NREL
Transforming ENERGY

2022 AIChE ANNUAL MEETING

Building a prospective LCA framework to analyze emerging technologies in a dynamic system context

Supported by: AMO, SA

POP: FY21-23

Partners

Pacific Northwest NATIONAL LABORATORY

Joint Global Change Research Institute

UNIVERSITY OF MARYLAND

PBL Netherlands Environmenta Assessment Agency

PAUL SCHERRER INSTITUT PSI


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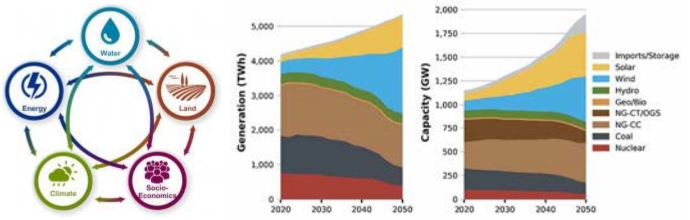
Shubh Upasani (inventories)

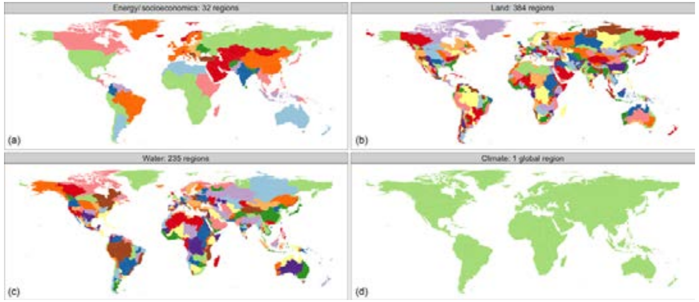

Patrick Lamers (PI)

November 17, 2022

Vision / Motivation

Prospective system models





Comprehensive but scenarios often depend on limited metrics. Models are primarily cost-driven.

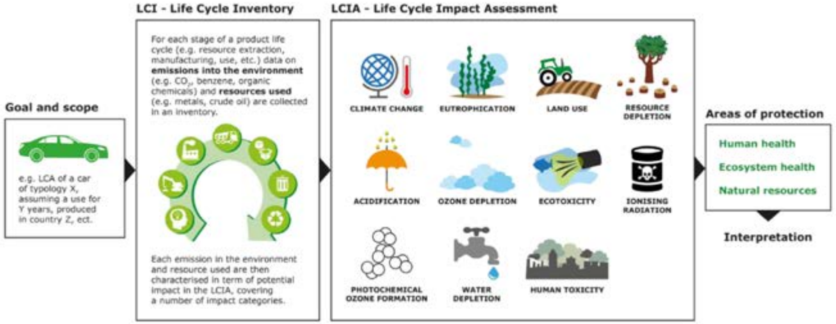
URL: nrel.gov; pnnl.gov

Phase 1 →

← Future

Life Cycle Assessment

Ecosystem Impacts	Human Impacts	Resource Depletion
Climate Change Acid Rain Eutrophication Land Use Change Solid Waste Toxicity	Ozone Depletion Smog Particulate Matter Carcinogens Toxicity	Fossil Fuel Freshwater Soil Forest Grassland Minerals



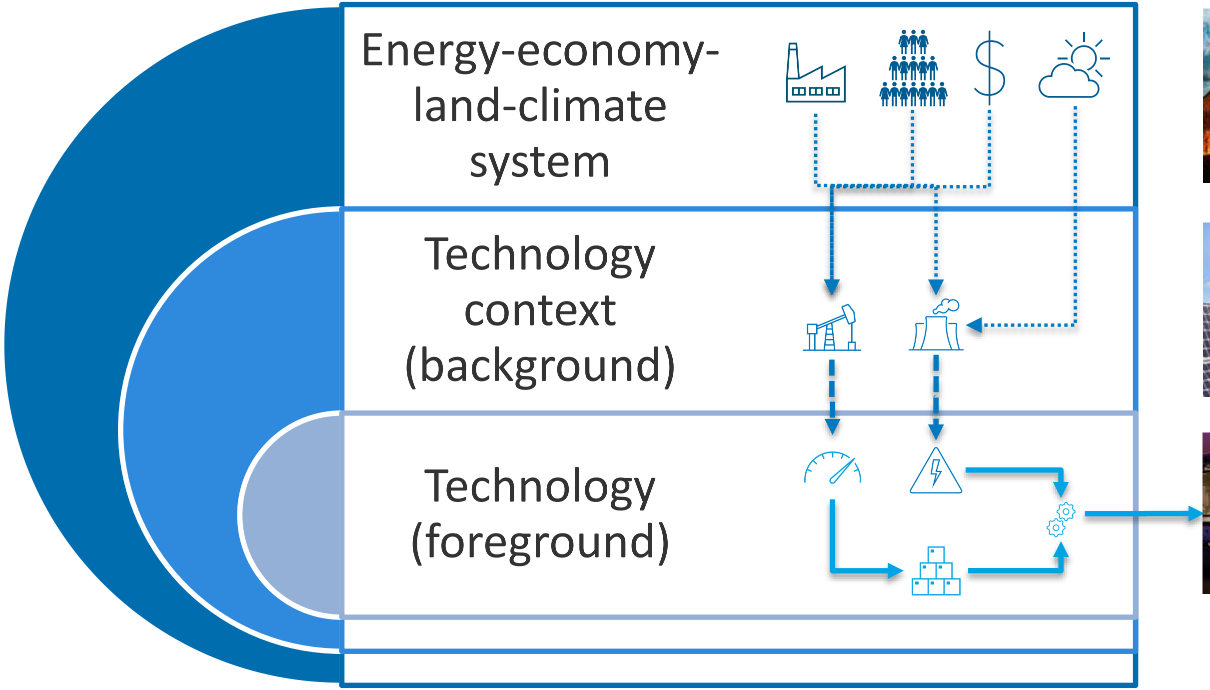
Multi-metric but results are context-specific. Analyses have varying system boundaries (hard to compare).

URL: https://eplca.jrc.ec.europa.eu/lifecycleassessment.html; https://www.sciencedirect.com/topics/engineering/life-cycle-impact-assessment

Phase 1

Prototype

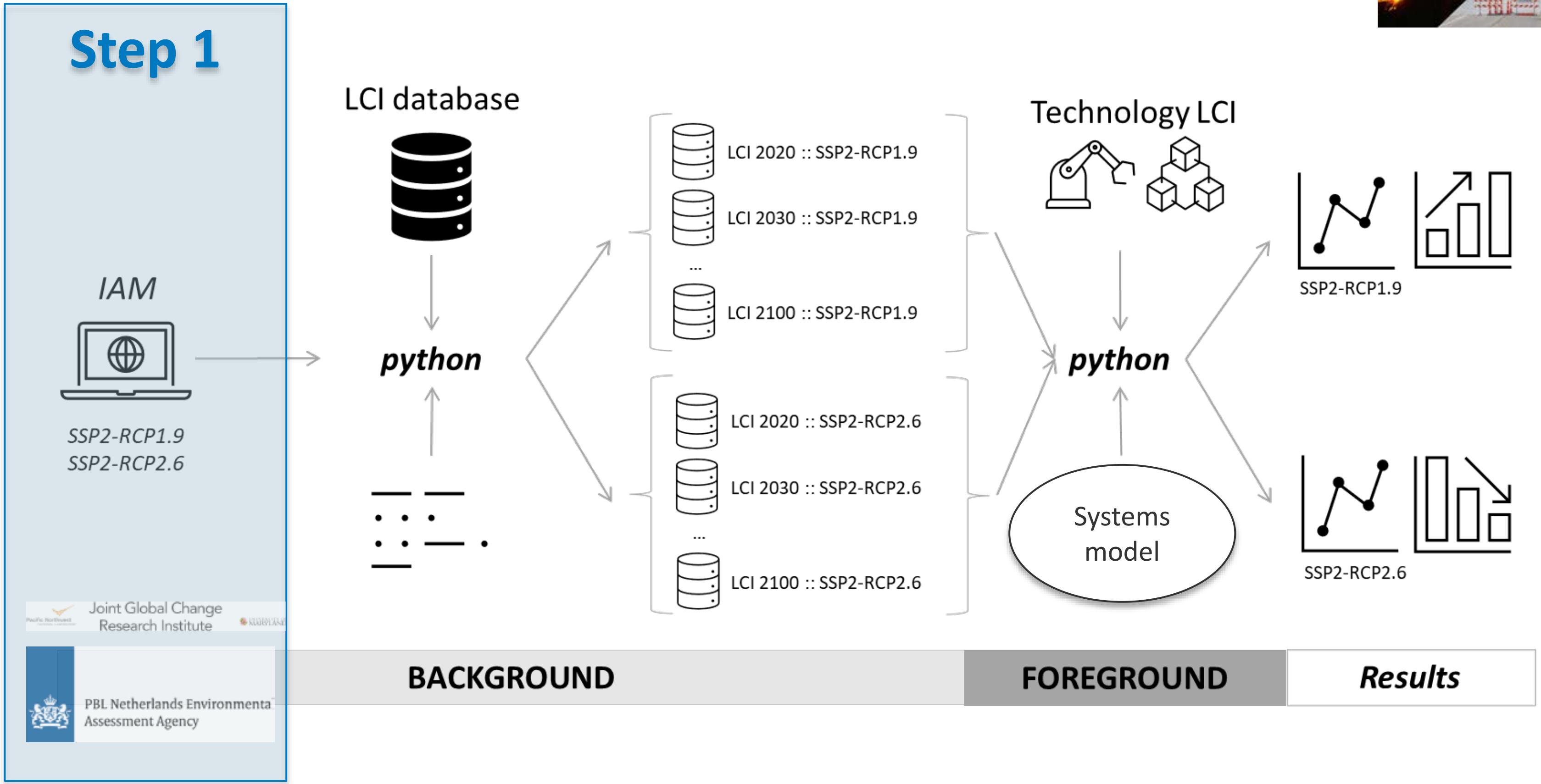
Code-based
HPC-compatible



1 kg of H_2

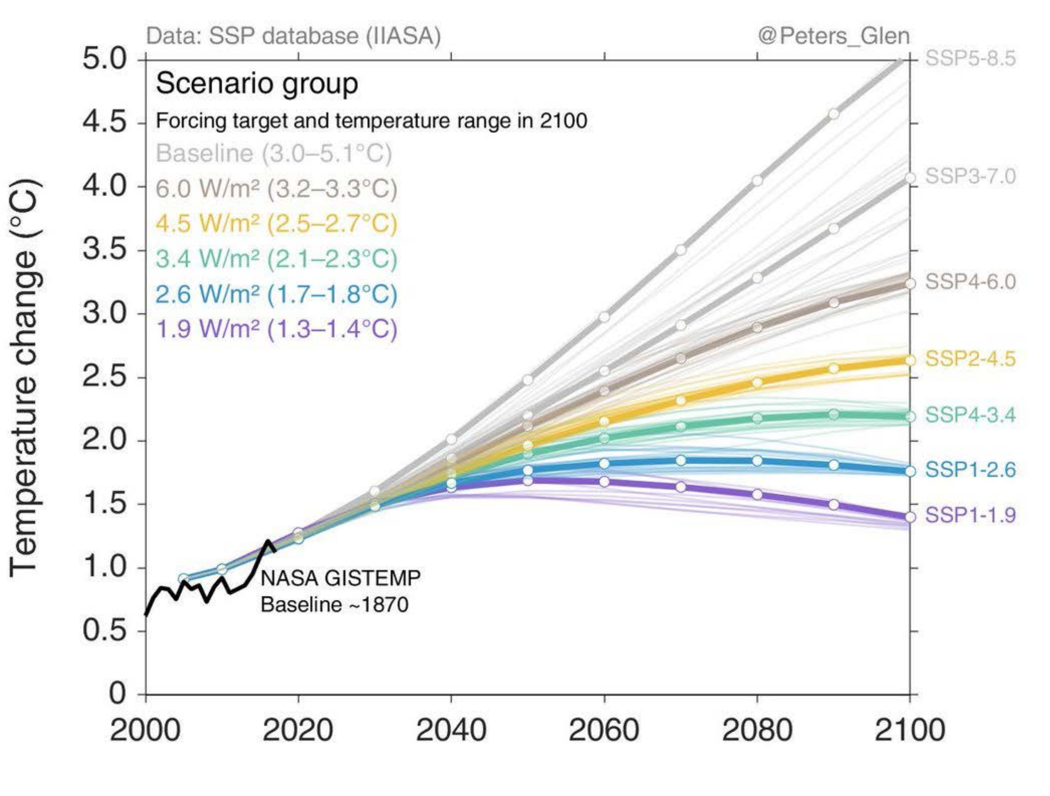
Cradle to grave LCA
Midpoint assessment

Methodology



Climate Change 2022

Mitigation of Climate Change



Shared-Socioeconomic Pathways (SSP):
socioeconomic challenges for mitigation and adaption

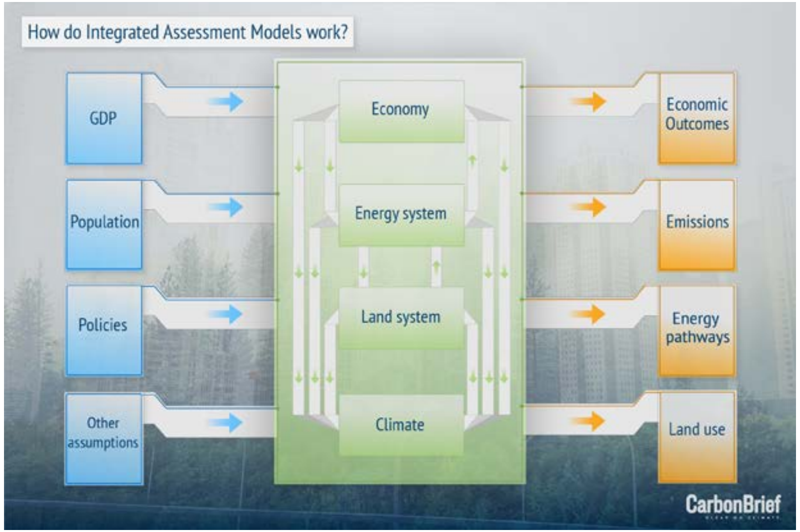
Representative Concentration Pathways (RCP):
global radiative forcing levels (W/m^2)

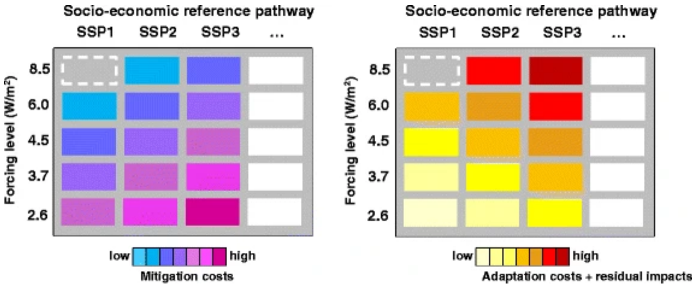
https://www.ipcc.ch/report/ar6/wg3/

Integrated background scenarios

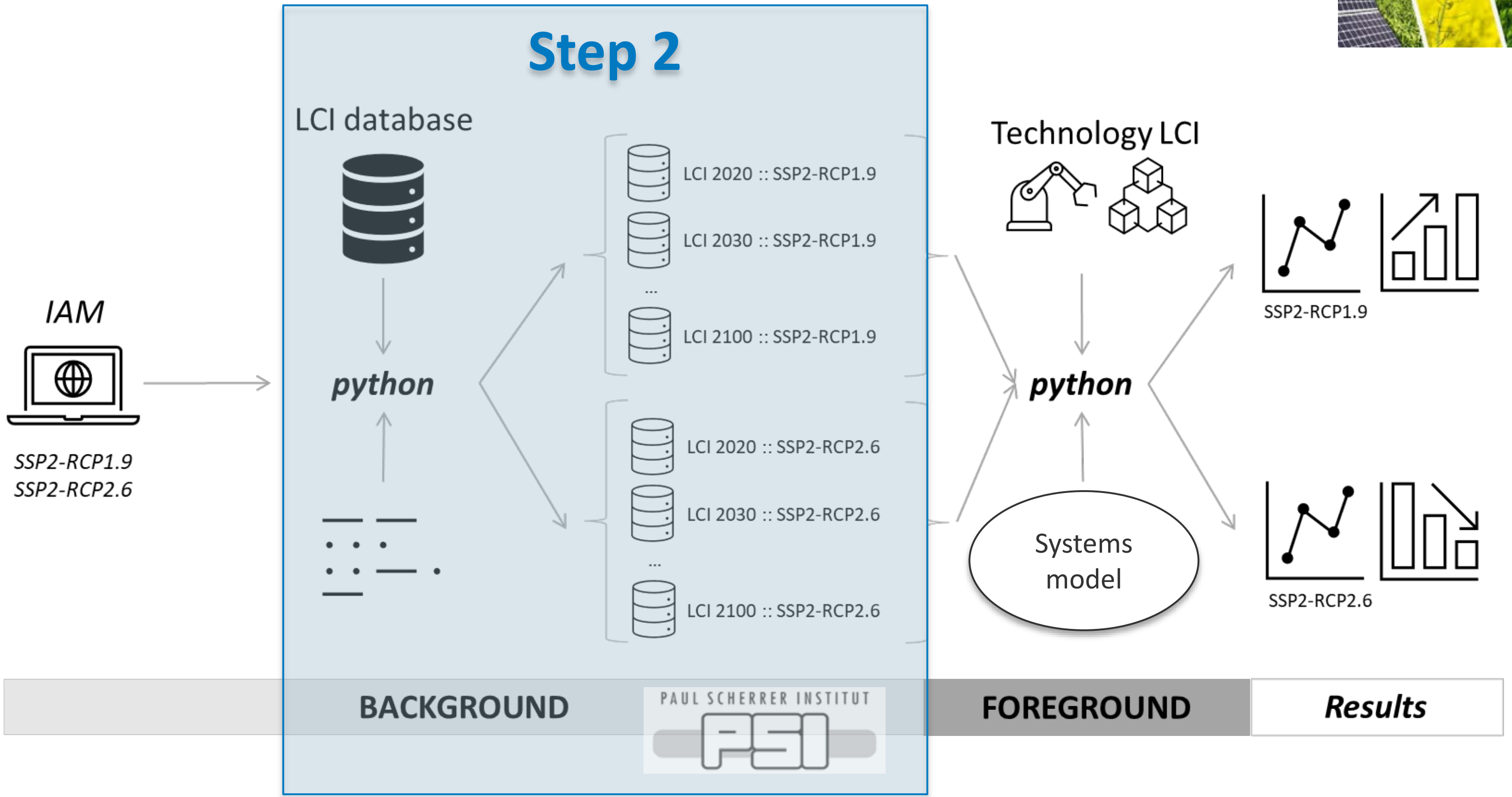
- Long-term, global projections of the coupled energy-economy-land-climate system.
- Derived from Integrated Assessment Models (IAM), e.g., GCAM (PNNL).
- Highly stylized but comprehensive.
- All scenarios are coherent, cross-sectoral and represent dynamics across physical and social systems.

- Comparability: Standardized outputs (SSP-RCP combinations).





Methodology

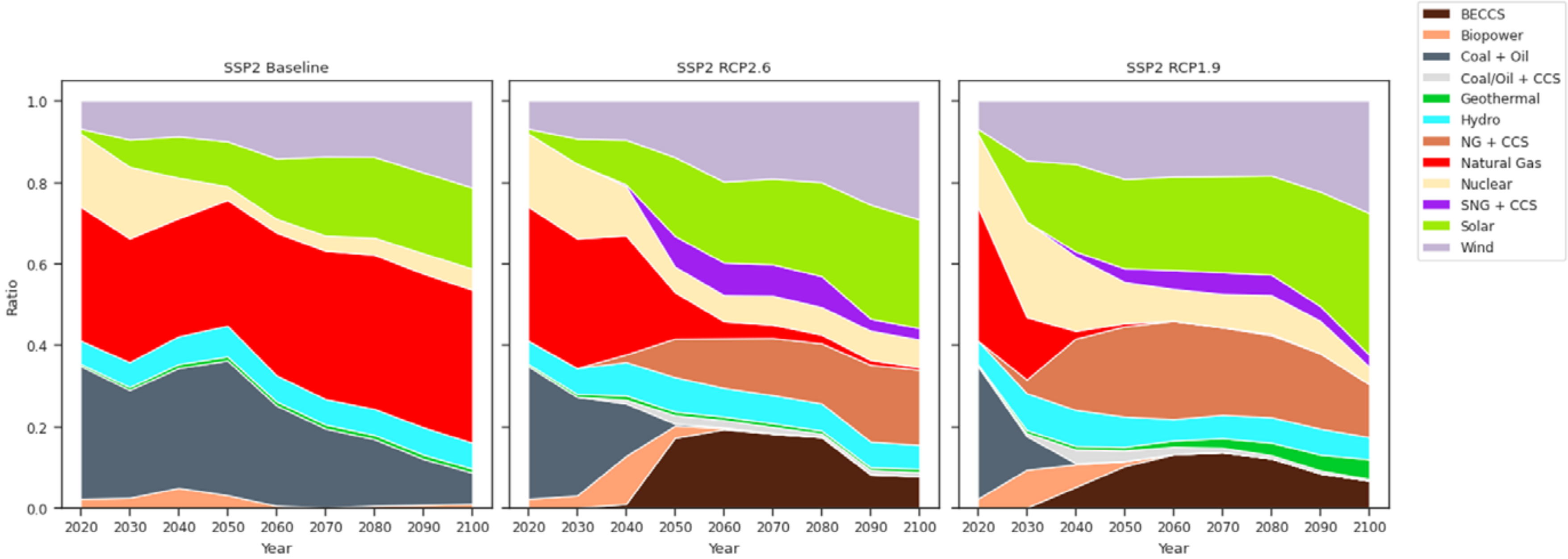


Sector projections

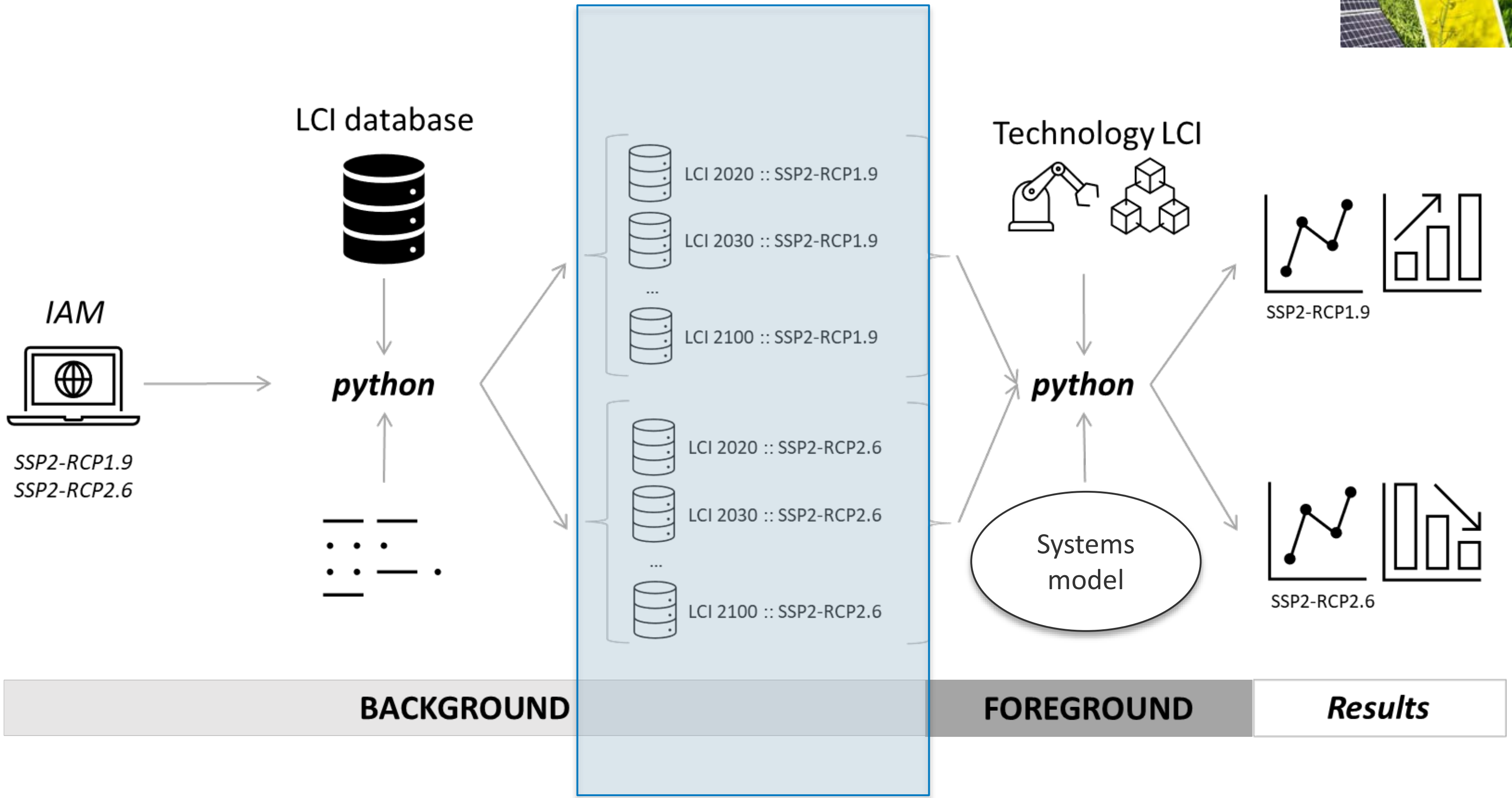
From the background scenarios, we derive technology compositions and efficiencies across four sectors:

- Power/Electricity,
- Cement,
- Steel,
- Transport fuels.

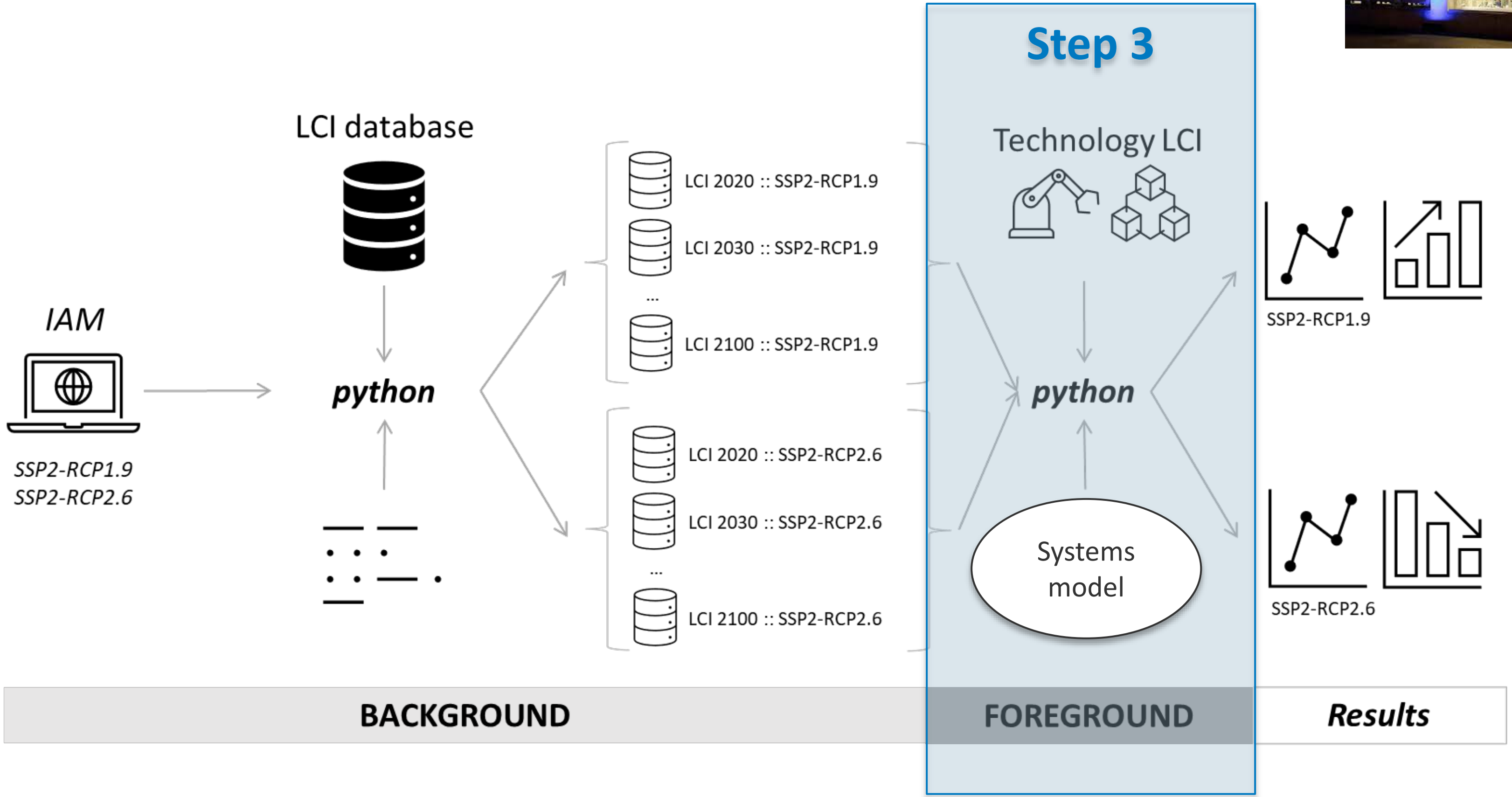
Example: US power sector development



Time-series LCI databases

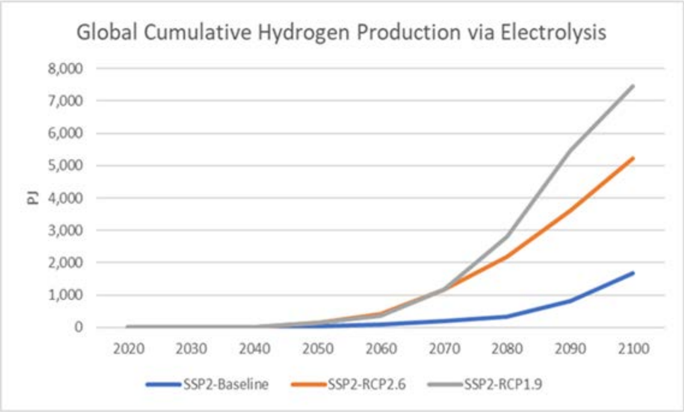


Case study: Power-to-H_2



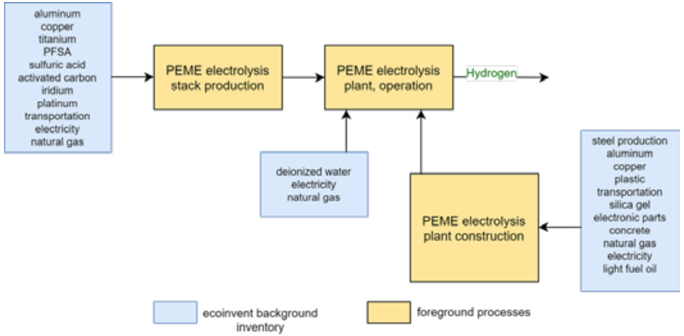
Process-level LCA/LCI

1. **Create the inventories (Test case: PtH_2),**
2. **Read into the code (automated via a tabular file),**
3. **Foreground dynamics: Track future improvements in the learning-by-doing stage (deployment).**
4. **Scenarios – SSP2 Baseline, SSP2 RCP2.6 and SSP2 RCP1.9**

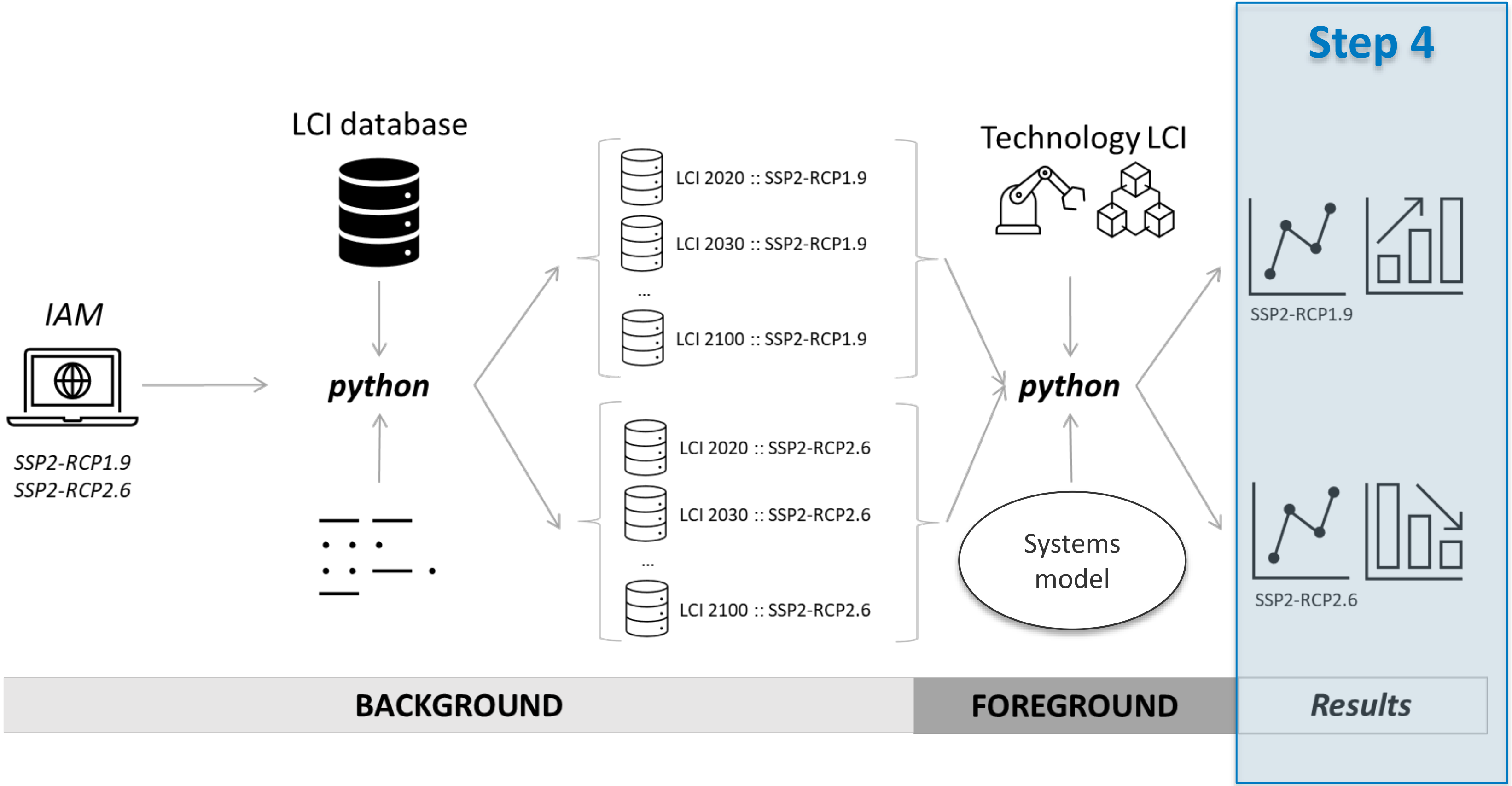


Technologies:

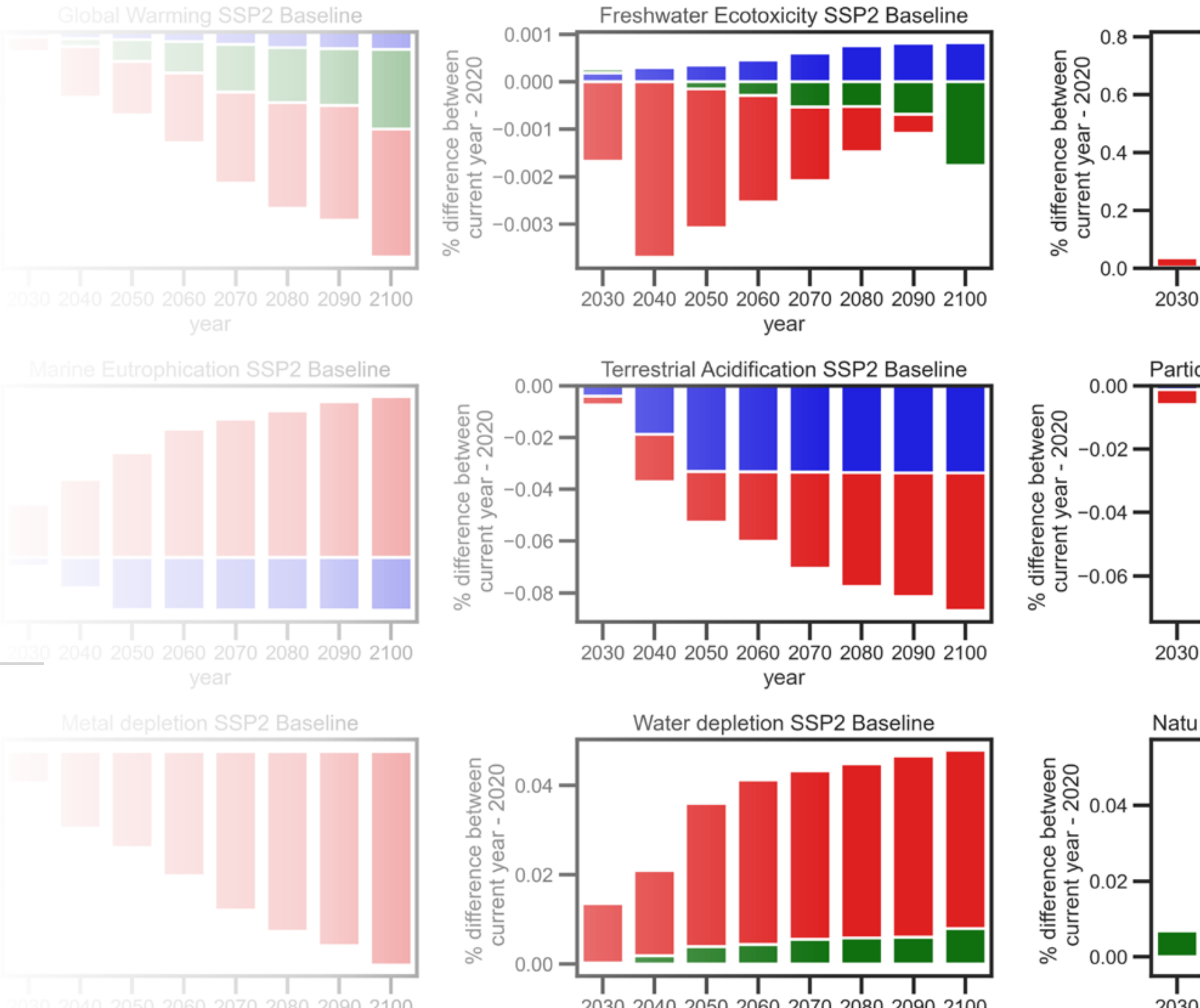
- **Steam methane reforming (reference) : H_2 generation via reforming natural gas (methane) using steam via WGSR to produce syngas and then H_2. *(Baseline)***
- **SOX : H_2 generation via electrolysis in a fuel cell with a solid oxide/ ceramic electrolyte (adv: high efficiency)**
- **PEME : H_2 generation via electrolysis in a cell with a solid polymer electrolyte (adv: low weight and volume)**



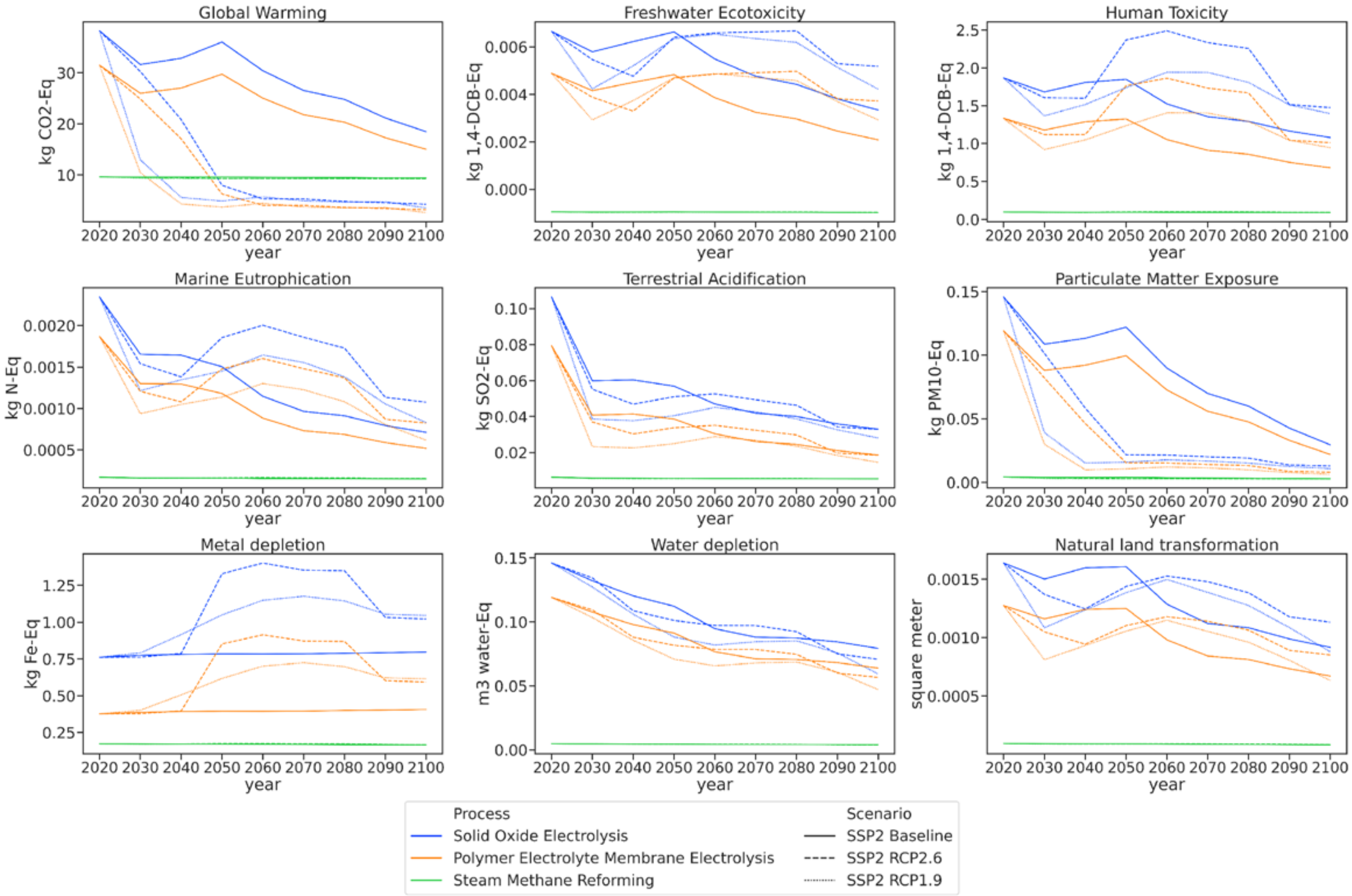
Results & Analysis



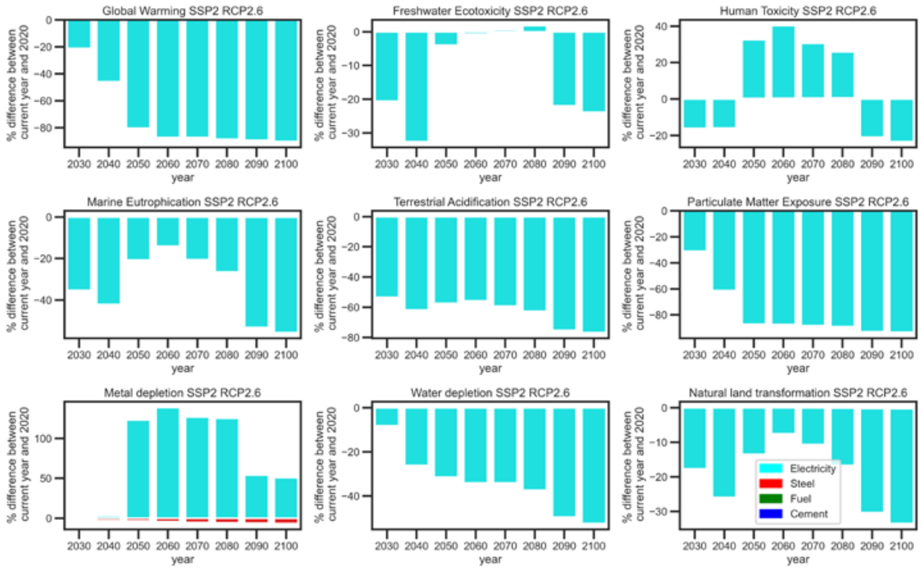
Background dynamics



Future impacts (ReCiPe; 1 kg H_2) only due to changes in the cement, steel, power, transport fuel sectors

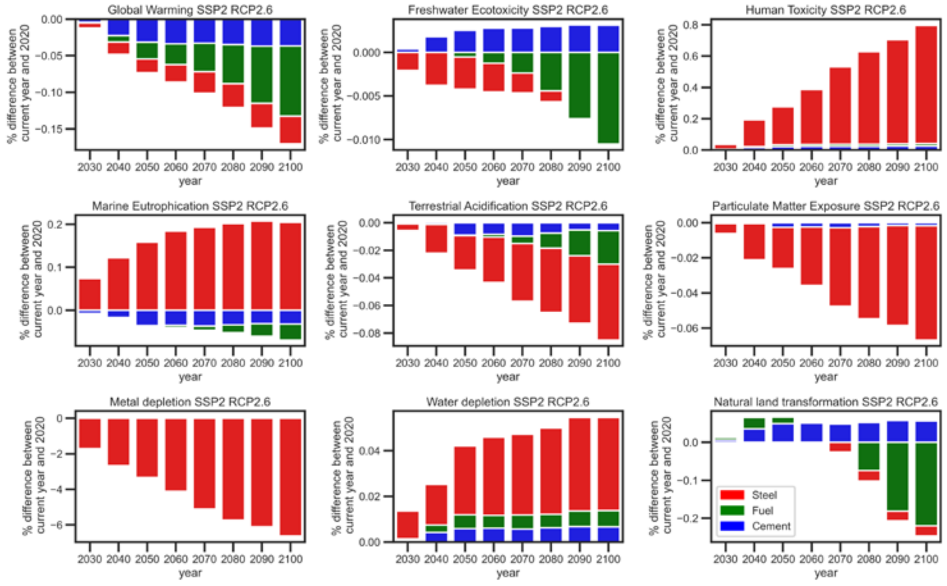


Specifying the dynamics per sector (background)

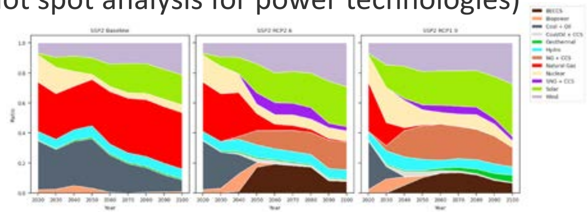


Example: PEME, SSP2-RCP2.6

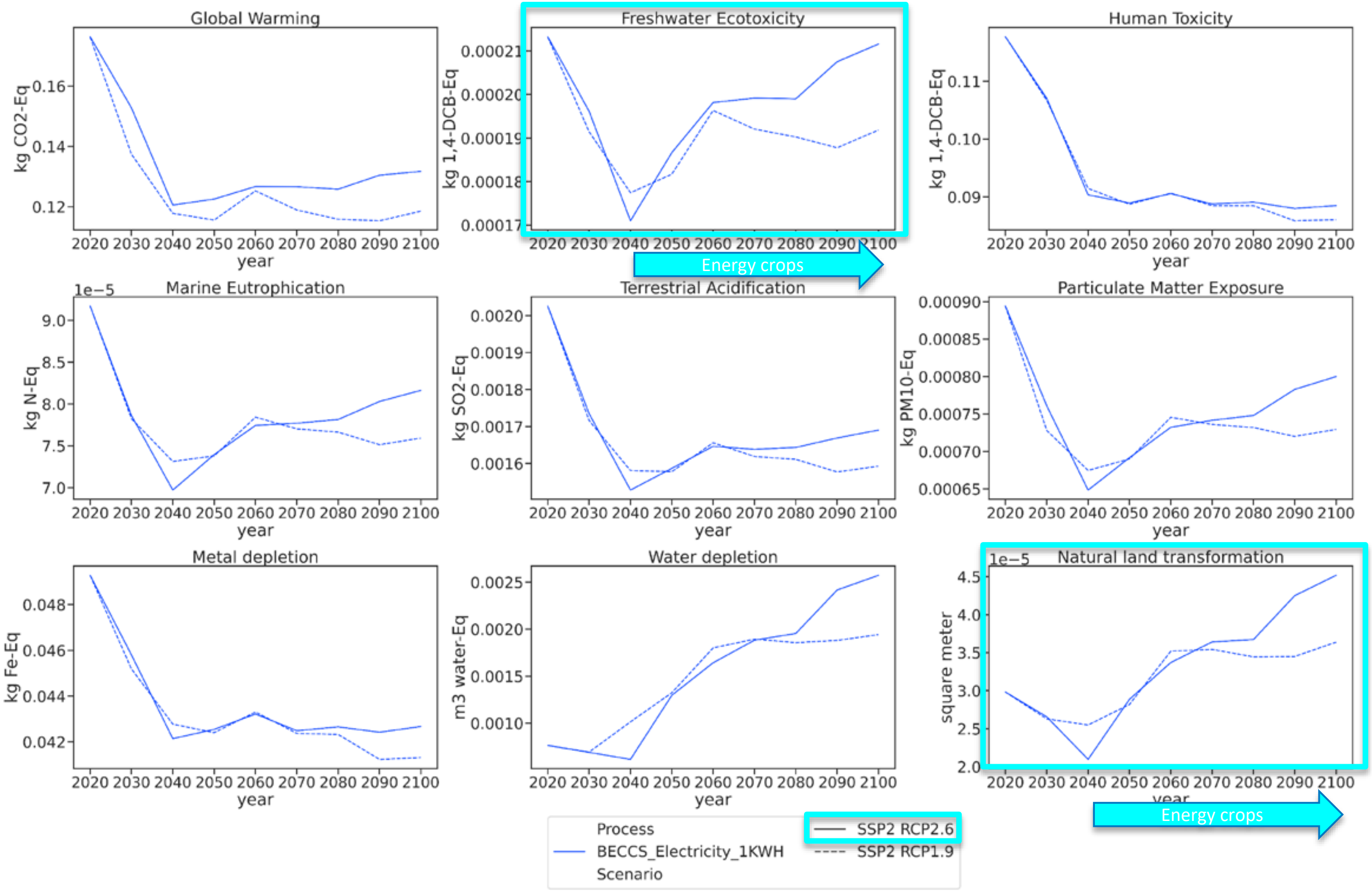
- Power sector exhibits the largest influence (up to -80%; top left).
- Metal depletion is linked to steel sector dynamics (recycling rates and efficiencies).
- Dynamics for other sectors are still observed, but they do not contribute significantly (<1%; bottom right).
- Land and water impacts link back to transport fuel sector dynamics.



LiAISON computes these results for each technology-scenario combination allowing us to identify:
1) The influences of the individual sector dynamics;
2) Potential tradeoffs and underlying dependencies (e.g., hot spot analysis for power technologies)



Example hot spot: BECCS (BIGCC unit w/ CCS per kWh)



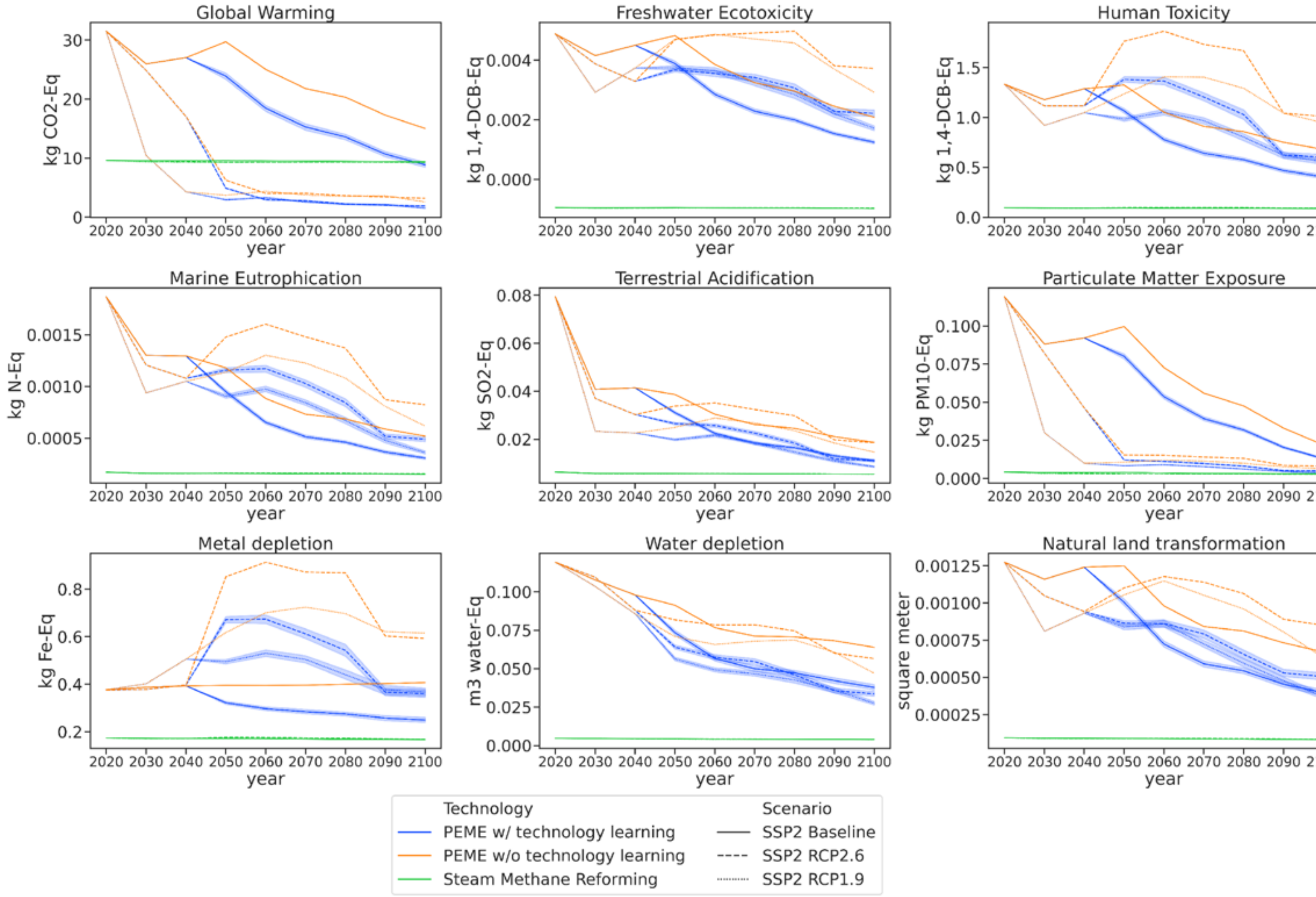
Background vs. Foreground changes

Beyond 2040 electrolysis is deployed globally on a large-scale, driving learning-by-doing improvements.

Learning-by-doing, further reduces impacts over time.

Benefits are largest for metrics that do not drop due to background changes, i.e., smaller benefits for GWP_{100} in mitigation scenarios, larger ones for impacts that rise, e.g., eutrophication.

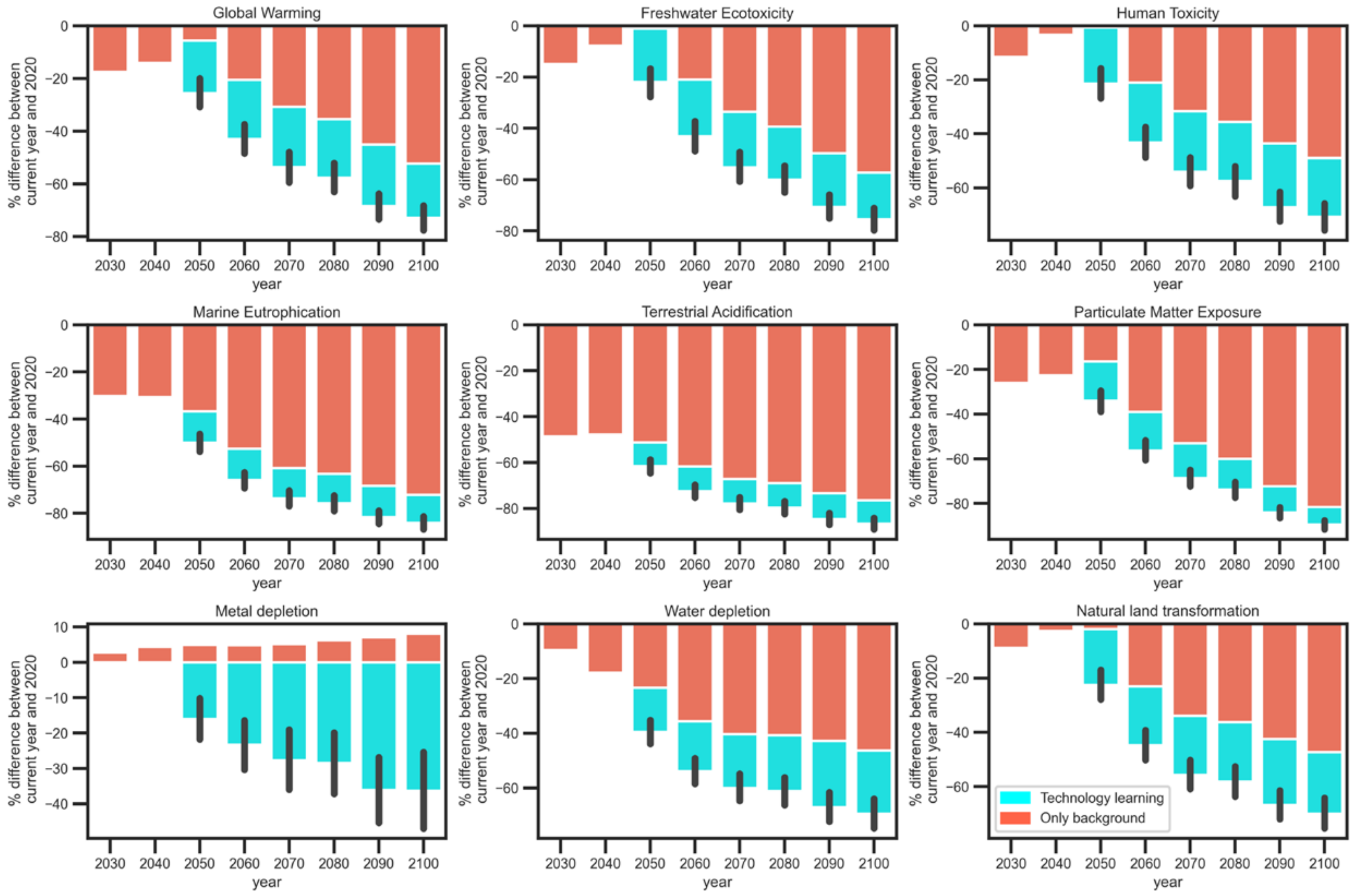
Blue bands: LR with triangular distribution.



PEME

ReCiPe

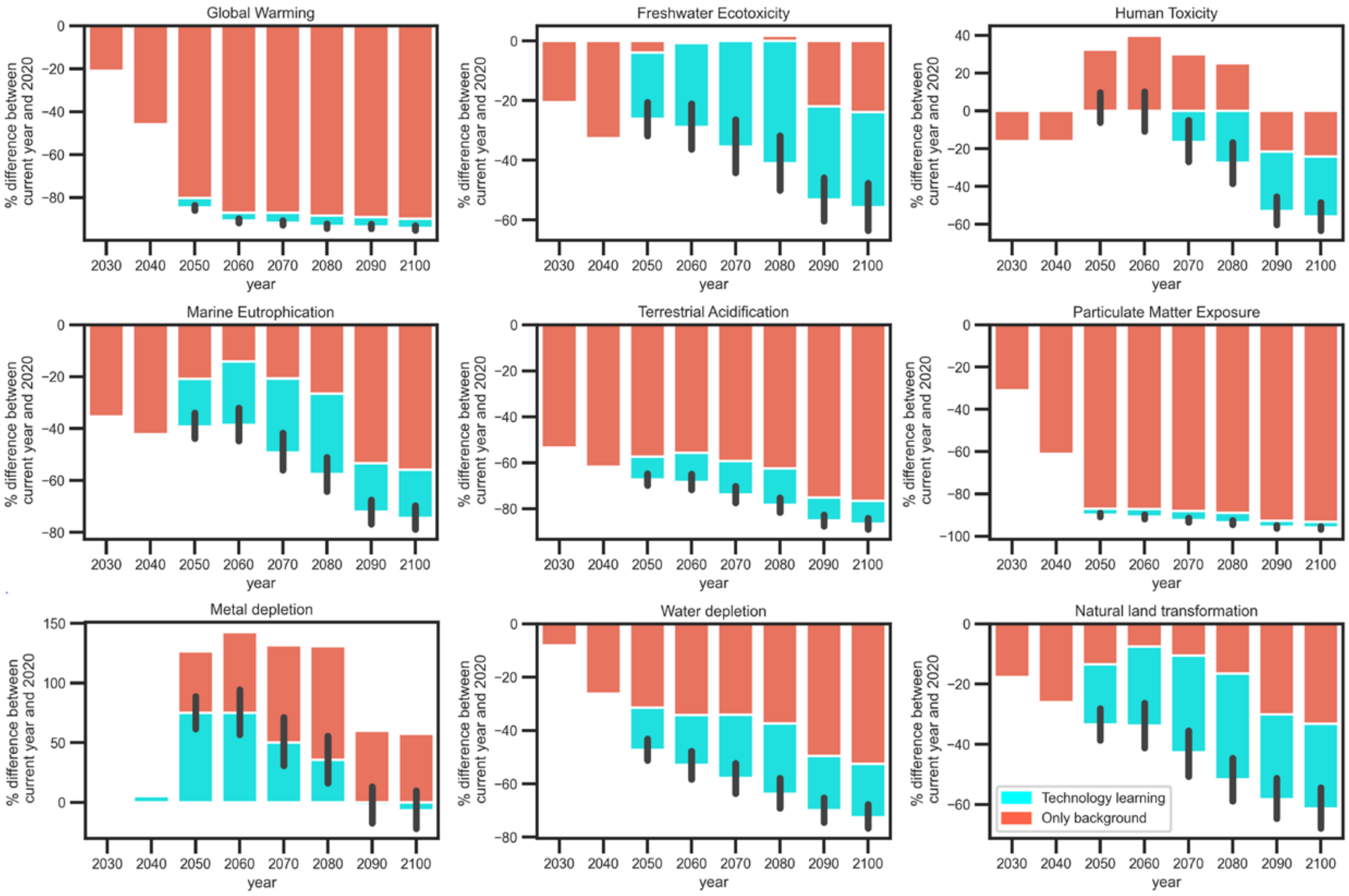
SSP2-Baseline



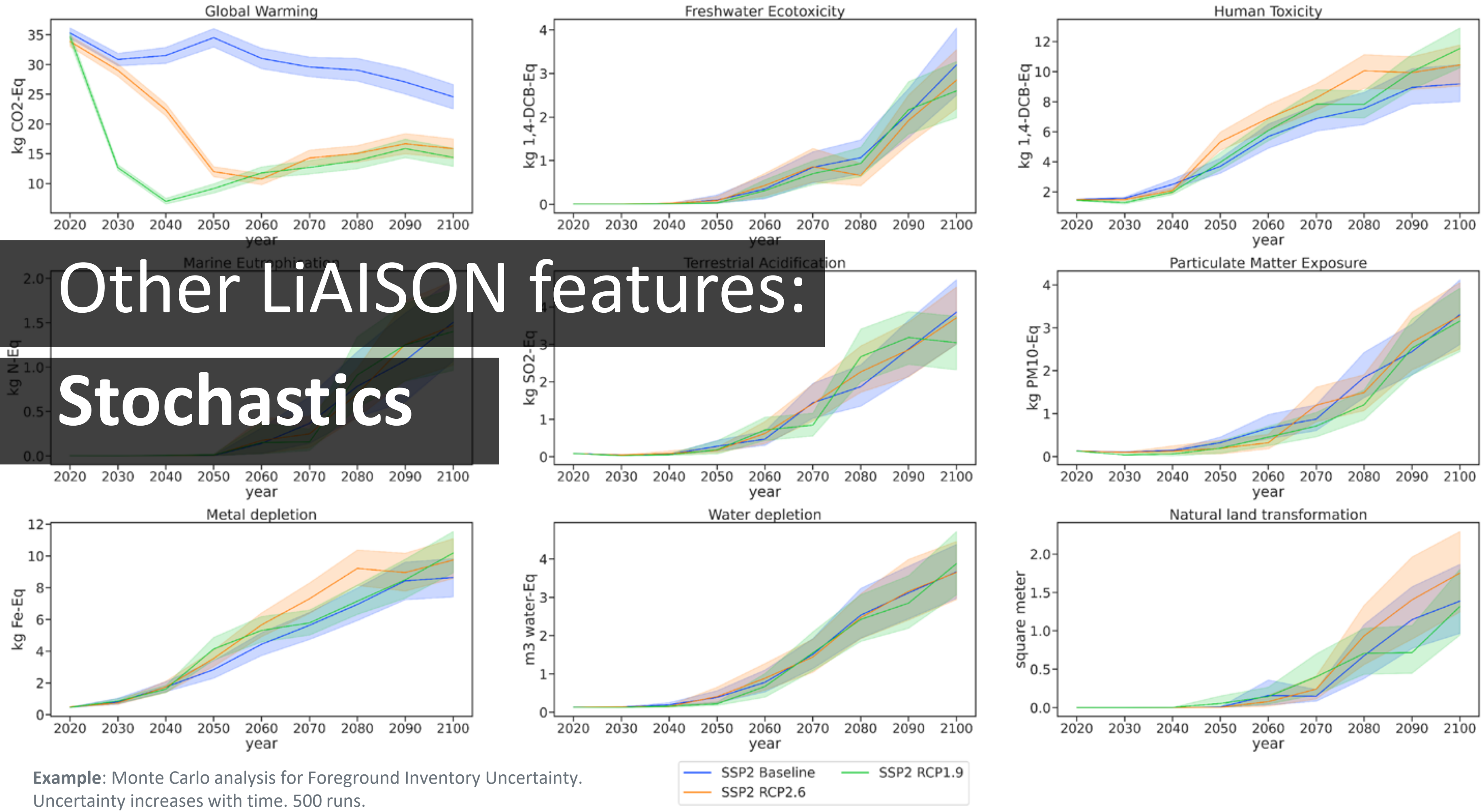
PEME

ReCiPe

SSP2-RCP2.6



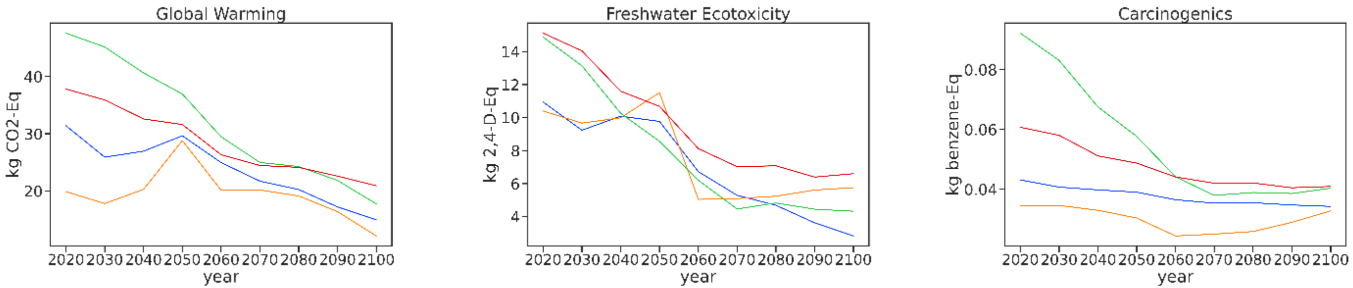
Other LiAISON features:
Stochastics



Example: Monte Carlo analysis for Foreground Inventory Uncertainty.
Uncertainty increases with time. 500 runs.
Formula: 2020: 0.1*Mean; 2030: 0.15*Mean; … ; 2100: 0.5*Mean.

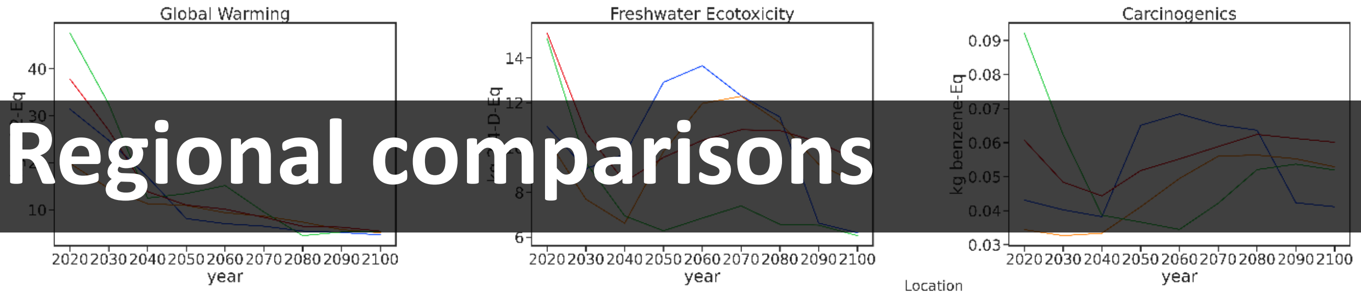
Regional comparisons

SSP2-Baseline

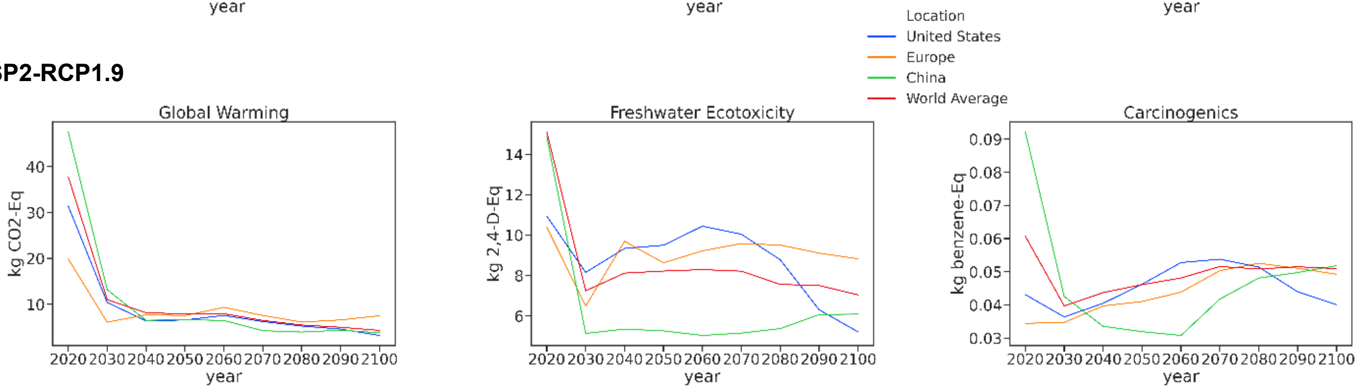


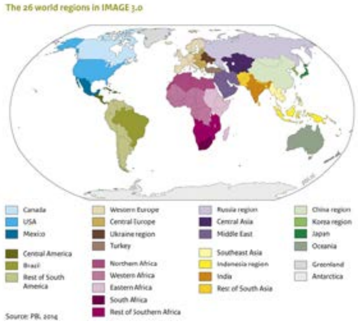
Example: Regional variations for PEME across the United States, Europe, China, compared to a global average.
Background dynamics: power sector only.
Foreground dynamics: none.
Functional unit: 1 kg H2.
LCIA method: TRACI.

SSP2-RCP2.6



SSP2-RCP1.9





Conclusions

Comparison to other LCA tools

Planned expansion

Summary

LCA tool comparison: Computation time

Functionality	Excel	openLCA	SimaPRO	LiAISON
Collection of inventory data	> 1 hour	> 1 hour	> 1 hour	> 1 hour
Foreground production system building	> 1 hour	< 1 hour	< 1 hour	< 5 mins
Linking with background inventory	> 1 hour	< 1 hour	< 1 hour	< 5 mins
Monte Carlo analysis	NA	< 5 mins	< 5 mins	< 1 hour
Regional sensitivity analysis	> 1 hour	> 1 hour	> 1 hour	< 5 mins
Technological learning sensitivity analysis	> 1 hour	> 1 hour	> 1 hour	< 5 mins
Prospective LCA	NA	NA	NA	< 5 mins
Plotting	< 1 hour	< 5 mins	< 5 mins	< 5 mins

NA

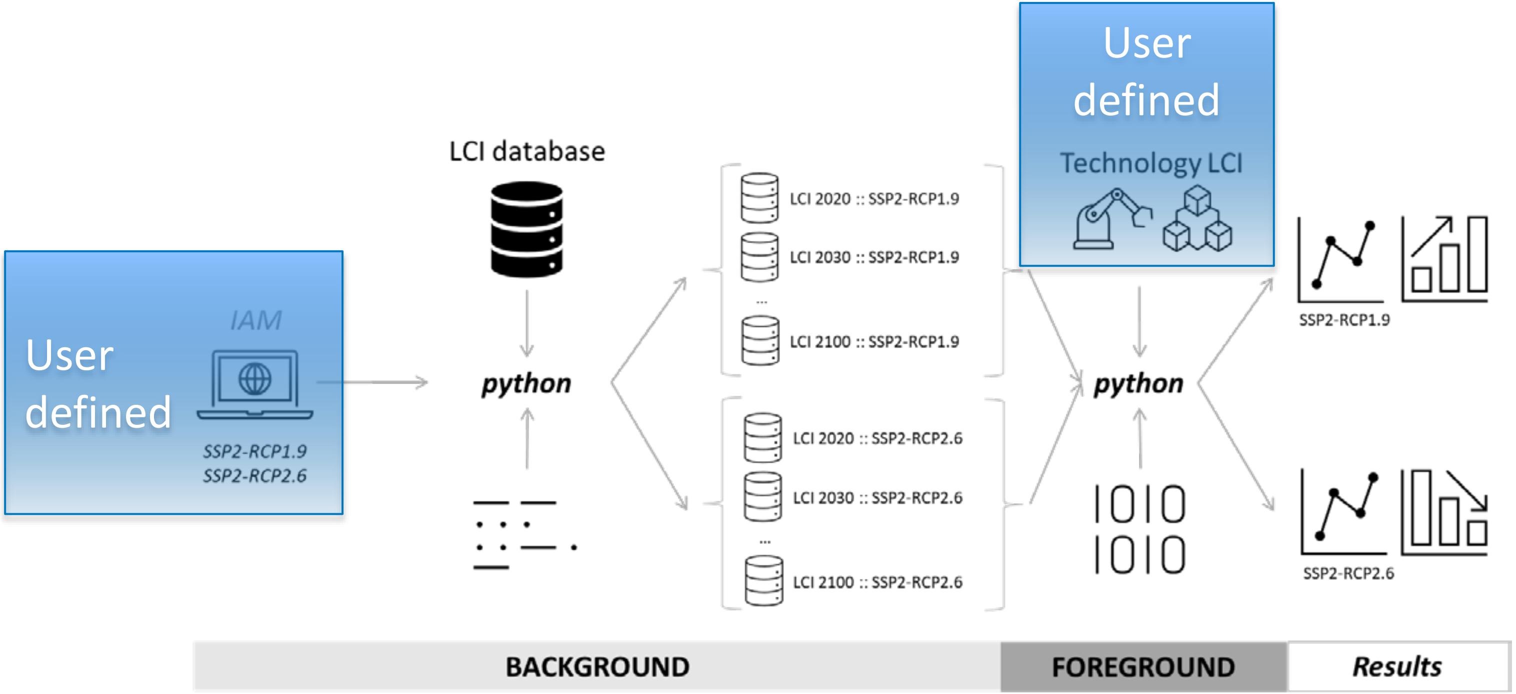
< 5 mins

< 1 hour

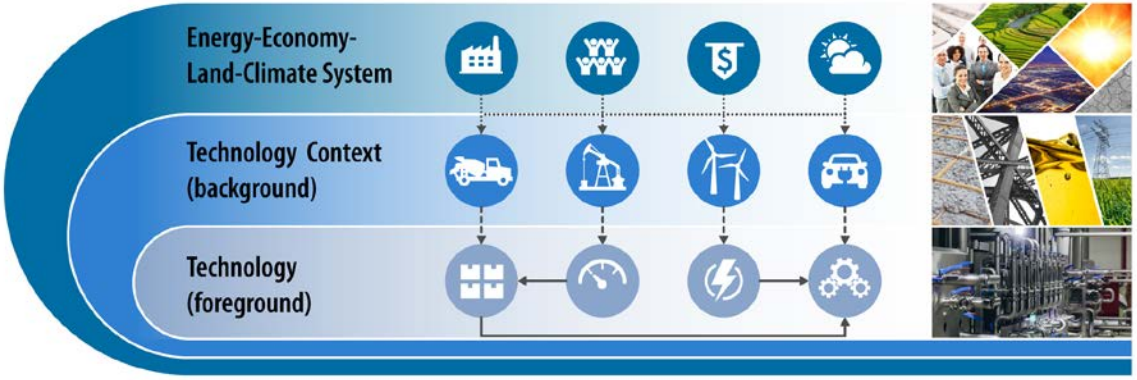
> 1 hour

*Assuming standard LCA with < 5 foreground processes, 500 MC runs, 3 regions

Prototype expansion



Lifecycle Analysis Integration into Scalable Open-source Numerical models



Funding: AMO, SA

POP: FY21-23

Project staff

Patrick Lamers (PI)

TJ Ghosh (code)

Shubh Upasani (inventories)

RQ: What are the future impacts and tradeoffs of present-day novel technologies accounting for transitions in the energy and manufacturing sectors as well as technology improvements?

Method: Coded, prospective life cycle assessment using long-term, coherent scenarios of the energy-economy-land-climate system to quantify the effects of background system changes and foreground technology improvements for various technologies.

Value-add: Inform R&D prioritization for novel technologies and preemptively address potential tradeoffs and unintended consequences of their large-scale deployment.

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PBL Netherlands Environmental Assessment Agency

PAUL SCHERRER INSTITUT PSI

Linkages: FECM, BOTTLE, others

Thank you

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NREL/PR-6A20-84483

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided through NREL's LDRD Program. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government.

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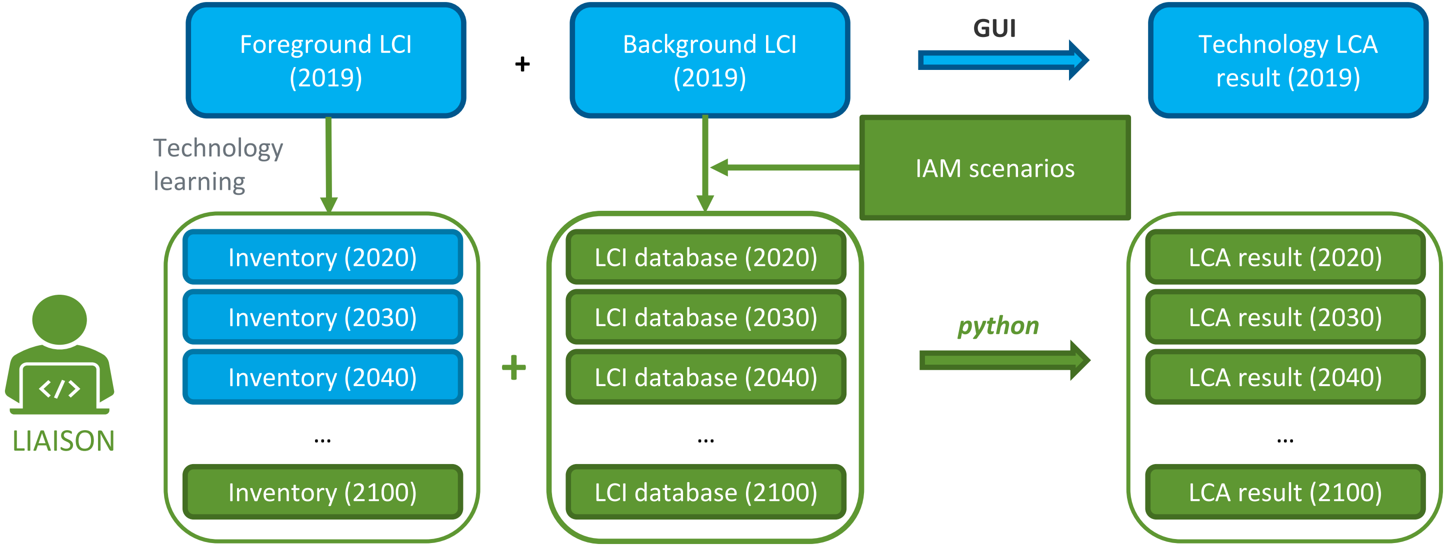
Difference to other LCA tools



- Code based: fast, versatile, batch-runs for Monte Carlo or sensitivity analyses, HPC compatibility (tested and vetted)
- GUI available for results viewing and analysis (e.g., Sankey diagram)