

Life Cycle Assessment of Indonesian Traditional Chicken Satay with Peanut Sauce

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ABSTRAK

Penelitian ini menerapkan metode Life Cycle Assessment (LCA) untuk mengevaluasi dampak lingkungan dari produksi sate ayam tradisional Indonesia dengan bumbu kacang menggunakan pendekatan gate-to-gate. Analisis dilakukan berdasarkan standar ISO 14040 dan ISO 14044 dengan bantuan perangkat lunak OpenLCA dan basis data Agribalyse_V3.0.1. Unit fungsional yang digunakan adalah 10 porsi sate ayam dengan bumbu kacang. Analisis dampak lingkungan menggunakan metode ReCiPe 2016 (H) midpoint yang berfokus pada lima kategori dampak, yaitu Pemanasan Global (9.406 kg CO₂ eq), Penggunaan Lahan (11.298 m²a crop eq), Pengasaman Terrestrial (0.087 kg SO₂ eq), Ekotoksitas Terrestrial (17.467 kg 1,4-DCB eq), dan Eutrofikasi Air Tawar (0.002 kg P eq). Hasil penelitian menunjukkan bahwa dampak terbesar berasal dari produksi bahan baku, khususnya peternakan unggas, budidaya kacang tanah, dan konsumsi energi selama proses pemanggangan. Penerapan teknologi hemat energi, penggunaan bahan baku berkelanjutan, dan pengurangan limbah makanan berpotensi mengurangi dampak lingkungan secara signifikan. Penelitian ini memberikan kontribusi terhadap kajian keberlanjutan pangan tradisional Indonesia dan pengembangan sistem produksi pangan yang lebih ramah lingkungan.

Kata kunci: Life cycle assessment, Sate ayam, Keberlanjutan pangan, Kacang tanah, ReCiPe 2016 midpoint

ABSTRACT

This study applies the Life Cycle Assessment (LCA) method to evaluate the environmental impacts of traditional Indonesian chicken satay with peanut sauce using a gate-to-gate approach. The analysis follows ISO 14040 and ISO 14044 standards using OpenLCA software and the Agribalyse_V3.0.1 database. The functional unit was defined as 10 servings of chicken satay with peanut sauce. Environmental impacts were assessed using the ReCiPe 2016 (H) midpoint method, focusing on five impact categories: Global Warming (9.406 kg CO₂ eq), Land Use (11.298 m²a crop eq), Terrestrial Acidification (0.087 kg SO₂ eq), Terrestrial Ecotoxicity (17.467 kg 1,4-DCB eq), and Freshwater Eutrophication (0.002 kg P eq). The results indicate that the largest environmental burdens originate from raw material production, particularly poultry farming, peanut cultivation, and energy consumption during the grilling process. Strategies such as adopting energy-efficient cooking technologies, sustainable raw material sourcing, and reducing food waste could significantly minimize environmental impacts. This study contributes to the sustainability assessment of Indonesian traditional foods and provides insights for developing more environmentally friendly food production systems.

Keywords: Life cycle assessment, Chicken satay, Food sustainability, Peanut, ReCiPe 2016 midpoint

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1. INTRODUCTION

Despite its cultural and economic importance, the production of traditional Indonesian chicken satay with peanut sauce faces several environmental challenges. The increasing demand for chicken satay has led to higher consumption of raw materials, energy, and water throughout the production process. In Indonesia, chicken satay is widely produced by small and medium enterprises (SMEs) using conventional cooking methods, particularly grilling

with liquefied petroleum gas (LPG) or charcoal, which contribute to greenhouse gas emissions and other environmental burdens (Azmi et al., 2023). In addition, the production of key ingredients such as chicken meat and peanuts is associated with significant agricultural impacts, including land use, eutrophication, and acidification. Recent life cycle assessment (LCA) studies also indicate that feed production and energy consumption are major

contributors to the environmental footprint of poultry-based food systems (Usva et al., 2023).

Environmental impact has become a critical issue in food production systems due to increasing concerns regarding resource depletion, climate change, and sustainable consumption (Chitaka & Goga, 2023). Life Cycle Assessment (LCA) has emerged as a comprehensive method for evaluating environmental impacts across product life cycles, including food processing systems. LCA enables the identification of environmental hotspots related to energy consumption, emissions, and raw material production (Ott et al., 2023). Several studies have applied LCA to food products and agricultural systems; however, studies focusing on traditional Indonesian foods remain limited, particularly for chicken satay with peanut sauce (Segovia-Hernández et al., 2023).

Although LCA has been widely applied in global food industries, its implementation in traditional Indonesian food production is still limited due to constraints such as limited inventory data, low environmental awareness among SMEs, and lack of standardized environmental assessment practices. Previous studies mainly focused on foods such as rendang, nasi goreng, and gado-gado, while research specifically evaluating the environmental impacts of chicken satay with peanut sauce is still scarce. This gap highlights the need for further studies to understand the environmental burdens associated with traditional Indonesian food production systems and to identify opportunities for sustainability improvement.

This study focuses on the production of traditional Indonesian chicken satay with peanut sauce produced by local SMEs using conventional grilling methods. As a representative case of traditional food production in Indonesia, the production process involves manual preparation, high energy consumption during grilling, and the use of agricultural-based raw materials that potentially contribute to environmental impacts.

The main objective of this study is to evaluate the potential environmental impacts of traditional Indonesian chicken satay with peanut sauce production and to identify environmental hotspots throughout its life cycle using the Life Cycle Assessment (LCA) approach. The study also aims to analyze major contributing factors within the production system based on selected impact categories, including global warming, land use, terrestrial acidification, terrestrial ecotoxicity, and freshwater eutrophication. The novelty of this research lies in the application of the ReCiPe 2016 (H) midpoint method to assess the environmental impacts of traditional Indonesian chicken satay production, providing practical insights to support more sustainable traditional food production systems in Indonesia.

2. MATERIAL AND METHODS

The Life Cycle Assessment (LCA) was performed using data sourced from the Agribalyse_V3.0.1 database and analyzed with the OpenLCA software, adhering to the ISO 14040 and ISO 14044 standards (ISO-14040, 2016). The impact assessment phase applies the ReCiPe 2016 (H) midpoint method to evaluate environmental burdens across multiple categories (Huijbregts et al., 2017). This section provides an overview of the key attributes of the chicken satay with peanut sauce preparation process and the essential data required for conducting the LCA.

2.1. Data Collection

Data for this study were gathered primarily through direct interviews with chicken satay business owners and production workers at a culinary center in Senayan, Jakarta, Indonesia, which is widely recognized for its high concentration of traditional chicken satay vendors. The interviews were conducted in March 2025. The interviews focused on collecting detailed information regarding raw material quantities, production processes, energy and water consumption, fuel usage, and waste generation at each production stage.

This direct approach allowed the researchers to understand actual production conditions in small and medium enterprises (SMEs), ensuring that the collected data represented real operational practices in traditional chicken satay production. Observations of the production environment also helped identify specific inputs consumed and outputs generated, including emissions, wastewater, and food waste. All inventory data used in this study were obtained from interview results and field observations.

The research location was selected because the area represents one of the largest traditional chicken satay culinary centers in Indonesia, enabling the collection of representative production data from vendors with relatively high production capacity. However, this study has limitations because the data were collected only from vendors located in this specific culinary area. Therefore, the environmental impacts identified in this study may differ from production systems in other regions due to variations in raw material sourcing, cooking methods, production scales, and energy consumption practices.

2.2. LCA analysis

This LCA analysis was conducted using OpenLCA 2.4.0 software, which is widely used by researchers and industries worldwide due to its accessibility and user-friendly interface. In this study, the LCA for assessing the environmental impact of 10 servings of chicken satay with peanut sauce was carried out following the ISO 14040 guidelines. The process is structured into four stages: goal and scope definition, inventory analysis, impact assessment, and interpretation (ISO-14040, 2016).

2.2.1. Goal and Scope Definition (System Boundaries and Functional Unit)

The functional unit in this study is defined as 6158.37 kg for 10 portions of chicken satay with peanut sauce, representing a standard serving size of a popular ready-to-eat food in Indonesia. This functional unit aims to provide a consistent measure for LCA analysis, aligned with the same production stages and enabling comparisons with other studies in similar fields (Nabilah et al., 2023). By adopting this portion format, the entire process from production to serving is considered, starting from the selection of high-quality raw materials to the final product ready for consumers. Through this functional unit, environmental impact analysis can be conducted more focused and contextually.

The system boundaries in this study cover key stages in the production of chicken satay with peanut sauce, including storage, cutting, seasoning preparation, grilling, and packaging. The storage stage involves managing raw materials such as chicken meat and spices to ensure freshness and food safety. Cutting and seasoning preparation focuses on processing ingredients before cooking, while grilling is the core stage that determines the flavor and texture of the product. Packaging plays a crucial role in maintaining product quality during distribution and storage until consumption (Frymaruwah et al., 2022). Each stage is evaluated to identify significant environmental impact sources and opportunities for improvement toward more sustainable production (Nahriana & Tawani, 2022). The LCA scope in this study includes all stages from storage to packaging but excludes stages such as chicken sourcing from farms, long-distance transportation, and final consumption. Focusing on the *gate-to-gate* stages aims to understand the environmental impacts during direct production processes, providing in-depth insights into how each stage contributes to environmental effects and how they can be improved for sustainability.

2.2.2. Life Cycle Inventory Analysis

In the Life Cycle Inventory (LCI) analysis for chicken satay with peanut sauce, the main raw materials include chicken, peanut sauce, oil, and energy sources such as charcoal or gas for the grilling

process. Chicken meat is sourced from farms with various rearing methods, while peanut sauce consists of ingredients such as peanuts, garlic, sweet soy sauce, and other spices (Rikhter et al., 2022). Each material has a different environmental footprint in terms of cultivation, harvesting, and processing. For example, chicken production involves the use of animal feed, which requires land and water, as well as greenhouse gas emissions from the rearing process (Руда et al., 2022). The use of oil and fuel for grilling also contributes to the total energy consumption in the production process, making it essential to document the characteristics of each material in this LCI.

Additionally, water consumption is a critical factor in the LCI, particularly in the context of agriculture and processing, where water is used for crop irrigation, cleaning raw materials, and during cooking to maintain food quality (Benitez et al., 2022). As a result of these processes, the waste generated, both solid and liquid, needs to be recorded and analyzed. Solid waste can come from meat scraps, packaging, and other unused materials, while liquid waste can result from washing raw materials and residual water use (Lagnelöv, 2023). In this context, the LCI aims to identify and document all energy and resource inputs, as well as waste and emission outputs related to chicken satay production, which can then be used for further environmental impact assessment.

2.2.3. Life Cycle Impact Assessment

In this study, several environmental impact categories analyzed include Global Warming Potential (GWP100a), Ozone Depletion, Human Toxicity, Photochemical Oxidation, Acidification, and Eutrophication. Each of these categories provides insights into different aspects of the environmental impacts that may arise from the production of chicken satay with peanut sauce. For instance, global warming is measured through specific greenhouse gas emissions, while ozone depletion is associated with harmful chemical emissions that can damage the ozone layer. Human toxicity refers to health risks that may arise from exposure to hazardous substances during the production process (Borusiak et al., 2024; Duan et al., 2023).

Table 1. Inputs and Outputs of 10 Serving Chicken Satay with Peanut Sauce

Input		Output	
Flow	Amount (gram)	Flow	Amount (gram)
Brown Sugar	500	Chicken Satay with Peanut Sauce	4150
Chicken, Breast	1000	TLEV Exhaust	5.41
Garlic	100	Waste Water	2000
Liquefied Petroleum Gas	1.8	Water	2.96
Palm Oil	450		
Peanut	500		
Pepper	50		
Salt	50		
Shallot	500		
Soy Sauce	1000		
Oxygen	6.57		
Water	2000		
Total	6158.37	Total	6158.37

The analysis results indicate that the grilling stage is a hotspot with the most significant impacts in several categories, particularly Global Warming Potential and Photochemical Oxidation. This process requires substantial energy, whether from charcoal or gas use, which generates CO₂ emissions and other pollutants (Borges et al., 2023). Grilling chicken not only contributes to greenhouse gas emissions but can also release particles that contribute to tropospheric ozone formation, posing health risks to humans and the surrounding environment. Additionally, the accessibility and use of peanut sauce also have a significant impact due to the characteristics of its raw materials, which can increase the overall carbon footprint of the production system (Henderson & Lankoski, 2023). Therefore, the grilling stage requires special attention in efforts to reduce the environmental impacts of chicken satay production.

2.2.4. Life Cycle Interpretation

The contribution analysis of the largest emission sources in the production of chicken satay with peanut sauce identifies the grilling stage as the dominant factor, significantly impacting Global Warming Potential (GWP100a) and photochemical oxidation. This is primarily due to the use of charcoal and gas, which generate high emissions during the grilling process. Sensitivity analysis reveals that changing grilling methods, such as switching to cleaner energy sources, can substantially reduce emission impacts, underscoring the importance of technology choices in efforts to lower carbon footprints. Identifying grilling as the process with the greatest environmental impact leads to improvement recommendations, including the adoption of more efficient grilling technologies, the use of renewable energy, and the utilization of local raw materials to reduce transportation emissions. Additionally, sustainable agricultural practices for peanut sauce ingredients should also be prioritized. With these measures, the environmental impact of chicken satay production is expected to be significantly minimized.

2.3. System Boundaries and Functional Unit

In this study, the Life Cycle Assessment (LCA) approach used is *gate-to-gate*, focusing specifically on the production process of chicken satay with peanut sauce without including distribution and consumption stages. The functional unit analyzed is ten portions of chicken satay with peanut sauce, providing a consistent measure for evaluating environmental impacts during the production process. The system boundaries encompass all necessary inputs, including raw materials such as chicken meat, spices, oil, sugar, water, and energy. The processes included in this system involve storage, cutting, spice mixing, grilling, and packaging, which are repeated to produce delicious and high-quality chicken satay. The system outputs consist of the final product, chicken satay with peanut sauce, as well as waste such as wastewater, exhaust gases, and steam,

all of which are analyzed to understand the environmental impact of this food production.

2.4. Inventory Analysis

In the Life Cycle Inventory (LCI) analysis for the production of chicken satay with peanut sauce, the resources used include key raw materials such as chicken meat, garlic, palm oil, peanuts, pepper, salt, shallots, soy sauce, palm sugar, and water, as well as energy in the form of LPG (Liquid Propane Gas) for the grilling process. The production processes studied encompass raw material storage, cutting and spice preparation, mixing, grilling, and final product packaging. The waste generated from this process includes wastewater from washing ingredients and equipment, exhaust gases from LPG combustion, and steam produced during grilling. By mapping all these components, the LCI analysis provides a comprehensive understanding of the inputs and outputs involved in chicken satay production and the environmental impacts of each process stage.

3. RESULT AND DISCUSSION

3.1. Environmental Impact Assessment

The environmental impact analysis of chicken satay with peanut sauce production evaluates each production stage, from raw material preparation to packaging. In this study, five environmental impact categories were assessed, namely Global Warming Potential (GWP), Land Use, Terrestrial Acidification, Terrestrial Ecotoxicity, and Freshwater Eutrophication using the ReCiPe 2016 (H) midpoint method. Based on the Life Cycle Impact Assessment (LCIA) results presented in Table 2, the production process contributes significantly to global warming, with a total impact of 9.406 kg CO₂ eq. In addition, the production system generated impacts of 11.298 m²a crop eq for land use, 0.087 kg SO₂ eq for terrestrial acidification, 17.467 kg 1,4-DCB eq for terrestrial ecotoxicity, and 0.002 kg P eq for freshwater eutrophication. Among all production stages, the grilling process showed the highest contribution due to the intensive use of LPG as an energy source and the emissions generated during combustion (Guercio et al., 2021; Magne et al., 2023).

3.2. Interpretation

The analysis reveals that the primary source of emissions originates from the grilling process, significantly contributing to GWP and photochemical oxidation. The Sankey diagram (Figure 2) illustrates that chicken breast, as the main ingredient, accounts for a substantial portion of environmental burdens, particularly in upstream emissions from poultry farming and transportation. Identifying these hotspots is crucial for formulating strategies to mitigate environmental impacts effectively (Karaeva et al., 2021; Salsabila et al., 2021).

The total Global Warming Potential generated from the production of chicken satay with peanut sauce was 9.406 kg CO₂-eq. The Sankey diagram

identifies chicken production, palm oil consumption, and peanut production as the primary environmental hotspots within the production system. Chicken breast production contributed the largest impact, accounting for approximately 53.937% of the total emissions or 5.073 kg CO₂ eq, mainly due to intensive poultry farming activities, feed production, and energy consumption during livestock production. Palm oil consumption also contributed significantly with 2.309 kg CO₂ eq (24.550%), followed by peanut production with 1.026 kg CO₂ eq (10.912%).

The Sankey diagram further confirms that the majority of Global Warming impacts originate from

upstream raw material production rather than the final preparation stage. In addition, the grilling process using LPG contributes substantially to greenhouse gas emissions due to fossil fuel combustion. These findings indicate that strategies to reduce environmental impacts should prioritize improving raw material sustainability, optimizing energy use during grilling, and reducing dependence on high-emission agricultural products. Transitioning to cleaner energy sources and implementing more sustainable supply chain practices could significantly reduce the overall carbon footprint of traditional chicken satay production.

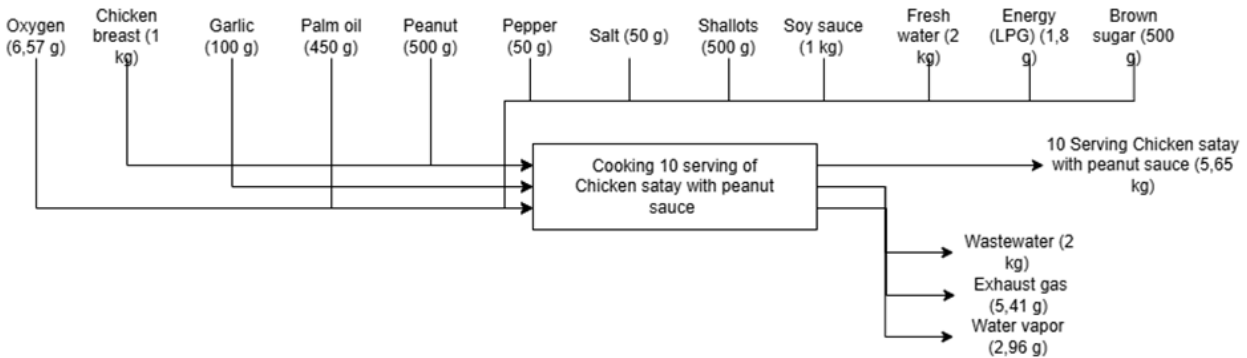


Figure 1. The Flow of Cooking 10 serving Chicken Satay

Table 2. Life Cycle Impact Assessment

Impact Category	Description	Unit	Result
Global Warming Potential (GWP100a)	A measure of contribution to global warming, expressed in CO ₂ equivalents.	kg CO ₂ eq	9.406
Land Use	The potential environmental impact caused by land occupation and transformation for agricultural production activities.	m ² a crop eq	11.298
Terrestrial Ecotoxicity	The potential toxic impact of chemical substances on terrestrial ecosystems and organisms.	kg 1,4-DCB eq	17.467
Terrestrial Acidification	The process of environmental acidification caused by acid emissions, such as SO ₂ and NO _x .	kg SO ₂ eq	0.087
Freshwater Eutrophication	The enrichment of nutrients in freshwater systems that can lead to excessive algal growth and ecosystem imbalance.	kg P eq	0.002

The data source is processed from the results of OpenLCA 2.1.

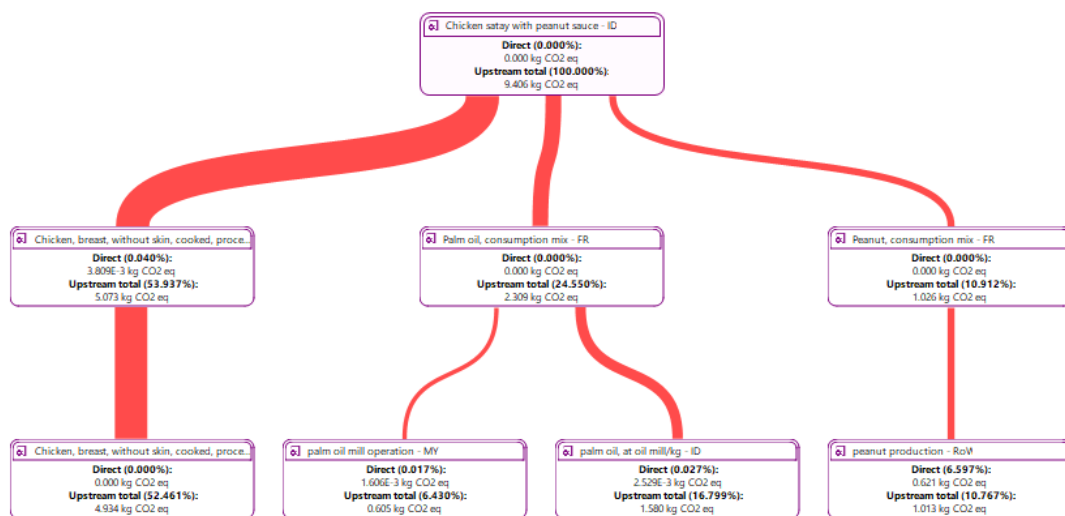


Figure 2. Sankey Diagram of Global Warming Potential

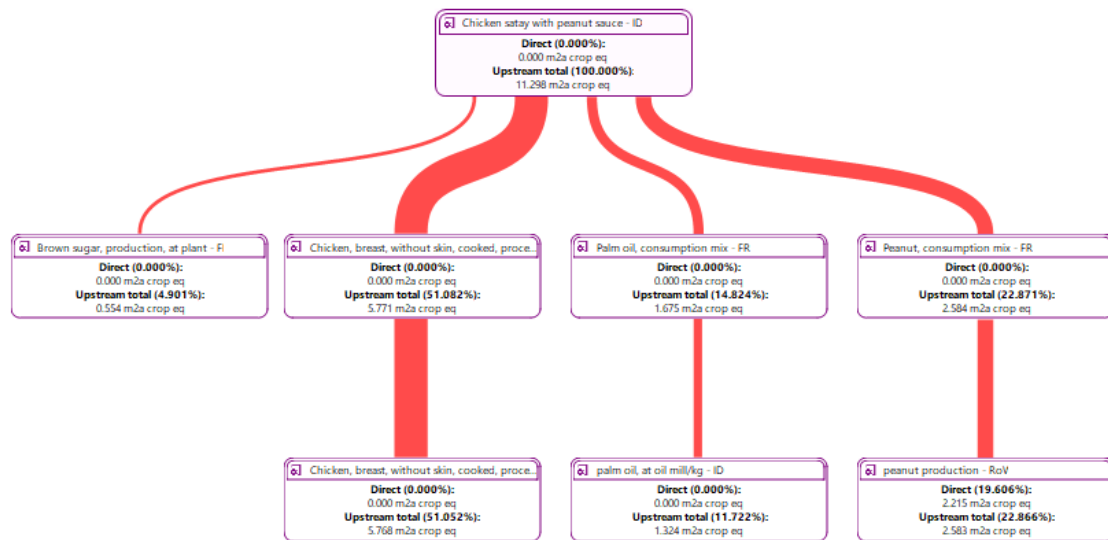


Figure 3. Sankey Diagram of Land Use

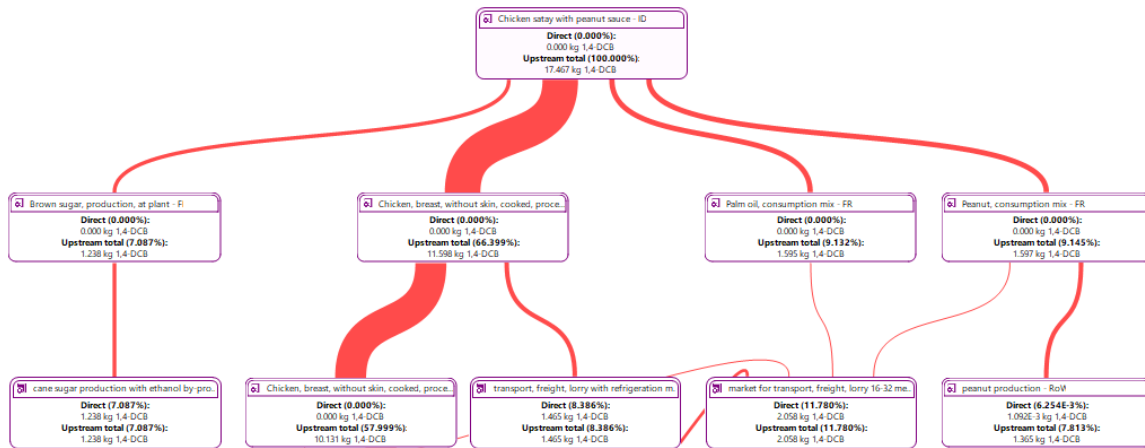


Figure 4. Sankey Diagram of Terrestrial Ecotoxicity

The total Global Warming Potential generated from the production of chicken satay with peanut sauce was 9.406 kg CO₂-eq. The Sankey diagram identifies chicken production, palm oil consumption, and peanut production as the primary environmental hotspots within the production system. Chicken breast production contributed the largest impact, accounting for approximately 53.937% of the total emissions or 5.073 kg CO₂-eq, mainly due to intensive poultry farming activities, feed production, and energy consumption during livestock production (Beal et al., 2023). Palm oil consumption also contributed significantly with 2.309 kg CO₂-eq (24.550%), followed by peanut production with 1.026 kg CO₂-eq (10.912%). Previous studies have shown that agricultural raw material production and fossil fuel utilization are major contributors to greenhouse

gas emissions within food supply chains (Liu et al., 2025). The Sankey diagram further confirms that the majority of Global Warming impacts originate from upstream raw material production rather than the final preparation stage. In addition, the grilling process using LPG contributes substantially to greenhouse gas emissions due to fossil fuel combustion. These findings indicate that strategies to reduce environmental impacts should prioritize improving raw material sustainability, optimizing energy use during grilling, and reducing dependence on high-emission agricultural products. Transitioning to cleaner energy sources and implementing more sustainable supply chain practices could significantly reduce the overall carbon footprint of traditional chicken satay (Bist et al., 2024).

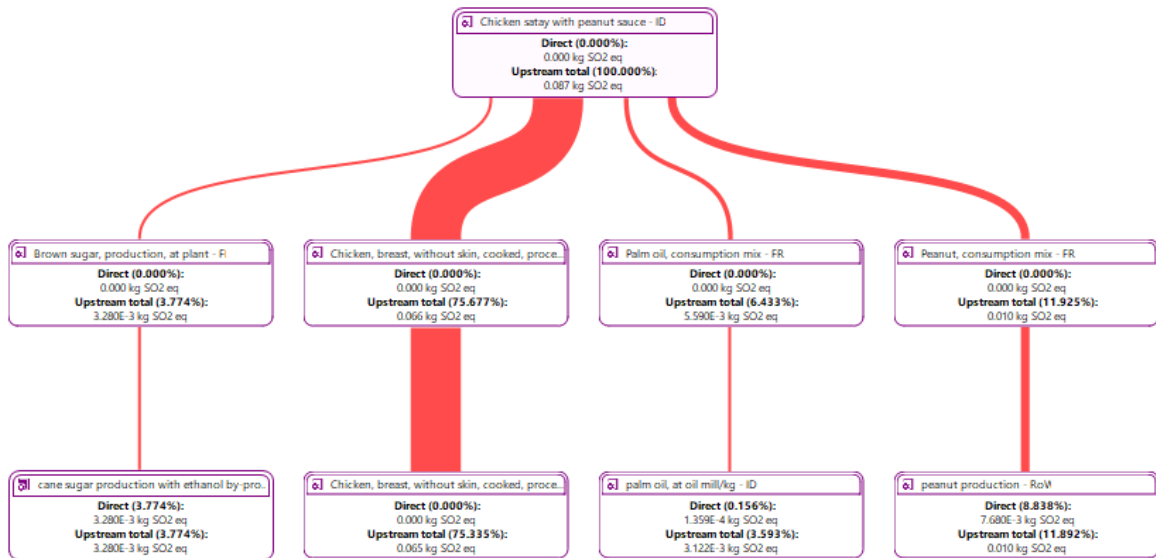


Figure 5. Sankey Diagram of Terrestrial Acidification

The Sankey diagram for the Terrestrial Ecotoxicity category illustrates the contribution of each raw material and production activity to the total ecotoxicity impact generated during chicken satay with peanut sauce production. The total terrestrial ecotoxicity impact identified in this study was 17.467 kg 1,4-DCB eq, with the majority of impacts originating from upstream agricultural production processes. Chicken breast production was identified as the largest contributor, accounting for approximately 66.399% of the total impact or 11.598 kg 1,4-DCB eq. This high contribution is mainly associated with poultry farming activities, feed production, chemical use, and transportation processes within the livestock supply chain (Gudda et al., 2024). Other significant contributors included palm oil consumption and peanut production, each contributing approximately 1.595 kg 1,4-DCB eq (9.132% and 9.145%, respectively). Brown sugar production also contributed 1.238 kg 1,4-DCB eq (7.087%) to the overall ecotoxicity impact. Previous studies have shown that intensive agricultural activities and pesticide applications can significantly increase terrestrial ecotoxicity and environmental pollution risks (Alaoui et al., 2024). The Sankey diagram further shows that transportation activities, particularly freight transport and market distribution, contributed additional ecotoxicity burdens due to fuel combustion and emissions. These findings indicate that agricultural production and transportation processes are the primary environmental hotspots in the Terrestrial Ecotoxicity category. Therefore, improving sustainable agricultural practices, reducing chemical inputs, and optimizing transportation efficiency are important strategies to minimize the

ecotoxicity impacts associated with traditional chicken satay production.

The Sankey diagram for the Terrestrial Acidification category illustrates the contribution of each raw material and production process to the total acidification impact generated during chicken satay with peanut sauce production. The total terrestrial acidification impact identified in this study was 0.087 kg SO₂ eq, with the majority of impacts originating from upstream agricultural and energy-related activities. Chicken breast production was identified as the dominant contributor, accounting for approximately 75.677% of the total impact or 0.066 kg SO₂ eq. This high contribution is mainly associated with emissions from poultry farming, feed production, and fuel combustion during livestock production processes (Rosa & Gabrielli, 2023). Other significant contributors included peanut production with 0.010 kg SO₂ eq (11.925%) and palm oil consumption with 5.590E-3 kg SO₂ eq (6.433%). Brown sugar production also contributed 3.280E-3 kg SO₂ eq (3.774%) to the overall acidification impact. The Sankey diagram further indicates that agricultural activities and industrial processing stages contribute substantially to acidifying emissions such as sulfur dioxide (SO₂) and nitrogen oxides (NO_x) (de Vries et al., 2024). These findings demonstrate that livestock production and agricultural commodity processing are the main environmental hotspots in the Terrestrial Acidification category. Therefore, improving fuel efficiency, reducing combustion emissions, and implementing more sustainable agricultural practices are important strategies to minimize acidification impacts in traditional chicken satay production systems.

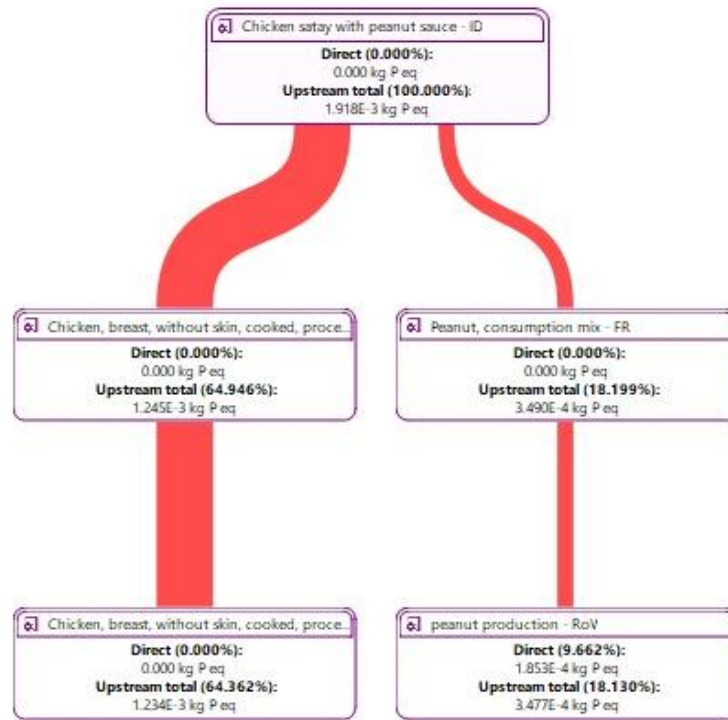


Figure 6. Sankey Diagram of Terrestrial Acidification

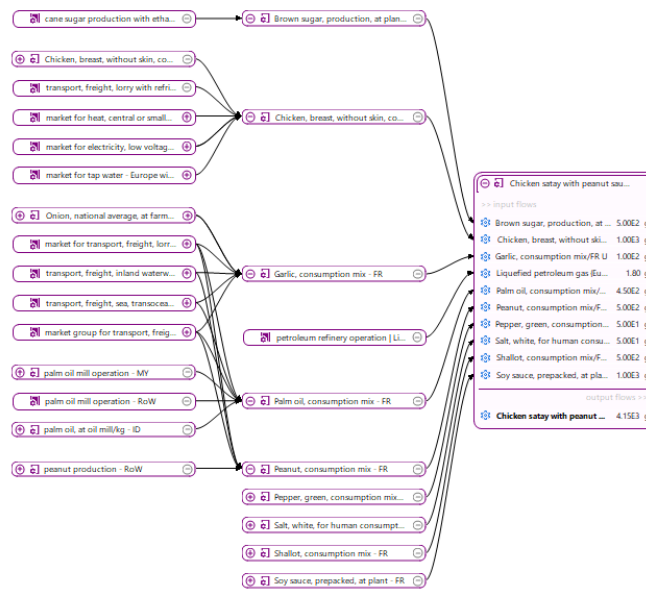


Figure 7. Model Graph for 10 Serving Chicken Satay with Peanut Sauce (Notes: Not All Branches are Expanded in the Graph)

The Sankey diagram for the Freshwater Eutrophication category illustrates the contribution of each raw material and production activity to nutrient enrichment impacts in freshwater ecosystems during chicken satay with peanut sauce production. The total freshwater eutrophication impact identified in this study was 0.002 kg P eq, with the majority of impacts originating from upstream agricultural activities. Peanut production was identified as the largest contributor, accounting for approximately 18.130% of the total impact or 3.477E-4 kg P eq. This high contribution is mainly associated with fertilizer application, nutrient runoff, and agricultural

cultivation processes during peanut farming (Madjar et al., 2024).

Chicken breast production also contributed significantly, accounting for approximately 64.946% of the total impact or 1.245E-3 kg P eq, mainly due to feed crop production and nutrient emissions from poultry farming systems. These findings indicate that agricultural raw material production is the primary environmental hotspot in the Freshwater Eutrophication category. Excessive nutrient releases from farming activities can potentially contribute to water quality degradation and ecosystem imbalance (Suresh et al., 2023). Therefore, improving sustainable agricultural practices, reducing fertilizer

losses, and optimizing raw material sourcing are important strategies to minimize freshwater eutrophication impacts in traditional chicken satay production systems.

3.3. Comparative Analysis

A comparative analysis of each production stage highlights that grilling not only produces greenhouse gas emissions but also other pollutants that affect air quality and human health. Conversely, the cutting and spice preparation processes exhibit relatively lower environmental impacts. The model graph (Figure 3) confirms that key input factors such as chicken, peanut sauce, and seasoning components contribute differently to the overall environmental load. Thus, future improvement efforts should focus primarily on optimizing the grilling process (Kabeyi & Olanrewaju, 2023).

3.4. Contribution Analysis

The contribution analysis shows that the grilling stage contributes the largest share of environmental impacts due to intensive LPG consumption and emissions generated during combustion. The highest impact category identified in this study is Terrestrial Ecotoxicity, reaching 17.467 kg 1,4-DCB eq, mainly associated with agricultural raw material production and energy-related processes. In the Global Warming Potential category, the production system generated 9.406 kg CO₂ eq, with major contributions originating from poultry farming, peanut cultivation, and fuel consumption during grilling activities.

In terms of Land Use, the production process resulted in 11.298 m²a crop eq, indicating the significant role of agricultural land occupation for feed crops and peanut production. Furthermore, Terrestrial Acidification reached 0.087 kg SO₂ eq, primarily caused by emissions related to fuel combustion and agricultural activities. Freshwater Eutrophication was recorded at 0.002 kg P eq, mainly associated with nutrient releases from agricultural production systems. These findings indicate that raw material production and energy consumption are the primary environmental hotspots within the chicken satay production system.

These findings highlight the importance of reducing LPG usage and transitioning to renewable energy sources to minimize the overall environmental footprint (Cascione et al., 2022; Guerid et al., 2022). Additionally, sustainable sourcing of chicken and peanuts, as well as optimizing ingredient production and supply chains, could further reduce emissions and other environmental burdens.

3.5. Sensitivity Analysis

Sensitivity analysis reveals that minor changes in production factors, such as reducing grilling time or adopting more efficient grilling technologies, can lead to significant reductions in greenhouse gas emissions. By optimizing these processes, improvements in energy efficiency can be achieved, contributing to an

overall reduction in environmental impact (Nyakudya et al., 2022).

3.6. Scenario Recommendation

Recommendations for improvement scenarios include the adoption of cleaner grilling technologies, such as the use of electricity from renewable sources, as well as the implementation of more effective waste management practices to reduce wastewater. Implementing these recommendations will enable more environmentally friendly chicken satay production while maintaining product quality (Kabeyi & Olanrewaju, 2023a).

3.7. Study Limitation

Although this analysis provides a comprehensive overview of the environmental impacts of chicken satay production, there are several limitations in this study, including uncertainties in the data used for LCI calculations and variability in agricultural and production practices that may affect the final results. Additionally, the database used in this study, Agribalyse_V3.0.1, primarily relies on reference processes from Europe, which may introduce discrepancies when modeling production processes in Indonesia due to differences in agricultural systems, energy sources, and supply chain logistics. Although efforts were made to collect primary data from one of the major chicken satay culinary centers that is highly relevant to the study topic, the production characteristics, raw material sourcing, and operational practices may still differ from those in other regions or production sites. Therefore, the environmental impacts identified in this study may not fully represent all chicken satay production systems in Indonesia. These variations could affect the accuracy and generalizability of the results. Further studies are needed to explore additional influencing variables and to conduct similar analyses in different locations to obtain a broader representation of the chicken satay production ecosystem (Cascione et al., 2022; Guerid et al., 2022; Nyakudya et al., 2022).

4. CONCLUSION

The results of the Life Cycle Assessment (LCA) for the production of chicken satay with peanut sauce indicate that raw material production and the grilling stage generate the most significant environmental impacts, particularly in the categories of Global Warming, Land Use, Terrestrial Acidification, Terrestrial Ecotoxicity, and Freshwater Eutrophication. Chicken production was identified as the main environmental hotspot due to intensive livestock farming activities, feed production, and high energy consumption throughout the supply chain. In addition, the use of LPG during grilling contributes substantially to greenhouse gas emissions and air pollution. The findings also highlight that agricultural commodities such as palm oil and peanuts contribute significantly to land occupation and ecotoxicity impacts. By identifying the environmental hotspots at

each production stage, this study provides important insights into the primary sources of environmental burdens within traditional Indonesian food production systems.

The proposed improvement strategies include reducing fossil fuel consumption during grilling, adopting energy-efficient cooking technologies, and improving sustainable sourcing practices for agricultural and animal-based raw materials. Furthermore, this study highlights the importance of increasing public awareness regarding the environmental impacts of animal-based food products, particularly poultry-based foods, which contribute significantly to greenhouse gas emissions and resource consumption. Rather than focusing solely on production activities, the identification of environmental hotspots clearly demonstrates that raw material production and transportation processes are dominant contributors across nearly all impact categories. Transportation activities contribute substantially to Global Warming and Terrestrial Ecotoxicity due to fossil fuel combustion and logistical demands. These findings emphasize the importance of integrating sustainability considerations into traditional food production systems to support environmentally friendly practices and long-term sustainability within Indonesia's food industry.

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