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ASSESSMENT OF ENVIRONMENTAL IMPACT OF THE GAYO ARABICA COFFEE PRODUCTION BY WET PROCESS USING LIFE CYCLE ASSESSMENT

– Research paper –

Ikhsan DIYARMA[1]*, Tajuddin BANTACUT**, SUPRIHATIN**

*Department of Natural Resources and Environmental Management, IPB University, Jalan Raya Dramaga, Bogor Regency, West Java, 16680, Indonesia.

**Department of Agroindustrial Technology, Faculty of Agricultural technology, IPB University, Jalan Raya Dramaga, Bogor Regency, West Java, 16680, Indonesia.

Abstract: Increasement of demand for gayo arabica coffee has influenced the coffee industry, either in increasing the coffee production and also in increasing the usage of coffee machinery and equipment significantly. However, combustion of oil fuels result 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. This study aimed to analyze the direct impact of gayo coffee production towards environment using the Life Cycle Assessment (LCA) method, including several stages such as (1) the goal and scope definition, (2) the inventory analysis, (3) the impact assessment, and (4) the interpretation. Results of this study showed that the energy needed to process 1000 kg of coffee was 7.67 MJ, while the produced liquid waste was 5 953.2 kg. The value of the global warming impact on the coffee *life cycle* was 56 807 165.63 CO_2eq.

Keywords: gayo arabica coffee, greenhouse gas (ghg) effect, life cycle assessment

INTRODUCTION

Arabica coffee is one of the plantation commodities that plays an important role in the international trade (Mussatto et al., 2011). The increasement of demand and interest in coffee makes it becomes one of the most popular types of beverages (Patino et al., 2014). Indonesia is able to contribute about 540 000 tons/year or 6.44% of the world coffee requirements (AEKI, 2014). One of the original Indonesian coffee varieties that has a high export value is gayo arabica coffee. This coffee variety is cultivated by community in Gayo highlands which are planted at an altitude of 950-1450 meters above sea level and have received the Geographic Index certification, Organic Certified, Fairtrade and Rainforest (ICCRI, 2008; Saputra, 2012 Putri, 2013; Herdyanti, 2013) with planting area of 97 796 ha (Fadhil et al., 2018). Coffee productivity in this area reaches 700 to 800 kg/ha, with production of 46 828 tons/year (Ministry of Agriculture, 2017).

Gayo arabica coffee is one of the highest selling prices in the world. This contributes greatly to the reduction of poverty and development of regional economic also at the national level (Chemura et al., 2014). The increasement of demand for Gayo arabica coffee in the world market is increasing every year regardless of the quality produced. Quality is greatly influenced by the coffee quality which is determined mainly from the treatment in the garden, transportation (40%), postharvest treatment (40%) and secondary processing (20%) (Musebe et al., 2007; Damanu, 2008).

The increasement of coffee plantation area is in accordance to the increasement of market demand and coffee production, has an impact on the increasing number of emissions as a result of the coffee processing process, where the processing of gayo arabica coffee mostly uses the wet processing methods or often called double washing.

The use of material, energy and equipment that is quite large in the processing of coffee could cause emission pollutions, both in the activities of the coffee production process, as well as in the management of the environment and the usage of resources, such as the usage of energy, water, machinery and equipment, and environmental management that is not optimal

[1] Corresponding author. E-Mail address: ikhsandiyarma@yahoo.com

and efficient (KIT and IIRR, 2008; Novita, 2012; Hassard et al., 2014; Cuong et al., 2014). Impact of the arabica coffee processing, especially in terms of climate change, is an important thing to be studied including the effects of processing, climate change mitigation, and the effects of greenhouse gases (GHG) (Noponem et al., 2012). According to IPCC (2006), the main gases which are categorized as greenhouse gases and have potential to cause the global warming are Carbon dioxide (CO_2), Nitrogen oxide (N_2O) and Methane (CH_4) (Rukaesih, 2004; Wielgosinski et al.,2017).

Method that can be used to evaluate these impacts is the Life Cycle Assessment (LCA) method. The LCA method is a good method to be used because: (i) Life cycle thinking is holistic (there is no shift in environmental problems: the media, region, or time involved), (ii) Early warning systems regarding to the future legal requirements and attention to the living environment, (iii) Identification of process improvements to overcome the environmental impacts, various production process technology alternatives and products as a basis for the best alternatives selection. Limit of the used system are used based on ISO standard of 14040 and 14044, with the Cradle to gate approach covering all processes from extracting the raw materials through the production stage (process in the factory) that is used to determine the environmental impact of a product production. The product or process has a life cycle, each stage of the life cycle uses energy and other additives to produce emissions and wastes (Jonsson et al., 1997; Azapagic, 1999; Janus and Blazejowska, 2015). This study aimed to assess the direct impacts of Gayo coffee production toward the environment through the LCA method, so that the data that is related to the use of raw materials in order to identify the impact of each stage of the processing process in the coffee life cycle could be obtained. The final stage later is to suggest solutions to minimize the environmental impact of the coffee processing and to improve the processing performance at the company level.

MATERIALS AND METHODS

This research was conducted in the district of Aceh Tengah, Bener Meriah and Gayo Lues, Province of Aceh, Indonesia.

Types and Sources of Data

Collection of the primary data were carried out through the field observations and direct interviews with coffee farmers, coffee processing businesses including: Gayo Mandiri, Permata Gayo, and Katiara Gayo and other relevant agencies.

The secondary data were collected from the current and previous years data which were obtained from the relevant agencies and literature studies. The literature study data were generally used as supporting data.

Stages of Research and Data Analysis

The stages of research according to each LCA step were described in the International standards (ISO 14040, ISO 14044 in 2006) showed that there are four stages for the LCA method, namely: (1) Defining objectives and scope, (2) Inventory analysis, (3) Impact analysis, and (4) Interpretation. Results of LCA are strongly influenced by the reliability and adequacy of the object data assessed (Searcy 2000). The processing system was restricted from the surrounding environment, the system limitations that was studied define the process to be included in the study and the calculations made on the basis of the functional unit (for 1000 kg of the product under study) (Yokoyama and Matsumura, 2008). The objectives, limitations and scope of the LCA will be reviewed as follows:

1. The observed company is in three companies as mentioned before, so that data information could be known in measuring the amount of resource consumption and the environmental emissions from the stage of raw material acquisition until production, usage, treatment at the end of production age, final disposal and environmental impact of the processing process of gayo arabica coffee.
2. Calculating input and output at each stage of the arabica coffee processing through a wet processing.
3. Analysis of environmental impacts of greenhouse gases (GHG) effect based on the results of the objectives (number one and two). Furthermore, determination of the pollution value from each stage of coffee processing process, such as carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4).

4. Result interpretation of the previous three stages of the process can be evaluated and the results of the impact analysis that has been obtained become a consideration for improving improvement efforts to reduce the negative impacts on the environment.

Limitation of this research system is as shown in Figure 1 with the Cradle to gate system approach that is used in an LCA study, including the activity from coffee plantations, transportation and processing of coffee fruit until the warehousing stage.

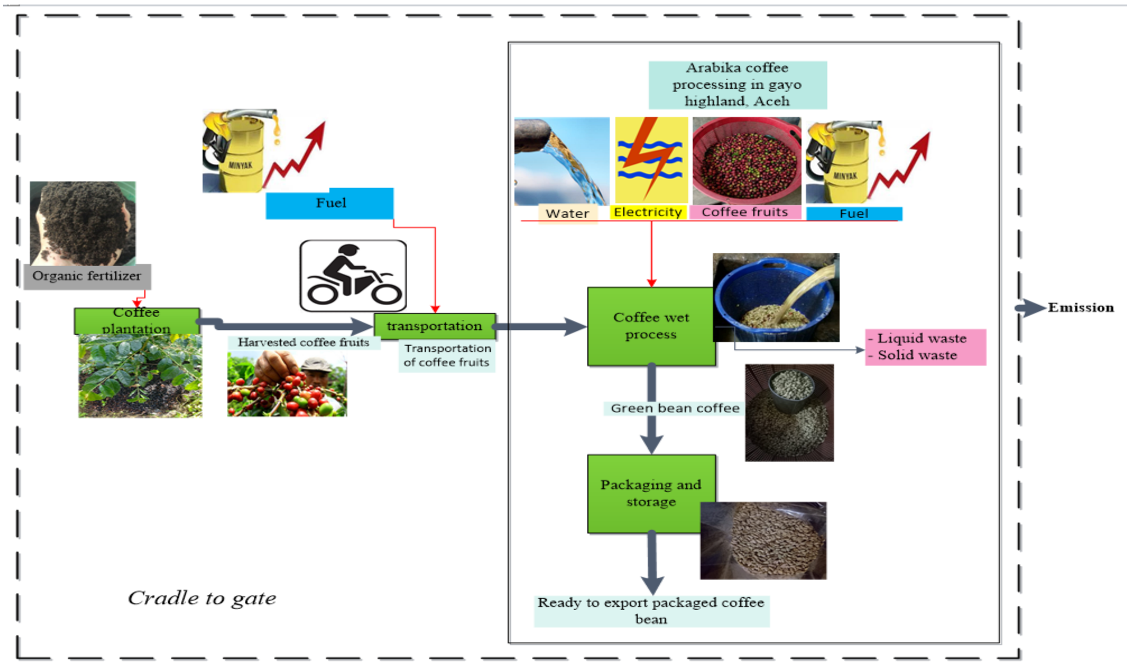

Figure 1. Limitation of the research system (Adapted from Iolanda De Marco et al., 2018)

RESULTS AND DISCUSSIONS

Scope of Life Cycle Assessment

This LCA study was conducted to determine the changes in the effects of global warming that occur in the Arabica coffee production process, so that the energy usage needs to be calculated. The usage of energy could affect the amount of global warming produced. Therefore, the energy use observed are including electricity, diesel and gasoline. Figure 2 shows the flowchart of wet processing process of Arabica coffee using cradle to gate approach from the plantation process to the storage process.

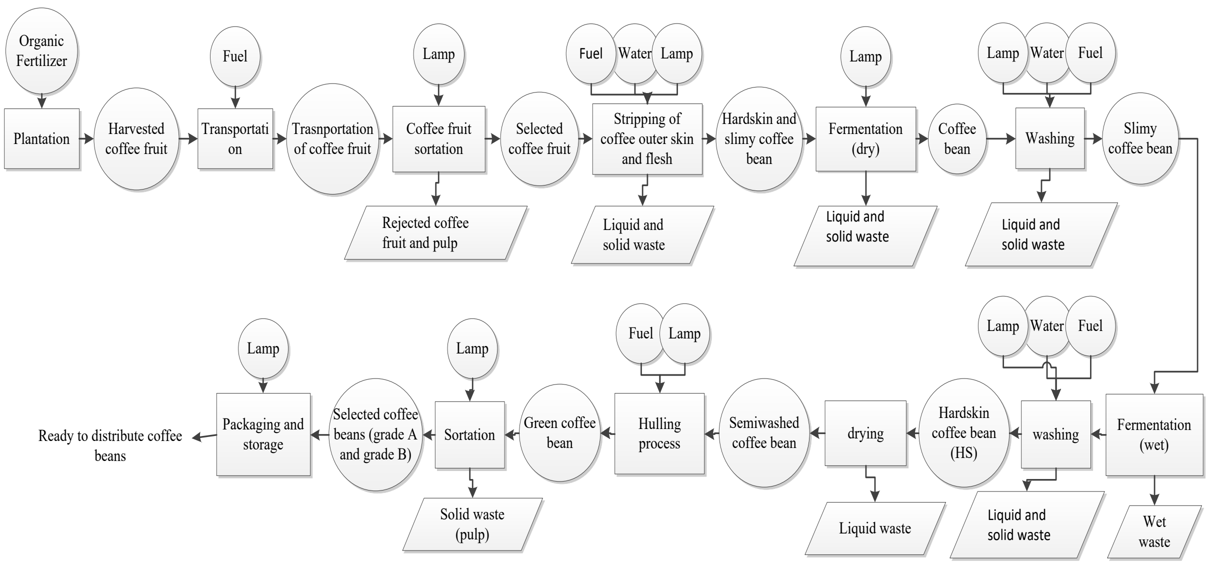

Figure 2. Flowchart of Arabica Coffee Wet Process

Inventory Analysis

Inventory analysis was conducted based on the material input and output in the system. Input data consisted of raw material requirements, fuel, energy/electricity and water usage. Table 1 shows the average value obtained from observation in three different companies, namely: Gayo Mandiri, Permata Gayo, and Katiara Gayo. Thus, the wet process of arabica coffee could be seen, starting from the plantation where 1 ha of plantation consisted of 1500 coffee trees, where the farmers provide the organic fertilizer with an average dose of 8 kg/tree/year, an average of 12 000 kg/ha of organic fertilizer.

This condition shows that the amount value is smaller compared to the coffee plantations in the Sumber Jaya Company, Province of Lampung, at a rate of 10 kg/tree/year (Verchot et al., 2006). The amount of fertilizer given to coffee plants could affect the increasement of emissions at the plantation level (Zhou et al. 2016). Processing of 1000 kg of arabica coffee could produce 121.8 kg of ready-to-export coffee. The amount of coffee beans obtained is determined by several factors such as varieties, rainfall, fertilizer and technology used during processing (Echeverria1 and Nuti, 2017). Liquid and solid waste produced depends on the usage of water and the initial sortation during processing, in this study the produced liquid waste was 5 953.2 kg and solid waste was 618.37 kg, which is smaller than the result of the research on plantations in Papua New Guinea with liquid waste production of 6 000 kg and solid waste of 1 200 kg (Calvert, 1999).

Analysis of all energy requirements such as electricity and diesel fuel will be summed to be calculated as a whole in one unit. All the energy components will be equalized to Mega Joule (MJ) as a total energy unit. In Table 2 we can see that the total energy requirement needed to produce 121.8 kg of Arabica coffee beans which are ready for export is a total of 7.67 MJ, which is smaller than the result obtained in the study conducted in Italy, which is 8.8 MJ (Marco et al., 2018). This difference occured due to the influence of the processing equipment used number.

Table 1. Process of gayo arabica coffee wet processing

Stage of Process		Gayo Mandiri		Katiara gayo		Permata gayo		Average			
		Input (Kg)	Output (Kg)	Input (Kg)	Output (Kg)	Input (Kg)	Output (Kg)	Input (Kg)	Output (Kg)	Waste	
										Solid	Liquid
Plantation	Organic Fertilizer	15000		11000		10000		1200			
Transportation	Harvested coffee fruit	1000	1000	1000	1000	1000	1000	1000	1000		
Coffee Sortation	Selected coffee fruit	1000	830	1000	950	1000	930	1000	903	96.6	
Stripping the outher shell and flesh of coffee fruit	Slimmy and hardskin coffee beans	830	647.4	950	741	930	725.4	903	704.6	505.8	1029.8
Dry fermentation	Dried and hardskin coffee beans	647.4	647.4	741	741	725.4	725.4	704.6	704.6		
Coffee washing	Wet coffee bean	647.4	422.4	741	483.5	725.4	473.3	704.6	459.7	10.57	2278
Wet fermentation	Wet coffee bean	422.4	413.9	483.5	473.8	473.3	463.8	459.7	450.5		928.6
Coffee washing	Hardskin coffee beans	413.9	290.8	473.8	332.8	463.8	325.8	450.5	316.5	5.4	1435.2
Drying	Semiwashed coffee beans	290.8	218.1	332.8	249.6	325.8	244.3	316.5	217.3		
Hulling	Green Coffee beans	218.1	174.4	249.6	199.7	244.3	188.1	237.3	187.4		59.3
Coffee sortation	Coffee beans grade A	174.4	113.4	199.7	129.8	188.1	122.3	187.4	121.8		
	Coffee beans grade B	113.4	61	129.8	69.9	122.3	65.8	121.8	65.6		
Total										618.37	5953.2

Table 2. Energy Requirement in Coffee Production

Stages of the Process	Fuel (MJ)	Electricity/kg of coffee	Total Energi	Stages of the process (%)
Fertilization				
Transportation	0.16			2.03
Sortation		0.53	0.53	6.89
Stripping	0.00	0.08	0.08	1.08
Washing 1		0.60	0.60	7.82
Washing 2		0.60	0.60	7.82
Wet fermentation		1.55	1.55	20.14
Hulling process of coffee hardskin	0.00	0.58	0.58	7.50
Sortation		2.59	2.59	33.77
Storage		0.99	0.99	12.95
Total			767.556	100

Impact Analysis

Based on the objectives and scope specified at the beginning, this study only focuses on the impact of global warming (GHG). Based on the results of the LCA, for the production of 1000 kg of coffee requires energy of 7.67 MJ/ton-coffee. GHG emissions from this plantation area are dominated by N_2O gas, with total global warming potential (N_2O, NH_4 and CO_2) of 56 807 165.63 kg-CO_2-eq/ton-coffee. This condition is quite large if compared to the research of Naponen et al. (2012) where the total emissions generated by organic plantations are 25 500 000-31 200 000 kg-CO_2-eq/ton-coffee.

Results of the impact and contribution analysis show that the main problem that is a concern for recommended environmental improvements is the use of the largest organic fertilizer contributing to the life cycle of gayo arabica coffee. The use of organic fertilizers in an efficient manner will have a positive impact on reducing the greenhouse gas emissions such as good soil and plant management activities by utilizing the plantation waste as the source of organic fertilizer (Ayalev, 2014; Velmourougane, 2016).

Table 3. Greenhouse gas emissions

Unit Process	Emission of Green House Gas (GHG) (Kg)			CO_2-eq (Kg)	Unit Process
	CO_2	CH_4	N_2O		
Fertilization			56807163.07	56807163.07	99.99999550
Transportation	0.01	0.00	0.00	0.01	0.00000002
Sortation	0.26			0.26	0.00000046
Stripping of coffee fruit flesh & other skin	0.20	0.00	0.00	0.20	0.00000034
Washing 1	0.29			0.29	0.00000051
Washing 2	0.29			0.29	0.00000051
Wet fermentation	0.75			0.75	0.00000132
Hulling process of coffee hardskin	0.28	0.00	0.00	0.28	0.00000049
Packaging and Storage	0.48			0.48	0.00000085
Total				56807165.63	100

CONCLUSIONS

Production system of gayo arabica coffee using wet process uses the LCA method with the limits of the cradle to gate, there were 12 units of coffee production process that was observed. The highest energy requirements at the coffee beans sortation stage were 33.77%. The coffee production life cycle activities that most contribute to emissions are plantations, where to process 1000 kg of coffee requires energy of 7.67 MJ/ton-coffee, while the amount of liquid and solid waste are 5 953.2 kg and 618.3 kg, respectively, and the CO_2 released in the air is 56 807 165.63 kg-CO_2-eq/ton-coffee.

Understanding of the effective fertilization methods is needed to determine the technical control of environmental pollution in coffee plantations. Efforts to control the environmental impacts must be carried out in an integrated manner by utilizing all environmentally friendly technologies so that the pollution could be minimized.

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