p-ISSN 2615-787X e-ISSN 2615-790X
Accredited by Directorate General of Higher Education, Research, and Technology, Republic of Indonesia, No. 225/E/KPT/2022

Tropical Animal Science Journal, June 2023, 46(2):249-260
DOI: https://doi.org/10.5398/tasj.2023.46.2.249
Available online at http://journal.ipb.ac.id/index.php/tasj

The Assessment of Environmental Impact of the Chicken Meat Agroindustry in Indonesia: Life Cycle Assessment (LCA) Perspective

S. Azmi*, Suprihatin, N. S. Indrasti, & M. Romli
Department of Agroindustrial Technology, Faculty of Agricultural Technology, IPB University
Kampus IPB Dramaga, Bogor, West Java 16680, Indonesia
*Corresponding author: silmiazmiazmi@apps.ipb.ac.id
(Received 15-11-2022; Revised 03-03-2023; Accepted 16-03-2023)

ABSTRACT

Chicken meat agroindustry is one of the industries that contribute to environmental impacts. The environmental impacts are due to the use of resources, energy, and waste along the chicken meat chain. This study aimed to evaluate the environmental impacts along the life cycle of the chicken meat chain from cradle-to-grave using a life cycle assessment (LCA) approach. The data inventory consisted of inputs and outputs from five sub-systems: feed production, broiler production on the farm, carcass production at the slaughterhouse, supplier distribution, and consumer use. The impact categories included global warming, acidification, and eutrophication. The process of impact calculation used the CML-IA (Centre of Environmental Science of Leiden University Impact Assessment) baseline method on the SimaPro software. The results showed that consuming 1 kg of fried chicken resulted in a global warming impact of 5.86 kg CO_2 eq, acidification of 38.3 g SO_2 eq, and eutrophication of 24.1 g PO_4^{3-} eq. Feed production, litter, and energy usage were the most significant contributors to the environmental impacts. Improvement scenarios in reducing environmental impacts included reducing crude protein in feed, composting litter, installing inverters on refrigeration compressors, and electrical energy efficiency. The present study indicated the importance of environmental impact assessment on the entire chicken meat chain to improve environmental performance in the Indonesian chicken agroindustry.

Keywords: acidification; chicken meat agroindustry; eutrophication; global warming; life cycle assessment

INTRODUCTION

The poultry industry in Indonesia has grown rapidly. The contribution of poultry meat production to the total national meat production reaches 62.56%. Broiler chicken contributes to 84% of the poultry population in Indonesia (BPS, 2019). High productivity and relatively short maintenance time have caused the number of broiler farms to grow rapidly. Broiler production in 2019 reached 3.49 million tons, an increase of 2.64% from 2018 production. This figure is predicted to increase as Indonesia's population increases (BPS, 2019). Developing the chicken meat industry provides several benefits, including meeting domestic animal protein needs, becoming a source of state revenue, providing profit value for stakeholders, and opening job opportunities for the community.

Developing the chicken meat agroindustry in Indonesia provides benefits and has environmental impacts (Nurhayati *et al.*, 2016). The potential environmental impacts are not only caused by the extraction of raw materials in broiler chicken production (Suffian *et al.*, 2018) but also caused by carcass production, distribution, and product use (Skunca *et al.*, 2018). Using resources, energy, and waste from chicken meat production will cause global warming, acidification, and eutrophication (Silva *et al.*, 2014). The global warming impact on the environment includes rising sea levels, changing plant conditions and habitats, affecting changes in complex climate systems, and creating threats of natural disasters such as tornadoes, floods, and landslides (IPCC, 2006). Feed production and energy use are the most significant contributor to environmental impacts along the chicken meat chain (Skunca *et al.*, 2018). Improvement should be made through impact calculations throughout the product life cycle to improve environmental performance in the chicken meat agroindustry. The impact calculation is carried out using the LCA approach, which can comprehensively evaluate each input and output of the production system in quantitative impact categories. The results of the impact calculation can be used as a basis for product improvement or optimization of production processes, as well as for reducing environmental impacts.

Environmental management methods include clean production, eco-efficiency, and life cycle assessment. Indrasti & Fauzi (2009) state that cleaner production is an environmental management strategy that is preventive and integrated into processes, products, and services to increase efficiency and reduce environmental damage. Eco-efficiency is a strategy to reduce environmental impacts and increase production value. Meanwhile, a Life Cycle Assessment (LCA) is a method for evaluating the potential environmental impacts resulting from a product during its life cycle. The advantage of LCA is comprehensive because it can analyze the environmental impacts of a product in detail throughout its life cycle (ISO, 2006).

Several studies have evaluated the environmental impacts of the chicken industries with the LCA approach (Leinonen *et al.*, 2012; Silva *et al.*, 2014; Kalhor *et al.*, 2016; Cesari *et al.*, 2017; Pishgar-Komleh *et al.*, 2017; López-Andrés *et al.*, 2018; Lima *et al.*, 2019; Martinelli *et al.*, 2020). Most of these studies are still limited to the cradle-to-gate system boundary. Meanwhile, a comprehensive assessment from cradle-to-grave is still limited (Skunca *et al.*, 2018). LCA studies along the chicken meat chain with case studies in Indonesia are also very limited, especially with the cradle-to-grave perspective. There were two studies evaluating the environmental impacts of the chicken meat chain (Nurhayati *et al.*, 2016; Azmi *et al.*, 2021). Azmi *et al.* (2021) developed the design of a life cycle assessment system for broiler production based on the Digital Business Ecosystem. Meanwhile, Nurhayati *et al.* (2016) measured supply chain performance and green added value by considering the environmental aspects of the broiler chain. This research is still limited to the cradle-to-gate perspective. Assessment studies of environmental impact on the chicken meat agroindustry in Indonesia need to be carried out more comprehensively with the cradle-to-grave perspective. Therefore, impact calculations can be carried out for the entire chicken meat chain, which can identify opportunities to improve environmental performance in the chicken meat agroindustry.

The purpose of this study was to evaluate the potential environmental impacts throughout the life cycle of the chicken meat agroindustry with a cradle-to-grave perspective, starting from the feed production, broiler chicken production on the farm, carcass production in the slaughterhouse, distribution by the supplier, up to product use by the consumer. The results of this study can assist in controlling emission sources along the chicken meat chain so that the product's environmental performance can be improved. The results of the LCA calculation can also be used as the basis for a type III eco-label or Environmental Product Declaration (EPD). The existence of eco-labels will increase the competitiveness of products both in the local and global markets.

MATERIALS AND METHODS

The Life Cycle Assessment (LCA) method is based on the LCA principles and framework in ISO 14040:2006, which consists of four stages: setting goals and scope, life cycle inventory analysis, life cycle impact assessment, and life cycle interpretation (ISO, 2006).

Goal and Scope Definition

This LCA study aimed to evaluate the environmental impacts throughout the life cycle of the chicken meat agroindustry with a cradle-to-grave perspective. Scope determination included determining system boundary, functional unit, and environmental impact categories (ISO, 2006). The system boundary in this study was cradle-to-grave, starting from feed production, broiler production, carcass production, and distribution-to-consumer use (Figure 1). This research was an LCA study with a case study in an integrated company in Sukabumi, West Java, Indonesia. The market chain assessed included the feed factory, modern chicken farm, slaughterhouse, chicken meat supplier, and fast-food restaurant. A modern chicken farm is a chicken farm with a closed-house cage type. Cages with the closed house type are closed cages that are guaranteed biological safety and have good ventilation arrangements. The modern farm was chosen as the object of research because the supply chain of a modern farm was clearer than a traditional farm.

The system boundary was divided into five sub-systems: feed production, chicken farm, slaughterhouse, supplier, and consumer use. The feed production sub-system included feed ingredients production and feed processing. The feed production sub-system used secondary data from Ecoinvent 3 databases in the SimaPro software. The chicken farm sub-system included day-old chicks' production, sterilization, rearing, harvesting, and transportation. Day-old chicks' production used Agrifoot-print 5 databases in the SimaPro software. The slaughterhouse sub-system included receiving live chickens, stunning, slaughtering, draining blood, boiling, removing feathers, removing offal, cutting heads and legs, washing carcasses, packaging, chilling, freezing, carcass storage, and transportation to a supplier. The supplier sub-system included frozen storage, thawing, cutting, packaging, and transportation to the restaurant. The consumer uses sub-system included washing, fried chicken production, consumption of fried chicken, transportation, and final disposal of solid waste.

The impact calculation was based on the functional unit. The functional unit describes the quantification of the identified functions of the product as a reference in linking the input and output of the production system so that the results obtained can be compared (ISO, 2006). The impact calculation uses a functional unit per 1 kg of fried chicken consumed. The environmental impact categories analyzed were Global Warming Potential (GWP), Acidification Potential (AP), and Eutrophication Potential (EP), as dominant environmental indicators in the chicken meat chain (Skunca *et al.*, 2018).

Allocation Method

Allocation is one of the crucial things in LCA studies, which is the distribution of input or output flows from the production process to the product system under study (ISO, 2006). In this study, the allocation method used mass allocation as the calculation basis. Broiler chicken production produced live chickens

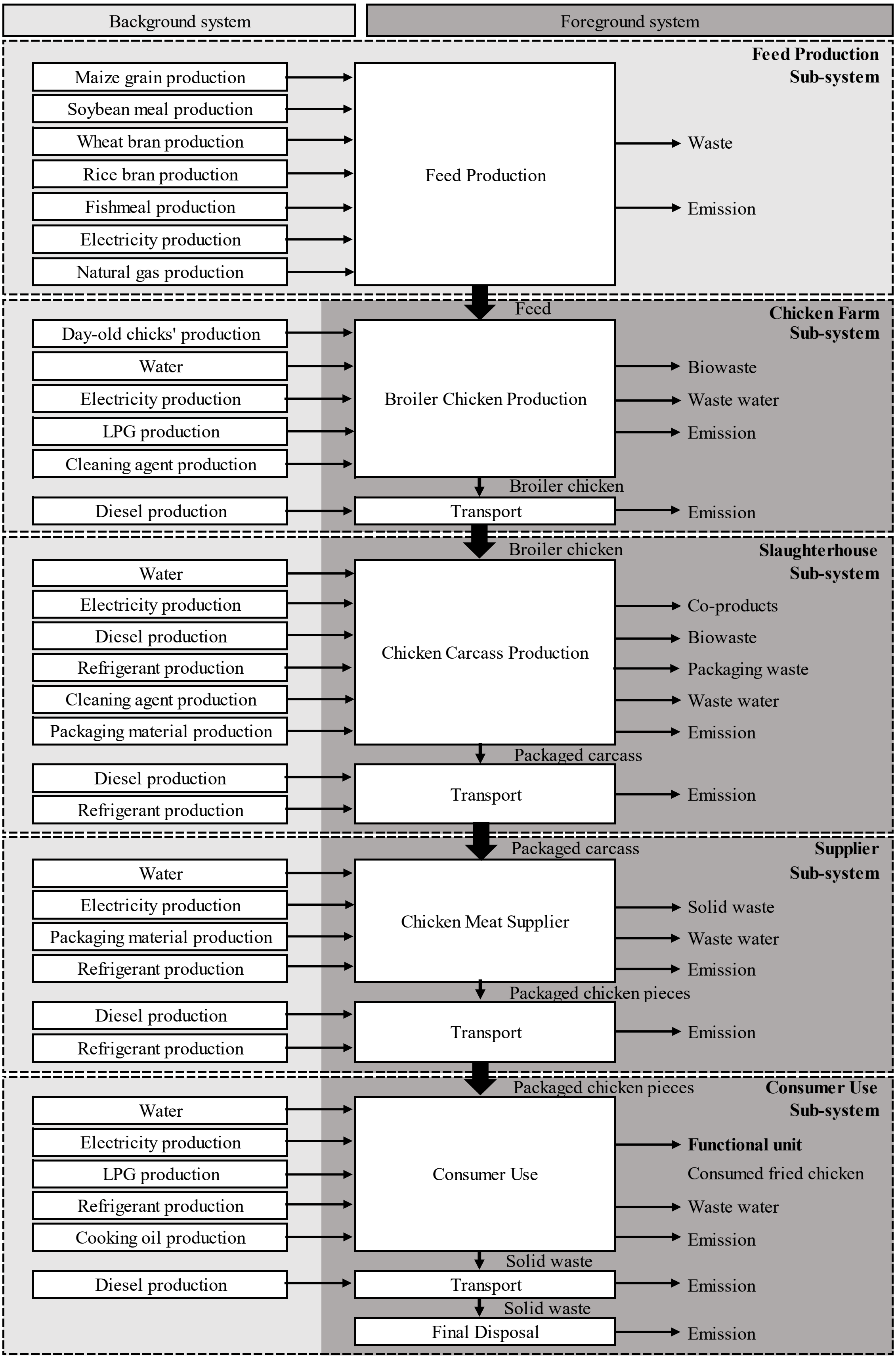

Figure 1. The cradle-to-grave system boundary in the chicken meat agroindustry

ready for slaughter. In addition, broiler chicken production also produced litter waste, which was sold to farmers as fertilizer. In carcass production, the main product was the chicken carcass. In addition to the main product, carcass production also produced co-products in the form of head, neck, liver, gizzard, intestine, heart, and chicken feet. Therefore, the environmental burden of carcass production in the slaughterhouse was allocated to two outputs, such as chicken carcass (75.86%) and co-products (24.14%).

Life Cycle Inventory Analysis

Inventory analysis included the process of collecting data and calculating data. The inputs and outputs from the five sub-systems were identified in the data collection process. The data collected consisted of primary and secondary data. Primary data, called foreground data, were collected directly from broiler chicken production, transportation, chicken carcass production, distribution, production and consumption of fried chicken. The data collected were in production data for 12 months in 2019 for all sub-systems (feed production, chicken farm, slaughterhouse, supplier, and consumer use). Respondents in this study were one integrated company (one chicken farm, one slaughterhouse, and one chicken meat supplier) and one fast food restaurant in Sukabumi, West Java, Indonesia. The respondent was determined by purposive sampling in integrated companies from chicken farms, slaughterhouses, and chicken meat suppliers. The determination of fast-food restaurants was based on the supplier market chain. The fast-food restaurant assessed in this study was the primary consumer of the chicken meat supplier. Sukabumi was chosen as the research location because it has high potential in developing the broiler farming sector in West Java Province. West Java Province was the most significant contributor (25.6%) of broiler production compared to the other provinces in Indonesia. Sukabumi was the fourth largest (7.33%) broiler production in West Java Province (BPS, 2019).

Secondary data, also known as background data, comes from Ecoinvent 3 and Agrifoot-print 5 databases in SimaPro software. The databases used include the production of fertilizers, pesticides, feed ingredients, day-old chicks, electricity, diesel, LPG, natural gas, cleaning agents, refrigerants, packaging materials, and cooking oil. The identified data were quantitatively calculated and validated using mass and energy balances to describe the flow of materials and energy. The inventory analysis results in the form of a summary of inventory data on the chicken meat agroindustry per functional unit can be seen in Table 1.

Life Cycle Impact Assessment

Life cycle impact assessment aims to evaluate potential environmental impacts based on the results of inventory analysis (ISO, 2006). All inventory data entered into the SimaPro software would automatically calculate emission value throughout the product cycle. Impact analysis used SimaPro software version 9.1.1.1 Faculty with CML-IA (Centre of Environmental Science of Leiden University Impact Assessment) baseline V3.06 method.

Life Cycle Interpretation

Interpretation of results is the final stage of LCA, where the results obtained from inventory analysis and environmental impact analysis will be considered simultaneously. The results of this interpretation can be in the form of conclusions and recommendations for improving environmental impact reduction (ISO, 2006).

Based on the results of the LCA, it can be identified that there was room for improvement in reducing environmental impacts. Identifying improvement options was carried out for all sub-systems, mainly in the feed production and chicken farm sub-system. Several improvement scenarios can be done, such as reduction of crude protein in feed (scenario A), litter composting (scenario B), installation of inverters on refrigeration compressors in the slaughterhouse (scenario C), installation of inverters in supplier (scenario D), the efficiency of electrical energy by the consumer (scenario E), and applying scenarios A, B, C, D, and E (scenario F). The impact of each improvement scenario was recalculated using the SimaPro software. The impact analysis results from the improvement scenarios were compared with the impact analysis results before the improvement.

RESULTS

Life Cycle Assessment Results

The total value of the environmental impacts produced in the chicken agroindustry can be seen in Table 2. The calculation results show that consuming 1 kg of fried chicken produces a global warming impact of 5.86 kg CO_2 eq. The feed production sub-system contributed the highest impact (2.93 kg CO_2 eq (50%)), while the consumer use sub-system contributed the lowest impact (0.22 kg CO_2 eq (3.75%)). The chicken farm sub-system contributed the second highest impact (1.40 kg CO_2 eq (23.90%)). Meanwhile, the slaughterhouse sub-system produced a lower impact value than the chicken farm sub-system (1.08 kg CO_2 eq (18.43%)). The supplier sub-system produced an impact value that is not much different from the consumer use sub-system (0.23 kg CO_2 eq (3.92%)).

The acidification value produced in the chicken agroindustry was 38.3 g SO_2 eq/kg of fried chicken consumed. Table 2 shows that the feed production sub-system significantly dominates (47.78%) the acidification value produced (18.30 g SO_2 eq). The chicken farm sub-system (13.70 g SO_2 eq (35.77%)) and the slaughterhouse sub-system (4.70 g SO_2 eq (12.27%)) produced relatively high acidification values. Meanwhile, the consumer use sub-system had the lowest contributor (0.60 g SO_2 eq (1.57%)).

Table 2 shows that consuming 1 kg of fried chicken will produce the eutrophication effect of 24.10 g PO_4^{3-} eq. The feed production sub-system contributed the highest eutrophication impact (8.27 g PO_4^{3-} eq (34.32%)), while

Table 1. Summary of inventory data in the chicken meat agroindustry

Input Output	Unit	Quantity (per functional unit[a])				
		Feed production[b]	Chicken farm[c]	Slaughterhouse[c]	Supplier[c]	Consumer use[c]
Input						
Maize grain	kg	1.65	-	-	-	-
Soybean meal	kg	5.70×10^{-1}	-	-	-	-
Wheat bran	kg	3.20×10^{-1}	-	-	-	-
Rice bran	kg	4.80×10^{-1}	-	-	-	-
Fishmeal	kg	1.60×10^{-1}	-	-	-	-
Water	m^3	-	7.45×10^{-2}	1.98×10^{-3}	2.38×10^{-3}	2.01×10^{-3}
Sodium hypochlorite	kg	-	2.40×10^{-5}	9.06×10^{-5}	-	-
Formaldehyde	kg	-	1.73×10^{-6}	-	-	-
Kalium permanganate	kg	-	7.99×10^{-4}	-	-	-
Benzal chloride	kg	-	7.83×10^{-4}	-	-	-
Rice husk	kg	-	4.30×10^{-1}	-	-	-
Day-old chicks	kg	-	5.00×10^{-2}	-	-	-
Cooking oil	kg	-	-	-	-	2.00×10^{-2}
Refrigerant NH_3	kg	-	-	6.11×10^{-5}	-	
Refrigerant R134A	kg	-	-	-	5.69×10^{-5}	4.11×10^{-6}
HDPE	kg	-	-	-	2.96×10^{-4}	-
LDPE	kg	-	-	4.60×10^{-3}	5.92×10^{-4}	-
Polypropylene	kg	-	-	2.29×10^{-3}	-	-
Electricity	MJ	9.47×10^{-1}	5.83×10^{-1}	4.17	7.12×10^{-1}	2.16×10^{-1}
LPG	MJ	-	2.45	-	-	2.45
Natural gas	MJ	4.06×10^{-1}	-	-	-	-
Diesel	MJ	-	-	7.40×10^{-1}	-	-
Transport	tkm[d]	-	5.17×10^{-2}	4.48×10^{-2}	3.01×10^{-3}	8.19×10^{-4}
Output						
Broiler feed	kg	3.18	-	-	-	-
Broiler chicken	kg[e]	-	1.95	-	-	-
Packaged carcass	kg[f]	-	-	1.32	-	-
Co-products	kg	-	-	4.20×10^{-1}	-	-
Packed chicken pieces	kg	-	-	-	1.31	-
Fried chicken consumed	kg	-	-	-	-	1
Wastewater	m^3	-	9.32×10^{-4}	8.00×10^{-2}	2.38×10^{-3}	1.20×10^{-2}
Biowaste	kg	-	2.97	1.30×10^{-1}	-	9.00×10^{-2}
Plastic waste	kg	-	-	5.87×10^{-6}	6.89×10^{-3}	8.87×10^{-4}

Note: a= per kg of fried chicken consumed; b= background system (secondary data from the Ecoinvent 3 database in the SimaPro software); c= foreground system (primary data); d= ton.km (transportation unit in SimaPro software); e= kg live weight; f= kg carcass. Assumption: Chicken farm= close-house chicken farm; Farm location to the slaughterhouse= 26 km; Slaughterhouse= modern slaughterhouse; Slaughterhouse location to supplier= 34 km; Supplier= chicken meat supplier; Consumer use= fast food restaurant; Supplier location to fast food restaurant= 2.3 km; HDPE= high-density polyethylene; LDPE= low-density polyethylene; LPG= liquefied petroleum gas.

Table 2. The value of environmental impacts in the chicken meat agroindustry per 1 kg of fried chicken consumed

Sub-systems	Global warming (kg CO_2 eq)	Acidification (g SO_2 eq)	Eutrophication (g PO_4^{3-} eq)
Feed production	2.93	18.30	8.27
Chicken farm	1.40	13.70	7.43
Slaughterhouse	1.08	4.70	6.00
Supplier	0.23	1.00	1.30
Consumer use	0.22	0.60	1.10
Total	5.86	38.30	24.10

the consumer use sub-system contributed the lowest eutrophication impact (1.10 g PO_4^{3-} eq (4.56%)). The chicken farm sub-system produced a higher eutrophication impact (7.43 kg CO_2 eq (30.83%)) than the slaughterhouse sub-system (6.00 kg CO_2 eq (24.90%)).

Environmental Impacts on Feed Production Sub-system

The impact value of each sub-system based on the emission source can be seen in Table 3. The environmental impacts generated in the feed production sub-system were from the feed ingredients production (maize grain, soybean meal, wheat bran, rice bran, fishmeal) and energy use (electricity and natural gas). Soybean meal production was the highest contributor to global warming (1.17 kg CO_2 eq (39.93 %)). In contrast, maize grain production was the most significant contributor to acidification (7.24 g SO_2 eq (39.61%)) and eutrophication (3.52 g PO_4^{3-} eq (42.56%)) in this sub-system (Table 3; Figure 2).

Environmental Impacts on Chicken Farm Sub-system

In the broiler chicken production sub-system, the environmental impacts were generated using day-old chicks, poultry bedding, cleaning agents, energy (LPG, diesel, and electricity), and waste (biowaste and waste-water). The relative contribution of the chicken farm sub-system to the environmental impacts can be seen in Figure 3. Biowaste, dominated by litter, significantly contributed to the global warming impact (0.47 kg CO_2 eq (10.95 %)). Day-old chicks' production has the higher contribution of acidification (7.63 g SO_2 eq (23.86%)) and eutrophication (3.11 g PO_4^{3-} eq (19.92%)) but has the smaller contribution to global warming (0.43 kg CO_2 eq (9.99%)) compared to biowaste. Wastewater

Table 3. Impacts value per 1 kg of fried chicken consumed from emission sources in each sub-system

Emission sources	Global warming (kg CO_2 eq)	Acidification (g SO_2 eq)	Eutrophication (g PO_4^{3-} eq)
Feed Production Sub-system			
Maize grain	8.00×10^{-1}	7.24	3.52
Soybean meal	1.17	4.78	1.71
Wheat bran	9.83×10^{-2}	1.03	8.13×10^{-1}
Rice bran	4.86×10^{-1}	1.04	1.55
Fishmeal	1.44×10^{-1}	1.35	6.22×10^{-1}
Electricity	2.07×10^{-1}	2.82	5.75×10^{-2}
Natural gas	2.11×10^{-2}	1.24×10^{-2}	1.40×10^{-3}
Chicken Farm Sub-system			
Day-old chicks	4.31×10^{-1}	7.63	3.11
Poultry bedding	4.37×10^{-1}	4.30	1.54
Cleaning agents	2.64×10^{-3}	1.15×10^{-2}	3.99×10^{-3}
Electricity	1.83×10^{-3}	7.89×10^{-3}	9.65×10^{-3}
LPG	2.22×10^{-2}	2.27×10^{-1}	2.51×10^{-2}
Wastewater	3.94×10^{-4}	3.14×10^{-3}	9.59×10^{-3}
Biowaste	4.72×10^{-1}	1.37	2.62
Transport	1.53×10^{-2}	1.22×10^{-1}	2.53×10^{-2}
Slaughterhouse Sub-system			
Cleaning agents	1.77×10^{-4}	8.79×10^{-4}	3.61×10^{-4}
Packaging materials	1.24×10^{-2}	4.54×10^{-2}	1.28×10^{-2}
Refrigerant NH_3	9.51×10^{-5}	3.35×10^{-5}	4.39×10^{-5}
Electricity	9.45×10^{-1}	4.07	4.98
Diesel	4.60×10^{-2}	1.21×10^{-1}	1.14×10^{-2}
Wastewater	3.55×10^{-2}	2.84×10^{-1}	8.64×10^{-1}
Biowaste	2.04×10^{-2}	5.94×10^{-2}	1.14×10^{-1}
Packaging waste	3.27×10^{-6}	8.81×10^{-7}	7.10×10^{-5}
Transport	2.06×10^{-2}	7.97×10^{-2}	2.01×10^{-2}
Supplier Sub-system			
Packaging materials	2.14×10^{-3}	7.78×10^{-3}	2.21×10^{-3}
Refrigerant R134A	8.79×10^{-4}	2.76×10^{-3}	5.71×10^{-4}
Electricity	2.21×10^{-1}	9.50×10^{-1}	1.16
Wastewater	1.33×10^{-3}	1.06×10^{-2}	3.24×10^{-2}
Packaging waste	4.83×10^{-3}	1.30×10^{-3}	1.05×10^{-1}
Transport	1.39×10^{-3}	5.39×10^{-3}	1.36×10^{-3}
Consumer Use Sub-system			
Refrigerant R134A	6.34×10^{-5}	1.99×10^{-4}	4.12×10^{-5}
Electricity	1.01×10^{-1}	2.92×10^{-1}	6.52×10^{-1}
Liquefied petroleum gas	2.82×10^{-2}	2.88×10^{-1}	3.18×10^{-2}
Cooking oil	2.20×10^{-2}	8.48×10^{-3}	7.80×10^{-2}
Wastewater	1.12×10^{-3}	8.95×10^{-3}	2.73×10^{-2}
Solid waste	6.78×10^{-2}	5.86×10^{-3}	3.57×10^{-1}
Transport	1.02×10^{-3}	4.76×10^{-3}	1.02×10^{-3}

was the smallest contributor to global warming (3.94 x 10^{-4} kg CO_2 eq (0.01%)), acidification (3.14 x 10^{-3} g SO_2 eq (0.01%)), and eutrophication (9.59 x 10^{-3} g PO_4^{3-} eq (0.06%)) (Table 3; Figure 3).

Environmental Impacts on Slaughterhouse Sub-system

The environmental impacts generated in the slaughterhouse sub-system were from energy (electricity and diesel), packaging materials, cleaning materials, refrigerants, and production waste (wastewater, bio waste, and packaging waste). Electrical energy was the most significant contributor to global warming (0.94 kg CO_2 eq (87.48%)), acidification (4.07 g SO_2 eq (87.34%)), and eutrophication (4.98 g PO_4^{3-} eq (82.96%)) in this sub-system (Table 3; Figure 4). Packaging waste has a minor contribution to global warming (3.27 x 10^{-6} kg CO_2 eq), acidification (8.81 x 10^{-7} g SO_2 eq), and eutrophication (7.10 x 10^{-5} g PO_4^{3-} eq) (Table 3).

Environmental Impacts on Supplier Sub-system

In the supplier sub-system, emission sources were energy (electricity and diesel), packaging materials, re-

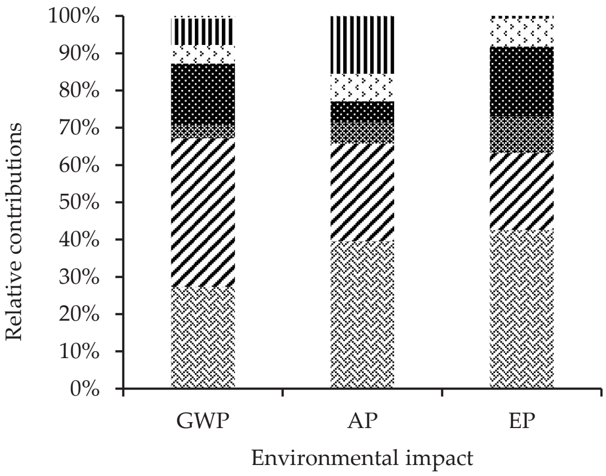

Figure 2. The relative contribution of the feed production sub-system to environmental impacts. GWP= global warming potential; AP= acidification potential; EP= eutrophication potential.

Maize grain | Soybean meal | Wheat bran | Rice bran | Fishmeal | Electricity | Natural gas

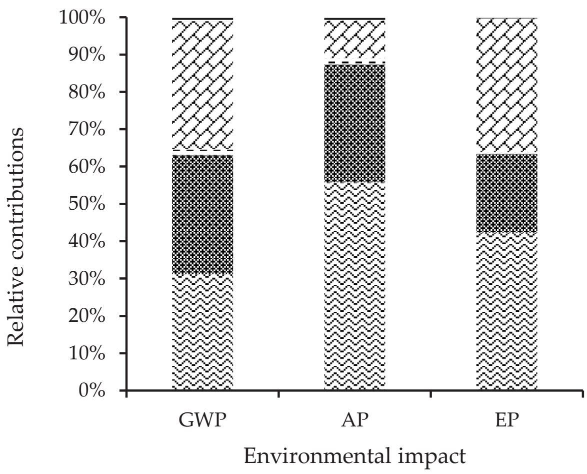

Figure 3. The relative contribution of the chicken farm sub-system to environmental impacts. GWP= global warming potential; AP= acidification potential; EP= eutrophication potential.

Day-old chicks | Poultry bedding | Cleaning agents | Electricity | LPG | Waste water

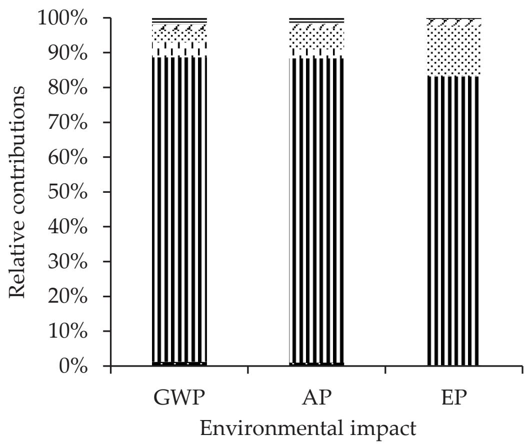

Figure 4. The relative contribution of the slaughterhouse sub-system to environmental impacts. GWP= global warming potential; AP= acidification potential; EP= eutrophication potential.

Cleaning agents | Packaging materials | Refrigerant NH3 | Electricity | Diesel | Waste water | Biowaste | Packaging waste | Transport

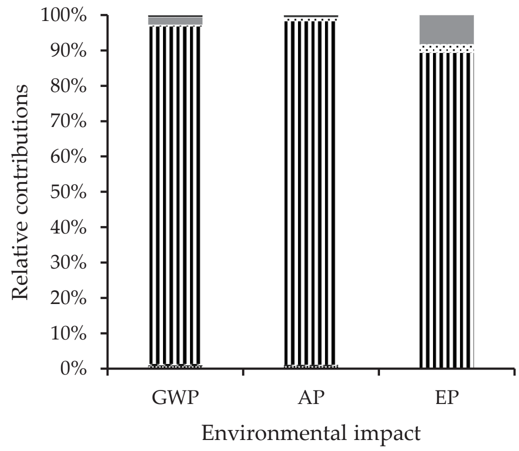

Figure 5. The relative contribution of the supplier sub-system to environmental impacts. GWP= global warming potential; AP= acidification potential; EP= eutrophication potential.

Packaging materials | Refrigerant R134A | Electricity | Waste water | Packaging waste | Transport frigerant, and waste (wastewater and packaging waste). Eelectrical energy was the most significant contributor to global warming (0.22 kg CO_2 eq (95.44%)), acidification (0.95 g SO_2 eq (97.15%)), and eutrophication (1.16 g PO_4^{3-} eq (89.12%)). Meanwhile, the refrigerant has a minor contribution to global warming (8.79 x 10^{-4} kg CO_2 eq (0.38%)) and eutrophication (5.71 x 10^{-4} g PO_4^{3-} eq (0.04%)) (Table 3; Figure 5).

Environmental Impacts on Consumer Use Sub-system

In the consumer use sub-system, environmental impacts were generated due to energy (electricity, LPG, and diesel), cooking oil, refrigerant, and waste (solid waste and wastewater). Table 3 and Figure 6 show that the use of electricity was the main contributor to the impact of global warming (0.10 kg CO_2 eq (45.66%)), acidification (0.29 g SO_2 eq (48.01%)), and eutrophication (0.65 g PO_4^{3-} eq (56.84%)). Refrigerant was a minor contributor to global warming (6.34 x 10^{-5} kg CO_2 eq), acidification (1.99 x 10^{-4} g SO_2 eq), and eutrophication (4.12 x 10^{-5} g PO_4^{3-} eq) in consumer use sub-system.

Improvement Scenario

Figure 7 shows a decrease in the environmental impacts of each scenario. The decreased environmental impacts of scenarios A and B were quite significant. The application of scenario A shows a decrease in the impact of global warming by 5.63%. The reduction in the impacts of global warming (10.41%), acidification (7.05%), and eutrophication (15.35%) in Scenario B were higher than in Scenario A. However, applying scenarios C, D, and E resulted in an insignificant decrease compared to Scenarios A and B. This nonsignificant decrease is because the environmental impacts generated by the slaughterhouse, supplier, and consumer use sub-systems were minimal compared to the feed production and chicken farm sub-systems. Therefore, when improvement efforts were only carried out on the slaughterhouse, supplier, and consumer use subsystems, the reduction in the impact of the entire product life cycle was insignificant. Applying scenario C can reduce the impacts between 0.78% and 1.66%. Scenario D can reduce the impact slightly lower, between 0.26% and 0.51%. Meanwhile, the impact decrease in scenario E was insignificant, with a range of 0.08% and 0.17%. However, if all scenarios were applied (scenario F), the impact decrease of global warming (18.26%), acidification (8.17%), and eutrophication (17.63%) would become more significant.

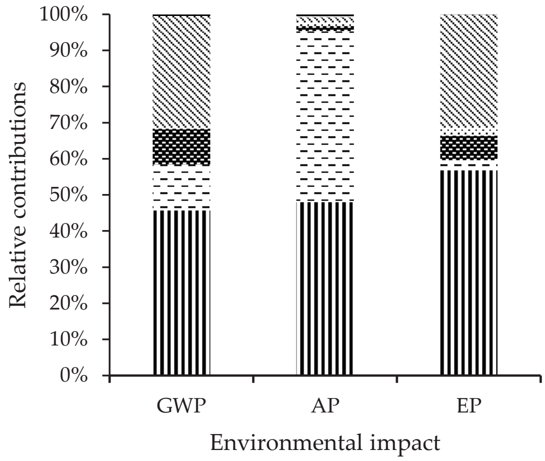

Figure 6. The relative contribution of consumer use sub-system to environmental impacts. GWP= global warming potential; AP= acidification potential; EP= eutrophication potential.

Refrigerant R134A; Electricity; LPG; Cooking oil; Waste water; Solid waste; Transport

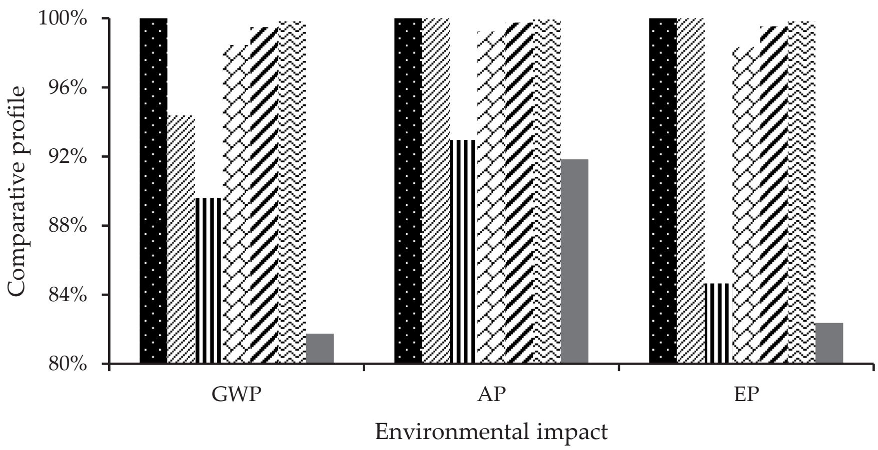

Figure 7. Comparison of the improvement scenarios implementation on environmental impacts. Scenario A= reduction of crude protein in feed; Scenario B= composting litter; Scenario C= inverter installation in the slaughterhouse; Scenario D= inverter installation at the supplier; Scenario E= electrical energy efficiency by the consumer; Scenario F= implementation of scenarios A, B, C, D, and E. Impact category acronyms: GWP= global warming potential; AP= acidification potential; EP= eutrophication potential.

Existing; Scenario A; Scenario B; Scenario C; Scenario D; Scenario E; Scenario F

DISCUSSION

In general, the results of this study were in line with those of the other LCA studies that analyze the environmental impacts of the chicken meat chain. Table 4 shows a comparison of the results of this study with those of several previous studies. The impacts of global warming and eutrophication in this study (Table 2) were higher than those reported by Skunca *et al.* (2018), which have impacts of 3.62 kg CO_2 eq and 3.01 g PO_4^{3-} eq. Meanwhile, the acidification value in this study was lower than that reported by Skunca *et al*. (2018) (80.74 g SO_2 eq). In the study of Skunca *et al.* (2018), some materials were not included in the inventory analysis, such as bedding materials and other feed ingredients (other than soybean meal, corn, and sorghum), which could affect impact values. Meanwhile, in this study, the environmental impacts were calculated on all feed ingredients (maize grain, soybean meal, wheat bran, rice bran, and fishmeal), including the impacts of rice husk as poultry bedding.

Feed production was the sub-system that most contributed to the environmental impacts. This is consistent with the results of other studies, which state that feed is the highest contributor to environmental impacts, both of which evaluated from a cradle-to-farm gate perspective (Pelletier, 2008; Leinonen *et al.*, 2012; Kheiralipour *et al.*, 2017; Pishgar-Komleh *et al.*, 2017; Suffian *et al.*, 2018; Arrieta & González, 2019; Lima *et al.*, 2019; Ramedani *et al.*, 2019; Martinelli *et al.*, 2020), as well as with a cradle-to-slaughterhouse gate perspective (González-García *et al.*, 2014; Silva *et al.*, 2014; Kalhor *et al.*, 2016; Cesari *et al.*, 2017; Wiedemann *et al.*, 2017; López-Andrés *et al.*, 2018), and which include the stages of product use (Skunca *et al.*, 2018). In this study, feed production contributed 50% to the global warming impact of the entire chicken meat chain. Meanwhile, in Leinonen *et al.* (2012), feed contributes more than 70% to the global warming impact. Pelletier (2008) reported that chicken feed contributed 82% to global warming, 96% to acidification, and 97% to eutrophication.

Feed was produced through several stages, including feed ingredients production, feed processing, and transportation. All of these activities were responsible for the environmental impacts of feed production. The feed composition was the main factor that caused differences in the impact values in several studies. The feed composition in this study included 51.4% maize grain, 18% soybean meal, 10% wheat bran, 15% rice bran, and 5% fishmeal. The feed ingredients' environmental impacts were dominated by crop cultivation rather than feed processing and transportation. This result is in line with those results reported by González-García *et al.* (2014) and López-Andrés *et al.* (2018) that the use of chemicals and energy in crop cultivation is the primary process that contributes to the high environmental impacts.

Biowaste was the most significant contributor to environmental impacts in the chicken farm sub-system. The biowaste was dominated by litter or chicken manure mixed with poultry bedding (98.73 %). This result is in line with the results reported by other studies (Leinonen *et al.*, 2012; González-García *et al.*, 2014; Kalhor *et al.*, 2016; Suffian *et al.*, 2018; Lima *et al.*, 2019) which state that biowaste management in chicken farm contributes highly to global warming, acidification, and eutrophication. The amount of feed consumed will affect the amount of manure produced, thus affecting the number of emissions in the cage. Litter waste is a source of NH_3, N_2O, and CH_4 emissions in chicken farms due to organic solid waste management (handling, storage, and application in the field) (Lima *et al.*, 2019). In

Table 4. Comparison of research results in several LCA studies of broiler chicken

Authors	Country	Hotspots	System boundaries				GWP (kg CO_2 eq)	AP (g SO_2 eq)	EP (g PO_4^{3-} eq)
			1	2	3	4			
(Pelletier, 2008)	US	Feed	x	-	-	-	1.40[a]	15.80[a]	3.90[a]
(Leinonen et al., 2012)	UK	Feed	x	-	-	-	4.41[b]-5.66[b]	46.75[b]-91.55[b]	20.31[b]-48.82[b]
(Silva *et al.*, 2014)	Brazil	Feed	x	x	-	-	1.45[a]-2.75[b]	31.40[a]-45.90[b]	14.00[a]-20.50[b]
(González-García *et al.*, 2014)	Portugal	Feed and on-farm emissions	x	x	-	-	1.62[a]-2.46[b]	-	-
(Kalhor *et al.*, 2016)	Iran	Feed and on-farm emissions	x	x	-	-	1.39[a]-5.36[b]	29.58[a]-61.90[b]	11.02[a]-19.34[b]
(Wiedemann *et al.*, 2017)	Australia	Feed	x	x	x	-	2.80[b]	-	-
(Pishgar-Komleh *et al.*, 2017)	Iran	Feed	x	-	-	-	6.83[a]-8.50[b]	-	-
(Cesari *et al.*, 2017)	Italy	Feed	x	x	-	-	3.03[a]-5.52[b]	14.30[a]-28.40[b]	10.00[a]-18.40[b]
(Kheiralipour *et al.*, 2017)	Iran	Feed	x	-	-	-	3.63[a]	24.00[a]	9.40[a]
(Skunca *et al.*, 2018)	Serbia	Feed and energy usage	x	x	x	x	2.44[a]-3.62[c]	75.06[a]-80.74[c]	1.90[a]-3.01[c]
(Arrieta & González, 2019)	Argentina	Feed	x	-	-	-	2.03[a]-2.22[a]	-	-
(Martinelli *et al.*, 2020)	Brazil	Feed	x	-	-	-	1.48[a]	17.00[a]	34.00[a]
This study	Indonesia	Feed, litter, and energy usage	x	x	x	x	2.93[a]-4.09[b]-5.86[c]	21.62[a]-27.80[b]-38.30[c]	10.61[a]-16.44[b]-24.10[c]

Note: System boundaries: 1= chicken farm; 2= slaughterhouse; 3= distribution; 4= consumer use; GWP= global warming potential; AP= acidification potential; EP= eutrophication potential; a= result per kg live weight (cradle-to-farm gate); b= result per kg carcass (cradle-to-slaughterhouse gate); c= result per kg of consumed chicken meat (cradle-to-grave).

this study, litter waste contributed 10.81% to global warming, 4.25% to acidification, and 16.60% to eutrophication. These results are in line with those reported by González-García *et al.* (2014), that manure and CH_4 emissions contributed 11% and 4%, respectively, to the impact of global warming. Meanwhile, Lima *et al.* (2019) reported that of the total emissions from manure management, the contribution of CH_4 emission is 18.9%, and the contribution of N_2O emission is 81.1%. The manure management in the farm evaluated in this study was still not optimal. The collected litter will be sold in raw form without being processed first. The litter was stored and piled up around the cage when it was not sold. This waste buildup can increase NH_3, N_2O, and CH_4 emissions, which can cause odors and fly around the cage. Improving manure management through processing litter into compost can be a solution to reducing environmental impact. As a comparison, Cesari *et al.* (2017) reported that 50% of manure waste from the farm is processed into compost, so the resulting global warming impact (3.03 kg CO_2 eq), acidification (14.30 g SO_2 eq), and eutrophication (10.00 g PO_4^{3-} eq) is smaller compared to the results of this study.

Several studies (González-García *et al.*, 2014; Kalhor *et al.*, 2016; Cesari *et al.*, 2017) reported that the slaughterhouses sub-system contributed to lower impacts than the chicken farm sub-system, which is also consistent with the results of this study. The slaughterhouse sub-system contributes to the impacts of global warming (18.43%), acidification (12.27%), and eutrophication (24.90%) due to the use of electrical energy (83.00%-87.50%). The slaughterhouse's primary source of electrical energy was used to operate the refrigeration compressor (97.32%). This result is in line with the report of Hafiz *et al.* (2017) that the percentage of electricity consumption is 72%. The high electricity consumption causes more CO_2, NO_x, and PO_4^{3-} emissions from the combustion of power plant fuels. According to López-Andrés *et al.* (2018), electricity, steam, and cooling processes significantly impact slaughterhouses. In line with the research of Skunca *et al.* (2018) that the impact contribution of slaughterhouses is dominated by energy use. The global warming impact on the slaughterhouse sub-system in this study (1.08 kg CO_2 eq) was higher than that reported by Skunca *et al.* (2018), which has an impact value of 0.41 ± 0.11 kg CO_2 eq. The result shows that chicken carcass production in the Indonesian slaughterhouse (4.17 MJ/functional unit) requires higher energy consumption compared to chicken carcass production in Serbia (1.40 ± 1.01 MJ/functional unit) in a study by Skunca *et al.* (2018). This difference is caused by differences in the energy efficiency of the machines used (shackle conveyor, stunner, scalder, automatic plucker, screw chiller, refrigeration compressor, flake ice machine, chiller, air blast freezer, and cold storage) and differences in the storage time of chicken carcasses in cold storage. Therefore, it can be stated that the slaughterhouse in Indonesia is less efficient than in Serbia.

The supplier sub-system contributes to the impact of global warming (3.92%), acidification (2.61%), and eutrophication (5.39%) due to energy use. This result is in line with that reported by Skunca *et al.* (2018), that energy use is the main contributor to the retail sub-system. The global warming impact on the supplier sub-system in this study (0.23 kg CO_2 eq) was smaller than that reported by Skunca *et al.* (2018), with an impact value of 0.49 ± 0.32 kg CO_2 eq. The supplier activities in this study (0.71 MJ/functional unit) require minor electrical energy consumption compared to retail activities in Skunca *et al.* (2018) (3.19 ± 2.15 MJ/functional unit). The use of electrical energy is the primary source of CO_2, NO_x, and PO_4^{3-} emissions that cause global warming, acidification, and eutrophication in the supplier sub-system.

According to the research results by Skunca *et al*. (2018), the consumer use sub-system was the lowest contributor to environmental impacts (1.57%-3.75%). The use of electricity as the most significant contributor to the impact on this sub-system was in line with the result reported by Skunca *et al.* (2018). The source of electrical energy was used to operate equipment and for cooling purposes. The global warming impact on the consumer use sub-system in this study (0.22 kg CO_2 eq) was smaller than that reported by Skunca *et al.* (2018), which has an impact value of 0.35 ± 0.11 kg CO_2 eq. Electrical energy consumption by consumers in this study (0.22 MJ/functional unit) was less than that reported by Skunca *et al*. (2018) (2.17 ± 0.70 MJ/functional unit). This difference is caused by differences in the electrical energy efficiency of their refrigerators and freezers and different storage times of chicken meat in refrigerators or freezers. Waste from product use in the form of leftover packaging and chicken bones also contributes to greenhouse gas emissions from waste management in the form of CH_4, CO_2, and N_2O (IPCC, 2006).

Improvement options to reduce environmental impact throughout the life cycle of the chicken meat chain can be implemented for each sub-system. In the feed production sub-system, soybean meal production produces a higher global warming impact than the other feed ingredients (1.17 kg CO_2 eq (9.93%)). The high crude protein content in soybean meal resulted in high nitrogen excretion in chicken manure (Giannenas *et al.*, 2017). Reducing crude protein in feed is a relevant strategy for reducing environmental impacts (Kebreab *et al.*, 2016; Garcia-Launay *et al.*, 2018; Tallentire *et al.*, 2018). Reducing crude protein by 1% can reduce nitrogen excretion by 10% (Giannenas *et al.*, 2017). Reducing crude protein and adding *protease* enzymes in feed can reduce the impact of global warming by 2% (Leinonen & Williams, 2015). According to Giannenas *et al.* (2017), adding *proteases* and substituting soybean meal has better environmental performance. Aligned with Arroyo *et al.* (2013), soybean meal substitution is very efficient in reducing the impact of global warming.

The strategy for reducing crude protein in feed (scenario A) can be partially or entirely substituting soybean meal with a lower crude protein content, such as coconut or palm kernel meal. Coconut meal and palm kernel meal have sufficient crude protein content to meet the nutritional needs of broiler chickens, with some modifications made to increase their nutritional contents, such as fermentation or adding enzymes. Using fermented coconut meal by Aspergillus Niger in feed can increase crude protein content, reduce crude fiber, increase phosphorus content, and increase live weight gain and feed conversion, with an optimal limit of 15% (Haryati *et al.*, 2006). Fermented palm kernel meal and the addition of enzymes can increase feed efficiency, improve feed conversion, reduce abdominal fat, and replace soybean meal by up to 18% in chicken feed (Pasaribu, 2018). Fermentation can cause the degradation of crude fiber into simple sugars and proteins into amino acids by microbes. Therefore, feed ingredients have a higher digestibility after fermentation and produce easily absorbed hydrolysate, which increases feed efficiency.

Coconut meal and palm kernel meal cultivations produce a smaller global warming impact (0.78 kg CO_2 eq for coconut meal and 0.22 kg CO_2 eq for palm kernel meal) than soybean meal cultivation (1.17 kg CO_2 eq). Coconut meal and palm kernel meal are local feed ingredients widely produced in Indonesia, which can replace soybean meal as an imported feed ingredient. Imported feed ingredients have a high environmental impact contribution due to fuel use in transportation. Using local feed ingredients can reduce the environmental impacts of the imported transportation process.

Litter produced on farms is usually sold directly in raw form without prior processing. Although selling raw litter waste can be more financially efficient, investing in the composting process of litter waste (scenario B) can provide long-term benefits for the company. Compost from litter waste has a higher market value than raw litter waste. Litter waste has a strong odor and can contaminate the environment if not properly processed. By composting litter waste, unpleasant odors can be reduced, creating a more environmentally friendly environment. The company can demonstrate its commitment to sustainable and environmentally friendly agro-industrial practices by composting litter waste. This approach can improve the company's image and reputation. The composting process, with the addition of good bacteria to speed up the decomposition process, can produce heat, allowing microorganisms in the litter to die and making it safer. The reduced emissions in this scenario occur due to the decomposition process of organic matter in the litter during composting. Using organic fertilizer from the litter can reduce the use of chemical fertilizers on agricultural land. According to González-García *et al.* (2014), applying manure as organic fertilizer can reduce the impacts of global warming, acidification, and eutrophication.

The scenario of installing inverters on refrigeration compressors in the slaughterhouse (scenario C) and supplier (scenario D) refers to Hafiz *et al.* (2017), which state that installing an inverter on a refrigeration compressor at a slaughterhouse in Malaysia can reduce electricity consumption by 10%. Reducing electricity consumption can reduce emissions that cause global warming (CO_2), acidification (SO_2 and NO_x), and eutrophication (NO_x).

The electricity efficiency scenario in the consumer use sub-system (scenario E) can be done through routine maintenance of the equipment used to maintain its efficiency. Electric savings can also be done by reducing the time to take and insert products from the refrigerator and using electricity wisely by turning off equipment when not in use.

CONCLUSION

The impact values of global warming, acidification, and eutrophication produced in 1 kg of fried chicken consumed were 5.86 kg CO_2 eq, 38.30 g SO_2 eq, and 24.10 g PO_4^{3-} eq. Feed production, litter, and energy use were the most significant contributors to the environmental impacts. Improvement efforts to reduce the emissions include reducing crude protein in feed, composting litter waste, installing inverters, and electricity efficiency. Applying all improvement scenarios in each sub-system can reduce the impacts of global warming (18.26%), acidification (8.17%), and eutrophication (17.63%) on the chicken meat agroindustry.

CONFLICT OF INTEREST

The researchers certify that there is no conflict of interest with any financial, personal, or other relationship with other people or organizations related to the material discussed in the manuscript.

REFERENCES

Arrieta, E. M. & A. D. González. 2019. Energy and carbon footprints of chicken and pork from intensive production systems in Argentina. Sci. Total Environ. 673:20–28. https://doi.org/10.1016/j.scitotenv.2019.04.002

Arroyo, J., L. Fortun-Lamothe, A. Auvergne, J. P. Dubois, F. Lavigne, M. Bijja, & J. Aubin. 2013. The environmental influence of maize substitution by sorghum and diet presentation on goose foie gras production. J. Clean. Prod. 59:51–62. https://doi.org/10.1016/j.jclepro.2013.06.051

Azmi, S., T. Djatna, Suprihatin, & N. S. Indrasti. 2021. Analysis and design of life cycle assessment system of chicken meat based on digital business ecosystem. J. Teknol. Ind. Pertan. 31:164–175.

BPS [National Bureau of Statistics]. 2019. Broiler Chicken Production by Province. National Bureau of Statistics, Republic of Indonesia, Jakarta.

Cesari, V., M. Zucali, A. Sandrucci, A. Tamburini, L. Bava, & I. Toschi. 2017. Environmental impact assessment of an Italian vertically integrated broiler system through a life cycle approach. J. Clean. Prod. 143:904–911. https://doi.org/10.1016/j.jclepro.2016.12.030

Garcia-Launay, F., L. Dusart, S. Espagnol, S. Laisse-Redoux, D. Gaudré, B. Méda, & A. Wilfart. 2018. The multiobjective formulation is an effective method to reduce the environmental impacts of livestock feeds. Br. J. Nutr. 120:1298–1309. https://doi.org/10.1017/S0007114518002672

Giannenas, I., E. Bonos, V. Anestis, G. Filioussis, D. K. Papanastasiou, T. Bartzanas, N. Papaioannou, A. Tzora, & I. Skoufos. 2017. Effects of protease addition and replacement of soybean meal by corn gluten meal on the growth of broilers and the environmental performances of a broiler production system in Greece. PLoS One. 12:1–26. https://doi.org/10.1371/journal.pone.0169511

González-García, S., Z. Gomez-Fernández, A. C. Dias, G. Feijoo, M. T. Moreira, & L. Arroja. 2014. Life cycle assessment of broiler chicken production: A Portuguese case study. J. Clean. Prod. 74:125–134. https://doi.org/10.1016/j.jclepro.2014.03.067

Hafiz, M. I. M., Z. M. Zulfattah, N. A. Munajat, A. B. F. Sakinah,

& H. M. Asyraf. 2017. Cleaner production implementation at chicken slaughtering plant. ARPN J. Eng. Appl. Sci. 12:4324–4328.

Haryati, T., M. H. Togatorop, A. P. Sinurat, T. Purwadaria, & Murtiyeni. 2006. Utilization of fermented coconut cake with Aspergillus niger in broiler feed. JITV. 11:182–190.

Indrasti, N. S., & A. M. Fauzi. 2009. Cleaner Production. IPB Press, Bogor.

IPCC [Intergovernmental Panel on Climate Change]. 2006. IPCC Guidelines for National Greenhouse Gas Inventories: Volume 2-Energy Chapter 2-Stasionary Combustion. IPCC, Washington, DC.

ISO [International Organization for Standardization]. 2006. ISO 14040:2006 Environmental Management-Life Cycle Assessment-Principles and Framework. ISO, Switzerland.

Kalhor, T., A. Rajabipour, A. Akram, & M. Sharifi. 2016. Environmental impact assessment of chicken meat production using life cycle assessment. Inf. Process. Agric. 3:262–271. https://doi.org/10.1016/j.inpa.2016.10.002

Kebreab, E., A. Liedke, D. Caro, S. Deimling, M. Binder, & M. Finkbeiner. 2016. Environmental impact of using specialty feed ingredients in swine and poultry production: A life cycle assessment. J. Anim. Sci. 94:2664–2681. https://doi.org/10.2527/jas.2015-9036

Kheiralipour, K., Z. Payandeh, & B. Khoshnevisan. 2017. Evaluation of environmental impacts in Turkey production system in Iran. Iran. J. Appl. Anim. Sci. 7:507–512.

Leinonen, I. & A. G. Williams. 2015. Effects of dietary protease on nitrogen emissions from broiler production: A holistic comparison using life cycle assessment. J. Sci. Food Agric. 95:3041–3046. https://doi.org/10.1002/jsfa.7202

Leinonen, I., A. G. Williams, J. Wiseman, J. Guy, & I. Kyriazakis. 2012. Predicting the environmental impacts of chicken systems in the United Kingdom through a life cycle assessment: Broiler production systems. Poult. Sci. 91:8–25. https://doi.org/10.3382/ps.2011-01634

Lima, N. D. S., I. A. Nääs, R. G. Garcia, & D. J. Moura. 2019. Environmental impact of Brazilian broiler production process: Evaluation using life cycle assessment. J. Clean. Prod. 237:117752. https://doi.org/10.1016/j.jclepro.2019.117752

López-Andrés, J. J., A. A. Aguilar-Lasserre, L. F. Morales-Mendoza, C. Azzaro-Pantel, J. R. Pérez-Gallardo, & J. O. Rico-Contreras. 2018. Environmental impact assessment of chicken meat production via an integrated methodology based on LCA, simulation, and genetic algorithms. J. Clean. Prod. 174:477–491. https://doi.org/10.1016/j.jclepro.2017.10.307

Martinelli, G., E. Vogel, M. Decian, M. J. U. S. Farinha, L. V. M. Bernardo, J. A. R. Borges, R. M. T. Gimenes, R. G. Garcia, & C. F. Ruviaro. 2020. Assessing the eco-efficiency of different poultry production systems: An approach using life cycle assessment and economic value added. Sustain. Prod. Consum. 24:181–193. https://doi.org/10.1016/j.spc.2020.07.007

Nurhayati, Marimin, T. Djatna, & I. G. Permana. 2016. Supply chain performance and value-added with the internalization of environmental aspect on the broiler supply chain. J. Teknol. Ind. Pertan. 26:311–320.

Pasaribu, T. 2018. Efforts to improve the quality of palm kernel meal through fermentation technology and the addition of enzymes for poultry. Wartazoa 28:119–128. https://doi.org/10.14334/wartazoa.v28i3.1820

Pelletier, N. 2008. Environmental performance in the US broiler poultry sector: Life cycle energy use and greenhouse gas, ozone depleting, acidifying and eutrophying emissions. Agric. Syst. 98:67–73. https://doi.org/10.1016/j.agsy.2008.03.007

Pishgar-Komleh, S. H., A. Akram, A. Keyhani, & R. van Zelm. 2017. Life cycle energy use, costs, and greenhouse gas emission of broiler farms in different production systems in Iran—a case study of Alborz province. Environ. Sci. Pollut. Res. 24:16041–16049. https://doi.org/10.1007/s11356-017-9255-3

Ramedani, Z., L. Alimohammadian, K. Kheialipour, P. Delpisheh, & Z. Abbasi. 2019. Comparing energy state and environmental impacts in ostrich and chicken production systems. Environ. Sci. Pollut. Res. 26:28284–28293. https://doi.org/10.1007/s11356-019-05972-8

Silva, V. P., H. M. G. van der Werf, S. R. Soares, & M. S. Corson. 2014. Environmental impacts of French and Brazilian broiler chicken production scenarios: An LCA approach. J. Environ. Manage. 133:222–231. https://doi.org/10.1016/j.jenvman.2013.12.011

Skunca, D., I. Tomasevic, I. Nastasijevic, V. Tomovic, & I. Djekic. 2018. Life cycle assessment of the chicken meat chain. J. Clean. Prod. 184:440–450. https://doi.org/10.1016/j.jclepro.2018.02.274

Suffian, S. A., A. A. Sidek, T. Matsuto, M. H. Al Hazza, H. M. Yusof, & A. Z. Hashim. 2018. Greenhouse gas emission of broiler chicken production in Malaysia using life cycle assessment guidelines: A case study. Int. J. Eng. Mater. Manuf. 3:87–97. https://doi.org/10.26776/ijemm.03.02.2018.03

Tallentire, C. W., S. G. Mackenzie, & I. Kyriazakis. 2018. Can novel ingredients replace soybeans and reduce the environmental burdens of European livestock systems in the future? J. Clean. Prod. 187:338–347. https://doi.org/10.1016/j.jclepro.2018.03.212

Wiedemann, S. G., E. J. McGahan, & C. M. Murphy. 2017. Resource use and environmental impacts from Australian chicken meat production. J. Clean. Prod. 140:675–684. https://doi.org/10.1016/j.jclepro.2016.06.086