

Can Attributional Life-Cycle Assessment tell us how to farm and eat sustainably?

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Life-Cycle Assessment (LCA) provides an invaluable framework to systematically assess the impacts of products or activities. This most commonly takes the form of Attributional Life-Cycle Assessment (ALCA), which tracks activities and inputs associated with environmental impacts through a product supply chain. In recent years, environmental impacts of food production, and potential ways to reduce them, have been highlighted in a number of high-profile research papers reviewing ALCAs of different foods (Poore and Nemecek, 2018) and global food system models using ALCA data (Springmann *et al.*, 2018). The publicity generated by these publications, in commercial and NGO communications, and a growing societal appreciation of the need to reduce environmental impacts, have introduced food and agricultural LCAs into the public realm. While increased awareness of the environmental impacts of food production is positive, and efforts to mitigate them should be encouraged, important limitations of agricultural LCAs remain. Researchers, stakeholders, and individuals seeking more sustainable consumption need to be cognizant of four challenges discussed below.

Reliability and specificity of underlying activity data

Collecting activity data for agriculture and food LCAs is challenging because it involves a large number of individual producers working independently in heterogeneous environments, who themselves may only be one part of a complex international supply chain. Reviews and global modelling studies generally use either inherently broad, top-down approaches (e.g., Gerber *et al.*, 2013), or bottom-up aggregation of individual system LCAs, which still have relatively low sample sizes (i.e., per product, per location) for the large uncertainties and heterogeneity inherent in agricultural systems (Poore and Nemecek, 2018). Individual studies also tend to fall back on default assumptions for many areas, particularly for any impacts occurring earlier in the supply chain. For example, an LCA study of a cattle production system will likely collect detailed on-farm management data, but may have considerable uncertainty pertaining to the impacts of any feedstuffs imported from elsewhere. This significantly constrains the reliability of any inferences when scaling up agricultural impacts to provide regional, national or global measures, and limits the specificity of information available to stakeholders (including individual consumers) at the point of decision-making. Demand for sustainable products may encourage improved supply chain monitoring, building on LCA principles, to provide product-specific certification.

Bridging the gap between indicators and environmental impacts

LCAs report on a number of standard indicators used to infer different environmental impacts, such as contribution to climate change or water pollution. These indicators do not always provide an unambiguous correlation to human health and environmental impacts. The gap between indicators and impacts can be especially pronounced for agriculture, where stressors may be multi-faceted and mediated through additional processes and interactions with other agents, acting independently of the system studied. Three examples are as follows:

1. total greenhouse gas (GHG) emissions are typically aggregated as a single carbon dioxide equivalent (CO_{2e}) footprint, obscuring temporal differences in the impacts of different gases;
2. nitrogen pollution risk is generally reported as a total nitrogen footprint, but the final environmental impacts also depend upon the chemical form of any nitrogen losses, biophysical flows (e.g., how lost via surface or groundwaters) and wider catchment inputs (including other farms and non-agricultural polluters); and,
3. the use of more specific modelling/reporting of land-use impacts reflecting the ultimate impacts of interest, such as predicted biodiversity loss, has been recommended versus simple footprints covering total area of use.

UNEP-SETAC guidance recommends using refined and additional reporting, for example, providing GHG footprints under multiple metrics to represent how aggregated climate impacts will differ according to the time-horizon of interest (Frischknecht and Joliet, 2016). In the context of nitrogen footprints, Einnarsson and Cederberg (2019) suggest that the significance of any indicator limitations depend on their intended use, with

a potential distinction between indicators that provide environmental integrity, and those that highlight broader pollution concerns to consumers.

Assigning impacts to an appropriate functional unit

Agricultural LCAs are typically reported in per unit of food produced, but the exact functional unit can vary, with kilograms (kg), kilocalories (kcal), and 100 g protein or serving all being commonly used, in addition to alternative nutrient density indices or even whole-dietary patterns. This variability in reporting can make standardised, meaningful comparisons challenging. In addition, since food is not the only output of agricultural systems, impacts are sometimes allocated to other functional units, such as non-food commodities (e.g., leather) or broader multi-functional outputs (e.g., rural employment, cultures and landscapes). This entails further decisions, and a number of different approaches are used (with biophysical or economic allocation of impacts most common). Social LCA approaches may provide insight into some of these areas and highlight interrelated concerns or conflicts among different goals.

Consequential understanding of alternative scenarios for food production and consumption

Finally, we can only make limited assumptions as to whether the benefits of switching from high to low impact products (as reported by ALCAs) will be realised, as detailed consequential analyses of alternative agricultural/food production scenarios are rarely explored. Global economic models of food supply and demand and marginal carbon [opportunity] costs of different land uses are increasingly used to give a systems-perspective capturing some consequential detail. The full impacts of potential dietary change and alternative land uses will likely be context and location-specific, however, and so these approaches can, at present, only provide a broad indication of potential impacts and benefits. This may also link with various difficulties outlined above, emphasizing consequential trade-offs among different environmental or social impacts: for example, a land-use footprint comparison may suggest one option, but with significant local socio-economic impacts revealed through more holistic approaches (De Rosa, 2018).

Implications

The challenges for agricultural and food LCAs illustrated by the four topics above are significant, but may not be insurmountable. There is already a large body of work dedicated to improving LCA characterisation factors and modelling techniques to link indicators to impacts, but these developments appear to be only infrequently applied in studies and are rarely noted in wider communications.

Do these limitations matter? If LCAs still provide a broad indication of environmental impact, and can encourage policy makers and individuals to make better decisions, then while improvements are academically useful, it can be argued that current approaches are already fulfilling their main purpose. However, stakeholders' faith in the usefulness or integrity of LCAs will be undermined if we do not acknowledge these (and doubtless other) difficulties and limitations.

Unless we appreciate that ALCAs can only take us so far, we risk making decisions based on incomplete information, which may ultimately fail to provide the predicted benefits, or even result in unanticipated negative consequences.

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