HABITAT, 33 (3), 2022, 308-319

DOI: 10.21776/ub.habitat.2022.033.3.29

Life Cycle Assessment of Gayo Arabica Coffee Green Bean at Aceh Province

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Received: 31 August 2022; Revised: 21 September 2022; Accepted: 30 November 2022

ABSTRACT

Indonesia's coffee production will reach 774.6 thousand tons in 2021, an increase of 2.75% from 2020, which was 753.9 thousand tons, and is the highest in the last decade and is expected to increase threefold in 2050. Hence, the evaluating environmental performance of the coffee agroindustry is essential if it is to become a more sustainable agroindustry. This paper aims to assess environmental performance (energy footprint, water footprint, and carbon footprint) in Gayo Arabica coffee green bean production with different agro-industry models. The method to evaluate environmental performance that can be used to identify indications of sustainability is Life Cycle Assessment (LCA) Method. The study was conducted on coffee production and exporter cooperatives in Central Aceh. Primary data were obtained through interviews with farmers, collectors, huller owners, and cooperative administrators. Secondary data comes from cooperative reports. The LCA study is described in two product systems, the model of 2015 and the model of 2016. The LCA model of 2015 is based on the green bean production system carried out in 2015 which includes water treatment, pulping, collecting, drying, hulling, finishing, and transportation. The LCA model of 2016 is based on the green bean production system carried out in 2016 until now which includes sub-processes for water treatment, pulping, collecting 1, hulling, collecting 2, finishing, and transportation. The results show that the energy footprint of the 2016 model (2.5128 MJ per f.u) is greater than that of the 2015 model (1.2336 MJ per f.u), the water footprint of the 2015 model is the same as the water footprint of the 2016 model product system, namely 0. 0086 m^3 per f.u., and the carbon footprint of the 2016 model (1.93 kg CO_2-eq per f.u) is greater than that of the 2015 model (1.48 kg CO_2-eq per f.u). The cooperative initiative (in the model of 2016) is for the purpose of process improvement but cannot reduce carbon emissions. To reduce emissions from the use of fossil fuels, it is necessary to optimize land transportation routes and energy efficiency.

Keywords: arabica green bean; environmental performance; energy footprint; water footprint; carbon footprint

How to cite:

Pramulya, R., Bantacut, T., Noor, E., Yani, M., & Romli, M. (2022). Life Cycle Assessment of Gayo Arabica Coffee Green Bean at Aceh Province. *HABITAT*, *33*(3), 308–319. https://doi.org/10.21776/ub.habitat.2022.033.3.29

1. Introduction

The International Coffee Organization (ICO) noted that in 2020, global coffee production was 10.521 million tons, up 6.3% from the previous year which amounted to 9.897 million tons. According to Statistics Indonesia (*Badan Pusat Statistik* – BPS) 2022, Indonesia's coffee production will reach 774.6 thousand tons in 2021, an increase of 2.75% from 2020, which was 753.9 thousand tons, and is the highest in the last decade and is expected to increase threefold in 2050. Indonesia's coffee production is the fourth largest in the world after Brazil, Vietnam, and Colombia. Hence, the evaluating environmental performance of the coffee agroindustry is essential if it is to become a more sustainable agroindustry. According to (Nab & Maslin (2020), sustainable coffee production in Brazil and Vietnam can reduce the carbon footprint by 77% compared to conventional production based on the type of pathway and means of transportation and the reduction of agrochemical inputs. The 2008 Deutschland Pilot Project reported that 55% of the carbon footprint of coffee production is generated during on-farm cultivation and processing, 30% during consumption, and the remaining 15% is generated from transportation, processing and

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waste disposal. Several previous studies also reported that the cultivation stage (including processing on farmers), and consumption had the greatest environmental impact (Killian et al., 2013); (van Rikxoort et al., 2013); (Domínguez-Patiño et al., 2014); (Hassard et al., 2014); (Maina et al., 2015); (Arzoumanidis et al., 2017). The high carbon footprint generated during on-farm processing is the focus of future research, especially in choosing technology and the stages of the green bean production process in the scope of farmers. The method to evaluate environmental performance that can be used to identify indications of sustainability is Life Cycle Assessment (LCA) Method.

The LCA can evaluate the overall environmental performance of activities in the field, transportation, material transformation, processing, distribution, consumer presentation, and final waste treatment (Rega dan Ferranti, 2019). LCA traces the potential environmental impacts of production activities throughout or part of the life cycle. The results of the assessment determine improvements to activities that have the greatest environmental impact (hotspots). LCA helps parties improve production processes and formulate alternative production systems. The LCA method, which has become the standard for assessing the life cycle of products and services, uses carbon emission indicators known as greenhouse gas LCAs (BSI 2011) or carbon footprints (Cordero, 2013).

Calculation of carbon footprint can be used to detect waste production upstream (garden and post-harvest), assess hotspots in the production process, identify resource and energy risks in product systems, and identify farmers and collectors who are willing to improve sustainability performance so that they can be involved and help implement practices. sustainability, identify energy efficiency so that it can be expected to reduce costs and improve product energy efficiency (Bockel & Schiettecatte, 2018).

The use of energy and water in the cultivation, primary processing, and serving of coffee by consumers has been evaluated in various life cycle assessment studies in Thailand (Phrommarat, 2019) and Mexico (Giraldi-diaz *et al.,* 2018). Concern for environmental impacts is increasing along with consumer concern for environmental sustainability throughout coffee production (Rega dan Ferranti, 2019).

The carbon footprint of a product is a measure of the potential global warming impact resulting from a production system and can be expressed in environmental labeling. The initial LCA study of coffee products used carbon footprint calculations to calculate CO_2-eq across all activities (Salomone, 2003). Carbon footprint indicators have been used to compare production models between organic and conventional cultivation (Trinh *et al.* 2019), variations in carbon stock and plantation management in coffee agroforestry (van Rikxoort *et al.* 2014), and the productivity level of coffee grounds (Maina *et al.* 2015). Transportation is the largest source of emissions in the imported coffee supply chain (Specification, 2008). Giraldi-diaz *et al.* (2018) concluded that transportation affects the sensitivity analysis because the distance between the material transformations determines the fuel consumption. LCA studies of coffee production have different assessment results and depend on the production model being evaluated. However, LCA studies comparing production models that have different stages of primary processing and transportation are still limited in Indonesia, especially on one of the main producers of Arabica coffee, namely the Gayo Highlands, Aceh Province, which includes the administrative areas of Central Aceh, Bener Meriah, and Gayo Lues. One of the largest suppliers of specialty and environmentally friendly coffee comes from a cooperative whose function is to manage the production of members of farmer groups, collectors, and huller owners. The cooperative was founded in 2010 to improve the quality of coffee beans by adopting organic coffee cultivation practices and providing added value to members through cooperation in fair trade certification and advanced primary processing technology facilities. In 2014, the importer evaluated sustainable management practices in handling hornbill waste at the cooperative location and recommended the addition of hulling processing facilities at the collector level. In 2016, all horn skin coffee beans were handled by hulling facilities located in 10 collection locations. Then the coffee beans (hulled) are transported back to the collector for drying (until they meet the moisture content accepted by the cooperative). This results in additional transportation routes and primary processing stages. The coffee beans should be sent for further processing at the cooperative location. However, due to the limitations of the drying floor facilities at the hulling process location, the coffee beans cannot be transported directly to the cooperative. This condition causes additional transportation routes.

Therefore, this paper aims to assess environmental performance (energy footprint, water footprint, and carbon footprint) in Gayo Arabica coffee green bean production with different agro-industry models. The study was conducted on coffee production and exporter cooperatives in Central Aceh. Primary data were obtained through interviews with farmers, collectors, huller owners, and cooperative administrators. Secondary data comes from cooperative reports. The LCA study is described in two product systems, the model of 2015 and the model of 2016. The LCA model of 2015 is based on the green bean production system carried out in 2015 which includes water treatment, pulping, collecting, drying, hulling, finishing, and transportation. This study contributes as a source of literature on the sustainability of Gayo Arabica coffee on environmental aspects. There are three impact categories analyzed, namely carbon footprint, energy footprint, and water footprint. We use SimaPro software to determine the amount of value generated in each impact category in both green bean production models. Furthermore, a sensitivity analysis was carried out on green bean production as an improvement scenario in the production model with the lowest environmental impact category value. Several parameters were determined in the sensitivity analysis: reduction of distribution distance for each distribution activity, reduction of water use, reduction of electricity use, increase in yield, and losses during production.

2. Theoretical Underpinning

According to Directorate General of Estate, Ministry of Agriculture, Indonesia 2021, arabica coffee production in Aceh Province increased by 2.65% from 2017 to 2019 (Kementan, 2021) with an average productivity of 650 – 750 $kgha^{-1}$ (Asis et al., 2020). One of the Gayo arabica coffee advantages is that it is organic coffee which has a distinctive delicious taste and that is produced using sustainable or sustainable agricultural understanding (Sinaga & Julianti, 2021). The taste of Gayo arabica coffee has been noted as one of the best specialties one in the world since 2000. This can be the result of many factors, such as the varieties of coffee planted on the unique geographical condition (high elevation form 900 m to 1,700 m a.s.l.), unique climate condition (1,643–2,000 mm of precipitation per year), soil interaction, and special techniques applied during post-harvesting (Sinaga & Julianti, 2021). In general, there are three main types of arabica coffee processing techniques, namely wet type (Sulaiman et al., 2021); (Abubakar et al., 2019), dry type (Sulaiman et al., 2021; Abubakar et al., 2019;); and semi-wet type (Abubakar et al., 2019; Sinaga & Julianti, 2021).

The advantages of gayo arabica coffee can be an option for coffee lovers in the world to try it as a daily stimulant booster (Machado-Fragua et al., 2019), especially in the morning or evening (Sulaiman et al., 2021). On the other hand drinking of coffee can provide health benefits (Wasim et al., 2020); (Grosso et al., 2017); (van Dam et al., 2020) such as cancer (Sartini et al., 2019; Wasim et al., 2020; Ellingjord-Dale et al., 2021; Chen et al., 2021; Nguyen et al., 2021), type 2 diabetes (Wasim et al., 2020; Jin et al., 2020; Hang et al., 2020), heart health (Bodar et al., 2020), depression (Wasim et al., 2020; Wang et al., 2016; Elstgeest et al., 2021), minimize the osteoporosis or osteopenia risk in premenopausal (Chang et al., 2017), and also keeps us healthy due to antioxidants and secondary metabolites (Loftfield et al., 2018). Therefore, drinking coffee can remain an icon of the modern lifestyle in most of the major cities around the world.

Based on several advantages of consuming coffee, making coffee as a refreshing agent that is continuously sought after by world coffee consumers. Therefore, with its unique taste and aroma, Gayo Arabica coffee has the potential to continue to be one of the coffees favored by world coffee consumers. This is a challenge for Gayo Arabica coffee farmers and producers. Strategies and innovations need to be developed to maintain and improve the quality of Gayo Arabica coffee. In addition, it is necessary to minimize the environmental impact generating from the activities of plantations and producers of Gayo Arabica coffee. This study will identify an innovative and technology management in Gayo Arabica coffee business model that is environmentally friendly towards sustainability.

Globally, LCA in agroforestry and agroindustry of coffee has been widely carried out. The goal, of course, is to identify the environmental impacts generated in one coffee life cycle towards sustainability. LCA takes into account all activities involved in product creation with a holistic approach, such as raw material handling, transportation, manufacturing, distribution, use, and disposal (Abbasi et al., 2019). The LCA study begins with determining the goals and scope followed by quantifying all material and energy inputs used in the process of producing the product (Pryshlakivsky and Searcy 2021). All inputs, outputs, and related potential environmental impact of a product throughout its life cycle will be calculated using LCA (Pryshlakivsky and Searcy 2021). The implementation of LCA is based on the guidelines of the ISO 14040:2006 standard which states the principles and framework for LCA, and the ISO 14044:2006 standard which states the requirements and guidelines for LCA. Based on the standards of ISO 14040:2006 and ISO 14044:2006, there are four recommended phases in an LCA study, namely the purpose and scope of the definition, Life Cycle Inventory Analysis (LCI), Life Cycle Impact Assessment (LCIA), and interpretation (Figure 1).

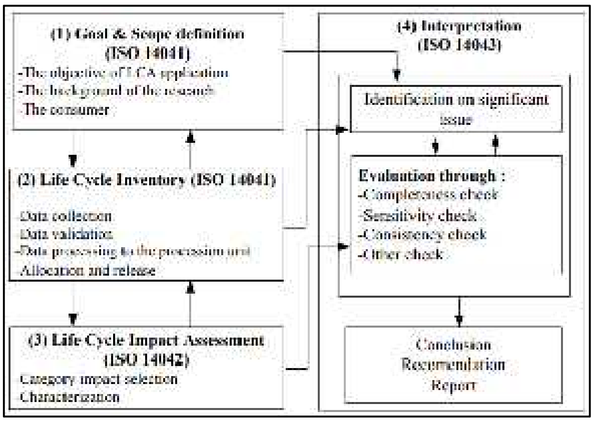

Figure 1. Stages of Life Cycle Assessment (LCA)

3. Research Methods

The study was conducted on coffee production and exporter cooperatives in Central Aceh. Primary data were obtained through interviews with farmers, collectors, huller owners, and cooperative administrators. Secondary data comes from cooperative reports. The data and information collected from each of the Gayo arabica coffee processing actors are in the form of material and energy input data used as well as product output, co-products, and waste or emissions produced in each Gayo Arabica coffee processing activity.

The limitation of the coffee product system is cradle to gate (primary processing activities in farmers, transportation, and primary processing) with a functional unit of 1 kg green beans with SNI standards. The greenhouse gas LCA method uses the PAS 2050 (BSI 2011), IPCC 2006 (Killian *et al.* 2013), and ReCiPe 2016 (Giraldi-diaz *et al.* 2018) standards. The overall objective of the study is to evaluate the location choice policy of the hulling production process and its impact.

Life Cycle Inventory (LCI) involves the collection of environmental load data required to meet the research objectives. The environmental load is determined by the raw materials and energy used in a system as well as the emissions released by liquid waste and solid waste into the environment. The Life Cycle Impact Assessment (LCIA) aims to interpret environmental loads that have been measured in the LCI stage. In the LCA study of greenhouse gases, coffee products only use the potential impact of global warming with carbon emission indicators. The last stage, interpreting the results of the LCA study. If there are additional transportation routes, there may be an increase in emissions from fuel consumption. Improvement of overall environmental performance is expected to start from the stage of the production process which has the highest hotspots.

4. Results and Discussion

4.1. Production System Model

The LCA study is described in two product systems, the model of 2015 and the model of 2016. This is done to see how much change the environmental impact results from the two production system models. LCA model of 2015 is based on the green bean production system carried out in 2015 which includes water treatment, pulping, collecting, drying, hulling, and finishing processes as well as transportation that moves intermediate products from the previous process to the next process (Figure 2). LCA model of 2016 is based on the green bean production system carried out in 2016 until now which includes sub-processes for water treatment, pulping, collecting 1, hulling, collecting 2, and finishing as well as transportation that moves intermediate products from the previous process to the next process (Figure 3).

In general, the processing units in the coffee agroindustry in Indonesia, consist of pulping, washing, drying, hulling, and finishing (Mawardi et al., 2020). Appropriate technology in the post-harvest coffee production process is one of the main indicators in improving the quality of the product produced. In addition, the coffee production system model is also an indicator in minimizing the emissions produced (Basavalingaiah et al., 2022).

ISSN: 0853-5167 (p); 2338-2007 (e)

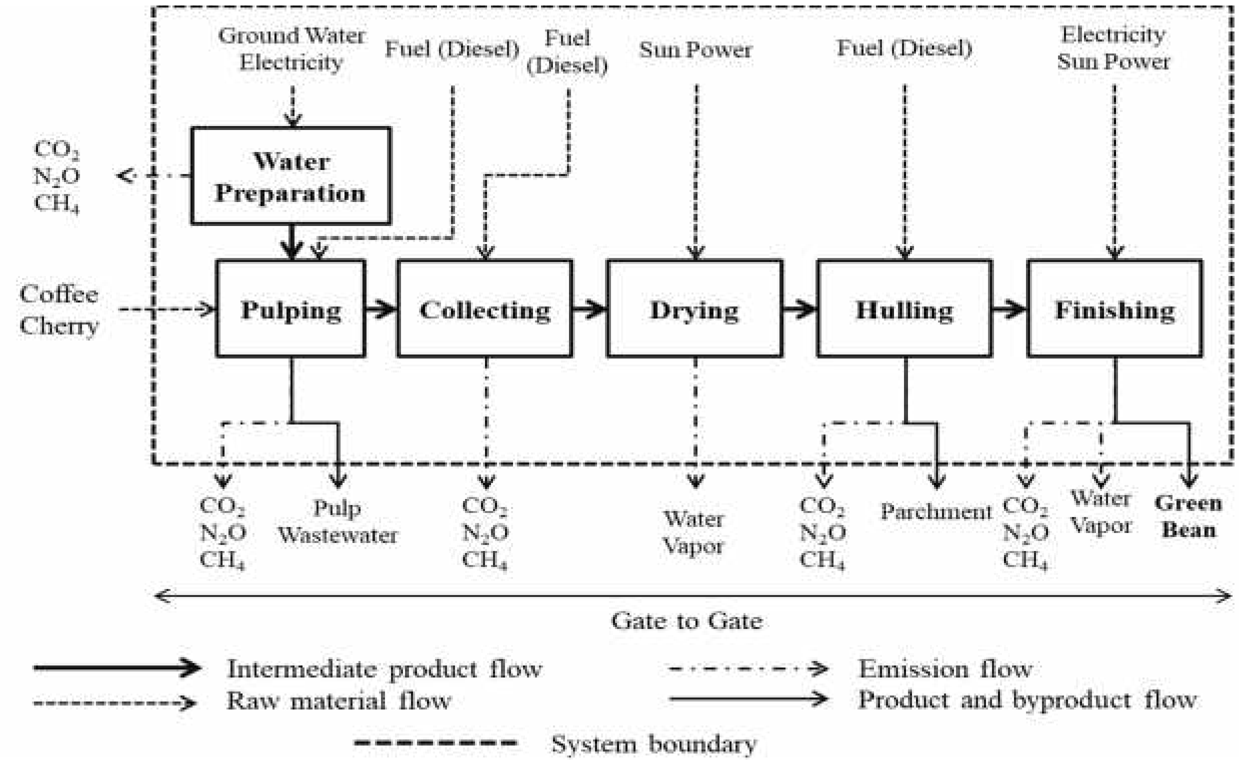

Figure 2. System constraints Model 2015

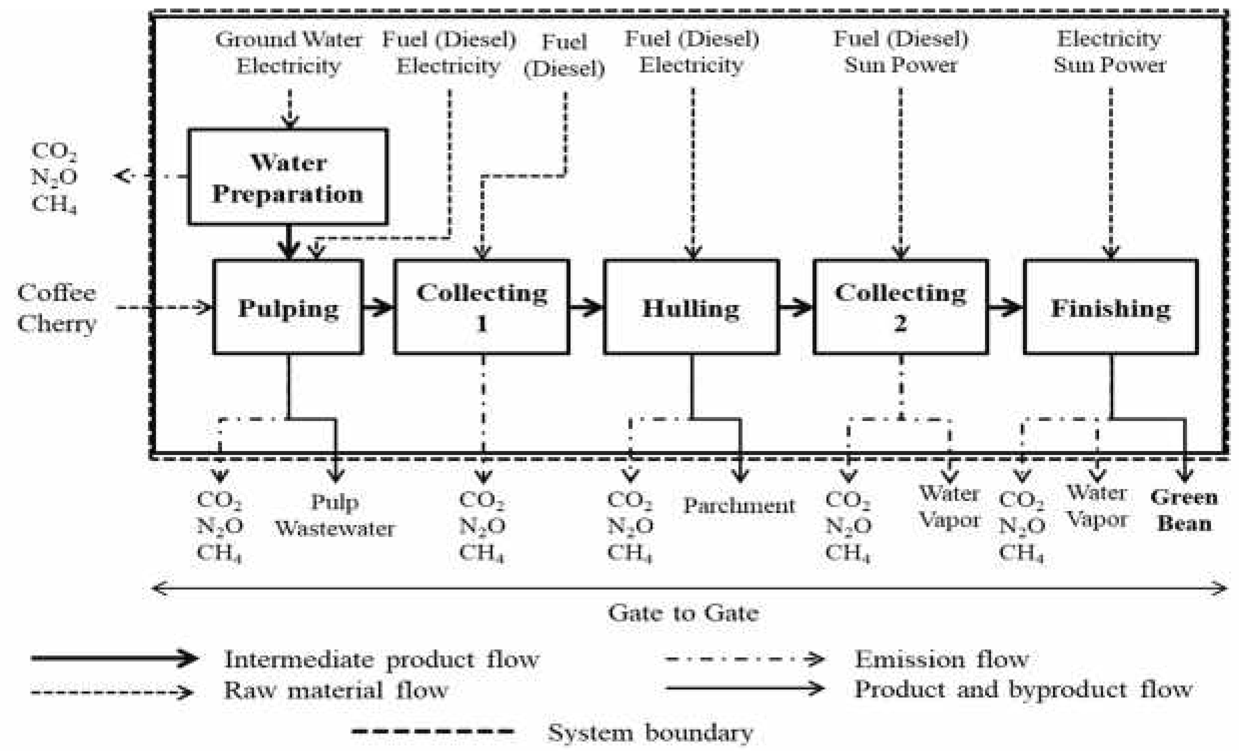

Figure 3. System constraints Model of 2016

4.2. Inventory of Production System Model

The LCI of green bean production in wet processing shows the input and output flow for each sub-process in the green bean production system (Table 1). The number of inputs and outputs is shown based on the unit function (UF) which is 1 kg of green beans. The input of coffee cherry in the model of 2015 is 24,017,945 kg with the number of green beans produced beings 5,554,150 kg. The input of coffee cherry in the model of 2016 is 14,693,268 kg with a total of 3,397,818 kg of green beans produced. The water requirement for each production system model is 2 times the number of coffee cherries to be processed into green beans. The amount of energy required in each model of the product system corresponds to the energy requirements of each process. Beside on each of inventory of production system model of Gayo arabica coffee, the three hotspots in the model of 2015 are the use of diesel in the pulping process (0.6070 MJ/UF or 607.0 kJ/UF), the use of diesel in collecting fot transport fuel from the collector to the cooperative (0.1649 MJ/UF or 164.9 kJ/UF), and the use of diesel in the Hulling process (0.1154 MJ /UF or 115.4 kJ/UF). In the model of 2016, three hotspots are the use of diesel in collecting for transport fuel from collector to huller ((1.0000 MJ/UF or 1000,0 kJ/UF), the use of diesel in the hulling process (0.6560 MJ/UF or 656.0 kJ/UF), and the use of diesel in the pulping process (0.6070 MJ/UF or 607.0 kJ/UF). The model of 2016 also has high electricity usage in the finishing process, which is 0.4141 MJ/UF or 414.1 kJ/UF and is the fourth-highest hotspot in this model. The water used that has the potential as wastewater in both models shows the same amount per UF, as well as co-products (pulp and parchment). In both the Model of 2015 and Model of 2016, the three highest hotspots resulted from the use of diesel fuel. According to Diyarma et al. (2019) the combustion of oil fuels results in the emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) which increase the effect of greenhouse gases from the coffee production process. The same thing was said by Giraldi-diaz et al. (2018).

Tabel 1. LCI green bean production model of 2015 and model of 2016

Model of 2015				Model of 2016			
Sub-Process	Input and Output	Value	Unit/ UF	Sub-Process	Input and Output	Value	Unit/ UF
Water preparation	Input:			Water preparation	Input:		
	1. Groundwater	0.0086	m³		1. Groundwater	0.0086	m³
	2. Electricity	0.0649	kWh		2. Electricity	0.0180	kWh
	Output:				Output:		
	1. Water	0.0086	m³		1. Water	0.0086	m³
Pulping	Input:			Pulping	Input:		
	1. Water	0.0086	m³		1. Water	0.0086	m³
	2. Coffee Cherry	4.3243	kg		2. Coffee Cherry	4.3243	Kg
	3. Fuel for pulper engine (diesel)	0.6070	MJ		3. Fuel for pulper engine (diesel)	0.6070	MJ
	4. Transport fuel from farmer to collector (gasoline)	0.0738	MJ		4. Transport fuel from farmer to collector (gasoline)	0.0757	MJ
	Output:				Output:		
	1. Washed parchment coffee	1.7632	kg		1. Washed parchment coffee	1.7297	kg
	2. Pulp	2.5611	kg		2. Pulp	2.5611	Kg
	3. Wastewater	0.0087	m³		3. Wastewater	0.0087	m³
Collecting	Input:			Collecting	Input:		
	1. Washed parchment coffee	1.7632	kg		1. Washed parchment coffee	1.7297	Kg
	2. Transport fuel from the collector to the cooperative (diesel)	0.1649	MJ		2. Transport fuel from collector to huller (diesel)	1.0000	MJ
	Output:	1.7632	kg		Output:	1.7297	Kg
	1. Washed parchment coffee				1. Washed parchment coffee		
Drying	Input:			Hulling	Input:		
	1. Washed parchment coffee	1.7632	Kg		1. Washed parchment coffee	1.7297	Kg

Model of 2015				Model of 2016			
Sub-Process	Input and Output	Value	Unit/ UF	Sub-Process	Input and Output	Value	Unit/ UF
	2. Sun power	1.6620	MJ		2. Huller engine fuel (diesel)	0.6560	MJ
	Output:				Output:		
	1. Dry parchment coffee	1.2055	kg		1. Wet Green bean	1.5135	Kg
	2. Steam	0.5578	kg		2. Parchment Coffee	0.2162	Kg
Hulling	Input:			Collecting	Input:		
	1. Dry parchment coffee	1.2055	kg		1. Wet Green bean	1.5135	Kg
	2. Huller engine fuel (diesel)	0.1154	MJ		2. Transport fuel from huller to collector (diesel)	0.0735	MJ
	Output:				3. Sun power	1.3345	MJ
	1. Dry Green bean	1.0476	kg		4. Transport fuel from collector to cooperative (diesel)	0.1120	MJ
	2. Parchment	0.1579	kg		Output:		
					1. Dry Green bean	1.0476	Kg
					2. Steam	0.4659	Kg
Finishing	Input:			Finishing	Input:		
	1. Dry Green bean	1.0476	kg		1. Dry Green bean	1.0476	Kg
	2. Electricity	0.0390	MJ		2. Electricity	0.4141	MJ
	3. Sun power	0.3462	MJ		3. Sun power	0.3132	MJ
	Output:				Output:		
	1. Green bean	1.0000	Kg		1. Green bean	1.0000	Kg
	2. Steam	0.0476	Kg		2. Steam	0.0476	Kg

4.3. Energy and Water Consumption

Energy use based on the unit function in each model is calculated based on the total energy from the use of fuel oil and electricity use. The footprint of energy use in the model of 2016 is greater than that of the model of 2015 (Figure 4). This is because the model of 2016 production system uses a large amount of diesel fuel when moving intermediate products from certain process sub-systems to other process sub-systems (1.2613 MJ/kg green beans), as well as very large electricity consumption (0.4789 MJ/kg green beans).

Water use based on its functional unit in each production system model is calculated based on twice the total number of coffee cherries to be processed (Figure 4). The water usage footprint in the model of 2015 product system is the same as the water usage footprint in the model of 2016 product system.

The carbon footprint generated by functional units in the model of 2016 production system is larger than the model of 2015 (Figures 4 and 5). This is because the model of 2016 product system uses a large amount of diesel fuel when moving intermediate products from certain process sub-systems to other process sub-systems (1.2613 MJ/kg green bean), as well as very large electricity consumption (0.4789 MJ/kg). green beans).

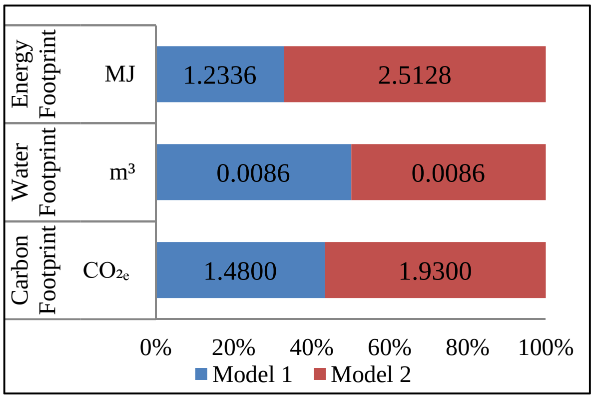

Figure 4. Comparison of water use, energy and CO_2-e emissions

This condition both on energy footprint, water footprint, and carbon footprint are quite large if compared to the research of Diyarma et al. (2019), where the energy footprint for processing 1000 kg of coffee cherry or 231,25 kg of green bean is 7.67 MJ or 0.0332 MJ/UF, produces 5953.2 kg of liquid waste, and a carbon footprint of 2.56 CO_2-e or 0,0111 CO_2-e/UF. According to several previous researchers, the primary production stage in the coffee chain is the most important contributor to the carbon footprint (Büsser & Jungbluth, 2009); (Humbert et al., 2009); (Hicks, 2018).

Emissions of electricity use in each model are 0.374 kg CO_2-e /kg green beans in the model of 2015 and 0.536 CO_2-e/kg green beans in the model of 2016 (Figure 5). Emissions from the use of diesel fuel in each model are 0.153 kg CO_2-e/kg green beans in the model of 2015 and 0.1833 kg CO_2-e/kg green beans in the model of 2016 (Figure 5).

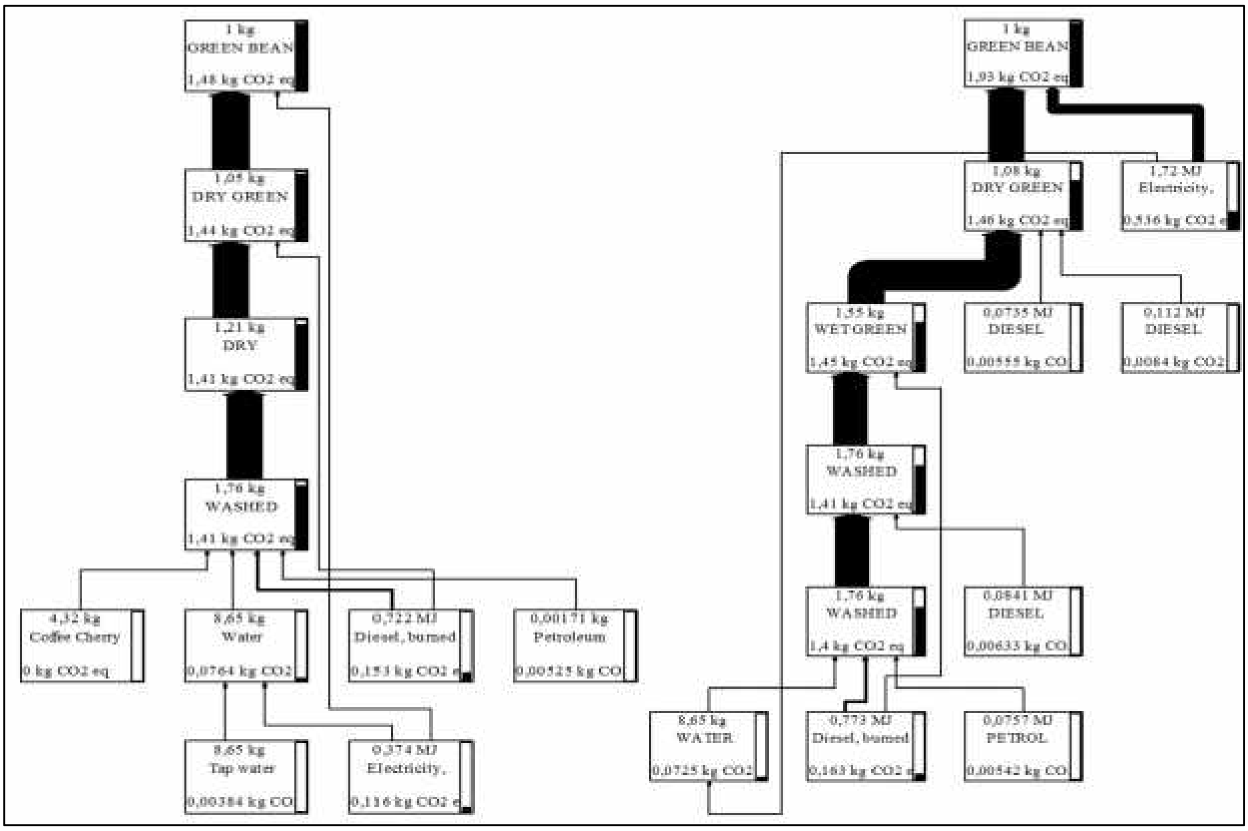

Figure 5. Hot spots of 2015 and model of 2016s of green bean production

4.4. Sensitivity Analysis

Sensitivity analysis was carried out on wet processing green bean production in the model of 2016 improvement scenario. Several parameters were determined in the sensitivity analysis, namely: (1) 10% reduction in distribution distance for each distribution activity, (2) 50% reduction in water use, (3) 50% reduction in electricity use, (4) 10% increase in yield, and (5) 10% loss during production.

From the results of the evaluation of the comparison of parameters to the New Scenario 2 model using SimaPro 08 software, it is found that if the distance is reduced by 10% it will have an impact on reducing the impact of emissions by 0.105%, if the use of water is reduced by 10% it will have an impact on reducing the impact of emissions by 0.314%, if the use of electricity is reduced by 50% it will have an impact on reducing the impact of emissions by 47.065%, if there is a loss during the process by 10% it will have an impact on increasing the impact of emissions by 10%, and if the yield is increased by 10% it will have an impact on reducing the impact of emissions by 9.219%.

Table 2. Sensitivity analysis results

Parameters	Percent Variation (%)	Carbon Emission (kg CO_2-e/kg green bean)		Percent Change from Baseline (%)
		Baseline	After Change	
Distribution distance reduction	10	0.954	0.953	0.105
Reducing water use	50	0.954	0.951	0.314
Reducing electricity usage	50	0.954	0.505	47.065
Loss during the process	10	0.954	1.060	-10.000
Yield increase	10	0.954	0.867	9.119

5. Conclusion

This paper aims to assess environmental performance *(*energy footprint, water footprint, *and* carbon footprint*)* in Gayo Arabica coffee green bean production with different agro-industry models. *The* method *to evaluate* environmental performance that can be used to identify indications of sustainability *is* Life Cycle Assessment (LCA) *Method*. The study was conducted on coffee production and exporter cooperatives in Central Aceh. Primary data were obtained through interviews with farmers, collectors, huller owners, and cooperative administrators. Secondary data comes from cooperative reports. The LCA study is described in two product systems, the model of 2015 and the model of 2016. The LCA model of 2015 is based on the green bean production system carried out in 2015 which includes water treatment, pulping, collecting, drying, hulling, finishing, and transportation. The LCA model of 2016 is based on the green bean production system carried out in 2016 until now which includes sub-processes for water treatment, pulping, collecting 1, hulling, collecting 2, finishing, and transportation. The results show that the energy footprint of the 2016 model (2.5128 MJ per f.u) is greater than that of the 2015 model (1.2336 MJ per f.u), the water footprint of the 2015 model is the same as the water footprint of the 2016 model product system, namely 0. 0086 m^3 per f.u., and the carbon footprint of the 2016 model (1.93 kg CO_2-eq per f.u) is greater than that of the 2015 model (1.48 kg CO_2-eq per f.u). The cooperative initiative (in the model of 2016) is for the purpose of process improvement but cannot reduce carbon emissions. To reduce emissions from the use of fossil fuels, it is necessary to optimize land transportation routes and energy efficiency.

To reduce carbon emissions based on sensitivity analysis, further analysis is needed of the overall transportation routes of actors, reuse of water used in primary treatment processes in farmers and management of electricity use in cooperatives. The limitations of this research are also in the scope of the study which is still limited to Gate to Gate, so the results of the study do not yet interpret overall sustainability based on the environmental performance. Therefore, further research on the scope of the Cradle to Grave study needs to be carried out.

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