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Critical Review of Life Cycle Assessment of Local and Imported Food Commodities

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Abstract: This study aims to critically reviews Life Cycle Assessment (LCA) research in Indonesia's food sector, focusing on both locally produced and imported commodities. Employing a critical review methodology, peer-reviewed articles and international reports published were analyzed for compliance with ISO 14040/44, data transparency, system boundary definitions, and methodological gaps. The results reveal substantial variability in environmental impacts: local rice and soybean value chains exhibit high methane emissions and fertilizer-related effects, whereas imported wheat, soybean, and beef accrue larger carbon footprints due to long-distance transport. Moreover, most studies adopt a cradle-to-gate scope with limited sensitivity or uncertainty analyses, which undermines result robustness. We conclude that standardizing LCA protocols, expanding primary data collection, and incorporating cradle-to-grave scopes and uncertainty analyses are vital to enhance the reliability of LCA for Indonesia's sustainable food policy

Keywords: Critical Review, Indonesia, Life Cycle Assessment, Sustainable Food Systems, System Boundaries, Transparency

Introduction

Food security is a highly strategic issue in the context of sustainable development, particularly for developing countries such as Indonesia (Yusriadi et al., 2026). With a growing population and a high dependence on imported food, Indonesia faces major challenges in ensuring the availability of sufficient, sustainable, and environmentally friendly food supplies (Bangun, 2024; Susanti et al., 2024). Most of the country's key food commodities, such as wheat, soybeans, and beef, are still reliant on supplies from abroad (Armawi, 2009). This dependence increases the country's vulnerability to global price fluctuations and disruptions in international supply chains, which can threaten domestic food stability. From an environmental perspective, the food sector contributes significantly to greenhouse gas (GHG) emissions, land use, and ecosystem degradation (Bhatti et al., 2024; Sarangi et al., 2024). Food that is intensively produced and transported over long distances carries a substantial carbon footprint (Olusola et al., 2025). Meanwhile, local food systems in Indonesia, although often having more environmentally friendly potential, still face challenges in terms of production efficiency and productivity.

Life Cycle Assessment (LCA) is a methodology used to evaluate the environmental impacts of a product throughout its entire life cycle (Kaynak et al., 2025). LCA measures various environmental impact categories, including greenhouse gas (GHG) emissions, water use, energy consumption, as well as impacts on ecosystems and soil quality (ISO 14040, 2006). This methodology consists of four main phases: (1) goal and scope definition, (2) life cycle inventory (LCI), (3) life cycle impact assessment (LCIA), and (4) interpretation of results (Finkbeiner et al., 2006). The application of LCA in Indonesia's food sector is important as it provides a comprehensive overview of the environmental impacts associated with both local and imported food production. Through LCA, policymakers can identify actionable steps to reduce environmental impacts and enhance the sustainability of Indonesia's food system. Although the application of LCA in Indonesia remains limited, this methodology has strong potential as an effective tool to drive transformation toward a more sustainable food system.

In recent years, LCA studies in Indonesia have begun to develop with the publication of various research papers addressing the environmental impacts of food products and other sectors (Go et al., 2025; Gustiningrum, 2024; Hartini et al., 2023; Supartono et al., 2021). However, most of these studies are limited in scope, often only covering cradle-to-gate analyses and excluding the entire life cycle (cradle-to-grave) of the product. This limitation can restrict the ability of studies to provide a complete picture of the environmental impacts of food products, whether locally produced or imported.

This critical review aims to evaluate the quality and relevance of existing LCA studies in Indonesia's food sector, with a focus on imported and exported food commodities. While several previous reviews have primarily concentrated on specific commodity-based food industries or on fertilizer application within agricultural systems (Haryanto et al., 2026; Kurniadi et al., 2026), they have not comprehensively examined LCA studies across Indonesia's broader food sector, particularly in relation to trade-related food commodities. By synthesizing the findings reported in these studies, this review seeks to provide a more integrated perspective on environmental impacts along Indonesia's food supply chains. It also aims to identify the potential application of LCA in shaping Indonesian food policy that supports environmental impact reduction and enhances national food security.

Methodology

This review adopts a critical review approach to evaluate existing Life Cycle Assessment (LCA) studies in Indonesia's food sector, with a focus on both local and imported food commodities. The review examines the methodological consistency applied in these studies, as well as gaps in local data availability and transparency of reported results. The aim is to assess the quality and relevance of the methodologies used in existing LCA studies and to identify existing gaps in the application of LCA within Indonesia's food sector. The analysis method employed is comparative analysis, which involves comparing local and imported food commodities across four key aspects: transportation method, Greenhouse Gas (GHG) emissions, sustainability aspects, factors, and strategies to reduce emissions.

The main focus of this study is on environmental sustainability related to the production of local and imported food. The data used in this research were sourced from scientific publications published in internationally and nationally indexed journals (such as Scopus and Web of Science). Additionally, reports published by international institutions such as FAO and the WRI were also used to provide a broader context regarding food policy in Indonesia. The analytical approach involves comparing the methodological quality applied in the reviewed LCA studies. The analysis focused on the following:

1. Compliance with global LCA standards (ISO 14040 and ISO 14044).
2. Data transparency, such as whether the study provides sufficient information to replicate the research and verify the results.
3. Identification of gaps in local data, especially related to the limited availability of primary data in Indonesia and the lack of standardized methodology.

Result and Discussion

Identification of LCA Studies in Indonesia

Life Cycle Assessment (LCA) research in Indonesia remains relatively limited, particularly in the food sector. Existing studies are often confined to cradle-to-gate approaches and rarely involve more comprehensive cradle-to-grave analyses. Most studies rely on international databases, such as Ecoinvent, which do not always reflect local Indonesian agricultural conditions. Several significant studies have included environmental impact analyses of local food products like rice and soybeans, but there are gaps in primary data for some local commodities, leading to inaccuracies in environmental impact calculations, particularly regarding water usage and greenhouse gas emissions.

Furthermore, few studies comprehensively examine imported food commodities. Existing research is often limited to transportation analysis and does not consider the entire product life cycle from cradle to grave. Consequently, there is an urgent need to develop broader LCA studies based on local primary data to support more sustainable food policies in Indonesia. Table 1 lists various LCA studies conducted in Indonesia, focusing on local and imported food commodities and the methodological limitations of each study.

Table 1. LCA studies in Indonesia Relevant to the Food Sector

Study	Commodity Focus	LCA Approach	Methodology	Limitations and Gaps
(Sari et al., 2024)	Rice	Cradle-to-Gate	Local primary data, Recipe method	Geographically limited to West Java
(Hartini et al., 2023)	Soybeans	Cradle-to-Grave	Combination of primary & Ecoinvent data	Limited data for processing and waste management phases
(Supartono et al., 2021)	Tempeh	Cradle-to-Gate	Local primary data, ISO 14040	No uncertainty analysis included
(Rahmah et	Cocoa Beans	Cradle-to-Gate	Primary data, CML	Limited to small-scale

Study	Commodity Focus	LCA Approach	Methodology	Limitations and Gaps
al., 2024)			baseline	farmers, incomplete transportation data
(Gustiningrum, 2024)	Fish Processing Products	Gate-to-Gate	Primary data from the processing industry	Does not cover raw material production and *end-of-life* phases
(Pharmawati et al., 2023)	Organic Rice	Cradle-to-Gate	Local primary data, IPCC 2013	Limited comparison with conventional systems

LCA of Local Food Commodities

LCA studies related to local food commodities in Indonesia generally focus on primary products such as rice, soybeans, and corn, as well as processed products like tempeh and tofu. Although the results indicate that local food production has the potential for lower environmental impacts—particularly in land use and methane emissions—many studies have yet to adopt a cradle-to-grave approach, which limits the understanding of the full life cycle impact of these products. Some studies have shown that local farming systems in Indonesia can have significant environmental impacts, especially from land use and high methane emissions from irrigated paddy fields. A study by (Wihardjaka, 2016) found that local rice production contributes substantially to greenhouse gas (GHG) emissions, mainly in the form of methane released during the flooding of rice paddies. In addition, the use of chemical fertilizers also contributes to emissions, although organic farming systems show potential in reducing these emissions.

Environmentally friendly agricultural practices such as the use of organic fertilizers and alternate wetting and drying (AWD) irrigation techniques can reduce methane emissions by up to 40% compared to conventional irrigation systems. This highlights that local food has the potential to be more sustainable if supported by eco-friendly farming techniques. Another study by M. Ifdholy (Ifdholy et al., 2019) on tempeh made from local soybeans showed that locally produced tempeh has a lower carbon footprint compared to tempeh made from imported soybeans. This is due to reduced carbon emissions during the transportation phase and improved energy efficiency in local-scale processing.

LCA of Imported Food Commodities

Imported food commodities such as wheat, soybeans, and beef demonstrate larger environmental impacts, particularly due to emissions associated with international transportation. For instance, wheat imported from Australia shows high production efficiency due to large-scale mechanical farming systems. However, when these products are transported to Indonesia, the carbon emissions from sea and land transportation become significant, increasing the total carbon footprint of the product (Armawi, 2009). Similarly, soybeans from Brazil demonstrate efficiency in land and water usage in the country of origin, but significant impacts emerge during intercontinental transportation (Liu et al.,

2021). Frozen beef from the United States also has high environmental impacts during distribution, requiring continuous cooling throughout the supply chain (Rotz et al., 2019).

Comparison of Local vs. Imported Food Transportation

Table 2 presents a comparison between local and imported food transportation, focusing on greenhouse gas (GHG) emissions generated during transportation:

Table 2. Comparison Between Local and Imported Food Transportation

Aspect	Local Food Transportation (Indonesia)	Imported Food Transportation
Transportation Method	Trucks, Short-distance Sea Vessels	Sea Vessels, Airplanes, Trucks (Long-distance)
Greenhouse Gas (GHG) Emissions	Lower due to shorter transportation distances	Higher due to longer transportation distances
Sustainability	More environmentally friendly, supports sustainable food systems	Vulnerable to fluctuations and larger carbon footprint due to long-distance transportation
Examples	Local foods like rice, vegetables, and fish	Imported foods like wheat, beef, soybeans
Emission Reduction Factors	More efficient fuel use for short distances, crop rotation, and organic fertilizer use	Uses airplanes and ships with higher fuel consumption
Study	(Mujianto, 2024)	(Rum et al., 2024)

From the table above, it can be observed that local Indonesian food transportation tends to be more environmentally friendly compared to imported food. Local foods have shorter transportation distances and use more efficient transportation methods, such as trucks and short-distance sea vessels. In contrast, imported foods, despite being produced with higher efficiency in their country of origin, add to their carbon footprint through long-distance transportation, requiring more fuel-consuming airplanes and ships.

LCA Study Quality: Validity and Transparency

A review of the quality of the LCA methodologies used indicates that most studies still have limitations in terms of boundary coverage (more cradle-to-gate than cradle-to-grave) and the availability of local primary data. For example, many studies in Indonesia rely on the Ecoinvent database, which is Europe-based and therefore does not always reflect local geographic conditions and technologies (Chaerul & Allia, 2019). In addition, only a few studies include sensitivity or uncertainty analysis, even though this is essential to assess the validity and robustness of the results. Sensitivity analysis can help determine how much the results depend on changes in variables, such as variations in transportation systems or changes in fertilizer types. Without this analysis, the conclusions of LCA studies risk being

overly generalized. Some more advanced studies have begun using a hybrid approach, combining field-collected primary data with secondary data from commercial software such as SimaPro or OpenLCA, although this practice remains limited to certain academic institutions.

One of the main challenges in LCA studies in Indonesia is the lack of a life cycle inventory (LCI) database that is specific to the local context. A study by Pauter et al. (Pauer et al., 2020) revealed that using international databases such as Ecoinvent or Agri-footprint can result in inaccuracies of up to 40% in estimating environmental impacts for certain impact categories, particularly those related to land and water use. It emphasized the importance of region-specific data, especially for agricultural inputs such as fertilizers and pesticides, which can have significantly different environmental profiles depending on local practices and climatic conditions.

The variability in LCA methodologies applied in Indonesia leads to difficulties in comparing results across studies. The Product Environmental Footprint (PEF) guidelines developed by the European Union offer a standardized framework that can be adapted to the Indonesian context (Mordaschew & Tackenberg, 2024). The implementation of standardized methodologies, as proposed by Chaerul & Allia (Chaerul & Allia, 2019), could improve the comparability and reliability of LCA studies in Indonesia. This approach includes harmonizing system boundaries, selecting allocation methods, and using characterization factors tailored to the local context.

Conclusion

This review demonstrates that local food products in Indonesia, such as rice and tempeh, have the potential for lower environmental impacts compared to imported foods like wheat and beef, particularly in terms of greenhouse gas (GHG) emissions associated with transportation. However, most LCA studies in Indonesia remain limited to the cradle-to-gate approach and do not yet include sensitivity or uncertainty analyses, which can reduce the validity and reliability of the results. The reliance on foreign databases such as Ecoinvent also introduces estimation biases for certain impact categories. Therefore, there is a need to strengthen the use of local primary data, harmonize methodologies, and adopt a cradle-to-grave approach in food-related LCA studies in Indonesia. The government and research institutions should promote the development of a national LCA database and the integration of these studies into sustainable food security policies. Future research should prioritize cradle-to-grave LCA studies that incorporate sensitivity and uncertainty analyses to improve robustness in Indonesia's food sector assessments. Developing region-specific life cycle inventory (LCI) datasets through collaboration among academia, government, and industry is also essential. The use of consequential and scenario-based LCA approaches would better inform trade and food import substitution policies. Establishing a national LCA database supported by standardized guidelines tailored to Indonesian conditions is necessary to enhance methodological consistency. Integrating LCA findings into food

security strategies and Indonesia's Nationally Determined Contribution (NDC) framework would strengthen its role in supporting a low-emission and resilient food system.

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