bw_timex: a python package for time-explicit life cycle assessment

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Summary

bw_timex is a Python package for time-explicit Life Cycle Assessment (LCA). Time-explicit LCA enables the quantification of environmental impacts of products and processes over time, considering their temporal distribution and evolution. Accordingly, bw_timex allows to simultaneously account for:

- the timing of processes throughout the supply chain (e.g., end-of-life treatment occurs 20 years after construction),
- variable and/or evolving supply chains and technologies (e.g., increasing shares of renewable electricity in the future), and
- the timing of emissions (e.g., enabling the use of dynamic characterization functions).

To achieve this, bw_timex uses graph traversal to convolute process-relative temporal distributions through the supply chain, and then automatically relinks Life Cycle Inventories (LCIs) across time-specific LCI databases. The resulting time-explicit LCI reflects the current technology status within the product system at the actual time of each process. Moreover, bw_timex preserves the timing of emissions, enabling the application of dynamic characterization methods alongside standard static characterization factors.

Statement of need

LCA traditionally assumes a static LCI, in which all processes occur simultaneously and do not change over time (Heijungs & Suh, 2002). To add a temporal dimension in LCA, the fields of dynamic LCA (dLCA) and prospective LCA (pLCA) have emerged. While dLCA focuses on when processes and emissions occur and how impacts are distributed over time (*temporal distribution*), it typically assumes the underlying product system remains the same (Beloin-Saint-Pierre et al., 2020). Conversely, pLCA tracks how processes evolve (*temporal evolution*) using future scenarios, but generally only assesses a single (future) point in time, overlooking that processes occur at different times across a product's life cycle (Arvidsson et al., 2024). Both fields have seen open-source tool development in recent years, including Temporalis (Cardellini et al., 2018) for dLCA and premise (Sacchi et al., 2022), Futura(Joyce & Björklund, 2022) and pathways (Sacchi & Hahn-Menacho, 2024) for pLCA. However, a comprehensive open-source package that allows consideration of both temporal distribution and evolution in a time-explicit LCA is currently lacking.

bw_timex addresses this gap by providing a framework for time-explicit LCA calculations within the Brightway ecosystem (Mutel, 2017). It combines considerations of temporal distribution and evolution by accounting for both the timing of processes and emissions as well as the

state of the product system at the respective points in time. This makes `bw_timex` particularly useful for studies involving variable or strongly evolving product systems, long-lived products, and biogenic carbon.

Acknowledgements

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