How to calculate the impact: towards an EU ecolabelling

Life Cycle Assessment in the agri-food sector: lessons learnt and challenges

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Introduction

Our food system has significant impacts on the environment and dominates several of the transgressed planetary boundaries (te Wierik 2025). To mitigate the environmental impacts of food production and consumption, we need objective, quantitative and evidence-based information on the environmental impacts of food products at different stages of their lifecycle. This allows producers to mitigate their impacts, supply chain actors (processors, retailers, caterers) to source products with low environmental impacts, consumers to guide their purchases towards low-impact food and policy makers to define adequate framework conditions for the food system.

Life Cycle Assessment of agri-food systems

Life Cycle Assessment (LCA) has developed over the last three decades into a standard method for the assessment of environmental impacts of products (Curran 2013) and the preferred method for eco-labelling (Garcia-Herrero et al. 2025). LCA is characterised by a comprehensive assessment of environmental impacts, ranging from the use of resources (land, water, minerals, metals), climate change, biodiversity, ecotoxicity, eutrophication, acidification to impacts on human health. It further considers the whole life cycle of a product from cradle to grave including raw materials, agricultural production means, agricultural production, processing, transport, storage, packaging, retail, consumption and final disposal (Thoma et al. 2022). Both characteristics prevent any burden shifting between lifecycle stages or environmental impacts from happening. The environmental impacts are expressed per unit of the product. This is particularly challenging for food products, which differ significantly in their nutritional profiles. Application of LCA in the agri-food sector encounters particular challenges (Nemecek et al 2024). Compared to many industrial sectors, farms are small while still encompassing numerous production units, which makes gathering representative data cumbersome.

Agricultural systems strongly depend on natural resources and are therefore "open" systems, which are difficult to control. This makes emission reductions in agricultural systems much more complex compared to controlled industrial systems, where emissions can be reduced by orders of magnitude (e.g., by using filters). Emissions and the use of natural resources is driven by climate, soil and topography, which leads to a high spatial and temporal variability. Similarly, management measures like the use of inputs such as fertilisers, pesticides or water for irrigation strongly depends on the local context.

Lessons learnt from agri-food LCA

Despite the high variability of environmental impacts in agri-food LCA, some general observations can be made. Most of the environmental impacts are caused by the primary production (crop production and animal husbandry, Poore and Nemecek 2018), although for some highly-processed foods, food processing considerably increases their impacts. Land-use change impacts can be of high relevance for some crops like soybean, sugarcane or palm oil and are mostly related to deforestation and the cultivation of peat soils, which can cause high emissions of greenhouse gases (CO^2, N^2O, CH^4). Food storage is most important for cold storage of fruits and vegetables. Transports matter for fruits and vegetables and foods transported via air freight (Bystricky et al. 2015), but in general, the advantages of regional or domestic production and the role of transports (food miles) are overestimated in the public perception. Seasonality matters for fruits and vegetables, notably those stemming from fossil-heated greenhouses (Stössel et al. 2012). Packaging is important for some products only, in particular for beverages (Poore and Nemecek 2018).

Numerous studies have shown that the environmental impacts from animal-sourced food (ASF) typically exceed those of plant-based food (Poore and Nemecek 2018); but ASF has also a higher nutrient concentration and nutrient availability than the latter.

Mitigation options

To mitigate environmental impacts, the consumption of animal-sourced food, in particular red meat should be reduced (von Ow et al. 2020). Substitutes for meat emerge as promising alternatives, while the generally lower nutritional values and higher water scarcity of milk substitutes are less favorable (Mehner et al. 2025). Diets optimised from an environmental perspective are closer to the recommended diet than the current consumption, showing synergies between healthy and sustainable food. Following the dietary recommendations would hence reduce environmental burdens in most cases. However, for some food groups like fruits, vegetables, seafood, nuts and seeds trade-offs exist, since they are recommended from a health perspective, but they also raise some sustainability issues (Hallström et al. 2026).

Food waste is considerably increasing environmental impacts and should be avoided as much as possible (Beretta and Hellweg 2019), while still respecting food safety rules. Not only the amount wasted should be considered; the environmental impacts caused by wasting food and the nutrients lost should be taken into account as well. Although avoiding unnecessary packaging can reduce environmental impacts, packaging can also extend the shelf life of food products. Since the impacts of the food protected by the packaging normally largely exceed the impacts of the packaging itself (Williams and Wikstrom 2011), this trade-off needs to be carefully considered.

A couple of general options to mitigate environmental impacts were identified in crop production from LCA studies: (i) cultivate the right crop at the right place, which concretely means avoiding crops on peat soils and in deforested areas, avoiding areas with endangered species, avoiding growing crops with high water demand in arid areas; (ii) avoid unnecessary fertilisation, plant protection, and irrigation (as much inputs as needed, not less, not more). (iii) To achieve the highest yields, often excessive amounts of inputs are used with related environmental burdens. Optimum yields with lowest environmental impacts per product unit are typically below the maximal yields. However, if the yields fall too low, environmental impacts per unit of harvested product will increase.

For animal production mitigating environmental impacts means (i) to choose the adequate production system (e.g., beef from dairy systems and not from pure beef systems), (ii) to develop animal-friendly and low-emission husbandry systems, (iii) to increase the feed conversion efficiency, (iv) to produce and use feedstuffs with low environmental impacts, and (v) to increase the use of by-products from animal slaughtering for human consumption (“nose-to-tail” strategies).

Nutritional LCA and Life Cycle Sustainability Assessment

To better reflect the trade-off between nutrition and environmental impacts, nutritional LCA, which combines LCA with the consideration of the nutritional profiles or human health impacts, has emerged (McLaren et al. 2021; Green et al. 2023). Nutrient-food quantity-based, guideline-based, diversity-based, nutrient quality-based, and health-based metrics were identified (Reguant-Closa et al. 2024), each of them highlight different nutritional aspects. Using aggregated nutritional metrics, such as the nutrient rich food index (NRF) as a functional unit in food LCA, is a common approach and makes different food items comparable. The methods of nutritional LCA are promising, but currently not standardised enough to be regularly included in eco-labelling. The application of LCA for the environmental assessment is well established. Social LCA and life cycle costing have been developed as methods for the other two dimensions of sustainability. However, compared to the environmental LCA, they are much less developed, harmonised and used. Their inclusion in sustainability labelling would be premature at this stage.

Conclusion

During the last decades, the LCA method has developed into a standard method for the assessment of environmental impacts of LCA. It allows to identify the hotspots in production systems and supply chain and to choose the most preferable among several alternatives. It provides an evidence-based foundation for the eco-labelling of food. However, it has also some limitations and is not yet capable of covering all sustainability aspects (Seval et al. 2024). Thus, it needs further development and/or the use of additional indicators to provide a fully comprehensive assessment.

References

Beretta and Hellweg. 2019. Potential environmental benefits from food waste prevention in the food service sector. Resources, Conservation and Recycling. 147: 169-178. https://doi.org/10.1016/j.resconrec.2019.03.023

Bystricky et al. 2015. Life-cycle assessment of Swiss agricultural products compared with imports. Agrarforschung Schweiz. 6: 264-269. https://www.agrarforschungschweiz.ch/en/2015/06/life-cycle-assessment-of-swiss-agricultural-products-compared-with-imports/

Curran. 2013. Life cycle assessment: a review of the methodology and its application to sustainability. Current Opinion in Chemical Engineering. 2(3): 273-277. https://doi.org/10.1016/j.coche.2013.02.002

Garcia-Herrero et al. 2025. Life Cycle Assessment (and Environmental Footprint) to support food labelling schemes: an overview of current proposals and future directions. Cleaner Environmental Systems. 19: 100334. https://doi.org/10.1016/j.cesys.2025.100334

Green et al. 2023. A proposed framework to develop nutrient profiling algorithms for assessments of sustainable food: the metrics and their assumptions matter. The International Journal of Life Cycle Assessment. 28: 1326-1347. https://doi.org/10.1007/s11367-023-02210-9

Hallström et al. 2026. Co-benefits and trade-offs between environmental impact and diet quality: insights from observational dietary data in a Swedish population. European Journal of Nutrition. 65(1): 31. https://doi.org/10.1007/s00394-025-03855-y

McLaren et al. 2021. Integration of environment and nutrition in life cycle assessment of food items: opportunities and challenges. Fao, Rome. 161 p. https://doi.org/10.4060/cb8054en

Mehner et al. 2024. Fleisch- und Milchersatzprodukte - besser für Gesundheit und Umwelt? Auswirkungen auf Ernährung und Nachhaltigkeit, die Sicht der Konsumentinnen und Konsumenten sowie ethische und rechtliche Überlegungen. Ed. TA-SWISS, vdf Hochschulverlag AG. 300 p. https://doi.org/10.3218/4194-1

Nemecek et al. 2024. Swiss Agricultural Life Cycle Assessment: A method to assess the emissions and environmental impacts of agricultural systems and products. Int J LCA. 29 : 433-455. https://doi.org/10.1007/s11367-023-02255-w

Poore and Nemecek. 2018. Reducing food's environmental impacts through producers and consumers. Science. 360: 987-998. https://doi.org/10.1126/science.aaq0216

Reguant-Closa et al. 2024. Review of diet quality indices that can be applied to the environmental assessment of *foods and diets. Curr Nutr Rep. 13: 351-362. https://doi.org/10.1007/s13668-024-00540-0*

Seval et al. 2024. State of the art analysis of LCA-based ecolabelling schemes in Europe. Wageningen, Wageningen Economic Research. Report 2024-125. https://edepot.wur.nl/680057

Stöessel et al. 2012. Life cycle inventory and carbon and water foodprint of fruits and vegetables: application to a Swiss retailer. Environmental science & technology. 46(6): 3253-3262. https://pubs.acs.org/doi/10.1021/es2030577

te Wierik et al. 2025. Identifying the safe operating space for food systems. Nat Food. 6: 1153-1163. https://doi.org/10.1038/s43016-025-01252-6

Thoma et al. 2022. Life cycle assessment of food systems and diets. pp. 37-61 in: Food system modelling, eds. Peter C.J. & Thilmany D.D. Academic Press, Elsevier. 390 p. https://doi.org/10.1016/C2019-0-03225-6

von Ow et al 2020. Environmental optimization of the Swiss population's diet using domestic production resources. J Clean Prod. 248: 119241. https://doi.org/10.1016/j.jclepro.2019.119241

Williams and Wikstrom. 2011. Environmental impact of packaging and food losses in a life cycle perspective: a comparative analysis of five food items. J Clean Prod. 19: 43-48. https://doi.org/10.1016/j.jclepro.2010.08.008