The Challenge of Temporal Resolution in Dynamic LCA

Didier Beloin-Saint-Pierre, Pierryves Padey, Kyriaki Goulouti, Pierre Collet, Arnaud Hélias, Roland Hischier

The Challenge of Temporal Resolution in Dynamic LCA

Didier Beloin-Saint-Pierre[1], Pierryves Padey[2], Kyriaki Goulouti [2], Pierre Collet[3], Arnaud Hélias[4], and Roland Hischier[1]

[1] Empa, Lerchenfeldstrasse 5, 9014 St. Gallen, Switzerland
[2] HEIG-VD, Avenue des sports 20, 1401 Yverdon-les-Bains, Switzerland
[3]IFP Energies nouvelles, 1-4 Avenue du Bois Préau, 92852 Rueil-Malmaison, France
[4]ITAP, Irstea, Montpellier SupAgro, Univ Montpellier, ELSA Research Group, Montpellier, France
E-mail contact: dib@empa.ch

1. Introduction

The last 10 years of research in the field of life cycle assessment (LCA) have unveiled many possible pathways to consider the effects of temporal variations from supply chains on the assessment of potential environmental impacts for products, services and markets with dynamic LCA (i.e. DLCA) frameworks. Such variations might be inherent to the modeled systems, like changes of an electricity mix at different periods of a day, or they might be evolutions on longer periods like increased thermal efficiency of buildings. These variations over time then create fluctuations in the rate of elementary flows, which can significantly affect some results of LCA studies. In this context, defining “useful” levels of temporal resolution for the description of flows in LCA databases will require the combined expertises of system modelers and creators of impact assessment methods. We therefore propose to start a discussion on key consideration of temporal resolution with examples of electricity mixes variations, which could lead to common basic structures in DLCA studies.

2. Discussion

2.1. State-of-the-art

From the perspectives of system modeling and life cycle inventory (LCI) calculations, recent propositions for DLCA frameworks bring many promises. Indeed, novel approaches and tools [1, 2] are showing similarities in favored pathways for the computational structure to account for dynamics of systems. Moreover, some level of agreement is emerging on the use of process-relative temporal distributions [1-4] to feed temporally differentiated LCI calculations. This data format has even been recently used to describe many processes in version 3.2 of the ecoinvent database [4].

From the perspective of life cycle impact assessment (LCIA), the impact categories of climate change [5-7], photochemical oxidant formation [8], freshwater ecotoxicity [9] and toxicity [10] are some of the examples that were investigated with time-dependent characterization factors (CFs). The choice of time horizons and the inherent variations of the environment’s reactions to emissions made during different periods are some of the more explored temporal considerations to define new time-dependent CFs.

In some cases [11, 12], dynamic LCIA (DLCIA) methods have been combined with temporally differentiated LCIs, but most investigations have tackled them separately. This partitioning now raises concerns since requirements to create such links can drive the amount of data gathering efforts to provide useful temporal descriptions for different flows in LCA databases. For example, the description of an electricity mix with average monthly flows induces the use of monthly-based CFs for the impact assessment since uses of CFs with lower temporal resolutions would be unrepresentative. Such monthly-based CFs will then be linked to a certain level of temporal uncertainty that will limit the possibility to differentiate two electricity mixes.

2.2. Key considerations of temporal resolution in DLCA

The first example of a temporal consideration describing temporally differentiated LCIs relates to the use of calendar-based information to define when elementary flows are occurring during the life cycle of a system. DLCA computation tools can now consider this data, but the relevance and necessary precision for different impact categories has not been explored. For instance, the assessment of climate change might only require knowledge on the year of electricity use, but specific daily use of electricity might be more relevant to assess ozone and smog formation because it depends on NOx levels that can vary quickly in some regions.

Figure 1 then presents an example for the propagation of temporal resolution in LCI calculations. In this case, the hourly resolution from nuclear production is kept in the LCI of the electricity mix since it is always available in the flows of the right path. Conversely, the hourly precision of reservoir production will be lost since hydroelectricity flows are informed at the monthly level. The yearly emissions of run-of-river production will then be added to the LCI of the electricity mix to offer temporally differentiated flows at 3 levels of resolution. Evaluating the impacts of these flows will thus require the use of CFs with three levels of resolution bringing various levels of uncertainty on the assessment. This complexity can be handled by increasing the resolution of flows from some processes in this simple example, but such data gathering efforts might become unmanageable for background database.

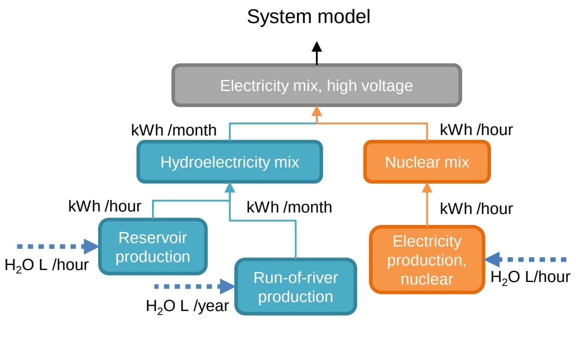

Figure 1: Propagation of temporal resolution in the model of a supply chain

The third important consideration for the management of temporal resolutions in a DLCA framework relates to the assessment of temporal uncertainty for CFs, which comes with different levels of precision on the period of emissions. Indeed, an assessment of the possible variability of CFs over specific periods seems like a relevant first step to assess the temporal uncertainty that comes with lower temporal resolution. For instance, if the CF of water use can vary by three orders of magnitude during a year, then using a yearly temporal resolution for water flows in temporally differentiated LCI will bring high uncertainty on results. It might then be useful to offer a seasonal or monthly precision to carry out a DLCIA with lower uncertainty.

2.3. Proposed development pathways

To manage temporal resolution and its potential increase in a DLCA framework, we suggest:

– To avoid the use of temporal differentiation in the description of elementary flows whenever high precision is required. For instance, provide use day and night as a property for flows, when relevant.
– Assess the level of uncertainty on CFs that comes with the use of different temporal resolutions for the description of elementary flows in a temporally differentiated LCI.
– Provide high resolution on process flows and necessary level of precision for elementary flows in a LCA background database after the evaluation of related temporal uncertainty on CFs of different categories.

3. References

[1] Tiruta-Barna L, Pigne Y, Gutierrez TN, Benetto E. 2016. Framework and computational tool for the consideration of time dependency in Life Cycle Inventory: proof of concept. J Clean Prod 116, 198-206
[2] Cardellini G, Mutel CL, Vial E, Muys B. 2018. Temporalis, a generic method and tool for dynamic Life Cycle Assessment. Sci Total Environ 645, 585-595
[3] Beloin-Saint-Pierre D, Heijungs R, Blanc I. 2014. The ESPA method: a solution to an implementation challenge for dynamic life cycle assessment studies. Int J Life Cycle Ass 19, 861-871
[4] Pigné Y, Gutiérrez TN, Gibon T, et al. 2019. A tool to operationalize dynamic LCA, including time differentiation on the complete background database. Int J Life Cycle Ass
[5] Levasseur A, Lesage P, Margni M, Deschenes L, Samson R. 2010. Considering Time in LCA: Dynamic LCA and Its Application to Global Warming Impact Assessments. Environ Sci Technol 44, 3169-3174
[6] Cherubini F, Peters GP, Berntsen T, et al. 2011. CO_2 emissions from biomass combustion for bioenergy: atmospheric decay and contribution to global warming. GCB Bioenergy 3, 413-426
[7] Kendall A. 2012. Time-adjusted global warming potentials for LCA and carbon footprints. Int J Life Cycle Ass 17, 1042-1049
[8] Shah V, Ries R. 2009. A characterization model with spatial and temporal resolution for life cycle impact assessment of photochemical precursors in the United States. Int J Life Cycle Ass 14, 313-327
[9] Lebailly F, Levasseur A, Samson R, et al. 2014. Development of a DLCA approach for the freshwater ecotox. impact of metals and app. to a case study for Zn fertilization. Int J Life Cycle Ass 1745-1754
[10] Shimako AH, Tiruta-Barna L, Ahmadi A. 2017. Operational integration of time dependent toxicity impact category in dynamic LCA. Sci Total Environ 599-600, 806-819
[11] Beloin-Saint-Pierre D, Levasseur A, Margni et al. 2017. Implementing a Dynamic Life Cycle Assessment Methodology with a Case Study on Domestic Hot Water Production. J Ind Ecol 21: 1128-1138
[12] Negishi K, Lebert A, Almeida D, Chevalier J, Tiruta-Barna L. 2019. Evaluating climate change pathways through a building's lifecycle based on Dynamic Life Cycle Assessment. Build Environ 164, 106377