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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). Unlike conventional LCA, time-explicit LCA allows the quantification of environmental impacts of products and processes *over time*, considering their temporal distribution and evolution. As such, `bw_timex` enables simultaneously accounting for:

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

To achieve this, `bw_timex` uses graph traversal to convolve process-relative temporal distributions through the supply chain. From the resulting timeline of technosphere exchanges, Life Cycle Inventories (LCIs) are automatically linked across time-specific background 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 both dynamic and static Life Cycle Impact Assessment.

Statement of need

LCA traditionally assumes a static system, where all processes occur simultaneously and do not change over time (Heijungs & Suh, 2002). To add a temporal dimension to 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 that the underlying product system remains the same (Beloin-Saint-Pierre et al., 2020). Conversely, while pLCA tracks how processes evolve (*temporal evolution*) using future scenarios, it generally only assesses a single (future) point in time, ignoring that processes occur at different times across a product's life cycle (Arvidsson et al., 2024).

`bw_timex` provides 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, biogenic carbon, and scenario analyses.

State of the field

Existing dLCA tools such as `Temporalis` (Cardellini et al., 2018) handle temporal distributions but not system evolution. Conversely, pLCA tools like `premise` (Sacchi et al., 2022), `Futura` (Joyce & Björklund, 2022), and `pathways` (Sacchi & Hahn-Menacho, 2024) model evolving systems but not temporal distributions within the supply chain. Two recent tools combine both temporal distribution and evolution: `ProsperDyn` (Lang-Quantzendorff & Beermann, 2025) and `TRAILS` (Sacchi, 2026). `ProsperDyn` is presently provided as a collection of research notebooks with limited documentation and without a consolidated, performance-oriented software architecture suitable for broader reuse. `TRAILS`, although methodologically advanced, currently relies on annual discretization and sequential year-specific calculations rather than a unified matrix-based integration of both dimensions.

`bw_timex` uniquely embeds the time dimension directly into the technosphere and biosphere matrices, enabling flexible temporal resolution within a single matrix-based framework. This allows efficient computation and seamless integration with the broader `Brightway` ecosystem.

Workflow

A time-explicit LCA with `bw_timex` follows four main steps, as illustrated in Figure 1. First, a conventional product system model is temporalized by adding process-relative temporal distributions (rTDs) to the exchanges (cf. Cardellini et al. (2018)). These rTDs describe how the amount of a technosphere or biosphere exchange is distributed over time, relative to the consuming or emitting process. In addition, temporal evolution of foreground processes can be defined through time-specific parameters. In Step 2, a timeline of technosphere exchanges is constructed by convolving rTDs along the supply chain, starting from the absolute reference time for the demand, which is defined by the user. In Step 3, the exchanges in the timeline are re-linked to time-specific background databases that reflect the technology landscape at specific points in time. Based on the temporally re-linked product system, a time-explicit LCI is calculated, preserving the timing of processes and emissions. The inventory is calculated following the conventional matrix-based LCA formulation (Heijungs & Suh, 2002), with the time dimension embedded in the matrices through additional row/column pairs. In Step 4, these emissions are characterized, either using standard characterization factors or by applying dynamic characterization functions that take the emissions' timing into account.

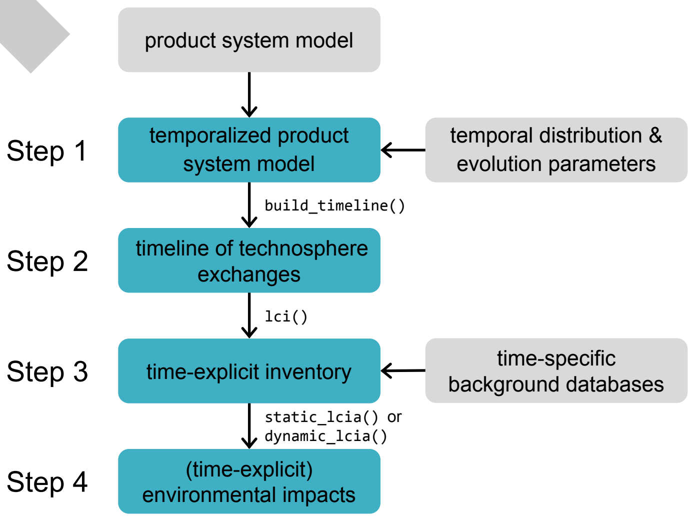

Figure 1: Workflow for a time-explicit LCA with `bw_timex`.

Further reading

The documentation of the bw_timex package, including installation instructions, extensive example notebooks and detailed API reference, can be found at https://docs.brightway.dev/projects/bw-timex. For a detailed explanation of the framework of time-explicit LCA, please refer to our accompanying publication (Müller et al., 2025).

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References

Arvidsson, R., Svanström, M., Sandén, B. A., Thonemann, N., Steubing, B, & Cucurachi, S. (2024). Terminology for future-oriented life cycle assessment: Review and recommendations. *The International Journal of Life Cycle Assessment*, *29*(4), 607–613. https://doi.org/10.1007/s11367-023-02265-8

Beloin-Saint-Pierre, D., Albers, A., Hélias, A., Tiruta-Barna, L., Fantke, P., Levasseur, A., Benetto, E., Benoist, A., & Collet, P. (2020). Addressing temporal considerations in life cycle assessment. *Science of The Total Environment*, *743*, 140700. https://doi.org/10.1016/j.scitotenv.2020.140700

Cardellini, G., Mutel, C. L., Vial, E., & Muys, B. (2018). Temporalis, a generic method and tool for dynamic Life Cycle Assessment. *Science of The Total Environment*, *645*, 585–595. https://doi.org/10.1016/j.scitotenv.2018.07.044

Heijungs, R., & Suh, S. (2002). *The Computational Structure of Life Cycle Assessment* (A. Tukker, Ed.; Vol. 11). Springer Netherlands. https://doi.org/10.1007/978-94-015-9900-9

Joyce, P. J., & Björklund, A. (2022). Futura: A new tool for transparent and shareable scenario analysis in prospective life cycle assessment. *Journal of Industrial Ecology*, *26*(1), 134–144. https://doi.org/10.1111/jiec.13115

Lang-Quantzendorff, L., & Beermann, M. (2025). Prosperdyn—a tool to describe dynamic transitions in prospective life cycle assessment. *The International Journal of Life Cycle Assessment*. https://doi.org/10.1007/s11367-025-02515-x

Müller, A., Diepers, T., Jakobs, A., Cardellini, G., von der Assen, N., Guinée, J., & Steubing, B. (2025). Time-explicit life cycle assessment: A flexible framework for coherent consideration of temporal dynamics. *The International Journal of Life Cycle Assessment*. https://doi.org/10.1007/s11367-025-02539-3

Mutel, C. (2017). Brightway: An open source framework for Life Cycle Assessment. *Journal of Open Source Software*, *2*(12), 236. https://doi.org/10.21105/joss.00236

Sacchi, R. (2026). *TRAILS: Temporal routing and aggregation of impacts across life-cycle systems* (Version v1.0.0). https://trails.readthedocs.io/en/latest/

Sacchi, R., & Hahn-Menacho, A. J. (2024). Pathways: Life cycle assessment of energy transition scenarios. *Journal of Open Source Software*, *9*(103), 7309. https://doi.org/10.21105/joss.07309

Sacchi, R., Terlouw, T., Siala, K., Dirnaichner, A., Bauer, C., Cox, B., Mutel, C., Daioglou, V., & Luderer, G. (2022). PRospective EnvironMental Impact asSEment (*premise*): A streamlined approach to producing databases for prospective life cycle assessment using integrated assessment models. *Renewable and Sustainable Energy Reviews*, *160*. https://doi.org/10.1016/j.rser.2022.112311