Carbon Footprint Calculation for Gayo Arabica Coffee Primer Processing

Rahmat Pramulya, Tajuddin Bantacut, Erliza Noor, Mohamad Yani

Abstract— The carbon footprint of coffee production has links to the issue of climate change. Greenhouse gas emissions as a result of the activities of the coffee production system unit are calculated based on the amount of CO_2, N_20, and CH_4 compounds. Sources of emissions come from fossil fuels, electricity, decomposition of organic matter in liquid waste and pulp, and burning of parchment skins. The purpose of the paper or research objective is to identify the footprint of carbon emissions in each unit of the semi-wet primary coffee processing system in order to determine the hot spots that will be the focus of efforts for sustainable improvement. System limits are “gate to gate” with pulping, collector, hulling, and cooperative system units. Based on the identification results, the highest to lowest carbon footprint footprints for each system unit are pulping, cooperative, collector, and hulling with carbon equivalent emission values in a row of 0.214 kg CO_2-e/kg green bean (62.87%), 0.1 kg CO_2-e/kg green bean (29.27%), 0.019 kg CO_2-e/kg green bean (5.47%), and 0.008 kg CO_2-e/kg green bean (2.39%). The high carbon emission in the pulping system unit is due to the presence of waste produced in the form of naturally decomposed liquid waste with a carbon emission value of 0.125 kg CO_2-e/kg green bean. Therefore, the hot spots in this identification is the use of water in the pulping system unit. For continuous improvement, it is necessary to minimize the use of water in the pulping system unit.

Index Terms— carbon footprint, coffee production, semi wet primer processing, gate to gate

1 INTRODUCTION

The life cycle study of the coffee production chain evaluates the environmental impacts caused by primary agricultural and processing activities. The use of chemicals in the form of fertilizers and pest and disease control as inputs in the farm produces indirect and direct emissions. In primary treatment, liquid and solid waste that is mishandled (through combustion and decomposition of organic matter) cause emissions of methane gas and carbon monoxide. Food and agriculture carbon footprints are related to climate change [1]. Agricultural production activities to meet food have contributed to greenhouse gas (GHG) emissions [2]. GHG sources from carbon dioxide (CO_2) and other than CO_2 (for example, methane (CH_4) and nitrogen dioxide (N_2O) derived from plant respiration, decomposition of dead plant biomass, and soil organic matter, and combustion processes. CO_2 emissions also come from land use by humans (eg, management of agricultural land, forest, savanna land, and coastal wetlands) and land use/land cover change (eg, conversion of forest land and savanna land to agriculture). Emission sources other than CO_2 (eg, methane from livestock and paddy fields, nitrogen dioxide from manure and agricultural land stock, and biomass burning.

The calculation of the carbon footprint of coffee production is part of the life cycle analysis (3), which aims to understand the environmental impacts that occur along the production chain and provide a solution to its mitigation. Besides, it seeks to determine the amount of environmental impact (equivalent to CO_2 emissions) on products or formulate optimization of the production process [4]

A carbon footprint study was carried out to analyze the carbon footprint in the Gayo Arabica Coffee production system using a GHG calculation model [3]. In addition to identifying GHG "hot spots" to determine climate change mitigation efforts in the coffee production sector and at the same time, evaluate their impact on the overall production system. Therefore the range of carbon footprint studies is carried out on the activities of farmers, collectors, huller owners, and cooperatives.

RESEARCH METHODOLOGY

Arabica coffee cultivation (*Coffea arabica*) in the Gayo Plateau uses a coffee agroforestry model [5]. Coffee agroforestry includes land-use systems where coffee plants and other plants grow. Plant interactions have a combination of biological, ecological, cultural, agronomic, and social factors [6]. The types of plants in the farm and supporting coffee agroforestry have economic value and provide environmental services [7]. Common types of plants grown with Arabica coffee are lamtoro (*Leucaena glauca*), Gayo Keprok orange (*Citrus reticulata*), Sengon (*Albizia Chinensis*) and Gamal (*Gliricidia sepium*). Lamtoro and Gamal function as permanent shade plants, and Gayo Keprok orange and Sengon function as “economic value” plants [8]. A carbon footprint study of Gayo Arabica coffee production was carried out on agricultural activities in the farm, and primary processing carried out by farmers, collectors, huller owners and cooperative in 2016 (in Fig 1).

- ***Rahmat Pramulya.*** *Faculty of Agriculture, Universitas Teuku Umar, Kampus Alue Peunyareng, Aceh Barat, Aceh, Indonesia. rahmatpramulya@utu.ac.id*
- ***Tajuddin Bantacut, Erliza Noor, Mohamad Yani; D****epartment of Agroindutrial Technology, Bogor Agricultural University, Kampus IPB Dramaga, Bogor, Indonesia.*

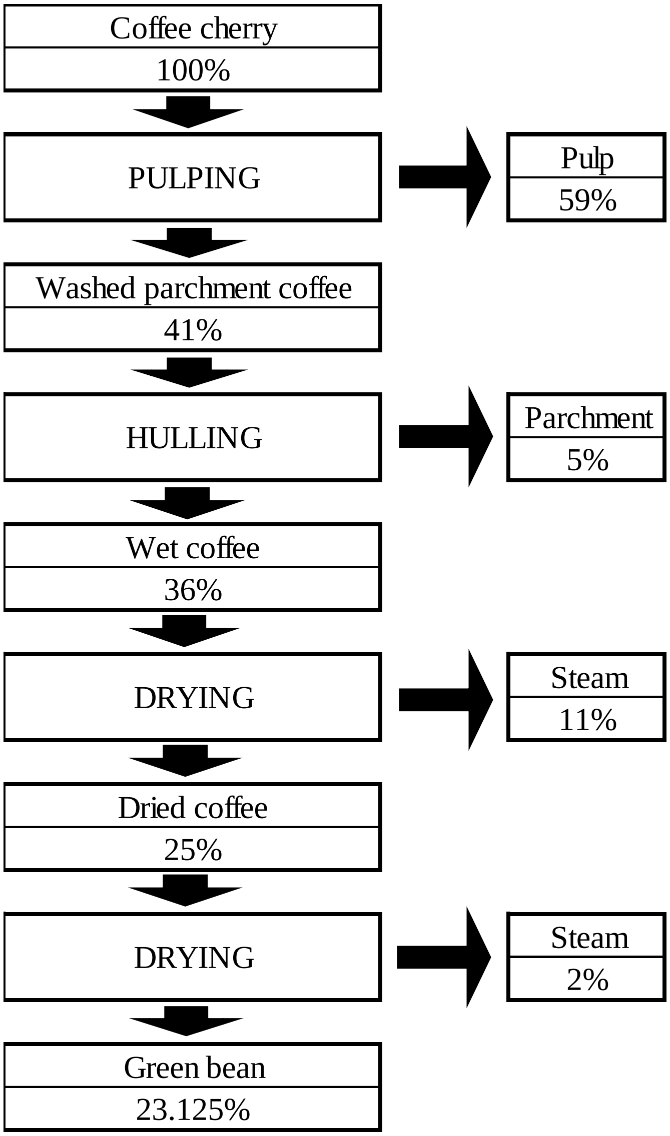

Fig 1. *System boundaries in carbon study studies*

Material change activities throughout the production system produce intermediate products (washed parchment coffee, wet coffee, and dried coffee), waste (parchment and pulp) and water vapor, and green beans. Data collection is carried out at the cooperative production chain, which has members from farmers, collectors, and huller owners. Primary data collection comes from all actors related to primary processing and transportation. Secondary data comes from the kind relating to the purchase of raw materials and electricity needs.

Cherry Coffee (coffee fruit) comes from an area of 4,272 ha. The primary processing of coffee fruit aims to separate the beans from the components of the coffee fruit and ensure the excellent quality of the final product. Techniques must be adequate to protect coffee from undesirable characteristics during the processing (Ferrão, 2009). Coffee fruit has five protective layers that need to be removed to produce coffee beans. From the outside in, the coffee fruit is composed by skin (epicarp or exocarp), pulp (mesocarp), parchment or parchment skin (endocarp), silver skin (or husk), and seeds in the form of ellipses or green coffee beans (green bean).

The primary processing refers to the method used to convert coffee fruits into green beans that are ready for roasting and then mashed to be brewed for consumption. There are three known primary treatment methods, namely dry, wet, and semi-wet processing. A carbon footprint study was conducted on the semi-wet processing method.

Green bean production from coffee fruit components (wet processing) can be seen in Figure 1. **Pulping.** The semi-wet pulping process is the same as the wet processing. The pulping process is carried out by the farmer and the labu coffee (washed parchment coffee) produced will be sold to the collector and the collector will be sold back to the Cooperative.

Drying Stage 1. The drying process is carried out to reduce the water content of labu coffee from 36% to ± 25%. The mass balance in the drying process is indicated that in 1 kg of coffee fruit or 0.6 kg of labu coffee will produce 0.33 kg of dry labu coffee (33%) and 0.07 kg of water vapor (11%). Stage 1 drying is carried out by the cooperative.

Hulling. Semi-wet processing hulling process is the same as wet processing. The difference in mass balance where in semi-wet processing is indicated that in 1 kg of coffee fruit or 0.33 kg of dry labu coffee with a moisture content of ± 27% will produce 0.28 kg of grain coffee (28%) with a moisture content of ± 27% and 0,05 kg parchment skin (5%) with a moisture content of ± 27%. Another difference is that the hulling process is carried out by the cooperative.

Drying Stage 2. The drying process is carried out to reduce the water content of grain coffee from ± 27% to ± 16%. The mass balance in the drying process is indicated that in 1 kg of coffee fruit or 0.28 kg of grain coffee will produce 0.23 kg of green bean (23%) and 0.05 kg of water vapor (5%). Phase 2 drying process is carried out by the cooperative.

Calculation of carbon footprint.

The calculation begins to determine the number of coffee beans, intermediate products, and coffee beans in each primary processing to get a reference so that emissions in each process are distinguished according to the specific source of emissions[9].

Calculation of emissions from each source explains that each activity (for example the amount of fuel) will be multiplied by the related specific emission factors so that the equation becomes:

CO_2 emissions = source of emissions or activity data x emission factors (1)

Equation (1) for calculating emissions from consumption of fossil fuels for machinery and transportation and electricity usage

Carbon emissions from methane (CH4) from the decomposition of organic matter wastewater are calculated based on the equation of the IPCC waste section as follows:

Total organic material that can decompose in wastewater	=	Total industrial products x waste water released x COD (Chemical Oxygen Demand)	(2)
Emission factor	=	Maximum methane production capacity x methane correction factor for handling	(3)
Clean methane emissions	=	(Total organic matter that can decompose in wastewater - discarded sludge) x emission factors)) - recovered CH4	(4)
CO_{2e}	=	Clean methane emissions x (44/16)	(5)

Where number 44 is the molecular weight of CO_2 and number 16 is the molecular weight of CH_4

Emissions due to biomass burning are calculated based on equation (6) of the IPCC energy portion. GHG emissions (CO_2, CH_4, and N_2O) and the magnitude of each emission from biomass combustion are calculated based on equation 7. The emissions of each gas are multiplied by the potential for global warming (Global Warming Potential = GWP) to convert CH4 and N2O emissions to equivalent CO2 values. Then calculation results are accumulated in total as a value of CO2 emissions from biomass burning.

Consumption (TJ)	=	Consumption (mass unit, volume or energy) x conversion factor (TJ/unit)	(6)
CO_2 Emission	=	Consumption (TJ) x emission factor (kg CO_2/TJ)x efficiency factor (0.98)	
CH_4 Emission	=	Consumption (TJ) x emission factor (kg CO_2/TJ)x efficiency factor (0.98)	(7)
N_2O Emission	=	Consumption (TJ) x emission factor (kg CO_2/TJ)x efficiency factor (0.98)	
CO_{2e}	=	CO_2 Emission x 1(GWP) + CH_4 Emission x 25 (GWP) + N_2O Emission x 298 (GWP)	(8)

Stage 3: Calculation of the overall carbon footprint

All emissions in each process are calculated and standardized in kg CO2e. Total amount of coffee beans produced or processed is a representation of the distribution of emissions. The result is the carbon footprint shown in kg CO2e kg-1 green coffee 9).

Carbon footprint = emission/*green coffee*

kg CO_2 kg^{-1} *green coffee* = emisission kg CO_2/*green coffee* produced or processed (9)

RESULTS AND DISCUSSION

Emission Sources

Sources of GHG emissions differ in each coffee production activity [9]. Besides, primary treatment methods lead to different environmental impacts [10]. Emission sources come from farmers, collectors, huller owners, and cooperatives. Emissions of fossil fuels come from the use of transportation along the production chain, lawnmowers, and hullers. Indirect emissions from the use of electricity for operational and administrative activities in cooperatives and water pumping plants. Direct emissions from the decomposition of organic wastewater and pulp from primary processing activities in the garden. Parchment burning combustion emissions occur in huller owners and cooperatives.

The study of carbon footprints at locations and products analyzes direct and indirect carbon emissions based on the level of control. Some of these are direct emissions from sources of emissions in a controlled location (scope 1), indirect emissions from power generation facilities or off-site generating fuel (scope 2) and indirect emissions that occur at the site but cannot control (scope 3) [11].

Table 1 Direct emissions of fossil fuels

Scope 1 Emission										
		Fuel Type	Activity Data	Unit Type	Distance (km)	Emission Factors		kg CO_2	tCO_{2e}	kg CO_{2e}/kg green bean
Direct Emission	Transportation from farmers to collector	Petrol	8,045	L	75	2.1515	kg CO_{2e}/ L petrol	17,308	17	0.005
	Transportation from collector to huller	Diesel	7,460	L	940.95	2.6485	kg CO_{2e}/ L diesel	19,758	20	0.006
	Transportation from huller to collector	Diesel	6,528	L	940.95	2.6485	kg CO_{2e}/ L diesel	17,289	17	0.005
	Transportation from collector to cooperative	Diesel	9,942	L	1919.35	2.6485	kg CO_{2e}/ L diesel	26,331	26	0.008
	Pulper machine	Diesel	14,693,268	kg		0.0029	kg CO_{2e}/ kg CC	42,137	42	0.012
	Huller machine	Diesel	5,877,307	kg		0.0020	kg CO_{2e}/ kg WPC	11,492	11	0.003
	Total Emission								134	
Where	CC: Coffee cherry WPC: Washed parchment coffee									

In the study of carbon footprints of Arabica coffee in the Gayo Plateau, the largest to the smallest direct and indirect emission sources came from electricity (530 tCO2-e), decomposition (477 tCO2-e), use of fuel (134 tCO2-e) and burning biomass (15 tCO2-e).

Direct emissions from the use of fossil fuels for transportation vehicles and machinery, indirect emissions from electricity consumption and indirect emissions from the decomposition of solid and liquid waste, and biomass burning. Direct emissions from the use of fossil fuels for fossil fuels (in full in Table 1) with the highest carbon emissions are generated by transportation from moving coffee beans. It produces 60% carbon emissions from total direct emissions. Another source of emissions is in pulper machine require diesel. Studies in the USA mention the amount of food transportation emissions are smaller than the emissions that occur in primary processing

[12].

The use of fuel in every kilogram of Arabica coffee beans in the Gayo Plateau (0.039 kg CO2-e) produces the lowest carbon emissions than in Tolima, Colombia [13] of 0.43 - 0.75kg kg CO2-e (fuel for engines and vehicles) and Costa Rica [9] of 0.076 kg CO2-e (diesel and gas fuel).

Liquid and solid wastes produced in the pulping process decompose and produce methane and nitrogen dioxide GHGs (More in Table 2). The carbon footprint calculation estimates that the biggest carbon emission (89%) comes from coffee liquid waste. The value of BOD and Nitrogen as a parameter of the process of decomposition of organic matter is a determinant of the number of carbon emissions [14].

Another source of carbon emissions (11%) comes from the process of decomposition of pulp that occurs in the field following the composting process where the remaining skin and pulp of fruit from the pulping process are stored in holes and then piled up. Then, in the harvest preparation season the following year, organic material that resembles compost is removed and farmers use it as organic fertilizer.

Carbon emissions from the decomposition of wastewater and pulp in every kilo gram of green bean coffee beans in the Arabica coffee production system in the Gayo Highlands (0.14 kg CO2-e) are lower than those in Costa Rica [9] of 0.374 kg CO2-e. The difference is likely due to the estimated BOD value and Nitrogen content in the Costa Rica coffee production system.

Table 2. Indirect decomposition emissions

Scope 2 Emission															
		Activity Data	Unit Type	Total BOD and N in Wastewater			Emission Factors			GWP		kg CO_2	tCO_{2e}	tCO_{2e}	kg CO_{2e}/kg green bean
Direct Emission	Decomposition of organic matter in wastewater	29,500,407	L	BOD	0.0043	kg/L	CH_4	0.030	kg CO_{2e}/ kg CH_4	CH_4	25	94,918	94.92	425	0.125
				N	0.0001	kg/L	N_2O	0.251	kg CO_{2e}/ kg N_2O	N_2O	298	330,145	330.15		
	Decomposition of organic matter in pulp	8,702,089	kg					0.006	kg CO_{2e}/ kg pulp			52,213	52	52	0.015
	Total Emission													477	

Where BOD: Biologycal Oxygen Demand
N: Nitrogen

Calculation of a balanced carbon footprint between the use of electricity to drive a pump engine and operational activities - office administration in a cooperative (more complete in Table 3). The amount of water use that is inefficient and the pulping process that still uses a pulper machine that is not technically economically feasible has an impact on electricity usage.

Carbon emissions from electricity usage in every kilo gram of green bean coffee beans in the Arabica coffee production system in the Gayo Highlands (0.156 kg CO2-e) are lower than in Tolima, Colombia [13] of 2.77 - 49.04 kg kg CO2-e and Costa Rica [9] of 0.02 kg CO2-e. The difference in carbon emissions from electricity use is likely due to mixed energy sources where Indonesia still uses diesel fuel and coal as electricity generation.

Table 3. Indirect emissions of electricity usage

Scope 3 Emission								
		Activity Data	Unit Type	Emission Factors		kg CO_2	tCO_{2e}	kg CO_{2e}/kg green bean
Direct Emission	Elecricity for water pump	29,386,535	L	0.0065	kg CO_{2e}/ L water	191,086	191	0.056
	Electricity for all activities at cooperative	390,825	kWh	0.8670	kg CO_{2e}/ kWh	338,846	339	0.100
	Total Emission						530	

The carbon footprint resulting from the burning of the parchment skin (complete calculations in Table 4) is 15 tCO-e. Carbon emissions from biomass burning in every kilogram of green bean coffee beans in Arabica coffee production systems in the Gayo Highlands (0.005 kg CO2-e) are higher than Costa Rica [9] of 0.001 kg CO2-e.

Table 4. Indirect emissions of biomass burning

Scope 4 Emission															
		Activity Data (kg)	Heat Content (mmBtu per short	Consumption (TJ)	Conversion Factors (kg/TJ)		Efficiency factor	Emission (kg CO_2)		GWP		kg CO_2	tCO_2	tCO_{2e}	kg CO_{2e}/kg green bean
Direct Emission	Burning of organic matter in	734,663	10	8	CO_2	100	0.98	CO_2	748	CO_2	1	748	1	15	0.005
					CH_4	30	0.98	CH_4	227	CH_4	25	5,672	6		
					N_2O	4	0.98	N_2O	30	N_2O	298	8,874	9		
	Total Emission													15	

The amount of emissions in each activity.

The carbon footprint of the coffee production system differs between cultivation using chemical fertilizers, compost, manure, and organic fertilizer [3]. Calculations of the overall carbon footprint of the coffee production system with limits from the plantation to the processing stage show carbon emissions of one kilogram of Arabica coffee beans (green bean) in the Gayo Plateau lower (in Table 5) compared to carbon emissions of coffee produced in Costa Rica of 1.93 kg CO2-e [9], Mesoamerica at 6.2 - 10.8 kg CO2-e [15] and Kenya at 4 kg CO2-e [16].

The difference with Costa Rica lies in the use of chemical fertilizers even though the production system on the land applies agroforestry. Besides the use of other chemicals such as pesticides and herbicides. The difference with Mesoamerica also lies in the use of chemical fertilizers. Although using manure and compost, the production system in Kenya still uses chemicals, namely urea fertilizer, for application in the field.

The difference in the amount of carbon emissions in agricultural production systems can be derived from the carbon footprint calculation method. Calculation of carbon footprint between Arabica coffee in the Gayo Highlands and Costa Rica does not differ because it uses the same emission factors and conversion factors for fossil fuel emission sources and biomass burning. The difference lies in the value of the conversion factor for electricity usage in Indonesia and the estimated BOD value and nitrogen content in wastewater.

Table 5. Carbon Footprint of Four Stages of Coffee Production

Aktiftas	CO_{2e} Emissio	
	(kg CO_{2e} / kg green bean)	%
Furmer	0.214	62.87
Collector	0.019	5.47
Huller	0.008	2.39
Cooperative	0.100	29.27
Total	**0.341**	**100**

CONCLUSION

Calculation of the carbon footprint of Arabica coffee production systems in the Highlands succeeded in determining the hot spot of the biggest carbon emission spots in the cultivation activity (the farm stage). The process of decomposition of liquid waste accounts for 65 percent of the total carbon emissions of each green bean coffee bean. However, when compared with Arabica coffee beans from Costa Rica, Mesoamerica and Kenya, the carbon footprint of Arabica coffee in the Gayo Highlands is lower. Differences in the use of emission factors and conversion factors in the calculations cause the amount of carbon emissions in the whole coffee production system to differ from one study to another.

REFERENCES

[1]. Dijkman TJ, Basset-Mens C, Anton A, Nunez M. Chapter 29: LCA of Food and Agriculture. In: Life Cycle Assessment - Theory and Practice. 2018.

[2]. Smith P, Bustamante M, Ahammad H, Clark H, Dong H, Elsiddig EA, et al. Agriculture, Forestry and Other Land Use (AFOLU) Coordinating Lead Authors: Lead Authors. Clim Chang 2014 Mitig Clim Chang Contrib Work Gr III to Fifth Assess Rep Intergov Panel Clim Chang [Internet]. 2014;811–922. Available from: https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_chapter11.pdf

[3]. Bockel L, Schiettecatte LS. Life cycle analysis and the carbon footprint of coffee value chains. In: Philippe Lashermes, editor. Achieving sustainable cultivation of coffee [Internet]. Burleigh Dodds Science Publishing; 2018 [cited 2019 Jul 12]. p. 359–82. Available from: https://www.taylorfrancis.com/books/e/9781351114363/chapters/10.4324/9781351114363-22

[4]. Rega FV, Ferranti P. Life Cycle Assessment of Coffee Production in Time of Global Change. In: Encyclopedia of Food Security and Sustainability [Internet]. Elsevier; 2019 [cited 2019 Jul 12]. p. 497–502. Available from: https://www.sciencedirect.com/science/article/pii/B9780081005965221410

[5]. Mawardi S, Hulupi R, Wibawa A, Yusianto, Wiryadiputra S. Panduan Budidaya dan Pengolahan Kopi Arabika Gayo. Pusat Penelitian Kopi dan Kakao Indonesia. Jember: Pusat Penelitian Kopi dan Kakao Indonesia; 2008.

[6]. Toledo VM, Moguel P. Coffee and Sustainability: The Multiple Values of Traditional Shaded Coffee. J Sustain Agric. 2012;36(3):353–77.

[7]. E M. Guidelines for establishing coffee-agroforestry systems [Internet]. Bogor: World Agroforestry Centre; 217AD [cited 2019 Jul 12]. 146 p. Available from: http://outputs.worldagroforestry.org/cgi-bin/koha/opac-detail.pl?biblionumber=41852

[8]. Manurung M, Khalid, Sukanto, Purbayani D, Armiyadi. Buku Panduan Upaya Peningkatan Produksi dan Kualitas Kopi Arabika Gayo Yang Berkelanjutan. Takengon; 2012.

[9]. Killian B, Rivera L, Soto M, Navichoc D. Carbon Footprint across the Coffee Supply Chain: The Case of Costa Rican Coffee. J Agric Sci Technol B. 2013.

[10]. Giraldi-diaz MR, Medina-salas L De, Castillo-gonzales E, Cruz-benavides MD la. Environmental Impact Associated with the Supply Chain and Production of Biodiesel from Jatropha curcas L . through Life Cycle Analysis. 2018;

[11]. Robin K. Carbon footprinting. In: Energy Management in Plastics Processing. 3rd ed. Elsevier Ltd; 2018. p. 387–404.

[12]. Weber CL, Matthews HS. Food-Miles and the Relative Climate Impacts of Food Choices in the United States. Environ Sci Technol [Internet]. 2008 May [cited 2019 May 22];42(10):3508–13. Available from: https://pubs.acs.org/doi/10.1021/es702969f

[13]. Andrade HJ, Segura MA, Canal DS, Feria M, Alvarado JJ, Marín LM, et al. Chapter 3. The carbon footprint of coffee production chains in Tolima, Colombia. In: Sustainable agroecosystems in climate change mitigation. 2014.

[14]. Selvamurugan M, Doraisamy P, Maheswari M, Nandakumar N. High rate anaerobic treatment of coffee processing. Iranian J Environ Health Sci Eng. 2010;7(2):129–36.

[15]. van Rikxoort H, Schroth G, Läderach P, Rodríguez-Sánchez B. Carbon footprints and carbon stocks reveal climate-friendly coffee production. Agron Sustain Dev. 2014;34(4):887–97.

[16]. Maina JJ, Mutwiwa UN, Kituu GM, Githiru M. Evaluation of Greenhouse Gas Emissions along the Small-Holder Coffee Supply Chain in Kenya [Internet]. Vol. 2, Open Access Journal Journal of Sustainable Research in Engineering. 2015 [cited 2019 Jul 12]. Available from: http://sri.jkuat.ac.ke/ojs/index.php/sri/article/view/359