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 CO₂, N₂O and CH₄ 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 objectives 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, 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 CO₂-e/kg green bean (62.87%), 0.1 kg CO₂-e/kg green bean (29.27%), 0.019 kg CO₂-e/kg green bean (5.47%), and 0.008 kg CO₂-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 CO₂-e/kg green bean. Therefore, the hotspot 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 garden causes direct carbon dioxide emissions. In primary treatment, liquid and solid waste that is handled improperly (through combustion and decomposition of organic matter) causes 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 (CO₂) and other than CO₂ (for example methane (CH₄) and nitrogen dioxide (N₂O) derived from plant respiration, decomposition of dead plant biomass and soil organic matter, and combustion processes. CO₂ emissions also come from land use by humans (eg management of agricultural land, forest, savanna land and coastal wetlands) and transfer of land use/land cover (eg conversion of forest land and savanna land to agriculture). Emission sources other than CO₂ (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. In addition, it aims to determine the amount of environmental impact (equivalent to CO₂ emissions) on products coffee 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 in cooperatives.

RESEARCH METHODOLOGY

Gayo arabica coffee production system. 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]. Jenis tanaman dalam kebun dan lanskap agroforestri kopi memiliki nilai ekonomi dan memberikan jasa lingkungan [7]. Common types of plants grown with Arabica coffee are lamtoro (Leucaena glauca), Gayo Keprok orange (Citrus reticulata), Sengon (Albizia chinensis) and Gamal (Gilicidia 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, primary processing carried out by farmers, collectors, huller owners and cooperative in 2016 (in Fig 1).
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:

\[
\text{CO}_2 \text{ emissions} = \text{source of emissions or activity data x emission factors (1)}
\]

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:

\[
\text{Total organic material that can decompose in wastewater} = \text{Total industrial products x wastewater - discarded sludge x Emission factors)}
\]

Where number 44 is the molecular weight of CO2 and number 16 is the molecular weight of CH4.

Emissions due to biomass burning are calculated based on equation (6) of the IPCC energy portion. From biomass combustion, GHG emissions (CO2, CH4 and N2O) out and the magnitude of each emission are calculated through equation 7. To convert CH4 and N2O emissions to equivalent CO2 values, the emissions of each gas are multiplied by the following factors:

- CO2 emissions = (CH4 x 2.2) + (N2O x 310)
- CH4 emissions = CO2 emissions x (44/16)
- N2O emissions = CO2 emissions x (152/16)

Decomposition of organic matter wastewater is calculated as follows:

\[
\text{Carbon emissions from methane (CH4) from the decomposition of organic matter wastewater} = \text{Emission factor x (Total organic matter that can decompose in wastewater)}
\]

Where number 44 is the molecular weight of CH4.
potential for global warming (Global Warming Potential = GWP) and the calculation results are accumulated in total as a value of CO2 emissions from biomass burning.

$$\text{Consumption (TJ)} = \text{Consumption (mass unit, volume or energy)} \times \text{conversion factor (TJ/unit)}$$  \hspace{1cm} (6) \\

$$\text{CO}_2\text{Emission} = \text{CO}_2\text{Emission (TJ)} \times \text{emission factor (kg CO}_2\text{TJ)x efficiency factor (0.98)}$$  \hspace{1cm} (7) \\

$$\text{CH}_4\text{Emission} = \text{CH}_4\text{Emission (TJ)} \times \text{emission factor (kg CO}_2\text{TJ)x efficiency factor (0.98)}$$  \hspace{1cm} (7) \\

$$\text{N}_2\text{O Emission} = \text{N}_2\text{O Emission (TJ)} \times \text{emission factor (kg CO}_2\text{TJ)x efficiency factor (0.98)}$$  \hspace{1cm} (7) \\

$$\text{CO}_2\text{eq} = \text{CO}_2\text{Emission x 1(GWP)} + \text{CH}_4\text{Emission x 25 (GWP)} + \text{N}_2\text{O Emission x 298 (GWP)}$$  \hspace{1cm} (8)

Stage 3: Calculation of the overall carbon footprint

Emissions in each process are calculated as a whole and are standardized in kg CO2e. Emissions are divided into the total number of coffee beans produced or processed. The result is a carbon footprint shown in kg CO2e kg-1green coffee (equation 9).

Carbon footprint = emisi/green coffee

$$\text{kg CO}_2\text{kg}^{-1}\text{green coffee} = \text{emisi kg CO}_2/\text{green coffee produced or processed}$$  \hspace{1cm} (9)

RESULTS AND DISCUSSION

Emission Sources.
Sources of GHG emissions differ in each coffee production activity [9]. In addition, 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 vehicles moving coffee beans in a production system that 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]. Carbon emissions from the use of fuel in every kilo gram of coffee beans produced by primary processing (known as green beans) in Arabica coffee production systems in the Gayo Plateau (0.039 kg CO2-e) are lower than in Tolima, Colombia [13] amounting to 0.43 - 0.75kg kg CO2-e (fuel for engines and vehicles) and Costa Rica [9] of 0.076 kg CO2-e (diesel fuel and gas). 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 amount 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.
Calculating the 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 kilogram 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.

The carbon footprint resulting from the burning of the parchment skin (complete calculations in Table 4) is 15ICO-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.

The amount of emissions in each activity. 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 2. Indirect decomposition emissions

<table>
<thead>
<tr>
<th>Activity</th>
<th>Unit Type</th>
<th>Scope 3 Emission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decomposition of organic matter in</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>Direct</td>
<td>BOD</td>
<td>29,954.807</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>0.019</td>
</tr>
<tr>
<td></td>
<td>Total Emission</td>
<td>5221.6</td>
</tr>
</tbody>
</table>

### Table 3. Indirect emissions of electricity usage

<table>
<thead>
<tr>
<th>Activity</th>
<th>Unit Type</th>
<th>Scope 3 Emission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity for water pump</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>Direct</td>
<td></td>
<td>29,386,535</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.065</td>
</tr>
<tr>
<td></td>
<td>Total Emission</td>
<td>191,086</td>
</tr>
</tbody>
</table>

### Table 4. Indirect emissions of biomass burning

<table>
<thead>
<tr>
<th>Activity</th>
<th>Unit Type</th>
<th>Scope 3 Emission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burning of organic matter in</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>Direct</td>
<td></td>
<td>754,565</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
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</tbody>
</table>

**Table 5. Carbon Footprint of Four Stages of Coffee Production**

<table>
<thead>
<tr>
<th>Aktiftas</th>
<th>CO₂ Emission</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Furmer</td>
<td>0.214</td>
<td>62.87</td>
</tr>
<tr>
<td>Collector</td>
<td>0.019</td>
<td>5.47</td>
</tr>
<tr>
<td>Huller</td>
<td>0.008</td>
<td>2.39</td>
</tr>
<tr>
<td>Cooperative</td>
<td>0.100</td>
<td>29.27</td>
</tr>
<tr>
<td>Total</td>
<td>0.341</td>
<td>100</td>
</tr>
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</table>

**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 garden 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 Highways 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.

**DAFTAR PUSTAKA**


