

PSI

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

Beyond elementary flows

Edge-based Impact Assessment for Context-sensitive LCA in Brightway

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Why a New Approach to LCIA?

Conventional LCIA applies CFs at the “elementary flow”

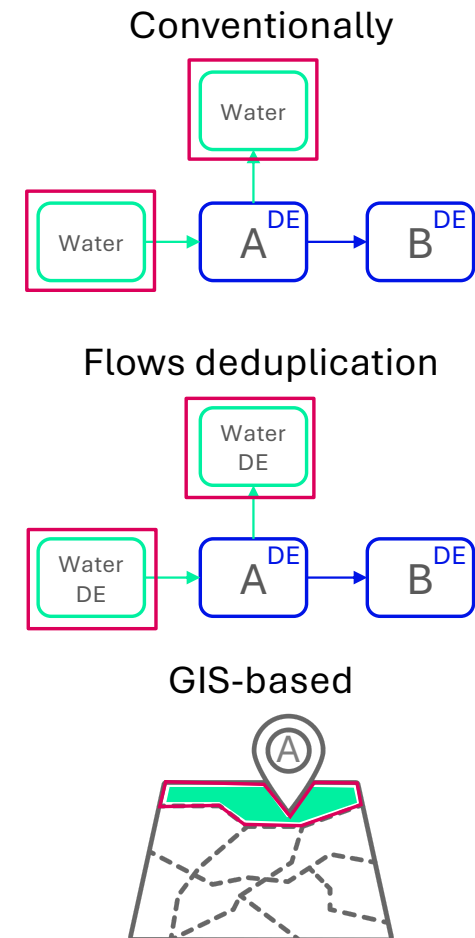
$$h = Q \cdot B \cdot A^{-1} \cdot f$$

with Q ($q \times 1$), a vector of CFs (one per elementary flow)

- Spatial and relational context is often lost during inventory aggregation
- Regionalized methods exist, but:
 - Deduplicating elementary flows (current practice): cannot scale, leads to complex, error-prone models
 - GIS^[1,2]: scientifically robust, but requires expertise (little uptake so far)
- Need: a scalable, context-sensitive, intermediate alternative

[1] Mutel, C. L., et al. (2012). GIS-based regionalized life cycle assessment: How Big is small enough? Methodology and case study of electricity generation. <https://doi.org/10.1021/es203117z>

[2] Li, J., et al. (2021). Spatializing environmental footprint by integrating geographic information system into life cycle assessment: A review and practice recommendations. <https://doi.org/10.1016/j.jclepro.2021.129113>



From Node to Edges

- Shifts CF application from nodes to edges (i.e., exchanges)

biosphere-to-technosphere edges

$$H = \sum_{i=1}^q \sum_{j=1}^p E_{ij} \cdot X_{ij} \cdot f = \sum (E \circ X) \cdot f$$

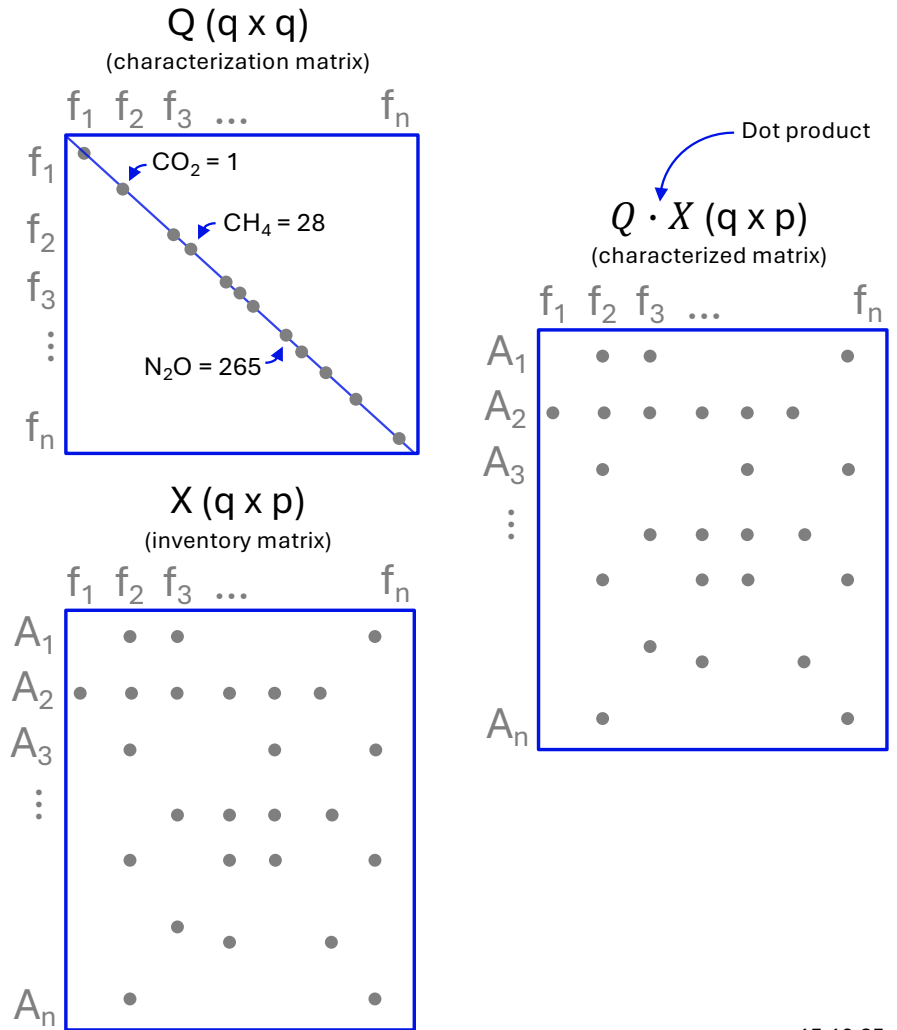
technosphere-to-technosphere edges

$$T = (-A \circ M) \cdot \text{diag}(s)$$

$$H = \sum_{i=1}^q \sum_{j=1}^p E_{ij} \cdot T_{ij} = \sum (E \circ T)$$

- Allows CFs to depend on any edge or node attributes:
 - Supplying & consuming nodes' location
 - Sector or activity type (e.g., CPC)
 - Scenario parameters (e.g., GHG concentrations)
- Implemented in open-source Python library *edges*^[3]

[3] <https://github.com/Laboratory-for-Energy-Systems-Analysis/edges>



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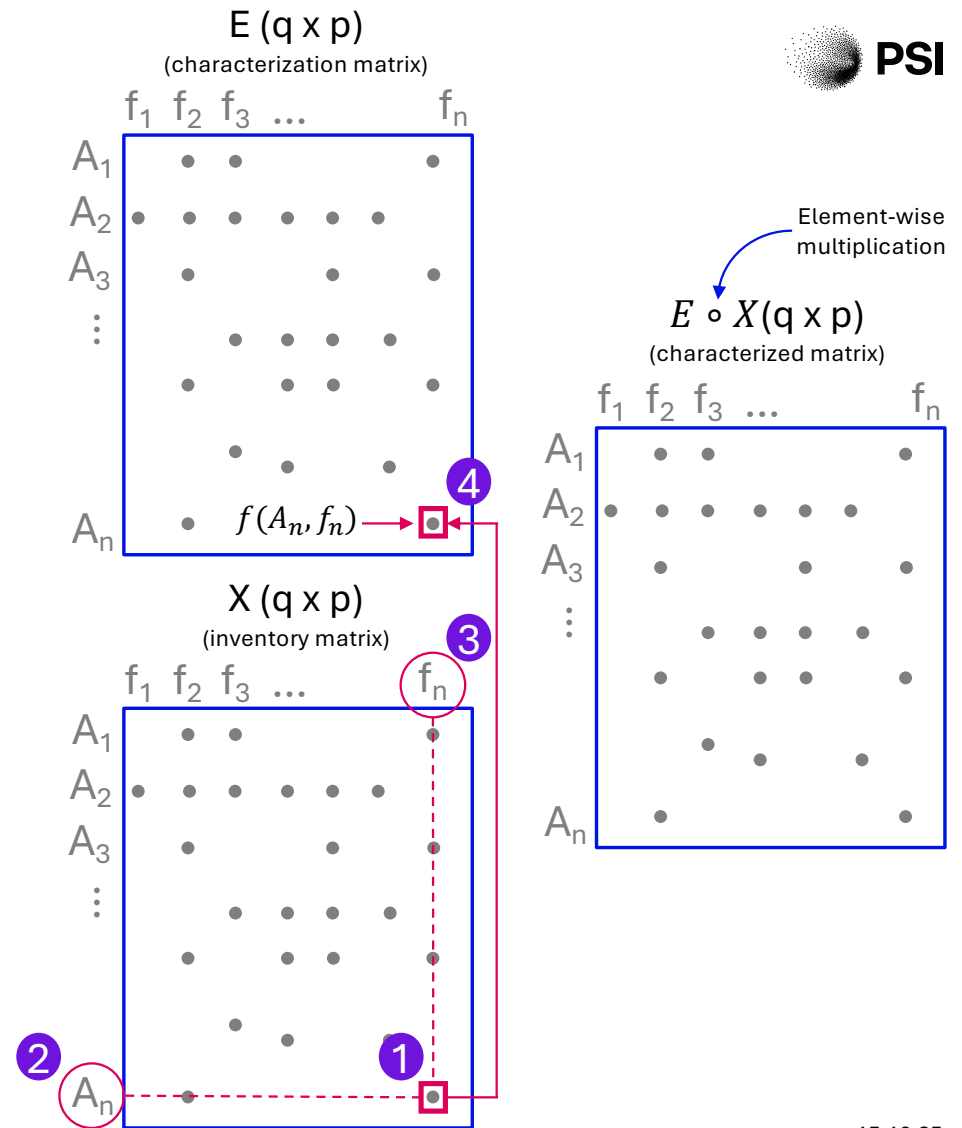
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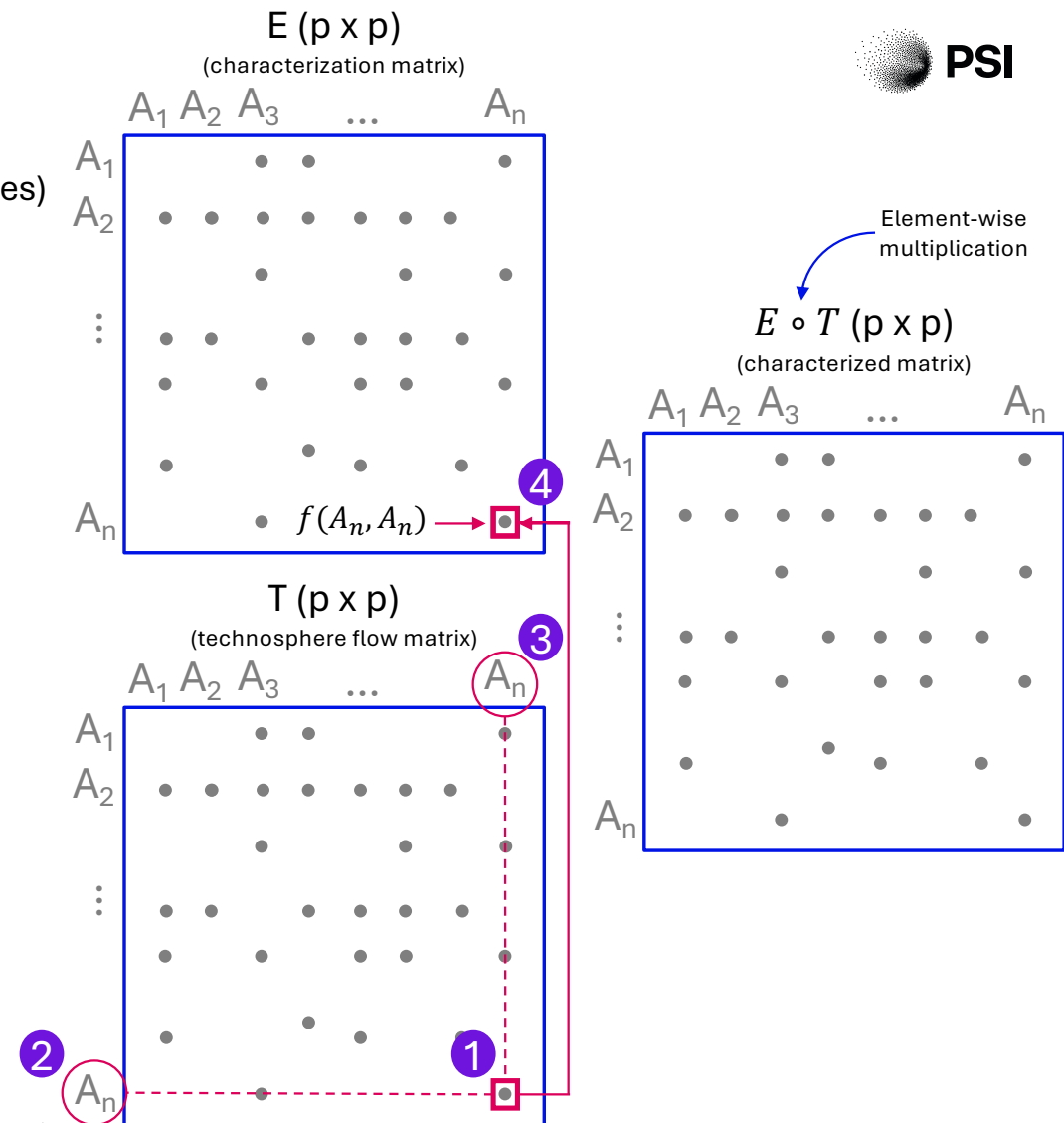
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Let's try it out!



Notebook: [brightcon-edges.ipynb](#)
Duration: 15 min

Use Case 1: regionalization

Scope

Edges LCIA method (excerpt)

- 1 kg of hydrogen from PEM electrolyzer in France
- AWARE 2.0
- Country-level CF
 - CPC:
 - Agricultural
 - Non-agricultural
 - Unknown
- Variability/uncertainty:
 - Conventional distribution types (normal, lognormal, etc.)
 - Discrete empirical
 - Nested distribution
 - Symmetrical sampling to avoid decorrelation during Monte Carlo

```

{
  "supplier": {
    "name": "Water, lake",
    "categories": [
      "natural resource",
      "in water"
    ],
    "matrix": "biosphere"
  },
  "consumer": {
    "location": "AM",
    "matrix": "technosphere",
    "classifications": {
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  "weight": 799882000,
  "uncertainty": {
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        0.969
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    }
  },
  "negative": 0
}

```

Location -specific

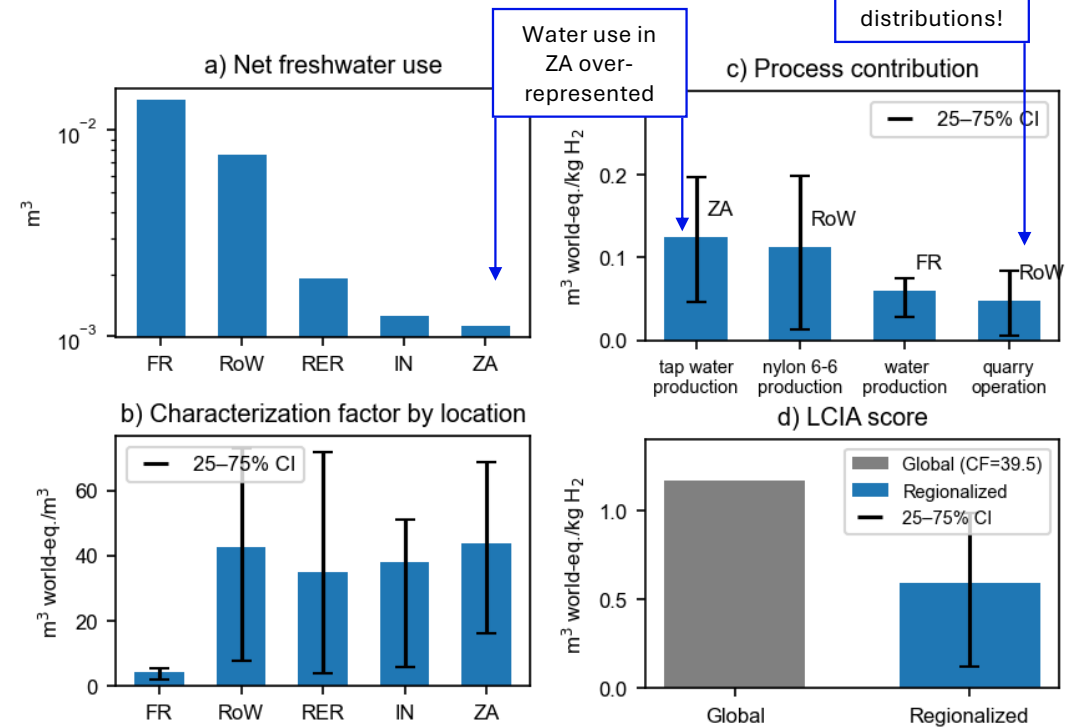
Targets farming activities

For weighted average CFs

Watershed-specific values

Weighted probabilities

Results

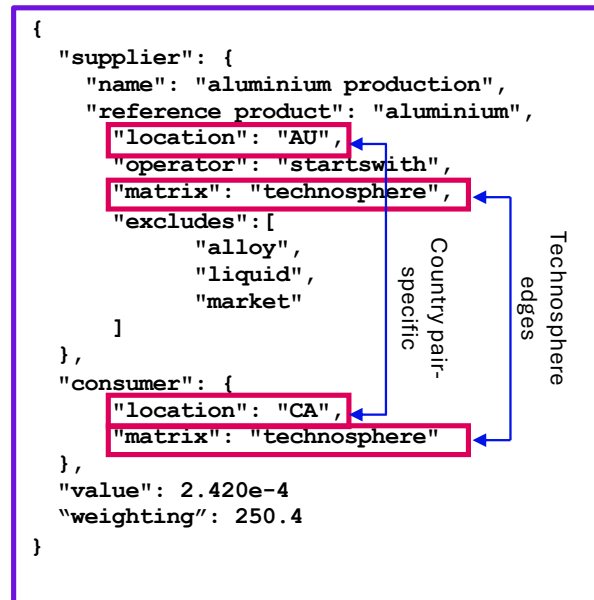


Use Case 2: technosphere characterization

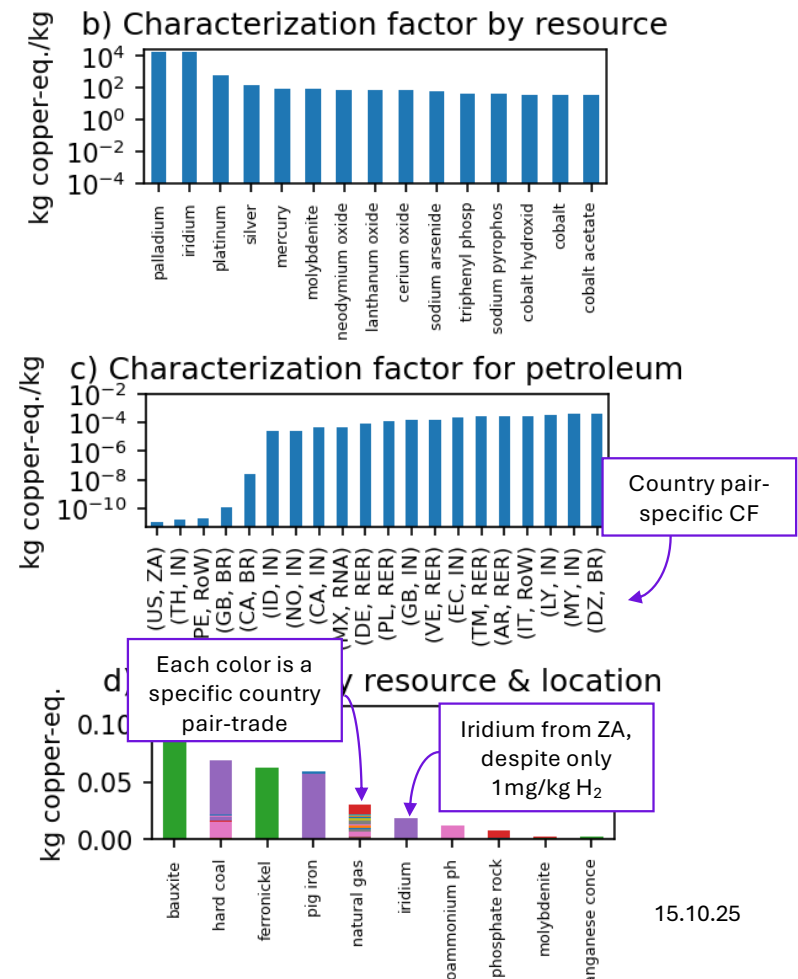
Scope

Edges LCIA method (excerpt)

- 1 kg of hydrogen from PEM electrolyzer in France
- GeoPolRisk 1.0^[4]
- Estimates supply risk due to the use of abiotic resources (an indicator of criticality)
- Country-to-country CF
- Builds upon a previous approach: characterizes intermediate resources («in ground» before losses and allocation)



Results



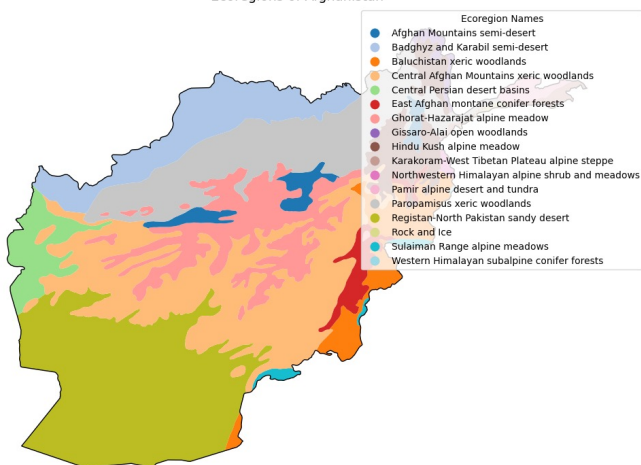
[4] Koyamparambath, A., Loubet, P., Young, S. B., & Sonnemann, G. (2024). Spatially and temporally differentiated characterization factors for supply risk of abiotic resources in life cycle assessment. *Resources, Conservation and Recycling*, 209(May), 107801.

Use Case 4: regionalization

Scope

- 1 kg of hydrogen from PEM electrolyzer in France
- GLAM, Land use impacts on biodiversity^[5]

Ecoregions of Afghanistan



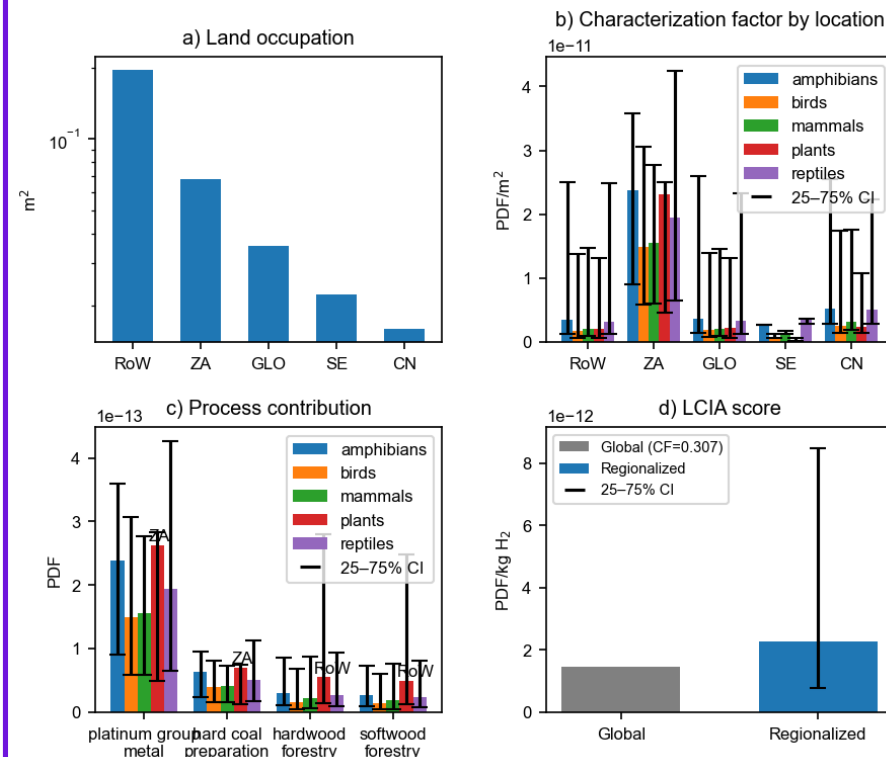
[5] Scherer L, Rosa F, Sun Z, et al (2023) Biodiversity Impact Assessment Considering Land Use Intensities and Fragmentation. Environ Sci Technol
<https://doi.org/10.1021/acs.est.3c04191>

Edges LCIA method (excerpt)

```
{
  "supplier": {
    "name": "Occupation, annual crop",
    "categories": [
      "natural resource",
      "land"
    ],
    "matrix": "biosphere"
  },
  "consumer": {
    "location": "AF",
    "matrix": "technosphere"
  },
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  "weight": 643830.73,
  "uncertainty": {
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    "parameters": {
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      ],
      "weights": [
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        ...
      ]
    }
  }
}
```

Ecoregions with area-weighted probabilities

Results

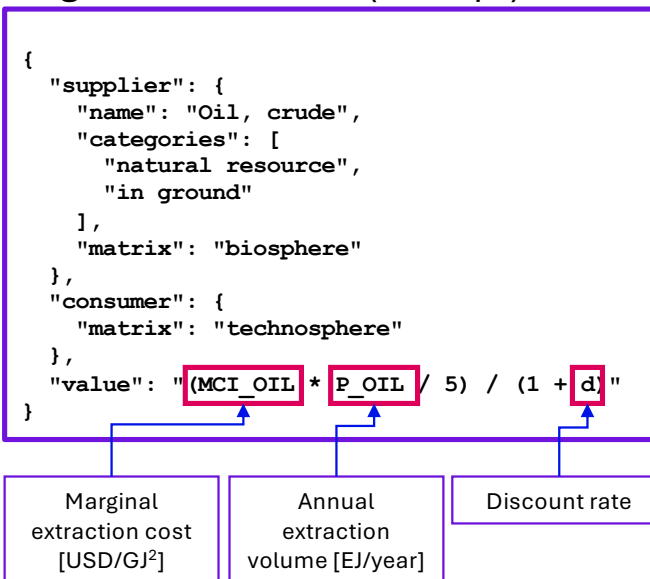


Use Case 5: scenario-based characterization

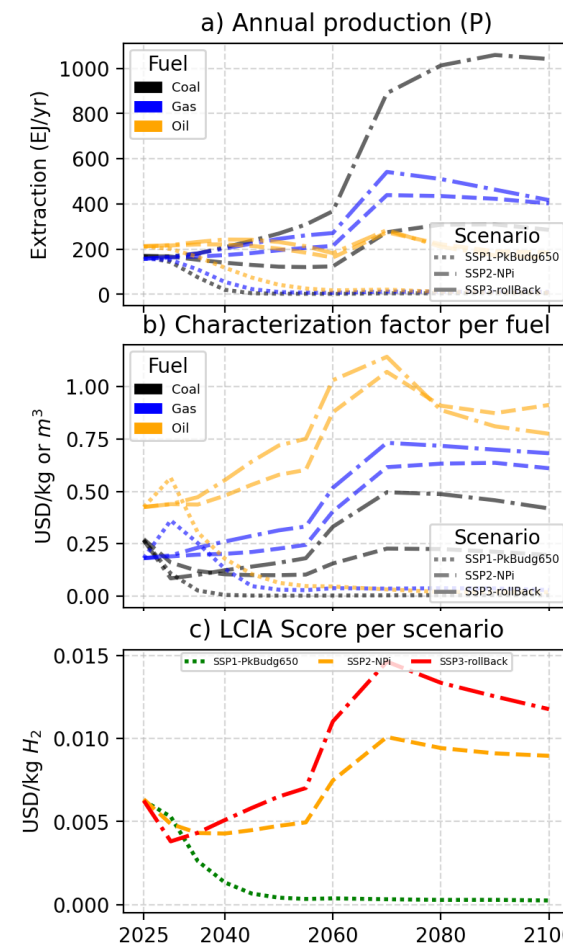
Scope

- 1 kg of hydrogen from PEM electrolyzer in France
- ReCiPe 2016, Fossil fuels scarcity^[6]
- Surplus extraction costs using static marginal cost increase (MCI) values per fossil fuel type
- Symbolic expression
- Recalculated using IAM scenario outputs

Edges LCIA method (excerpt)



Results



[6] Vieira, M. D. M., Ponsioen, T., Goedkoop, M., & Huijbregts, M. A. J. (2016). Fossil resource scarcity. In ReCiPe 2016. A harmonized life cycle impact assessment method at midpoint and endpoint level. Report I: Characterization (pp. 95–118).

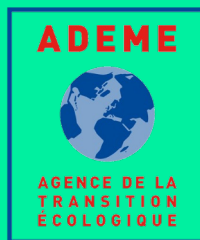
Limitations

- Does not replace site-specific impact assessment
 - Geo-referenced inventories coupled with tools to model fate, exposure, and effect based on real-world environmental data are preferable
- Relies on the availability and quality of relevant metadata (e.g., locations, classifications) in inventories and characterization factor definitions

Conclusions

- Represents a pragmatic and scalable advancement for context-sensitive environmental assessment
- Provides a robust yet accessible solution for regionalized, relational, and prospective life cycle assessments.

The development of this library was supported by the French agency for Energy ADEME, via the financing of the HySPI project.



R. Sacchi, A. H. Menacho, G. Seifudem, M. Agez, J. Schlesinger, A. Koyamparambath, J. Santillán-Saldivar, P. Loubet and C. Bauer, Int. J. Life Cycle Assess.

Learn more about PSI-LEA at <https://www.psi.ch/en/lea>.

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