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Carbon Footprint of the Coffee Roasting Process Based on Two Technologies with Different Sources of Energy in Peru

María de los Ángeles Franco[1], Karin Bartl[2]

Abstract

The objective of this study was to determine and to compare the Carbon Footprint (CF) of the coffee roasting process carried out by using two technologies with different sources of energy. To this aim, two coffee roasting companies were selected in the rainforest of Peru. These companies apply concentrated solar and photovoltaic energy, and electricity from the local grid as source of energy during the coffee roasting process. For this determination, primary data was collected from the two companies located in the province of Satipo, Junin, Peru. The information obtained was analyzed according to the procedures and requirements of ISO 14040 (Life Cycle Analysis) to obtain the carbon footprint, and then processed with the software "SimaPro" to evaluate the environmental impacts due to the effect of climate change. The results indicated a CF of the solar energy roasting process of 0.318 and a CF of the local electricity grid production of 0.744 kg CO2-eq per kg of roasted coffee. This represents a difference in greenhouse gases (GHG) emissions of 134%. Within the factory activities, the stage with the highest environmental impact or "hotspot" was the roasting stage, where the most sophisticated machines are used and generated emissions from the combustion of fossil fuels. From this, proposals and recommendations to improve the strategies include an approach to clean technologies for a sustainable development in the sector, among others.

Keywords: LCA, Carbon Footprint, Roasted Coffee, Renewable Energy, Photovoltaics, Concentrated Solar Energy

1. Introduction

Coffee is the main agricultural export product in Peru. It accounts 85% of the total crop exports and it is already delivered to 48 countries (Huerta- Mercado, 2012). Also, coffee has a very important role in the national economy. This commodity is the main livelihood of about 223,000 families from small producers in 425,000 hectares distributed in 17 regions (Agencia Andina, 2016).

Junin coffee production represents roughly 27% of the national production and it is now considered the most important coffee producing region of the country (The World Bank, 2016). In Satipo, a province in the region of Junin, coffee production accounts roughly 90% of its GDP. In this region, Chanchamayo and Satipo provinces perform this activity at a massive level, where 50% of its arable land is coffee (CRS, 2005). Also, national production shares from Satipo and Chanchamayo account 10% and 17%, respectively (The World Bank, 2016).

From the other side, there is enough scientific based evidence that shows climate sensitivity on coffee in terms of coffee suitability, yield, pests, diseases and farmers livelihood (Laderach, P. et al, 2017). For instance, a minimum variation in temperature of half a degree can make a big difference in coffee yield, flavor and aroma. This will turn

[1]Università degli Studi di Udine, Italia
[2]Pontificia Universidad Católica del Perú

into negative effects at the level of development in the coffee producing countries, and it will make difficult to respond to the global demand for this product (Watts, C.; 2016).
In Peru, the increase of temperatures and unpredictable weather patterns are changing historic trends in coffee growing areas. Crops lifespan is becoming shorter and farmers are reporting that the current typical behavior and maturing of coffee trees are tending to be at high-altitude than their low land counterparts. Also, floods, landslides and stronger winds are constantly damaging infrastructure and coffee plantations (ITC, 2016).
This decay of the coffee production is often addressed due to climate change events. For instance, considering that water is the most important input in coffee cultivation, rains are no longer predictable and these often appear when these are not required. Also, coffee productivity is not consistent (Gestión, 2012).
In response to this situation, the coffee sector is promoting solutions based on the transition to a sustainable low-carbon economy. For example, companies in the sector are implementing mitigation and adaptation strategies, which include the compliance with sustainability standards and certifications, the use of clean technologies and renewable energy, among others (Dominguez, S.; 2016). Within this path, mitigation strategies involving such as the implementation of clean technologies in the sector will contribute to the reduction of environmental impacts and will provide services to the habitants of the area (UNDP, 2012; Powermundo, 2016).
The present study aims to estimate and to compare the Carbon Footprint of the Coffee Roasting process that is performed with two technologies with different sources of energy following the Life Cycle Assessment (LCA) methodology. One company that is located in a rural rain forest area uses solar energy and solar concentrated energy, and the other company that is located in an urban area performs its activities with energy that comes from the local grid. Even though the company with clean energy based technology is one of the very few examples in the Peruvian coffee sector, insights and recommendations are brought in the behalf of the sector within a low-carbon economy.

2. Methodology

For this determination, primary data was collected from the two companies located in the province of Satipo, Junin, Peru. The information obtained was analyzed according to the procedures and requirements of ISO 14040 (Life Cycle Analysis) (see Figure 1).

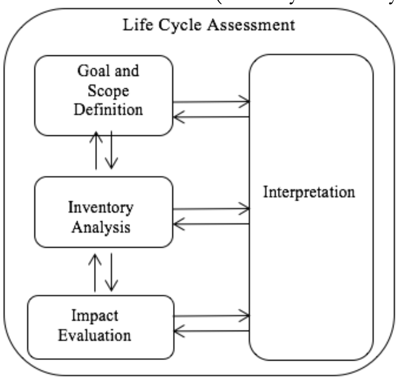

Figure 1.- Life Cycle Assessment Framework. (Source: own construction).

This management tool, which will be used in this study for environmental purposes, has the objective to identify the opportunities within the life cycle of a product or service, to reduce the consumption of non-renewable resources, the emissions and environmental impacts, to improve the performance of the processes involved, among others (Dantes, 2016; Tree). Later, the information gathered is processed with the software "SimaPro" to evaluate the environmental impacts due to the effect of climate change that will turn into the Carbon Footprint (CF).
The use of the LCA includes four main phases that will be develop in the present study: Definition of the Goal and Scope, where the limits of the study system are defined and the functional unit is determined. The inventory analysis, which consists of the collection and quantification of inputs and outputs of the product or service throughout its life cycle.
Then, the impact evaluation, which assess and quantifies the magnitude and significance of the impacts that occur in the water, in the soil, and/or in the air. Also, the impact categories to be analyzed are chosen (eutrophication, acidification, toxicity, etc.) here. Finally, the interpretation phase, where the conclusions and recommendations are generated for a further improvement within the systems analyzed (PRé Sustainability).

2.1 Scope

The scope of the current study is gate to gate. The activity assessed is the Coffee Roasting process that includes three stages: Selection, Hulling and Roasting. The following diagram corresponds to the Process of roasted coffee production based on two different roasted technologies that use different energy source (see Figure 2).

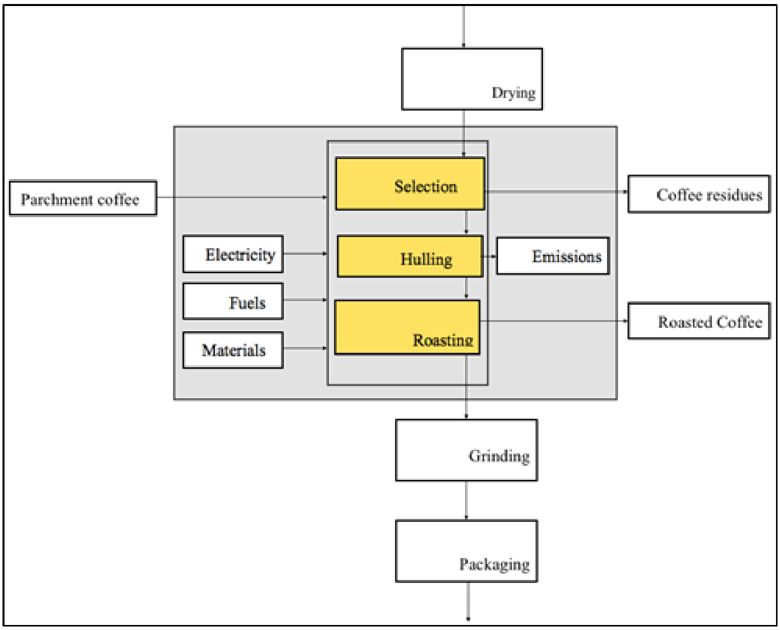

Figure 2.- The scope of the study is presented within the grey rectangle. It includes the inputs and outputs already mentioned. Also, the yellow rectangles are the stages assessed in the current study (Source: own construction).

The functional unit defined for this study was one kilogram of roasted coffee medium degree. Therefore, the results of the carbon footprint are presented as kilograms of carbon dioxide (CO2-eq) per one kilogram of roasted coffee (kg CO2-eq/kg roasted coffee).
Data collection was performed during the month of July 2017 in a visit field to the companies based in Satipo, Junin. Also, phone calls were made. Data corresponds to the frame time of June 2016 to June 2017. Some important inputs are located into chart 1.

Chart 1.- Main information of the two companies assessed *(Source: own construction)*.

Company	Solar Energy based	Local Electricity Grid based
Location	Rural area, rain forest	Urban area
Energy source	Photovoltaic, Concentrating Solar	Electricity, LPG
Annual production of roasted coffee (kg)	705.4	1772.1
Roasted coffee medium degree production (%)	100	70
Material based stages	Hulling, Roasting	Selection, Hulling, Roasting

2.2 Inventory

Inputs are electricity, fuels and materials for the equipment and facility. Outputs are coffee residues (e.g.: coffee defects) and emissions from the fuels used. Also, production of this materials and electricity generation are included based on a Peruvian average (see Figure 2).
For the Carbon Footprint calculation, SimaPro and Eco Invent database was used. Within this library, some assets that came out into the current study were not identified. To provide a solution, technologies were disaggregated into the most representative parts (steel, aluminum, mirror, as photovoltaic panels, batteries, LPG, among others). Within this process, inputs were modeled depending on the lifetime of the technology that are part and of the quantity of raw coffee that pass through these assets.
Moreover, only the main material of the technologies that were modeled is considered in the current study. The lifetime required for the calculation of the material flow corresponds to the whole technology. Also, to estimate the carbon contribution of the fuels used within this study, carbon dioxide emissions coefficients were identified following literature about the calculation of GHG emissions (Oficina Catalana del 'Camvi Climàtic, 2011).

3. Results

1. Carbon Footprint of the Coffee Roasting Process
The results indicated a CF of the solar energy roasting process of 0.318 and a CF of the local electricity grid production of 0.744 kg CO2-eq per kg of roasted coffee. This represents a difference in greenhouse gases (GHG) emissions of 134%.

Also, Energy Generation inputs are the most intensive contributors in both processes. From a Solar Energy based production, the production and distribution of main materials of the Solar Concentrator and the PV System accounts 0.252 kg CO2-eq/kg roasted coffee and represents 79% of the total CF (see Figure 3).

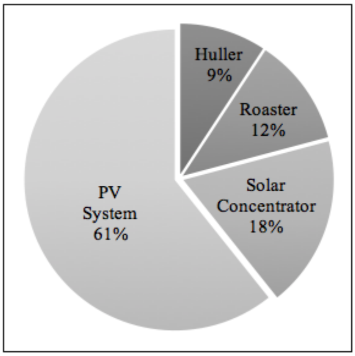

Figure 3.- Carbon Contribution in Solar Energy Roasted Coffee Production (Source: own construction).

From the other side, Energy Generation inputs from the Local Hydropower Electricity Grid accounts 0.724 kg CO2-eq/kg roasted coffee and represents 97% of the total carbon contribution of this process. An LPG fuel emissions input, which only accounts in this second local grid energy process, accounts 0.586 kg CO2-eq and represents 79% of the CF. This is due to the combustion of LPG fuel during the roasting stage for heating the drum.

Production of main materials for technologies in the all the process does not impact significantly (less than 3% in total). There, the Energy Generation input based on hydropower energy accounts 18% of the total carbon contribution. This includes electricity production and distribution from the local grid, and LPG production. Therefore, the largest contribution within this process is due to the emissions generated within the LPG combustion for the thermal energy production used in the roasting stage (see Figure 4).

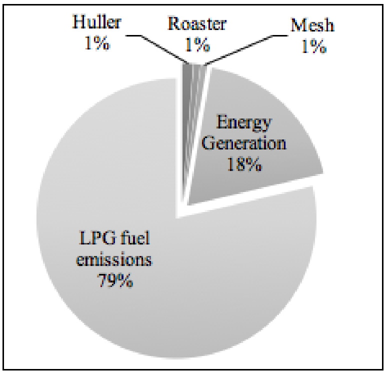

Figure 4.- Carbon Contribution shares of Local Hydropower Electricity Grid based Production (Source: own construction).

2. Carbon Contribution in Electricity Grid Roasted Coffee Production

Energy production in Junin is almost 100% hydropower source. There exists a negligible participation of thermal energy production that will not be considered in this assumption (INEI, 2014).

However, "peak hours", which means a large amount of energy consumption in the region in specific periods of time during the day, promote thermal energy production to fulfill this demand. This variation between energy shares is unknown. Due to this context, the system mentioned before will be assessed within two different scenarios: energy input as 100% Hydropower source and Peruvian Electricity Mix source.

The exchange of Local Hydropower Electricity Grid to the Peruvian Electricity Grid within the coffee roasted production varies from 0.744 to 0.801 kg CO2-eq and represents a 7% increase in the total carbon contribution (see Figure 5).

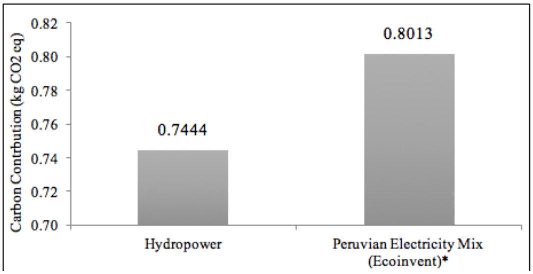

Figure 5.- Carbon Contribution in Electricity Grid Roasted Coffee Production with different Energy Matrix (Source: own construction).

From the other side, the energy consumption assessment was performed with the EcoInvent database. There, the Peruvian electricity matrix available was from the year 2008 and had the following electricity generation (Caceres, A., 2016) (see Figure 6).

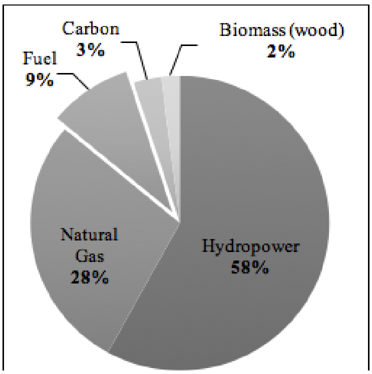

Figure 6.- Peruvian Energy Matrix in 2008. (Source: Cáceres, A.; 2016)

Between 2008 and 2016, the reduction of energy generation from fossil fuels was about 9%. The Peruvian energy matrix has kept the contribution of hydropower and thermal

energy as main sources of electricity in the country (95.5% by June 2016). This points to an advantage in environmental terms due to the country's natural geographical conditions (IBD, 2010).
Into this perspective, investment for electricity generation based on clean energy sources such as Eolic, Solar, Geothermal, Biomass and others are being promoted along the country. By June 2016, the contribution of this clean energy sources accounted roughly 4% of the total energy generation. This is a very important point of start considering that clean energy participation by December 2011 was less than 1% (PCR, 2016) (see Figure 7).

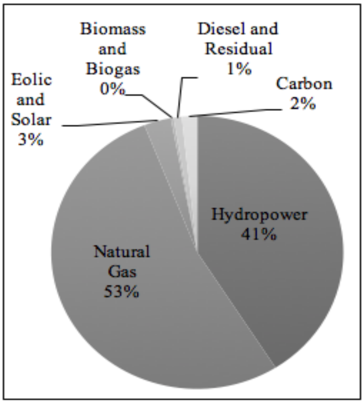

Figure 7.- Peruvian Energy Matrix in November 2016 (Source: Delta Volt, 2017).

3. Carbon Contribution in Roasted Coffee Production Facilities
The facilities of the production of roasted coffee by Solar Energy are of material of way, whereas the installations of the process by Electricity coming from the Local Network are of concrete.
The facility input in the Solar Energy based production represents 30% of the carbon contribution of this process stated in figure 18. This accounts 0.135 kg CO2-eq and is the second largest contribution after the PV system with 0.193 kg CO2-eq and a share of 43% within the whole process.
From the other side, the facility input in the local grid electricity generation roasted coffee production accounts just 5% of the carbon contribution of this process stated in Chart 2.

Chart 2. Carbon Contribution in Roasted Coffee Production (Source: own construction).

Type of Production	Carbon Contribution (kg CO_2-eq)	Carbon Contribution + Facility (kg CO_2-eq)
Solar Energy based	0.3178	0.4529
Local Hydropower Electricity Grid	0.7444	0.7857

4. Conclusions

1. The current study showed that the Local Hydropower Electricity Grid Roasted Coffee Production accounts the most intensive production process with 0.744 kg of roasted coffee versus 0.453 kg CO2-eq emitted in the Solar Energy based Roasted Coffee Production. This 139% difference is mainly because the use of LPG fossil fuel that

contributes to a 79% of the carbon contribution.
Across the coffee roasting process, the highest volumes of greenhouse gases are produced during the roasting stage due to the combustion of fuel for heating purposes. As a result, the main focus of the companies involved should be to improve their environmental performance in this stage. Then, different solutions can be considered, such as a change of energy matrix, a shift to more sustainable fuels, an improvement in efficiency in the process, as well as a shift to more sustainable technologies.
2. The material based facility can increase the carbon contribution from 5 to 30%. Even though facilities have a considerable impact, these are not linked to roasting technology. Thus, facilities should not be included when comparing roasting technologies.
3. The selection of Peruvian Energy Matrix for Electricity Generation does not have a major effect on the results. This is due to the important contribution of the hydropower energy source within the Peruvian energy matrix (Catholic Relief Services, 2005).

5. Discussions

1. Carbon Footprint, one of the indicators of the Life Cycle Assessment methodology helps us to make decisions on how to improve our environmental performance. Moreover, the the facility of communication and the understanding by the public is the main advantage of this impact category compared to a full LCA. Thus, the Carbon Footprint tool is also considered a marketing tool for manufacturing industries not only to show their commitment to reduce the environmental impact, but also to highlight the sustainability of their products (UNESCO, 2012).
2. Research on LCA and Carbon Footprint at a roasting level is often less likely to be developed since the cultivation stage accounts about 70% of the carbon contribution in the whole life cycle coffee production process. That stage includes agricultural inputs and emissions that affect directly biodiversity, water bodies and land erosion. However, there are other examples that provide results where inputs such as electricity consumption and fossil fuel are considered. Within this path, roasting stage accounts from a negligible value up to 6% of the total carbon contribution in its whole life cycle (BALAS, 2012; Pilotprojekt Deutschland, 2008; ITC, 2012 and Salomone, R.; 2003). Nevertheless, studies like the present research allow the recognition of these initiatives towards the reduction of environmental impacts in the sector as a mitigation strategy to tackle climate change.

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