Life cycle analysis (LCA) of the production of wood waste briquettes from *Pinus* spp.: Case study San Francisco Pichátaro, México.

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Abstract. This study shows a life cycle analysis (LCA) of the production of briquettes from wood residues of *Pinus* spp. in an indigenous community in Mexico. The analysis was carried out considering one Mega Joule (1MJ) of heat as a functional unit, including mainly environmental sustainability indicators, through the Life Cycle Analysis (LCA), and generating environmental impact scenarios for the functional unit by: a) comparing the carbon footprint using solar drying and firewood drying in the production of briquettes and (b) comparing the carbon footprint of the heat obtained by the briquettes from both previous systems with heat obtained from liquefied petroleum gas (LP gas) and firewood. The results show that solar-dried briquettes have the lowest carbon footprint, and more than 80% of the emissions are biogenic, making it an excellent choice as a clean and renewable energy source. In addition, the methane emissions from LP gas is much higher than emissions from briquettes, but the carbon monoxide (CO) and particulate matter (PM$_{2.5}$) emissions are lower. This methodology applied to the production process will help decision-making in the creation of a micro-enterprise for the generation of solid biofuels in rural communities in Mexico.

1. Introduction

Currently, the use of wood waste for the generation of thermal energy has taken great interest worldwide and the case of Mexico is no exception [1]. Bioenergy as a renewable energy source that comes from wood biomass, has the advantage of being flexible for the production of solid, liquid and gaseous fuels. In particular, the use of this biomass in the generation of solid biofuels could represent a sustainable energy alternative; one of the products with the greatest potential are briquettes, biofuels (generally of lignocellulosic origin) formed by compaction at high thermal temperatures, which in some cases use a natural binder [2].

Some investigations [3], mention that the large amount of waste generated by the wood industry, in the form of sawdust, shavings, trimmings and coasters, could be used as solid biofuels and be used in
the energy consumption matrix, generating low environmental impact with minimal cost[4]. These solid biofuels for heat production are used all over the world, mainly for domestic heating in small biomass boilers [5], therefore, its characterization during the production processes is important. There are methodologies to evaluate the environmental impact of the production process of these fuels, one of the most used methodologies is the life cycle analysis (Life Cycle Assessment, LCA), which allows identifying the relevance of production and its socioeconomic effects [6,7].

The present study shows a dimensional analysis of the environmental loads generated by the process of transformation of wood waste, of the indigenous community of San Francisco Pichátaro, Mexico, for the production of briquettes on a small scale, through the analysis of the life cycle; Furthermore, as comparison, the environmental impacts of briquettes with other fuels commonly used in the same community (Liquid petroleum LP-Gas and firewood) have been estimated.

2. Materials and Methods

For the purposes of the study, the functional unit has been established as 1 Mega Joule (1MJ) of heat. In addition, the carbon footprint and carbon monoxide (CO), methane (CH₄) and particulate matter (PM₂.₅) emissions of the briquettes from both systems were compared with heat obtained from LP gas and firewood from the same community. Also, 4 analysis scenarios have been established derived from the obtained results, which originate from the generation of the functional unit (1MJ generated): 1) heat generated by briquettes obtained with solar dehydration, 2) heat generated by briquettes obtained with dehydration with firewood, 3) heat by LP gas, 4) heat generated by firewood. The study was carried out in accordance to the Life Cycle Analysis (LCA) methodology, normalized and standardized by the “International Standards Organization” ISO 14040.

2.1. System function

The study area was the indigenous community of San Francisco Pichátaro (Latitude 19.55, Longitude -101.8) located in the state of Michoacán, Mexico[8]. One of the main end uses of biomass is to generate heat energy. Briquettes can satisfy this need, for this reason, the focus of the analysis is the use of heat for cooking food, for which the LCA methodology was used with the Open LCA® software, freely accessible. This analysis adheres to the ISO 14040 standard, which encompasses the reference framework and the principles of LCA, as well as the ISO 14044 standard itself that describes the requirements and the guide to develop the stages that incorporate the previous standard. From the stages of the life cycle, the focus of the analysis is called "from the grave to the grave", that is, the life of system "2" begins with residues from another system "1". System 1 is the activity of carpentry and elaboration of artisan furniture in the study community. System 2 consists of taking advantage of the waste from system 1 for the manufacture of briquettes, finally this leads to production and use (combustion), when the useful life of the product ends. The production of briquettes was studied in two possible ways: solar drying and drying in a wood oven, with their entrances and exits, and their final use (combustion) for the generation of 1MJ of heat is also indicated.

2.2. Inventory Analysis

The data were obtained from previous fieldwork investigations in the study community [9], as well as data measured in situ. Data were also obtained from the National Institute of Ecology and Climate Change (INECC, Mexico) [10] and from the OpenLCA “Secondary data” database. The calculations were made in consideration of theoretical assumptions (Table 1 and 2), and the guidelines indicated by the ISO 14040 standard.

| Table 1. Theoretical assumptions for life cycle assessment. |
|-----------------|----------------|-------------|
| Assumption       | Value          | Reference   |
| Briquettes calorific value (MJ/kg) | 18.3           | (1)         |
| Briquettes combustion CO₂ emission factor (kg CO₂/kg) | 0.309          | (1)         |
Table 2. Life cycle inventory in stages.

| Harvestphase                      |   |
|-----------------------------------|---|
| Transport (km)                    |  5 |
| Consumed Fuel (l)                | 0.41|

| Densificationphase                |   |
|-----------------------------------|---|
| Sawdust (g)                       | 300|
| Cornstarch (g)                    | 260|
| Water (g)                         | 1000|
| Mechanical energy (kj)            | 1  |

| Dryingphase                       |   |
|-----------------------------------|---|
| Scenariodryingwithfirewood:       |   |
| Firewood (kg)                     | 35.5|

| Solar drying scenario             |   |
|-----------------------------------|---|
| Solar energy (hours)              | 40 |
| % final moisture briquettes       | 12 |

| Distributionphase                 |   |
|-----------------------------------|---|
| Transport (km)                    | 5  |
| Consumed Fuel (l)                 | 0.41|

2.3. Proposed system

The proposed system for life cycle analysis is shown in figure 1.
Figure 1. Scheme of the briquette production system

a) Collection phase and transport to the processing site
In this stage, an average of 18 residual sawdust and shavings 7-kg sacks are transported to the collection and transportation site with a 4-cylinder Nissan pickup truck an average of 5 km away.

b) Densification phase
In this phase, the base mixture of sawdust, cornstarch and water is made and it is compressed under pressure with human mechanical force, from which 4 briquettes with high humidity are obtained.

c) Drying phase
The briquettes must lose moisture to concentrate their calorific value, this can be done using a solar dryer or using firewood.

d) Distribution phase
The briquettes are taken home where they will be used in improved stoves. For this study, the evaluation of impacts was referred to the category of global warming. CO₂ emissions were evaluated for scenarios 1, 2, 3 and 4.

e) Usage phase
In scenarios 1, 2 and 4 the briquettes are used in a stove where there is an \( \eta = 0.4 \) according to equation 1. Scenario 3 considers the generation of 1 MJ of heat produced with LP Gas according to the database from OpenLCA "Secondarydata".

\[
Eu = Ee \times \eta \quad \text{where} \quad Eu = 1 \text{MJ} \quad \eta = 0.4
\] (1)

Where \( Eu \) is the useful energy; \( Ee \) represents the input energy and \( \eta \) the efficiency of the stove.

3. Results and Discussion

3.1. Comparative analysis of CO₂ emissions from drying with solar energy vs drying with firewood. (Scenarios 1 and 2).
CO₂ emissions in scenario 1 are lower than scenario 2 with 51g and 249g respectively, as shown in Figure 2, this is mainly due to the use of firewood for drying.
3.2. \( \text{CO}_2 \), \( \text{CO} \), \( \text{CH}_4 \) and \( \text{PM}_{2.5} \) emissions for scenarios 1, 2, 3 and 4

For scenarios 1 and 2 the biogenic emissions are 42g and 243g of \( \text{CO}_2/MJ \) and the \( \text{CO}_2 \) emissions of 7g \( \text{CO}_2/MJ \), for scenarios 3 and 4 are 99g of \( \text{CO}_2 \) and 257g biogenic \( \text{CO}_2 \) respectively. The results found in scenarios 1 and 2 are in a range close to some investigations[11], comparing different models for the production of briquettes, where 39g of \( \text{CO}_2 \) and 121g of biogenic \( \text{CO}_2 \) were found. However, this study differs in techniques and context from the study site.

- CO emissions were 1.6g for both scenarios 1 and 2, and 0.05g and 5.42g for 3 and 4 respectively.
- \( \text{CH}_4 \) emissions were 31 mg for both scenarios 1 and 2, and 107mg and 118mg for 3 and 4 respectively.
- \( \text{PM}_{2.5} \) emissions were 164 mg for both scenarios 1 and 2, 3.96mg and 469mg for 3 and 4 respectively.

The respective analyzes can be seen in Figure 3.

The emissions of \( \text{CO}, \text{CH}_4 \) and \( \text{PM}_{2.5} \) can be observed in Figure 4.
4. Conclusions
This study applied the LCA methodology to evaluate the environmental impacts of the life cycle of the drying process of briquettes from wood waste from a study community in Mexico. The results show that briquettes represent a sustainable energy alternative when dried with solar energy since they have the lowest carbon footprint, and more than 80% of the emissions are biogenic, which makes it an excellent option as a source of clean energy, and renewable. In comparison, using firewood to dry briquettes results in a higher biogenic carbon footprint than using firewood directly to obtain the same amount of heat; however, the residual heat from a stove could be used to dry briquettes as an optimization strategy. But the methane emissions from LP gas are much higher than those generated by briquettes, but the CO and PM$_{2.5}$ emissions are lower. That is why the production chain and the drying of briquettes with solar energy for this research is more environmentally friendly than LP gas and is favorable compared to other types of solid fuels found in the same community such as Pinus firewood and Quercus. The production stage dominated most of the categories of environmental impacts, with the most significant potential for environmental improvements in this stage being the reduction of electricity consumption and that the device to produce the briquettes does not use electrical energy. Actions to include biomass with modern technologies in the Mexican energy system are so far isolated and insufficient, currently there are no specific policies or programs to promote the use of solid biomass in the cogeneration of electrical energy or its clean and efficient use in the sectors industrial and commercial; But these alternatives diversify the consumption matrix and offer energy security and resilience.

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