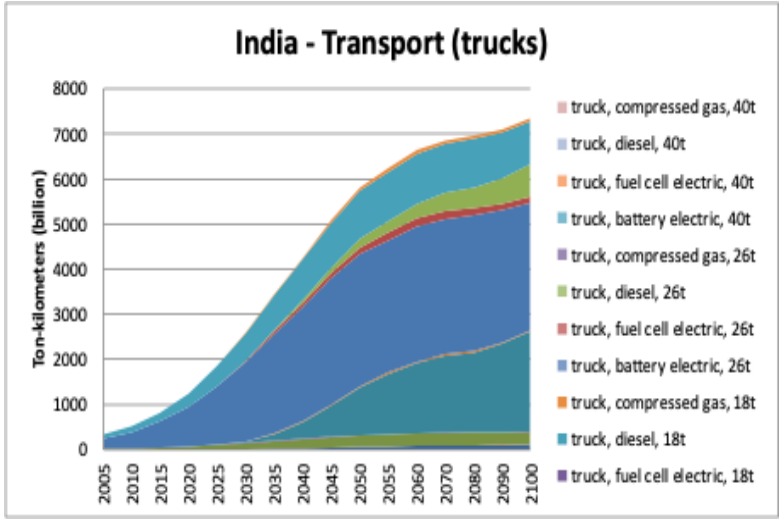


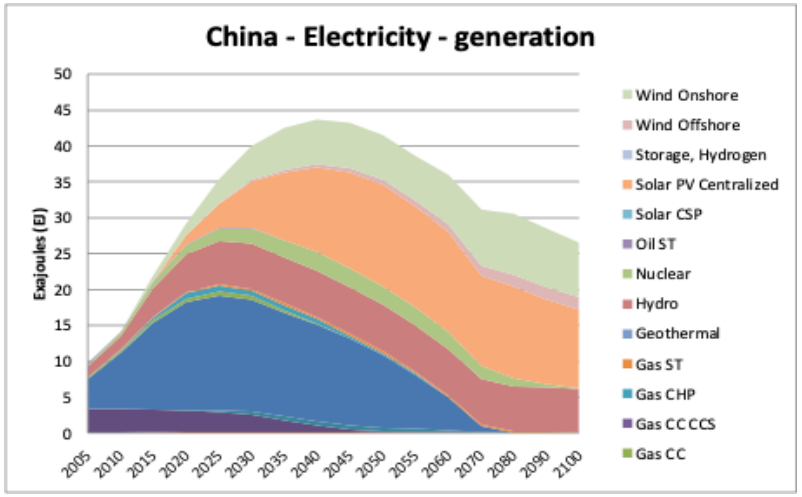
IAM: What elements useful for LCA do scenarios contain?

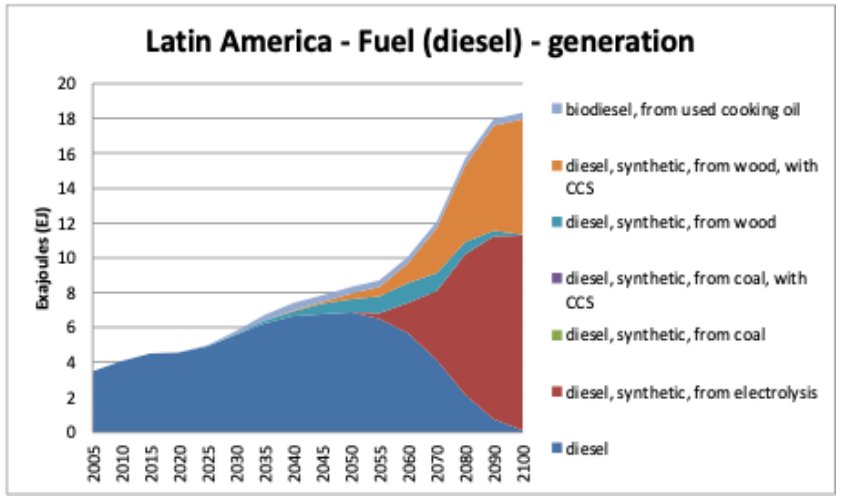
For each scenario, region & time step (focus on energy):

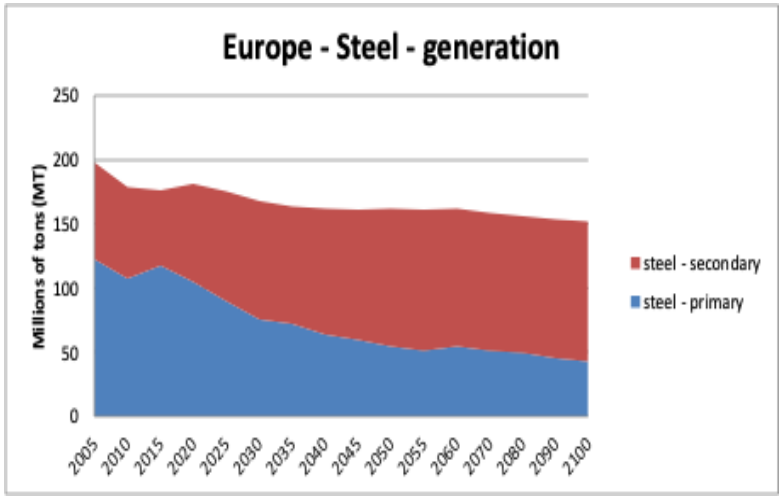
- Product/technology shares
- Technology efficiencies
- Air pollutant emissions
- Capacity build-up
- Electricity generation
- etc.



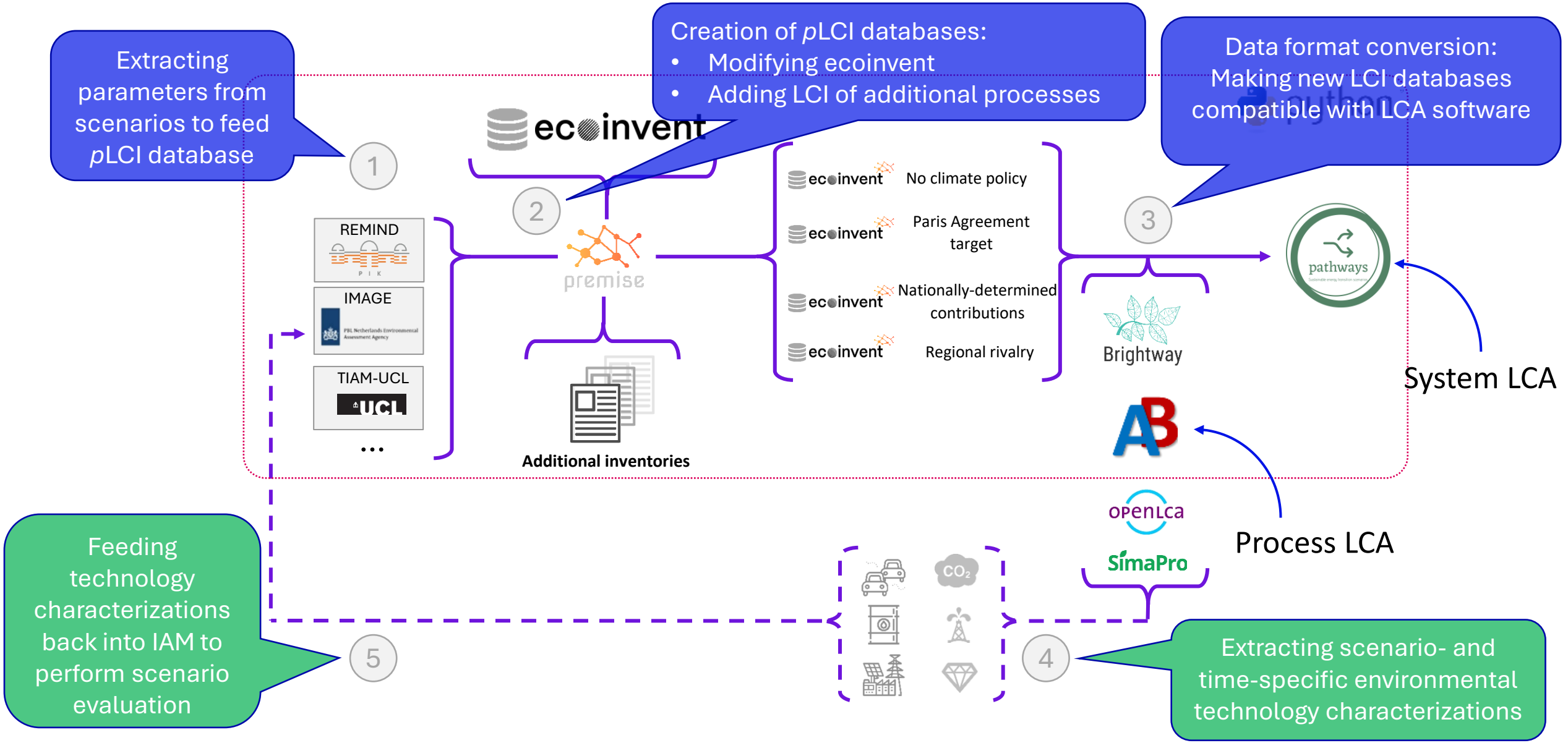








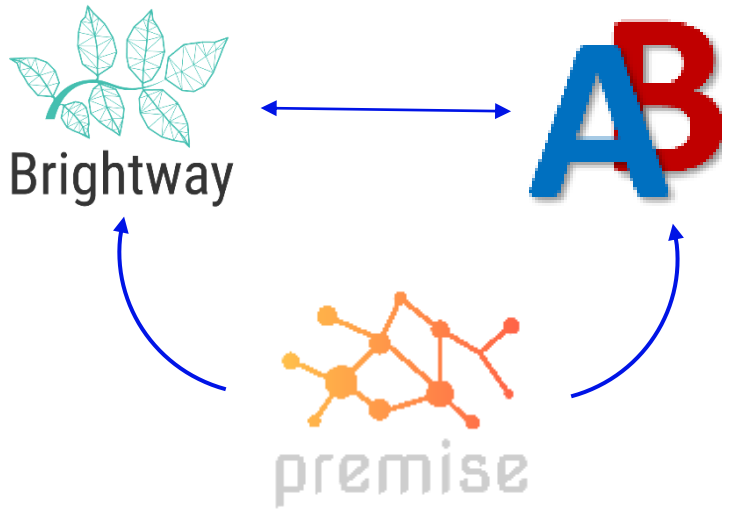
premise: workflow for linking LCI and IAM scenarios → *p*LCA



premise: some features and statistics

- Integrates projections from:
  - Power
  - Fuels
  - Biomass
  - Steel
  - Cement
  - Transport
- Links to 4 different IAM
  - 2 more to come
- Covers 23 IAM scenarios
  - Covering all SSPs
  - Combined with 3 RCPs

- Cited in >200 studies since 2022
- Used in >100 studies
- Mostly usedy with Brightway, and more specifically the Superstructure feature of Activity Browser

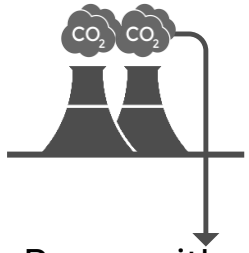


premise: (additional) prospective LCI (examples)

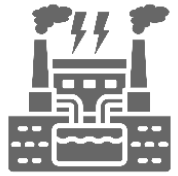
PV: GaAs, Perovskite, …

PtX fuels

Biofuels

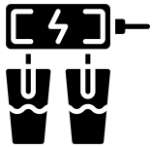


Power with CCS



Geothermal, wave power, …

Fuel cell: PEM, AEFC, SOFC, DMFC



Electrolyzer: PEM, AE, SOE

Batteries: LiB, SiB

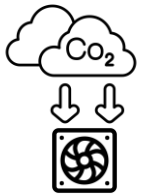
Trucks: EV, FC

Cars: EV, FC

Trains: PEM, D, EV, FC

Chemicals: MeOH, NH3

Metals: PGM, Li, Co



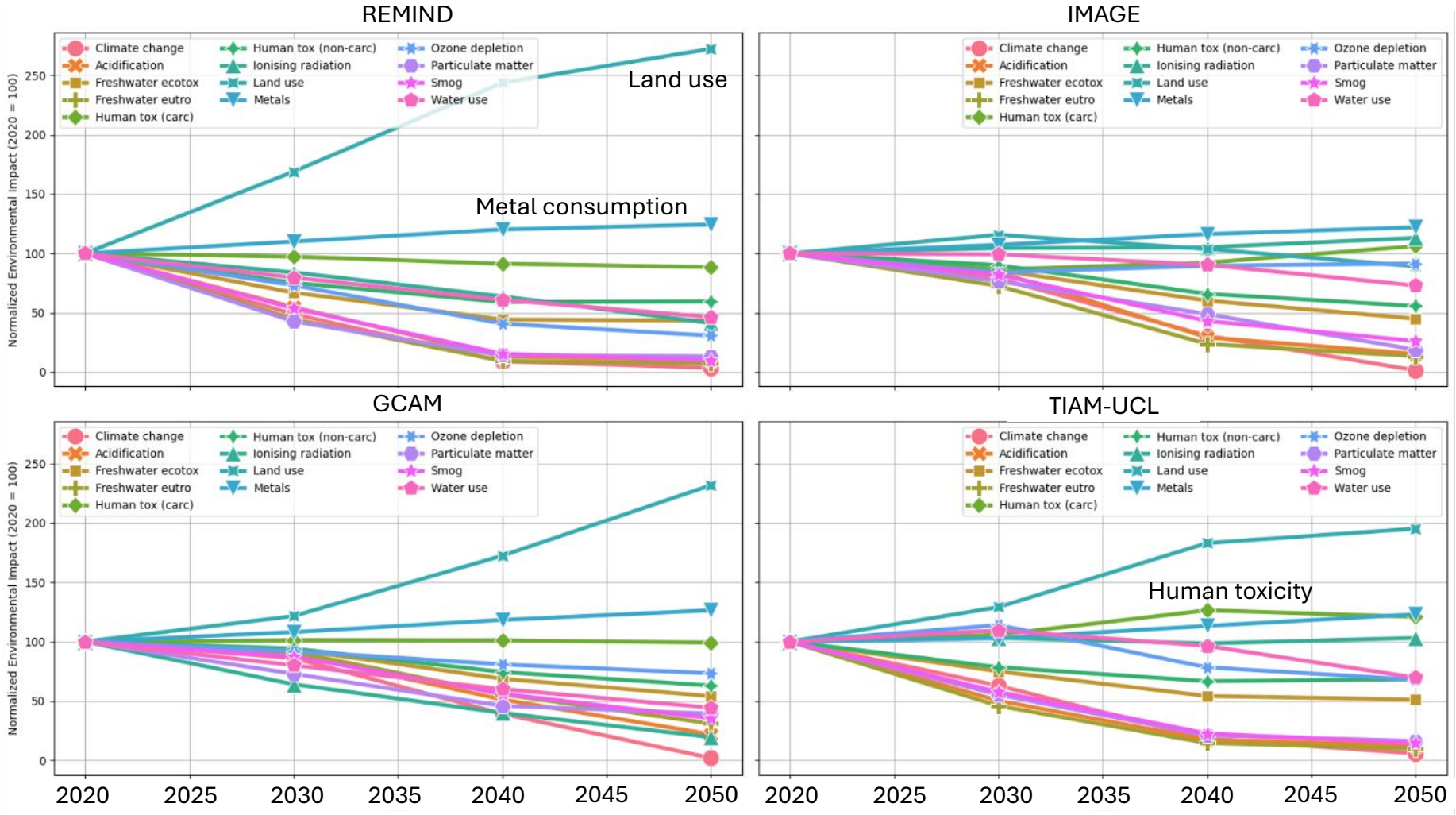
CDR: DACCS, BECCS, biochar

- +2’300 datasets
- Mostly peer-reviewed
- Documented
- ei v3.6-3.10

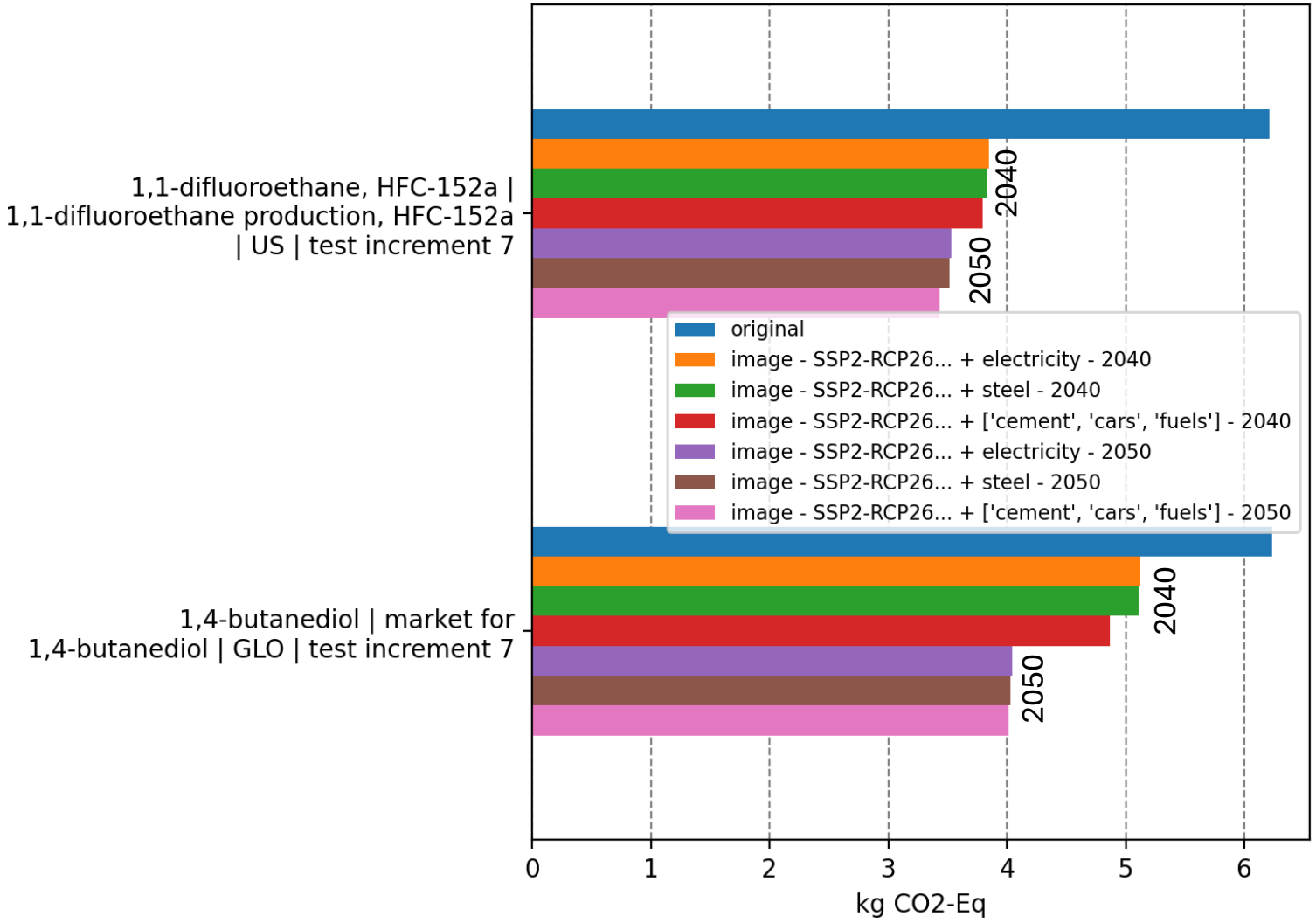
premise: some results

Impacts of 1 kWh electricity (GLO), relative to 2020

- GHG emissions reach zero (consistently)
- Some resource use indicators increase
- Most other indicators decrease, but by how much depends on the IAM and the way their electricity supply becomes fossil-free



premise: sector analysis with incremental databases



- ✓ Impacts on climate change of the production of two random chemicals over time according to one specific IAM scenario
- ✓ Step-by-step implementation of database modification:
  1. Electricity
  2. Steel
  3. Cement, transport, fuels
- ➢ Modification of the electricity sector results in the most substantial reduction of GHG emissions (consistent pattern)
- ➢ Further sector contributions depend on product, IAM scenario, and impact

Scenario-wide prospective LCA: *premise* & *pathways*

- Switzerland and several other countries aim for **net zero energy-related GHG** emissions **by 2050**.
- Energy system models (ESMs) analyze long-term pathways toward climate and targets.
- While ESMs excel in energy and economic analysis, they:
  - **overlook broader environmental impacts and burden-shifts**
  - **lack the appropriate technology resolution**

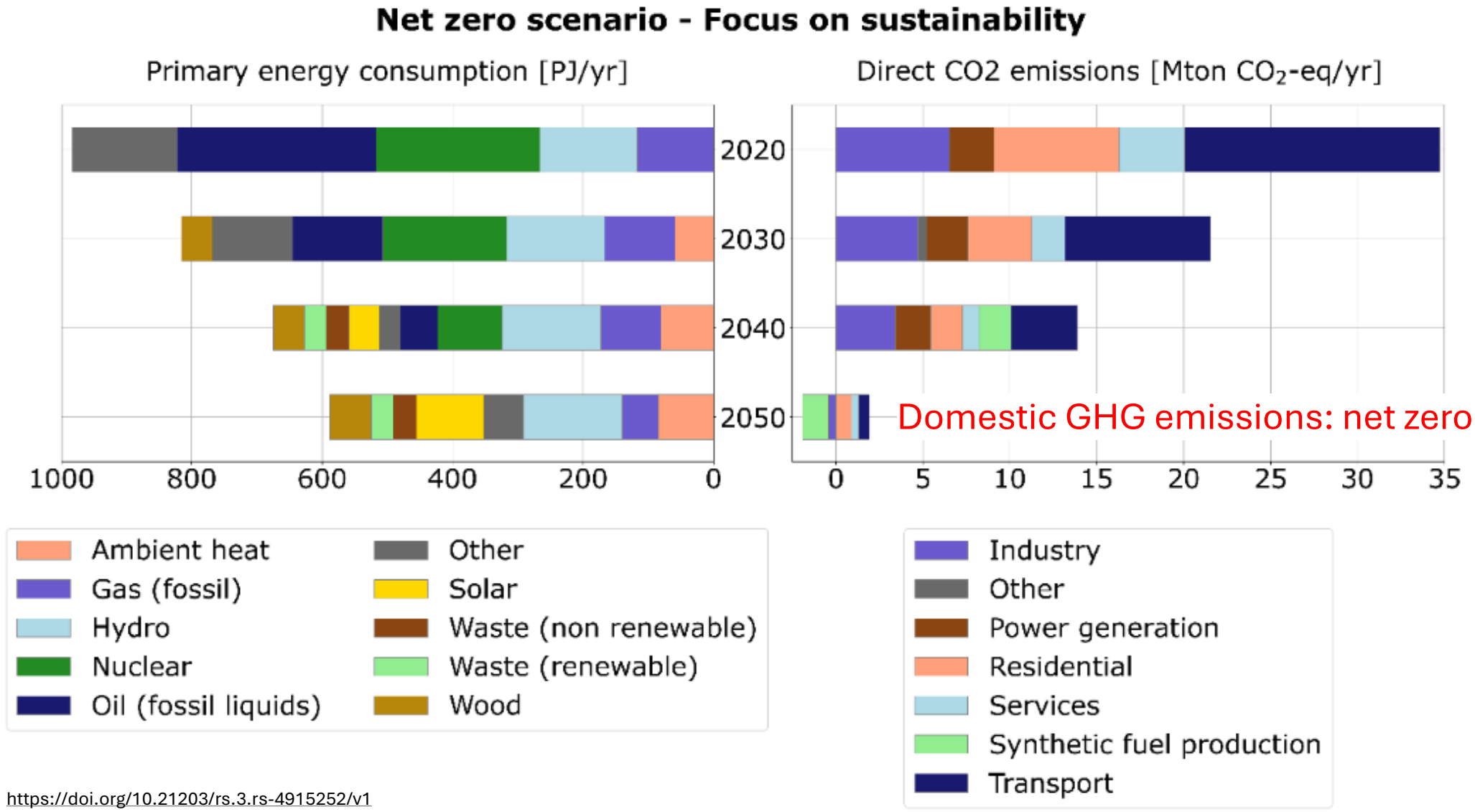
Research questions:

- What are environmental co-benefits and trade-offs of net zero energy scenarios considering a broader spectrum of environmental indicators?
- Can specific technologies exacerbate those trade-offs, if any?

Approach

- Combining ESM with *p*LCA to quantify LCIA indicators for entire transition scenarios
  → new tool "*pathways*" (doi: 10.21105/joss.07309)

Scenario-wide prospective LCA: *premise* & *pathways*

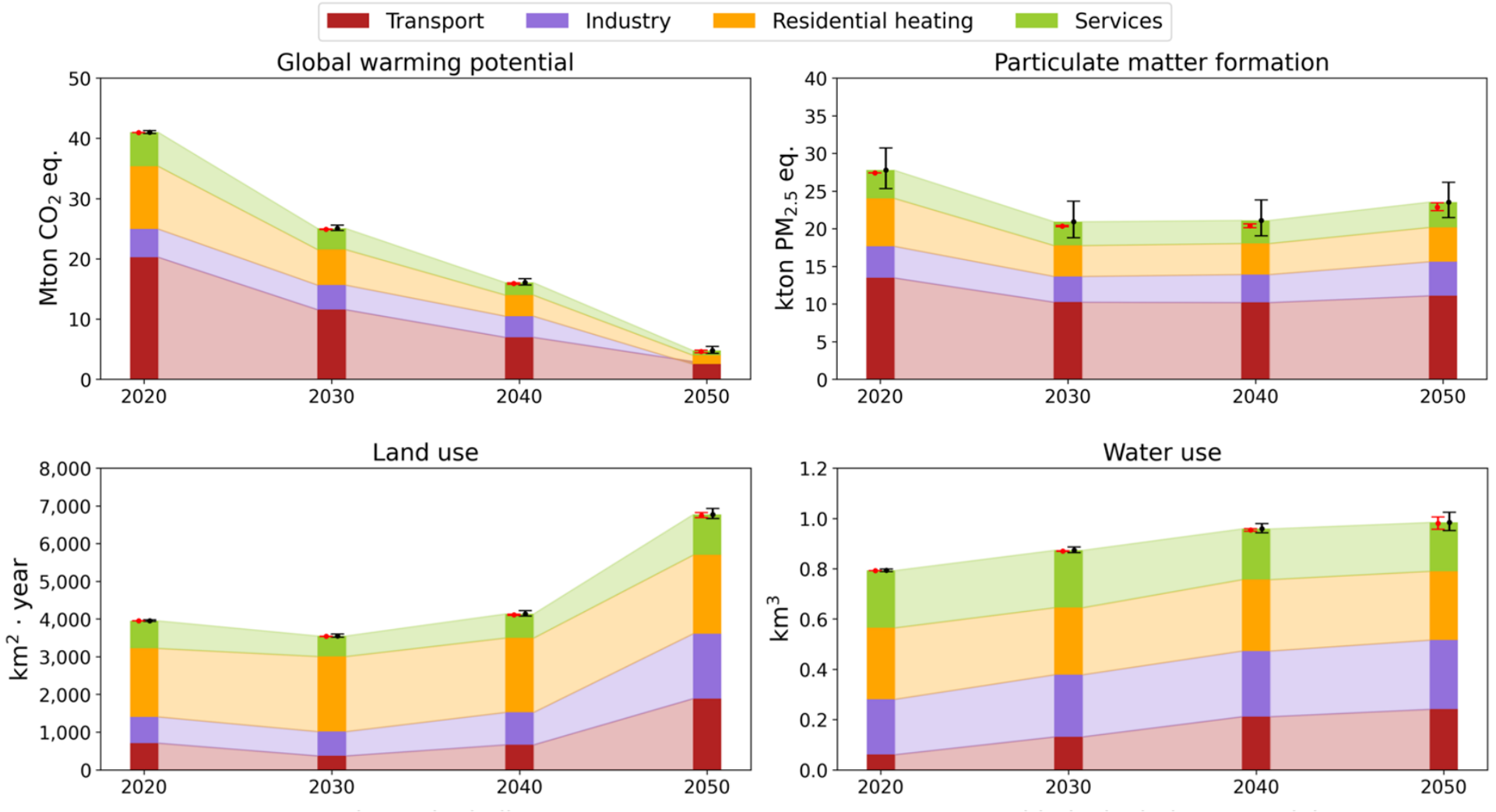


https://doi.org/10.21203/rs.3.rs-4915252/v1

Scenario-wide prospective LCA: *premise* & *pathways*

Life-cycle perspective:

- Substantial GHG emission reduction, but not to zero
- Minor reduction in PM formation
- Increasing land and water consumption

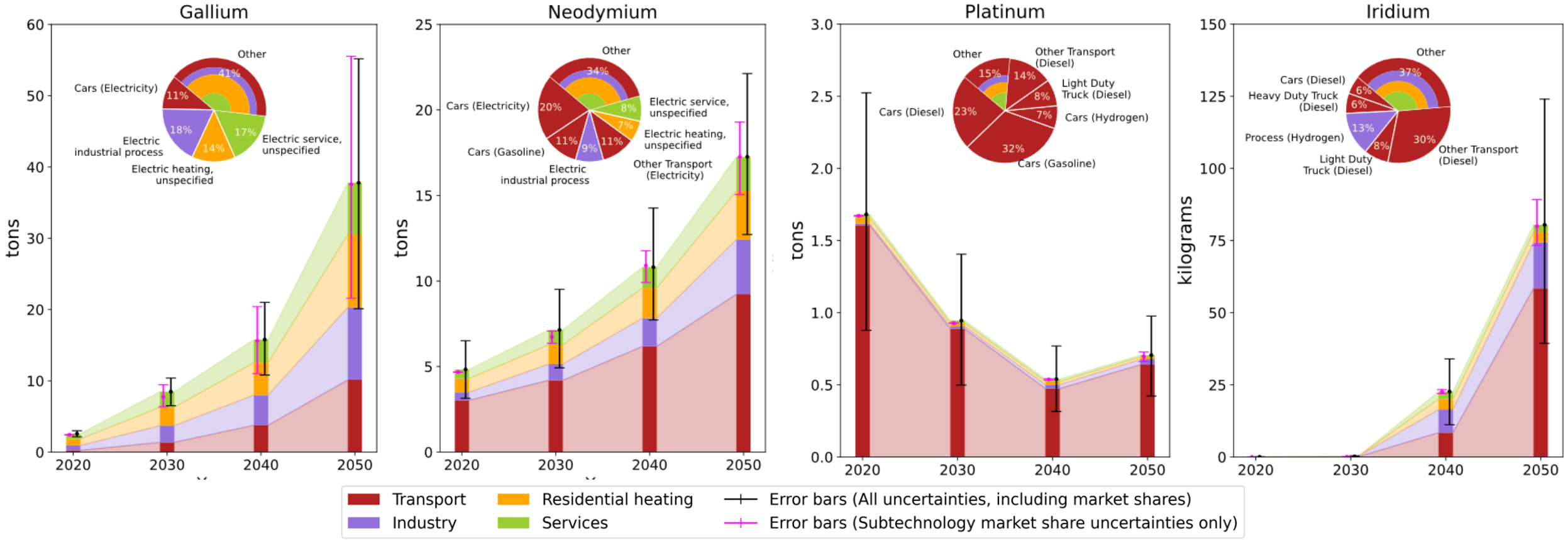


https://doi.org/10.21203/rs.3.rs-4915252/v1

Scenario-wide prospective LCA: *premise* & *pathways*

Demand for critical raw materials (CRM):

- CRM demand increases in general (some exceptions)
- Dependency on technology market shares and future CRM intensities



https://doi.org/10.21203/rs.3.rs-4915252/v1

Prospective LCA: Outlook & future research directions

- Better representation of direct and indirect land use
- Better representation of critical raw materials stocks and flows in scenarios: integrating Material Flow Analysis (MFA), LCA and IAM/ESM, including recycling and other circularity approaches
- Regionalized impact assessment (GIS-based) including prospective LCIA
- Tighter integration between *premise* and IAM/ESM
  - e.g., monetization of environmental impacts and consideration of these externalities in the objective function of IAM/ESM
- Further development of scenario-wide LCA (*pathways*)
  - Filling prospective LCI data gaps (e.g., mining sector)
  - Better representation of Carbon Dioxide Removal (CDR)
  - Better representation of agriculture

Take home messages

- **Yes, the background LCI system matters –** depending on the product system, the background system can generate the (vast) majority of environmental impacts
- Automated ways to generate scenario-specific prospective background LCI databases are indispensable
- ***premise*** can be considered the **"pseudo-standard"** for generating such background databases using projections from IAM and energy system models
  - builds upon ecoinvent
  - comes with many additional (prospective) LCI
  - is an open-source tool, to which the community can contribute
- ***premise*** and ***pathways*** allow for **LCA of entire** energy/economic **systems**
- **Outlook:**
  - closing data gaps (new technologies)
  - better representation of agriculture
  - better representation of CRM
  - coupling with MFA

Thanks for your attention!

Any questions?

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Further information:

premise paper: https://doi.org/10.1016/j.rser.2022.112311

premise on github: https://github.com/polca/premise

pathways tool: https://joss.theoj.org/papers/10.21105/joss.07309