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LCA FOR AGRICULTURE

Prospective LCA to support the agri-food sector's transition towards sustainability—89th LCA discussion forum conference report

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Abstract

Purpose The 89th Life Cycle Assessment (LCA) Discussion Forum (DF) on the use of prospective LCA (pLCA) to support sustainability transitions of the agri-food sector was held on the 4th of February 2025 in Zurich.

Methods This paper summarizes the main discussion points and challenges identified during the 89th LCA DF related to pLCA in the agri-food sector.

Results The presentations highlighted recent progress in inventory and impact modelling and featured case studies related to the technology- and system-wide application of pLCA to the agri-food sector. The Q&A sessions and panel discussion highlighted challenges related to pLCA in the agri-food sector and in general. These challenges relate to missing data, the complexity of pLCA and its associated uncertainties, as well as ensuring the usefulness of the conducted evaluations. Possible solutions relate to streamlining the communication of results, adapting them to the needs of different stakeholder groups, or exploring scenarios to showcase a range of possible futures. Additionally, more frequent collaboration with other research fields could help reduce uncertainty and improve data availability.

Conclusions While the challenges faced in the pLCA of agri-food systems are similar to those in other sectors, the lack of data on future developments and uncertainties is more pronounced. This is largely due to the dynamic character of these systems and their sensitivity to environmental conditions.

Keywords Prospective Life Cycle Assessment (pLCA) · Agri-food sector · Life Cycle Assessment (LCA)

1 Introduction

Prospective Life Cycle Assessment (pLCA) was defined by Arvidsson et al. (2024) as a Life Cycle Assessment (LCA) that models a product system at a future point in time relative to the time at which the study is conducted. Two dimensions are of particular importance: the temporal positionality (when the study is conducted compared to the product assessed) and the technology maturity at the time the study is conducted. To date, the majority of pLCA studies relate to the energy sector, e.g. Nurdiawati et al. (2025). However, this is not the only sector for which systemic evaluations of environmental impacts at future points in time are required. Mitigating environmental impacts is particularly urgent in the agri-food sector. While agriculture provides food for a growing world population, it is a major source of environmental pollution contributing to 24% of global greenhouse gas emissions, pesticide drift, and nutrient emissions (Foley et al. 2005). Ex-ante analyses are used to predict the effect of

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future changes of the systems under assessment, such as the impacts of mitigation measures in the Swiss agricultural sector (Bystricky et al. 2020). However, so far, they tend to only extrapolate the status quo without accounting for likely technological or environmental developments in other sectors of the economy or within the agricultural sector itself. The 89th LCA Discussion Forum (DF) held in Zurich on February 4, 2025, aimed to present the latest developments in the rapidly evolving field of pLCA by focusing on advances that support the agri-food sector's transition towards more sustainability. The DF improved understanding of pLCA beyond its application to innovative technologies, tackling its limitations and needs for future developments. The 89th LCA DF consisted of four presentation blocks including Q&A sessions, which were followed by a panel discussion. In total, 82 persons attended the conference in person and 36 online.

2 Setting the scene for prospective LCA of agricultural systems

The topic of the talk of Christian Bauer (Paul Scherer Institute) was the *premise*[1] workflow, which links Life Cycle Inventories (LCI) with Integrated Assessment Model (IAM)[2] scenarios to generate prospective background LCI databases (Sacchi et al. 2022). In doing so, *premise* combines the technological granularity of specific LCIs with the consistent global representation of economy-wide transition pathways according to IAM scenarios. The latest developments of premise include sector analysis with incremental databases and *pathways*, a tool that allows combining pLCA with energy system models to evaluate entire regions or sectors. In theory, these developments enable assessing the contribution of the future agricultural sector to a product life cycle or transition pathway. However, a key opportunity for further research that was highlighted is the lack of data on the potential future evolutions of the agricultural sector. Anne van den Oever (Vrije Universiteit Brussels) addressed advances in prospective Life Cycle Impact Assessment (LCIA) by organizing her talk around five questions regarding impact relevance, emerging substances, changes in characterization factors, normalization references, and weighting schemes when addressing prospective LCIA. Using ozone depletion as a case study, she illustrated the application of these questions and presented additional examples involving water scarcity, global warming, and freshwater eutrophication. Overall, enhancing regionalized LCIA can serve as a first step toward prospective LCIA, since future characterization factors often exhibit substantial spatial variability. This approach also enables the use of characterization models from regions with different climatic conditions as proxies for anticipating future impacts. Marco Springmann (University of Oxford and University College London) shared insights on approaches outside traditional LCA frameworks to evaluate health and environmental impacts of food system pathways relying on multiple model outcome combinations. His work represents a first step towards closing the prospective agri-food data gap and identifies several models useful for prospective agricultural modelling like the IFPRI-IMPACT model (Robinson et al. 2024) and the nitrogen balance model (Lassaletta et al. 2016). This first block of presentations stressed the need to account for changing backgrounds and impact assessment methods, as well as for models that capture the complexity of the agri-food sector in the future.

3 pLCA of agricultural systems and technologies

The challenge of evaluating environmental impacts of cultivated meat with pLCA was addressed by Hanna Toumisto (University of Helsinki and Natural Resources Institute Finland – LUKE), highlighting difficulties related to defining the system boundaries and cut-off criteria, missing data and the use of proxies causing uncertainties, and missing prospective LCIA methods. Pierre Jouannais (INRAE) drew conclusions from a combination of Representative Concentration Pathways (RCPs[3]), Shared Socioeconomic Pathways (SSPs[4]), IAMs, and LCA on regions in the Mediterranean area where agrivoltaics systems outperformed conventional photovoltaic. Joan Muñoz-Liesa (KTH and Agroscope) evaluated the environmental impacts of controlled environmental agriculture in comparison to open-field and conventional

[1] https://github.com/polca/premise

[2] Integrated Assessment Models integrate knowledge from multiple disciplines—such as climate science, economics, energy systems, and land use—to simulate and analyse the interactions between human and environmental systems. They are used to assess the potential impacts of climate change, evaluate mitigation and adaptation strategies, and inform policy decisions by projecting future socioeconomic and environmental outcomes under various scenarios (https://www.iamconsortium.org/what-are-iams/).

[3] Representative Concentration Pathways are standardized greenhouse gas concentration trajectories adopted by the climate modelling community to represent different possible future radiative forcing levels by the year 2100. RCPs serve as an input for climate models to project climate variables under varying emission scenarios (https://www.nccs.admin.ch/nccs/en/home/climate-change-and-impacts/climate-basics/what-are-emission-scenarios-.html).

[4] Shared Socioeconomic Pathways are a set of narratives and quantitative pathways describing plausible alternative futures of societal development, including demographic, economic, technological, social, and environmental factors. They are used in combination with RCPs (https://earth.gov/sealevel/faq/124/what-are-shared-socioeconomic-pathways-or-ssps/).

greenhouse production using pLCA. To use all available data, the assessment relied on combining different agrifood LCA databases. These three presentations highlighted the diversity of technological innovation to be expected in the agri-food sector, which is associated with challenges such as increased uncertainty and the lack of harmonization of available (inventory) data.

4 Prospective environmental evaluations of the agricultural sector

Moving from individual technologies to sectors, Eléonore Loiseau (INRAE) presented the joint assessment of the environmental impacts and resource criticality of French food consumption scenarios in 2050. A higher share of organic farming was shown to reduce mineral resource criticality but increase land criticality. Giles Rigarlsford (Unilever) then evaluated climate and biodiversity impacts of a shift from meat-based to plant-forward meals in Germany and Singapore under current and future conditions. Impacts were reduced in the plant-forward meals compared to the meat-based ones, but the size of the reduction depended on the country context and the SSP pathways chosen. Transformations in the Swiss food system were finally assessed by Vasco Diogo and Albert von Ow (Agroscope) for multiple scenarios with the SWISSfoodSys model accounting for environmental, economic, social impacts, and policy targets. Synergies were observed, e.g. between nutrition and most environmental indicators; agricultural income and pesticide risks presented the most pronounced trade-offs. Such sectoral prospective evaluations highlight the importance of including different sustainability indicators to identify synergies and trade-offs.

5 Current challenges in pLCA of agri-food systems and the way forward

Finally, a panel discussion moderated by Stefanie Hellweg (ETH Zürich) brought together experts from different domains—Christian Bauer, Anne van den Oever, Marco Springmann, and Vanessa Burg (ETH Zürich)—to reflect on the state of pLCA and its potential role in supporting sustainability transitions in the agri-food sector. Challenges already touched upon in the Q&A sessions were discussed in more depth. The key statements are summarized below and do not necessarily reflect the opinion of each individual panellist. General concerns regarding the validity of current pLCA practices, as recently raised by de Bortoli et al. (2025), were not articulated.

Similarly to LCA in general, pLCA suffers from a lack of data, especially when projecting future developments of key drivers in the agri-food sector, such as pedoclimatic conditions, human behaviour, or advances in technology for crop and animal management. Engaging more intensively with other disciplines and R&D experimental labs was proposed as a solution to this challenge. Such exchanges are particularly valuable to help anticipate technology and agricultural practice change and diffusion, especially over long-time horizons (e.g. 2050). In addition, prioritizing the public availability of data and tools could also help fill data gaps.

Data scarcity in pLCA is further compounded by the complexity and multidimensionality of agri-food systems, especially considering that they are open systems with multiple interactions with the environment and thus subject to spatial and temporal changes. Prospective assessments must therefore navigate this complexity while dealing with the limitations posed by available data, methods, and models of science communication. In particular, pLCA analyses today are still insufficiently comprehensive since current tools lack the ability to incorporate such complex environmental changes affecting agri-food systems. Defining different types of scenarios for the long and short term may offer a structured approach for unpacking the role of key drivers in anticipating future developments in the agri-food sector.

The complexity of agri-food pLCA inherently introduces uncertainty, both in the data and in the modelling assumptions. In this case too, breaking down pLCA results into different scenarios, showing a range of possible futures, can be of use. Inter- and transdisciplinary collaboration can also help to identify and potentially reduce uncertainty.

The uncertainty and complexity associated with pLCA raised questions about its usefulness for decision-making. While the boost of electric mobility was cited as an example of successful decision support, there was still agreement that communicating pLCA findings to stakeholders outside the scientific community is challenging. To be effective, careful planning of communication was suggested, as well as thinking about a storyline, focusing communication on key aspects, and linking pLCA to broader system assessments which include, for example, nutritional aspects and cost–benefit frameworks to inform political decisions more effectively. Furthermore, it was argued that finding common terms across disciplines is essential for broader integration and collaboration among the different communities. The lack of harmonized methods and approaches was also linked to the need to improve comparability between prospective studies to transition from case studies to a common framework.

This common framework would imply harmonizing the terms used with pLCA (see for instance Arvidsson et al. (2024)) and could provide good practice guidelines for working with pLCA tools. Rather than providing guidelines, it was deemed more relevant to empower users to make careful and informed use of tools, understand the entire scenario space, and distinguish between likely developments and areas where large differences can be expected across scenarios.

Related to the available tools, the integration of pLCA with complementary modelling approaches (e.g. agent-based and economic models) was mentioned to identify alternative pathways for sustainable agri-food transformation. Furthermore, robust and flexible prospective modelling tools for the foreground system were found to be lacking, as well as for the visualization and communication of results.

The panel also reflected on the role of shock scenarios and disruptive events, such as geopolitical crises or natural disasters, and their potential impacts on food production and trade. While predicting such events is difficult, collaborating with experts in the field of foresight and future studies could help to incorporate them into scenario development.

System boundaries and rebound effects were also discussed. Several panellists highlighted that rebound effects are often insufficiently addressed, despite their importance in system-wide assessments. While IAMs and partial equilibrium models can capture some of these dynamics, LCA studies rarely integrate them fully.

Addressing the challenges outlined above will require both technical development and institutional collaboration, supported by harmonized approaches and better tools for integrating and communicating pLCA into sustainability decision-making in the agri-food sector.

6 Conclusion

The presentations of the 89th LCA DF showcased the latest advances in pLCA, going beyond its use for technological innovations and towards its use in more complex systems such as agricultural production. Approaches aiming at integrating several modelling frameworks with LCA to define actions for a more sustainable agri-food sector were presented. These approaches are essential to identify all potential synergies and trade-offs between sustainability dimensions inherent to agri-food systems but currently do not sufficiently consider future developments of technology, the environment, and socio-economic behaviours. The panel discussion and questions revealed several challenges associated with this. They are, for example, linked to the high level of uncertainty within models that must account for the complex interactions between agricultural production and its environment. A simpler communication of the results, tailored for different stakeholder groups, is crucial. Furthermore, more frequent exchanges with other research fields could contribute to reducing uncertainty and increasing data availability. Missing data representing future evolution is among the most prevalent challenges. Overall, the challenges encountered in the pLCA of agri-food systems resemble those faced in other sectors. However, they tend to be exacerbated by the fact that agricultural productions are open systems directly influenced by environmental factors and their future changes, as well as by the political context incentivizing, or not, certain behaviours.

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Data availability The recordings of the 89th LCA Discussion Forum are available here: LCA DF 89 – The use of prospective LCA to support sustainability transitions | ETH Zürich Videoportal https://video.ethz.ch/events/lca/2025/spring/89th.

Declarations

Conflict of interest The authors declare no competing interests.

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