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Linking Life Cycle and Integrated Assessment Modeling to Evaluate Technologies in an Evolving System Context: A Power-to-Hydrogen Case Study for the United States

Patrick Lamers,* Tapajyoti Ghosh, Shubhankar Upasani, Romain Sacchi, and Vassilis Daioglou

Cite This: Environ. Sci. Technol. 2023, 57, 2464–2473
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Life-cycle Assessment Integration into Scalable Open-source Numerical models (LiAISON) for analyzing emerging low-carbon technologies


TJ Ghosh
(PI)


Patrick Lamers
(Senior Advisor)


Shubhankar
Upasani
(inventories)

Supported by: US Department of Energy

POP: FY21-23

Partners

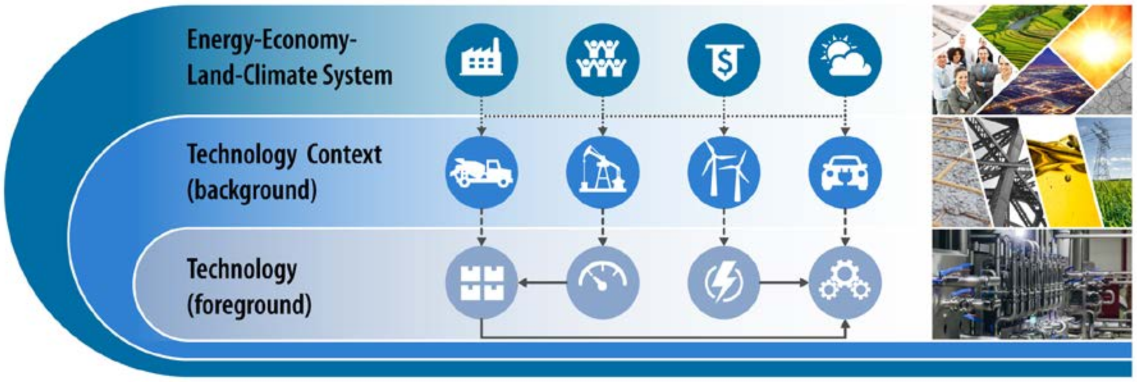
Pacific Northwest National Laboratory
Joint Global Change Research Institute
University of Maryland
PBL Netherlands Environmental Assessment Agency
Paul Scherrer Institut PSI

International Symposium on Sustainable Systems and Technology

June 14, 2023.

https://pubs.acs.org/doi/10.1021/acs.est.2c04246

Lifecycle Analysis Integration into Scalable Open-source Numerical models



Funding: Department of Energy

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Project staff

TJ Ghosh (PI)

Patrick Lamers (Senior Advisor)

Shubhankar Upasani (inventories)

Research Question: 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.

Partners

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UNIVERSITY OF MARYLAND

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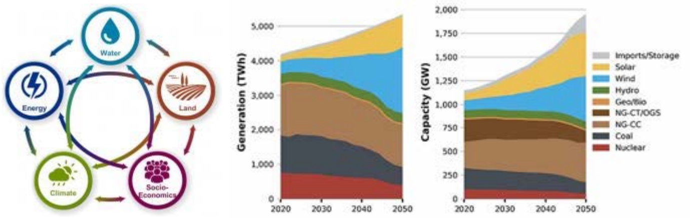
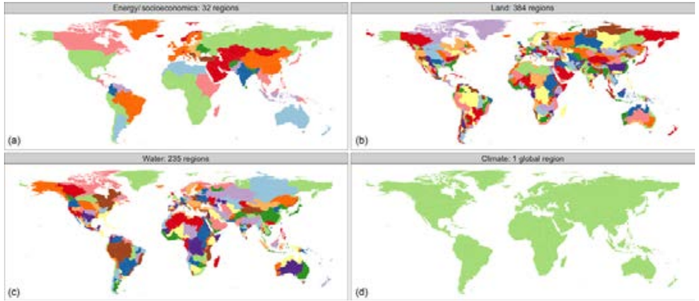
PAUL SCHERRER INSTITUT PSI

Linkages: FECM, BOTTLE, others

Vision / Motivation

Prospective system models





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

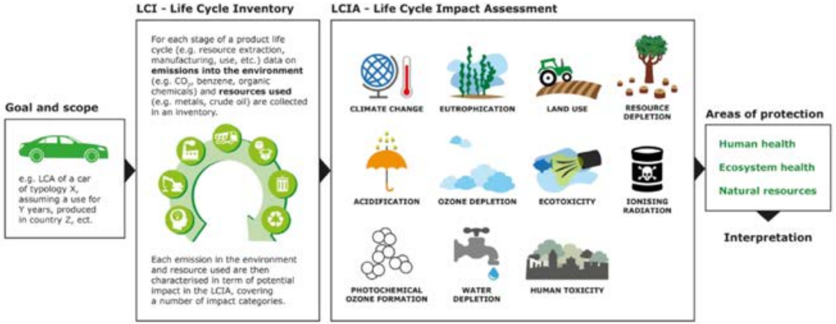
URL: nrel.gov; pnnl.gov

Phase 1

Future

Life Cycle Assessment

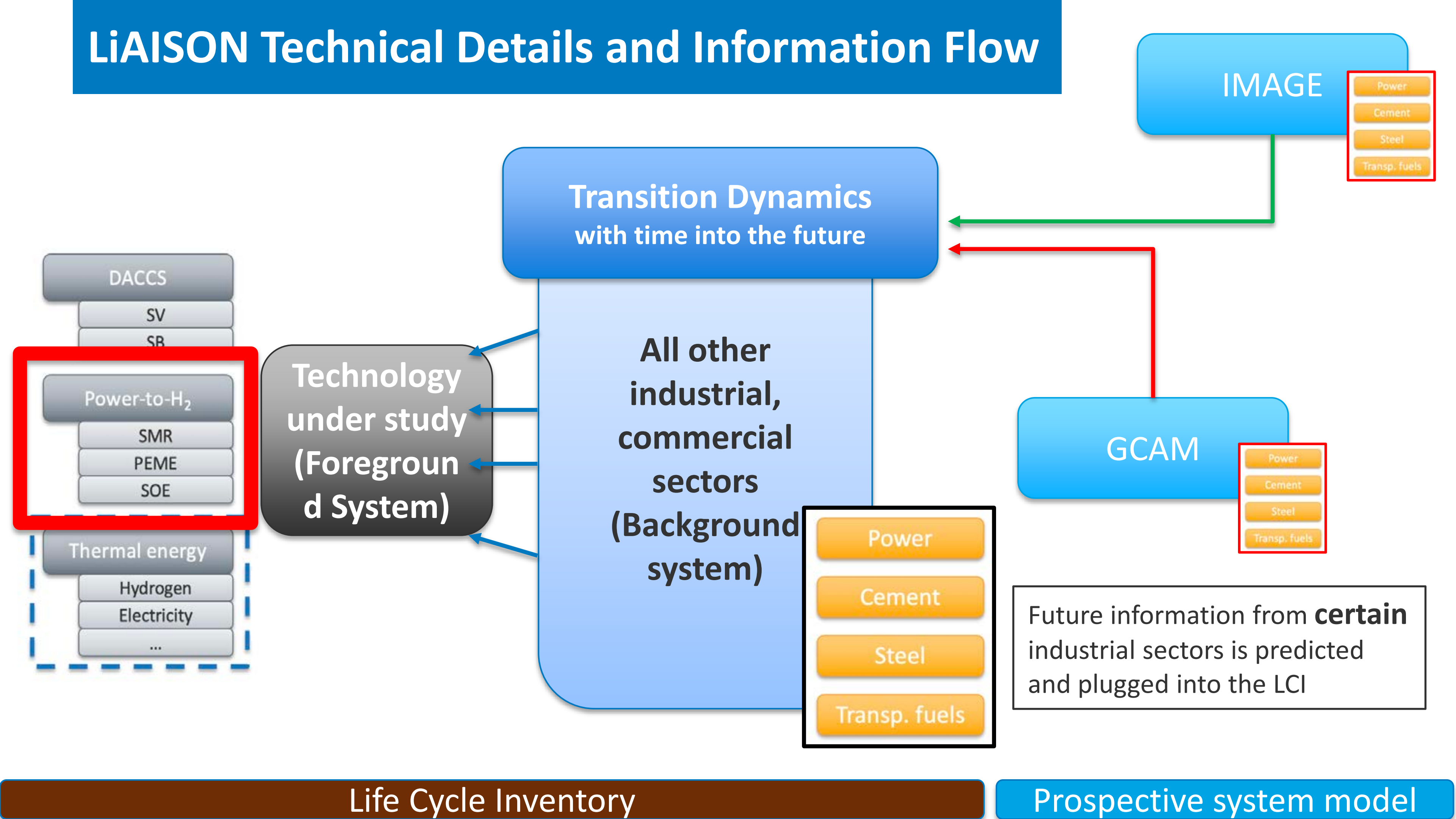
Ecosystem Impacts	Human Impacts	Resource Depletion
Climate Change Acid Rain Eutrophication Land Use Change Solid Waste Toxicity	Ozone Depletion Smog Particulate Matter Carcinogens Toxicity	Fossil Fuel Freshwater Soil Forest Grassland Minerals



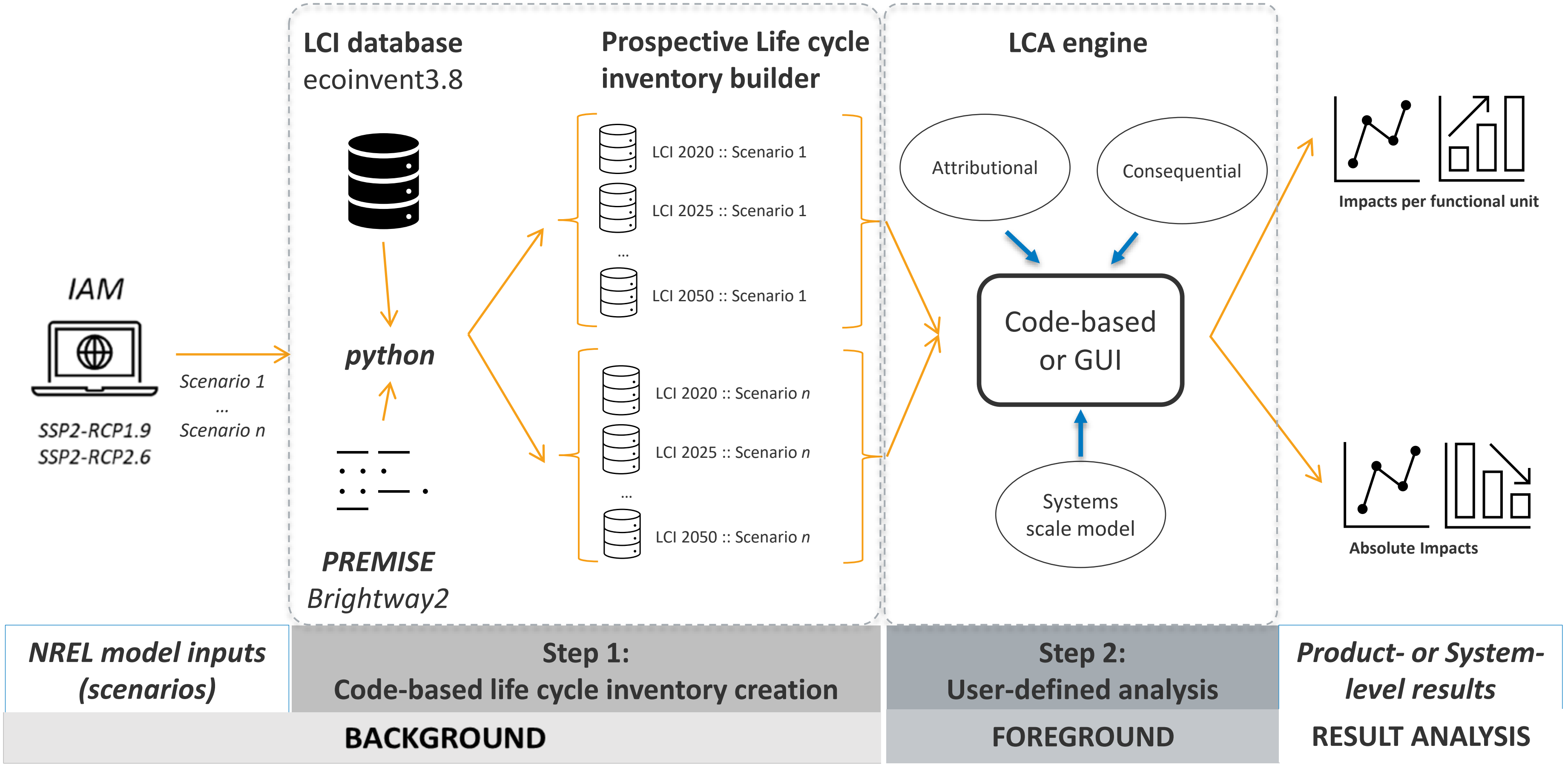
Multi-metric but results are context-specific. Analyses have varying system boundaries (hard to compare).

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

LiAISON Technical Details and Information Flow



Methodology - LiAISON Technical Details

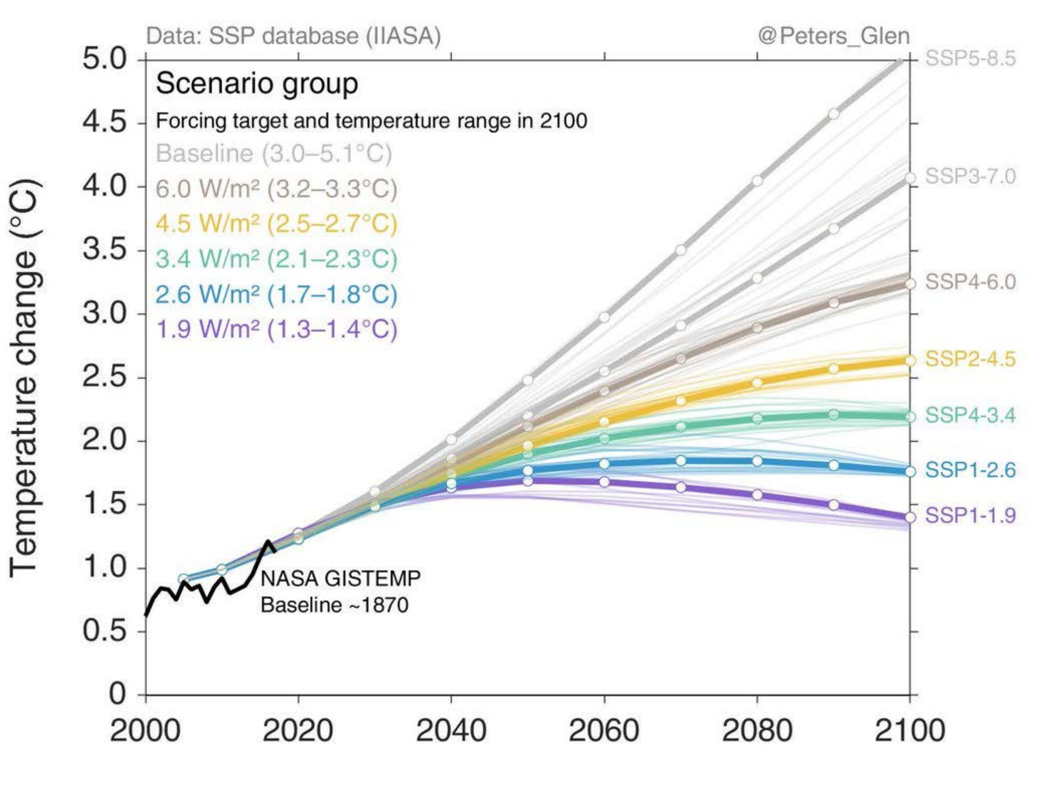


Sixth Assessment Report
WORKING GROUP III – MITIGATION OF CLIMATE CHANGE

INTERGOVERNMENTAL PANEL ON climate change

Climate Change 2022

Mitigation of Climate Change



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

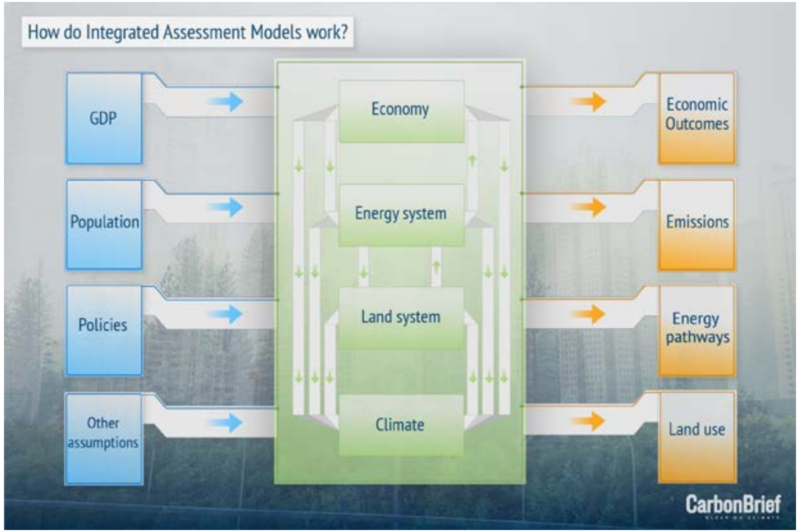
Representative Concentration Pathways (RCP):
global radiative forcing levels (W/m^2)

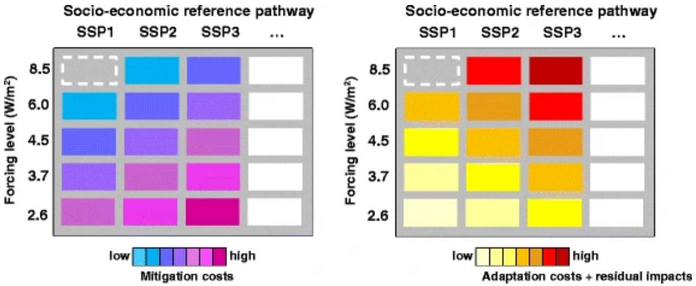
https://www.ipcc.ch/report/ar6/wg3/

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).





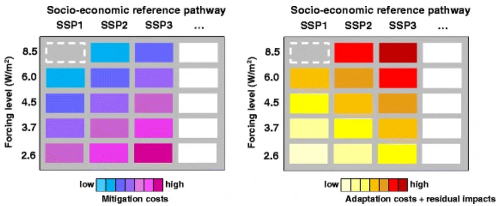
Sector projections

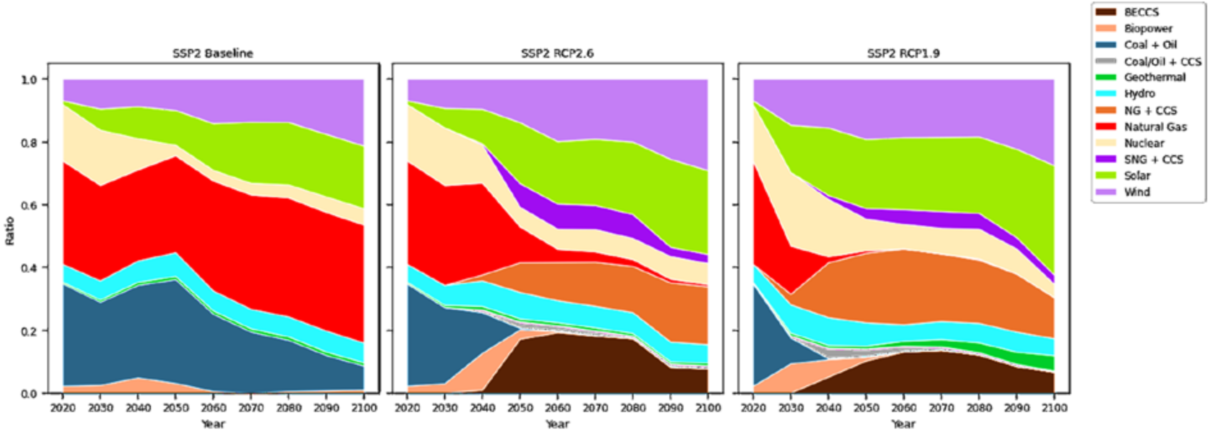
The background scenarios define technology compositions and efficiencies across four sectors:

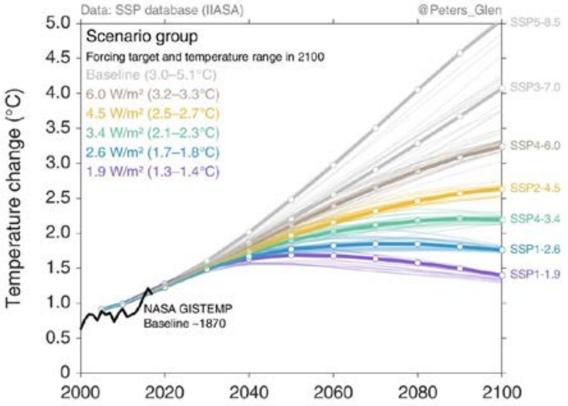
- Power,
- Cement,
- Steel,
- Transport fuels.

Example: power sector specifics – Shared Socio-Economic Pathways (IPCC)

- **SSP2-RCP1.9: net zero GHG economy by 2035, net zero GHG economy by 2050**
- **SSP2-RCP2.6: delayed by ~ 20 years**
- **SSP2-reference: no targets**





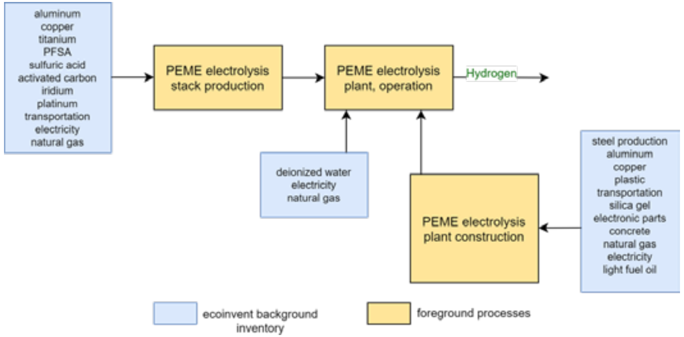


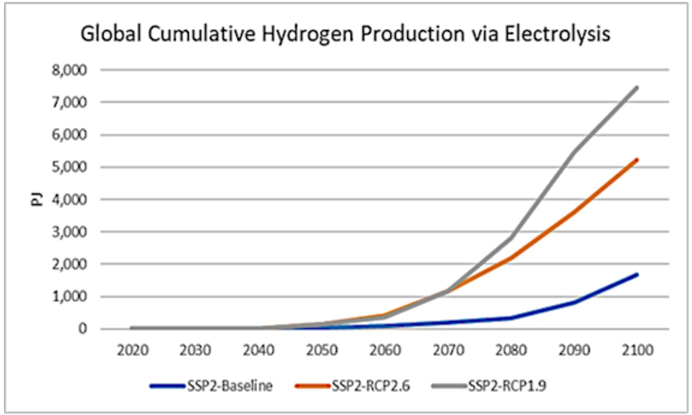
Power-to-Hydrogen (PtH_2)

Technologies:

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

Adjusted to background deployment levels in the respective scenarios.
Foreground dynamics via learning-by-doing in the deployment stage.



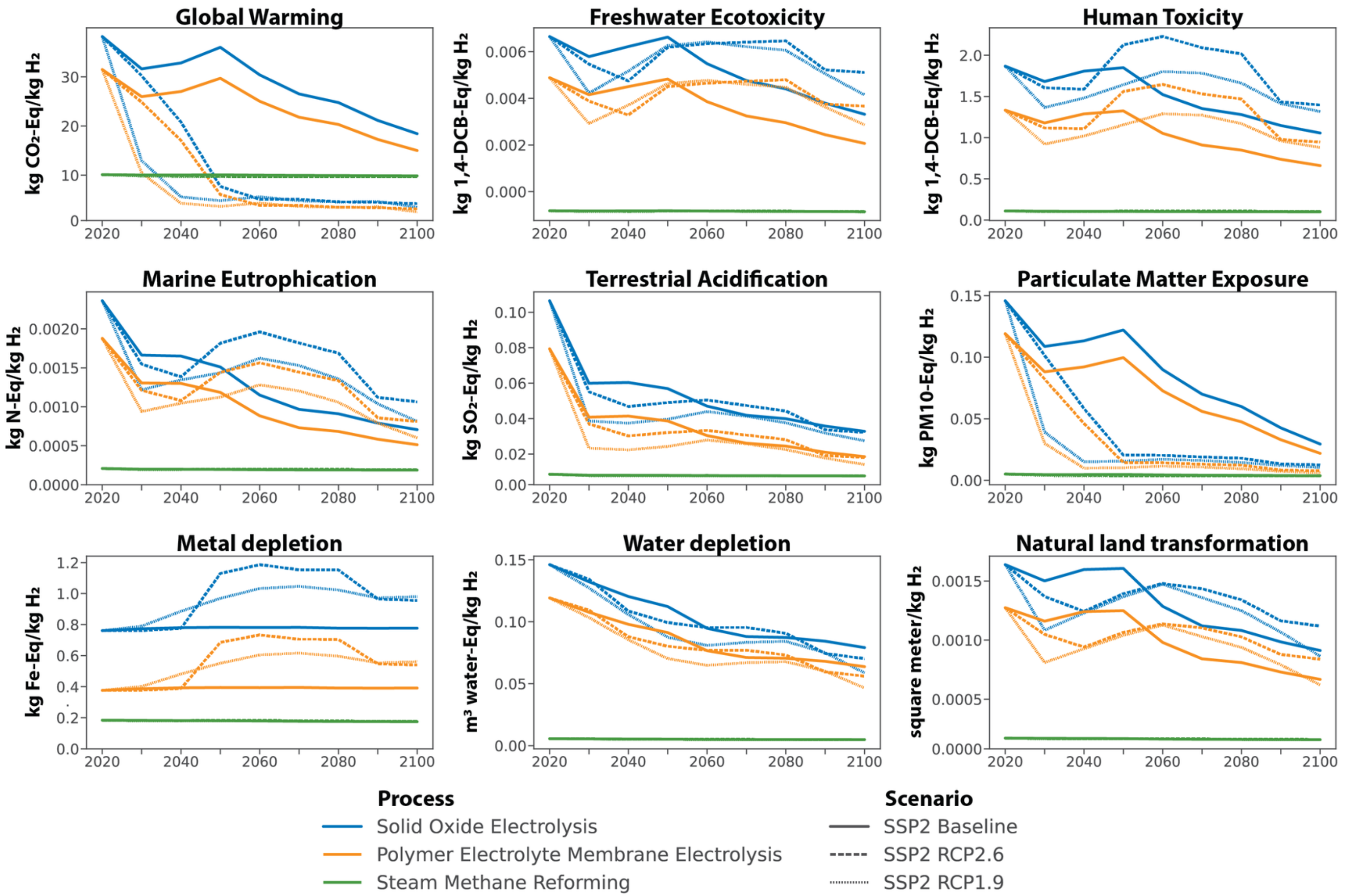


GWP, PEME and SOE reach parity with SMR in 2050 and 2030 for SSP2-RCP2.6 and SSP2-RCP1.9 respectively.

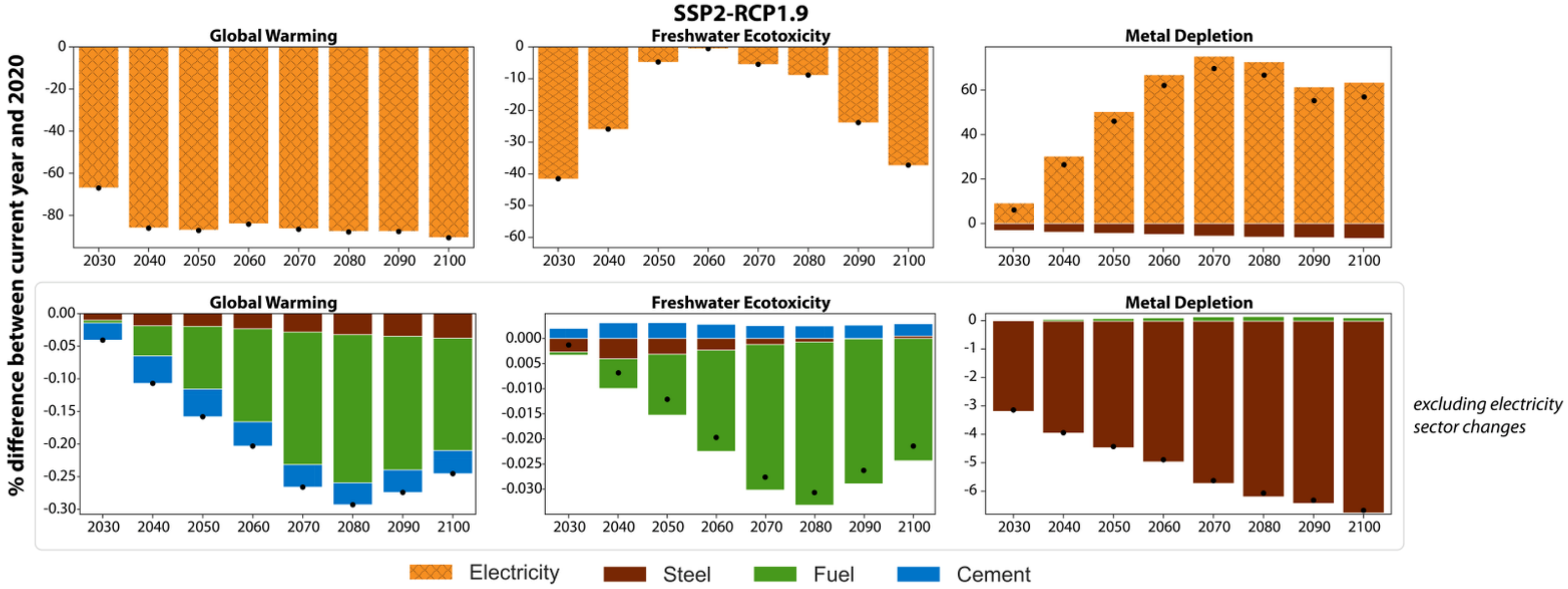
Do not reach parity with SMR for the baseline case.

Impacts such as marine eutrophication, metal depletion and human toxicity increase due to deployment of BECCS and increased used of solar and wind for the decarbonization pathways.

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



Specifying the dynamics per sector (background)



Example: PEME, SSP2-RCP1.9

- 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:

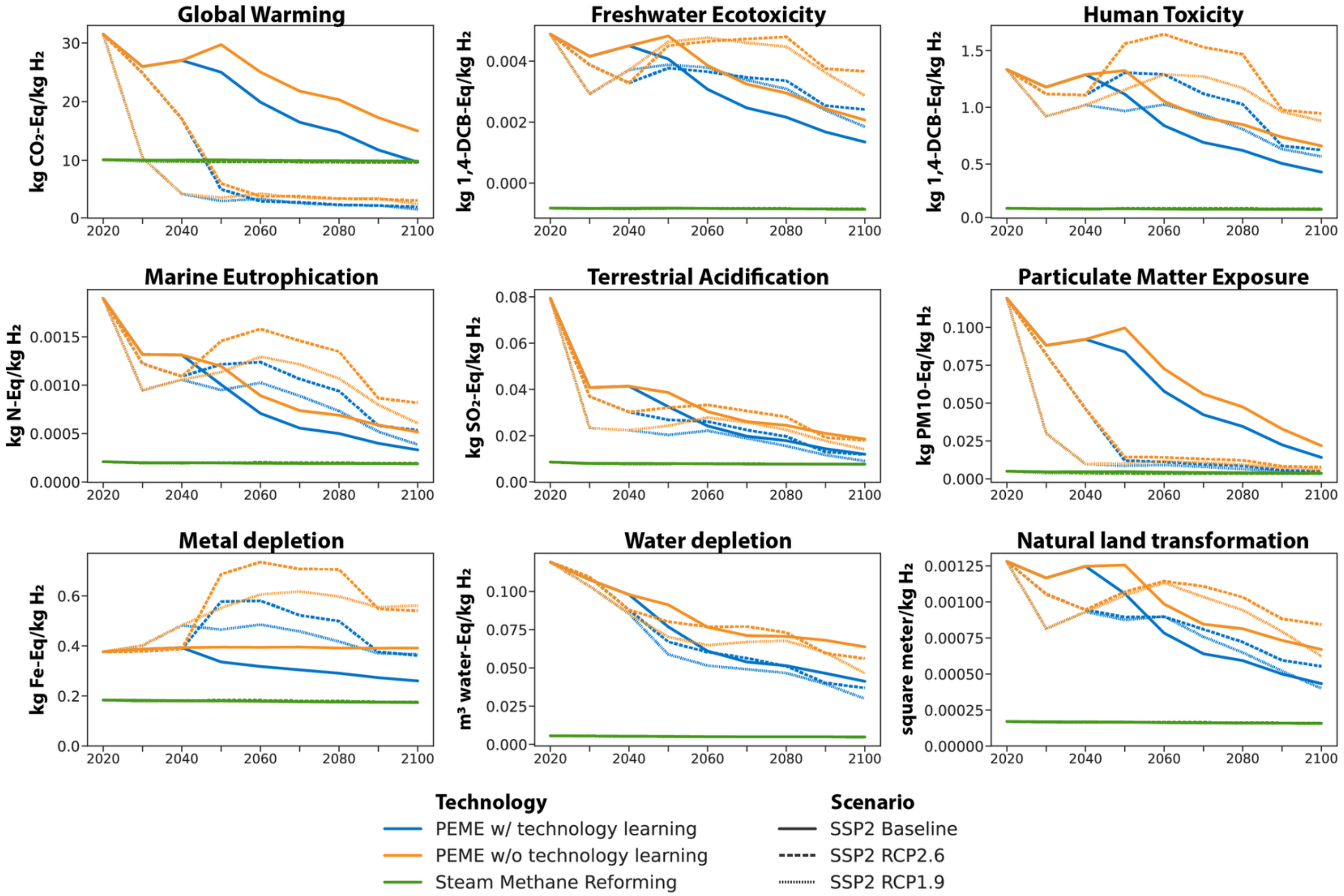
1) The influences of the individual sector dynamics;
2) Potential tradeoffs and underlying dependencies (e.g., hot spot analysis for power technologies)

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.

Future impacts (ReCiPe; 1 kg H_2) due to changes in the background superimposed with technology learning at 5% energy efficiency improvement per year



R&D influence *vs*. systems context

PEME

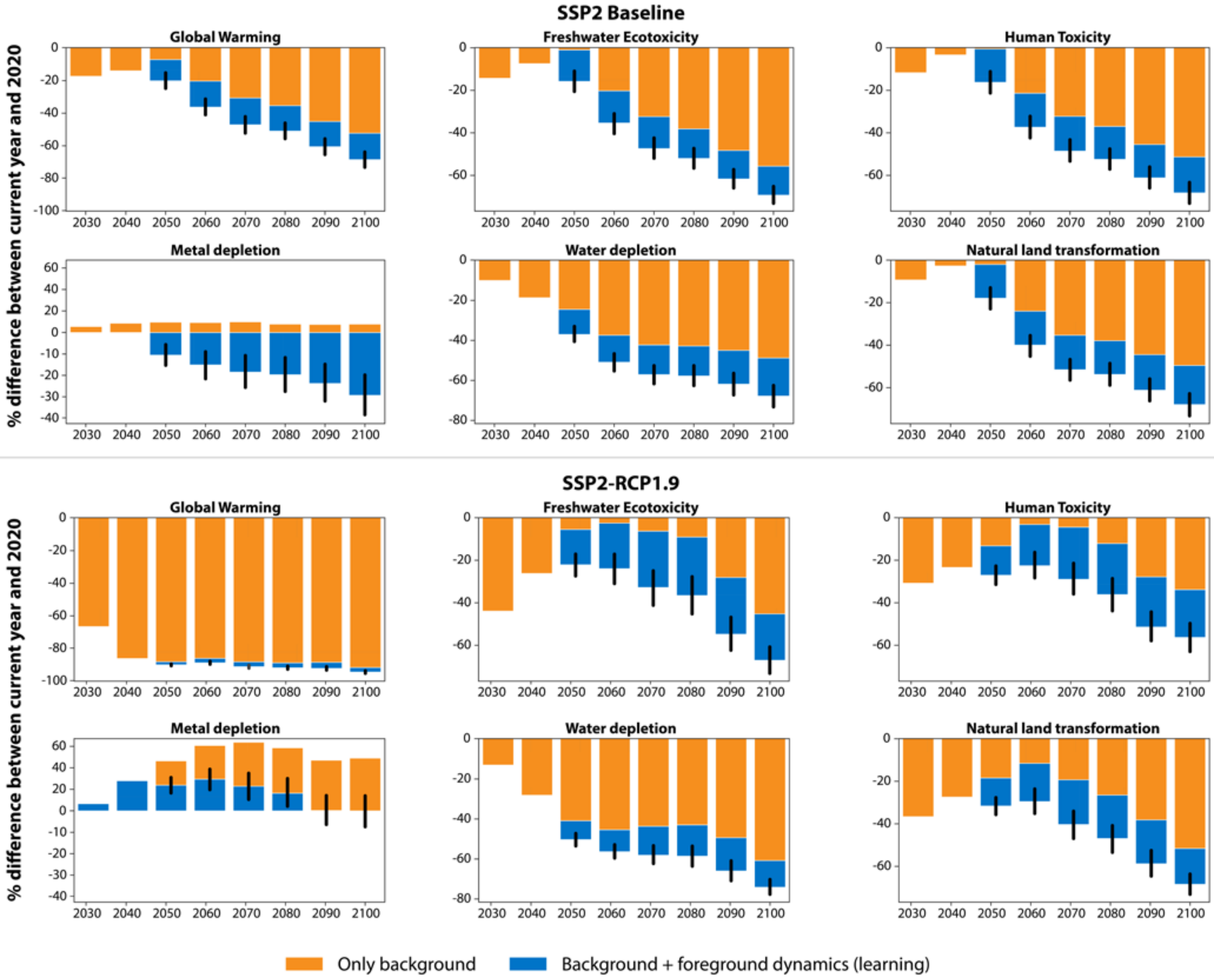
ReCiPe

SSP2-Baseline

PEME

ReCiPe

SSP2-RCP1.9



If the electricity grid evolves according to RCP1.9 pathway, PEME will have less contribution to decarbonization

Thus, evolving the background rather than improving PEME efficiency will have more impact on decarbonization.

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

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https://pubs.acs.org/doi/10.1021/acs.est.2c04246

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. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

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NREL/PR-6A20-86551

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 by U.S. Department of Energy Office of Fossil Energy and Carbon Management. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

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