Integrating Knowledge Co-Production with Life Cycle Assessment

Weiwei Mo[1,*], David Hart[2], Catherine M. Ashcraft[3], Mikhail Chester[4], Stefano Cucurachi[5], Zhongming Lu[6], Shelie Miller[7]

[1]Department of Civil and Environmental Engineering and Carsey School of Public Policy, University of New Hampshire, NH, USA

[2]Senator George J. Mitchell Center for Sustainability Solutions, University of Maine, Orono, ME, USA

[3]Department of Natural Resources and the Environment, University of New Hampshire, NH, USA

[4]Metis Center for Infrastructure and Sustainable Engineering, Civil, Environmental, and Sustainable Engineering, School of Sustainable Engineering and the Built Environment, Arizona State University, Tempe, AZ, USA

[5]CML – Institute of Environmental Sciences, Leiden University, Leiden, the Netherlands

[6]Division of Environment and Sustainability, Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong, China

[7]Center for Sustainable Systems, School for Environment and Sustainability, University of Michigan, Ann Arbor, MI, USA

[*]Corresponding Author: 35 Colovos Road, 334 Gregg Hall, Durham, New Hampshire 03824, Ph: +1-603-862-2808, Email: Weiwei.mo@unh.edu

Over the last decade, the life cycle assessment (LCA) methodology has significantly advanced to enable more realistic impact simulations and predictions with spatial and temporal considerations. Nevertheless, knowledge created through LCA efforts is still largely used as an information source, rather than as a process to engage stakeholders with the implementation of recommendations and to foster prompt and adaptive decision-making and changes towards sustainability, see for example (Davenport & Friedman, 2022). Concerns have also been raised regarding LCA's ease-of-use as well as its capability in fostering communication, open discussion, and public participation (Cowell et al., 2002). Linking knowledge with actions is a common challenge that was coined the "loading dock" problem. It describes the one-way transfer of knowledge from research communities to stakeholders, and the resulting limited use of scientific knowledge in actual decision-making. The loading dock problem is a particular concern in sustainability science, as tackling "wicked" problems often requires productive collaborations between stakeholders and research communities. LCA needs a paradigm shift in how we include and engage stakeholders. Traditionally, the LCA community has positioned itself as an honest broker of information focusing on making "factual" claims that lack specific bias. The contextual values that drive stakeholders' choices have been considered "not scientifically based", according to ISO 14040/44. This perspective could largely explain why the LCA community has not embraced disciplines such as decision science, political science, or behavioral economics. Nevertheless, LCA is inherently value laden. For example, the goal and scope are often defined by stakeholders that commission the study, which may or may not align with the perspective and values of other stakeholders who are impacted by or wish to use the results of an LCA study. Here we outline some barriers that may hinder linking LCA knowledge with actions.

- ***Representing and Engaging with Complexity***: Since its inception, LCA has boasted its "systematic" approach to sustainability problems as an alternative to the traditional reductionist approach. The problems LCA addresses often involve transboundary material and energy movements that involve multiple jurisdictions and geographical contexts at different time scales. The systems studied are commonly dynamic, non-linear, and governed by feedback. These complex environments raise challenges for LCA: 1) in model and scenario representation, and 2) communicating and fostering stakeholder engagement. Despite LCA's recent developments, its capability in capturing the complex human-environment dynamics remains limited. LCA results can be influenced and hence need to be updated based on new circumstances arising from stakeholders' decisions/actions. Ideally, LCA will facilitate engaging with complexity (Chester et al., 2021). Yet in practice, researchers must make choices about model complexity, system boundaries, and geospatial and temporal resolutions. It is also inherently difficult for researchers to communicate complexity. Engaging stakeholders with complex problems require all parties to have a certain level of capacity and interest in systems thinking to allow for collaborative problem solving.
- ***Diverse and Conflicting Interests***: Depending on the goal and context, stakeholders that need to be involved or considered in an LCA study can include regulators, resource/service managers, industries, consumers, or the public that might be affected by the decisions. This diversity presents three major challenges for effective stakeholder engagement. 1) The research and the stakeholder communities may have distinct motivations when it comes to LCA. Stakeholders often seek practical guidance for relevant decisions, which the research community or other stakeholders may not find interesting. 2) Different stakeholder communities can also possess different value systems. Impact weighting has been a long-standing challenge in LCA as stakeholders often weigh impacts differently. This can become even more complicated when economic and social impacts come into play. Stakeholders may also be most interested in reducing pollution within their local geographical boundaries and less concerned with pollution

occurring in other areas. 3) Solutions often need to be developed with multiple stakeholders or organizations to be trusted, consulted, and used. Systematic solutions can also be difficult to implement, requiring cross-institution/jurisdiction coordination and collaborations. All these challenges require LCA studies to be flexible and transparent enough to show how different value systems may lead to different actions and to identify universally sub-optimal actions that should be avoided.

- ***Information Access***: Information barriers between researchers and stakeholders can be bi-directional. On one hand, the vast practical knowledge that resides within the stakeholder community is often not publicly available, which requires engaging and learning from stakeholders from the beginning of the LCA process. On the other hand, stakeholders may have limited access to the LCA information being produced. Currently, the primary outlet of LCA information remains scientific journals, which may not be directly accessible to most stakeholders. LCA information produced without stakeholder involvement may be questioned for its saliency, credibility, and legitimacy, and hence may not be trusted by stakeholders. Furthermore, different stakeholder groups may have unequal access to the information, resulting in difficulties in open and meaningful discussions for consensus-building.
- ***Limitations in the Current LCA Framework:*** The LCA framework is highly structured, and it does not easily support decision-making. Factors such as institutional network structures, power dynamics, behaviors, or politics are typically not included in an analysis. LCA also relies heavily on existing data or known scenarios, and hence can be limited in its use for unprecedented scenarios and its adaptability to changes in real decision-making. Uncertainty in LCA is generally not well communicated in practical terms that make sense to a decision-maker; it is often simply characterized via sensitivity analysis on a few parameters and generally is not presented in ways relevant for decision-making (e.g., how the results can be impacted by specific stakeholder choices versus general uncertainty that cannot be impacted by stakeholder decisions). There is limited understanding regarding how uncertainty is perceived by different stakeholders and how it may influence actual decision-making.

To address these barriers, tools and methods should be borrowed from social sciences. Knowledge co-production has been increasingly recognized as a promising approach to address complex sustainability challenges (Norström et al., 2020). This approach is highly compatible with LCA. Knowledge co-production calls for iterative and collaborative processes involving diverse types of expertise, knowledge, and actors for context-based problem solving from the conceptualization to the completion of an entire project. Many participatory approaches exist in social sciences (e.g., scenario analysis workshops, role-play simulations/serious gaming, deliberative polling) to facilitate linking knowledge with actions and systems thinking and their success has been demonstrated (Norström et al., 2020). While research is needed to integrate knowledge co-production with LCA practices (e.g., mode of co-production, processes for engagement), lessons can be learned from the broader sustainability science community on these fronts (Chambers et al., 2021). It is important for the LCA community to broaden its umbrella to foster conversations and collaborations with social scientists towards faster and more meaningful life cycle evidence-based decision-making. As we develop more understanding about how to best integrate knowledge co-production with LCA, it is possible to diversify the training/skillsets of future LCA practitioners to include both those that are primarily trained in numerical analysis but recognize the importance of knowledge co-production, and those that are primarily trained in participatory processes but have a good understanding about what LCA is/does.

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