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Assessment of the Energy Potential of Agricultural Residues in Non-Interconnected Zones of Colombia: Case Study of Chocó and Putumayo

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The non-interconnected zones (ZNI, for its initials in Spanish) of Colombia correspond to regions that are not connected to the national system of generation and transmission of electricity. They are characterized by low population density and long distance from urban centers with difficulty access. However, in these regions there are a wide availability of resources in residual biomass from agricultural, industrial and forestry activities, which are not being given proper and productive use. The objective of this research was to evaluate the energy potential of crop residues of two departments in Colombia: Chocó and Putumayo, in order to know the energy potential of the waste for possible use in conversion thermochemical or biological process. For this study, the crops with greater crop area and annual production were selected in the two departments for a total of nine crop residues. One sampling of each of these residues was collected to determine the Residue to Product Ratio (RPR) and to analyze their calorific value. As a result, the potential of crop residues in Chocó and Putumayo was estimated corresponds to an energy potential of 397 GJ/y or 67.7 MWh.

1. Introduction

Despite the serious efforts already made, today an estimated 1.2 billion people – 17% of the global population – remain without electricity (IEA, 2015). The climatic and geographical conditions prevent easy access to rural or isolated areas; this hinders the extension of power grids to these places. An alternative to this problem are the renewable energy sources which are increasingly the source of electricity for isolated systems in rural areas (IEA, 2015).

The physicochemical characteristics of biomass make it an attractive source to be harnessed energy (Escalante, et al., 2010). So far, many studies in different countries have conducted for the assessment of availability of residual biomass. Scarlat, et al. (2011) assessed the availability of residual biomass of agricultural and forest crops suitable for bioenergy production in Romania. Crop yield, variation multi-annual yield, environmental and economic constraints and competitive uses were taken into account to estimate agricultural residues. A similar study was developed by Shonhiwa, (2013) who explored the magnitude of biomass available for energy production using thermochemical conversion technologies in Zimbabwe. On the other hand, Iye E., et al. (2013) assessed the availability of agricultural residues in Nigeria based in 6 areas; three scenarios were studied considering the collection and availability of biomass percentage. Moreover, Roberts J., et al. (2015) assessed the energy potential of residual biomass derived from herbaceous and horticultural crops, and urban forests in the Party of General Pueyrredón, Argentina. In Colombia, several studies were carried out to characterize residues from agriculture, animal, forestry and municipal solid waste in order to assess its energy potential (Escalante, et al., 2010; González, et al., 2014).

Due to its location in the tropics, Colombia has comparative advantages in the production of agricultural and forest biomass and its potential is sufficient to satisfy the energy demands (CORPOEMA, 2010).

According to Atlas of the Energy Potential of Biomass Residual in Colombia (2010), more than 71 million tons of agricultural residual biomass are produced annually, which represent energy potential about 331,000 TJ

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annually. These agricultural residues correspond to crops of rice, corn, banana, sugar cane, coffee, panela cane, oil palm and plantain (Escalante, et al., 2010).
However, for the future implementation of bioenergy projects and electrification is necessary to assess the energy potential with representative data and updated of the isolated areas.

1.1 Study area

In Colombia, the Non - Interconnected Zones (ZNI, for its initials in Spanish) correspond to regions that are not connected to the national system of generation and transmission of electricity. The ZNI cover 17 departments and correspond to 52 % of the national territory. They are characterized by low population density, long distance from urban centers with difficulty access and for its great wealth of natural resources. Nevertheless, the main difficulty in these areas is that the electrical service is not permanent or is null (Flórez, et al., 2009; Franco, et al., 2008). Figure 1 shown in light gray ZNI and dark gray departments of present study.
Actually, there are about 201,742 users attended and 215,568 kW installed of operational capacity, of which 2,600 kW are installed using renewables (IPSE, 2015).
Colombia has a Program of rational and efficient use of energy and other forms of non - conventional energy (PROURE, for its initials in Spanish) which defines as goal for 2020 a 30 % of non - conventional energy sources in the ZNI. (MME- PROURE, 2010). In isolated zones, is more likely implement energization projects based on non - conventional energy sources and is one of the most important niche markets for these energies and to mitigate the high level of poverty. Most departments of ZNI have a wide availability of resources in residual biomass from agricultural, industrial and forestry activities, which are not being given proper and productive use (CORPOEMA, 2010).

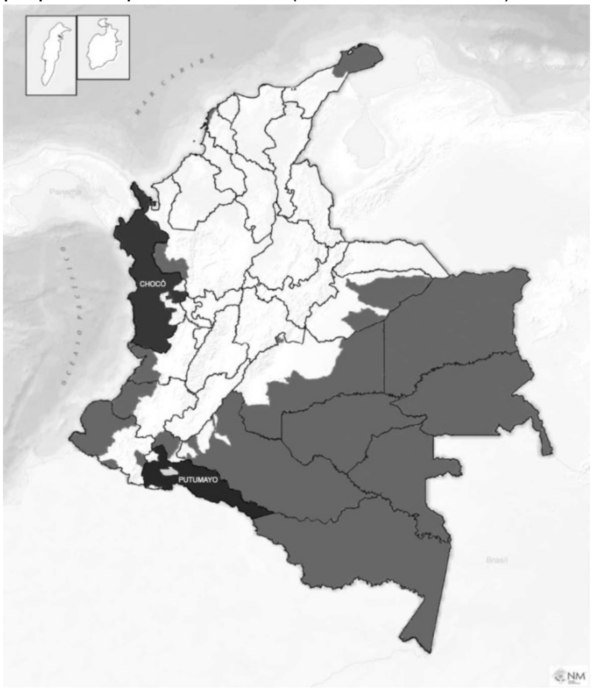

Figure 1: Map of the study areas.

Source: Adapted from Monthly Report from the Provision of Energy Service Power in Localities without Telemetry Systems of ZNI (IPSE, 2015).

1.2 The present study

The aim of this study is estimate the amount of biomass residues generated in harvesting of the most representative crops of Chocó and Putumayo and assess its energy potential in order to know the available for energy production using thermochemical or biological conversion.

2. Methodology

2.1 Crop selection

For this study, the crops with greater crop area and annual production were selected in the departments of Chocó and Putumayo according to data supplied by the Ministry of Agriculture and Rural Development. The crop residues selected were: leaves and buds of sugarcane, plantain leaves, plantain stem, corn stover,

banana leaves, banana stem, pruning of borojó, palmetto leaves and palmetto stem. Borojó (*Borojoa patinoi*) is an endemic fruit of the rainforests of Colombia, Brazil, Peru, Ecuador and Panama that is listed for approval as novel food in the European Union (Chaves, et al., 2015).
Alto Baudó (Chocó) and Orito (Putumayo) were selected as sampling sites because they have easy access and have large areas of crops study.
A random sampling of each of these residues was performed in a space of about 1 ha in order to determine the Residue to Product Ratio (RPR) and the calorific value. The sampling site, crops, annual production and the type of residue are listed in Table 1.

2.2 Residue to product ratio

The amount of residue was calculated by Eq. (1). Where CR is the crop residue [t], A is the cultivated area [ha/y], Y is the crop yield [t production/ha cultivated] and RPR is the Residue to Product Ratio [t residue/t product].

$$CR = A * Y * RPR \tag{1}$$

For this study, were taken data available in the Information and Communication Network of the Agricultural Sector – AGRONET for the year 2012 (AGRONET). The RPR of different crops varies significantly from country to country and even region to region (Kemausuor, et al., 2014; Angelis-Dimakis, et al., 2011; Iye, et al., 2013), therefore this study considered of great importance to know the values of RPR representative of the study sites. These values were calculated from the ratio of the weight of the residue generated at harvest and weight of the main product.

2.3 Estimation energy potential

The energy potential was calculated using Eq. (2) based on the model proposed by Orduz (2011). Where EP is the energy potential [TJ/y] CR is dry crop residue [t], F_{dr} is the fraction of dry residue [t dry residue/t wet residue], LVH is lower heating values [TJ/t] and AR is the residue availability factor. LVH values were obtained using the formula Dulong.

Table 1: Data of production, crops and residues selected for each department.

Sampling location		Crops	Crop residues	Production (t/y)[a]	Samples
Department	Village				
Chocó	Alto Baudó	Plantain 1	Leaves Stem	133,263	3 3
	Alto Baudó	Banana	Leaves Stem	5,531	3 3
	Alto Baudó	Corn[b]	Stover	18,623	---
	Alto Baudó	Borojó	Pruning	6,277	3
Putumayo	Orito	Plantain 2	Leaves Stem	39,709	3
	Orito	Sugarcane[c]	Leaves and buds	7,618	---
	Orito	Palmetto	Leaves Stem	494	3 3

Source: a: Statistical Yearbook of the Agricultural Sector 2012 (MINAGRICULTURA, 2013). b,c: These crops were not sampled.

$$EP = CR * F_{dr} * LVH * AR \tag{2}$$

There are different types of energy potential that can be calculated taking into account competing uses of the residue, collection costs, accessibility, etc., (Batidzirai, B., et al., 2012; Shonhiwa, C., 2013). In this study was calculated the technical energy potential considering a residue availability factor of 0.5.

3. Results

3.1 Residue to product ratio (RPR)

RPR values calculated for this research were compared with other studies (Table 2). It is observed that the RPR values obtained for plantain stem from Chocó and Putumayo are similar to those reported in the Atlas Residual Biomass in Colombia (Escalante, et al., 2010). By contrast, RPR values obtained for corn and sugarcane residues, 2.32 y 0.18 respectively, show a difference compared to the values reported in the Atlas (0.93 and 3.75, respectively). Although the above values are calculated in the same country, the difference

depends on various parameters such as geographic region, the moisture content at the time of sampling, crop yield, weather conditions, etc. (Kemausuor, et al., 2014; Angelis-Dimakis, et al., 2011; Iye, et al., 2013).
On the other hand, RPR values for residues of sugarcane and corn are similar to those reported by Cardoen (2015), Hiloidhari (2014) y Kemausuora (2014). RPR values for palmetto and borojó residues were not found in other studies.

Table 2: Residue to product ratio of present study and other studies.

Crops	Residues	RPR ($t_{residue}/t_{product}$)					
		Chocó	Putumayo	MME, 2010	Cardoen, et al., 2015	Hiloidhari, et al., 2014	Kemausuora, et al., 2014
Plantain	Leaves	0.35	0.33	---	---	---	0.50[b]
	Stem	3.91	4.16	5	---	---	---
Banana	Leaves	0.35	----	---	3	---	---
	Stem	5.6	----	5	---	---	---
Corn	Stover	2.32	----	0.93	1.60	2[a]	1.59[a]
Borojó	Pruning	0.12	----	---	---	---	---
Sugarcane	Leaves and buds	----	0.18	3.75	0.13	0.05	---
Palmetto	Leaves	----	5.07	---	---	---	---
	Stem	----	8.66	---	---	---	---

a: values for corn stalk, b: plantain leaves and steam.

Therefore, to assess the energy potential is of great importance calculating the RPR from the data obtained in the study area so that the results are representative.

3.2 Energy Potential

As shown in Table 3, both departments generated 829 t/y of residue in 2012. The assumption here is that only 50 % residues can be available for energy generation. Therefore, 415 t of residue is left in the field for soil conservation and in other areas a small proportion of this is used as animal feed. Accordingly, the two departments contribute an energy technical potential of 397 GJ/y corresponding to 67.7 MWh.
Plantain and corn of Chocó are the major contributors of crop energy potential given as shown in Figure 2. They contribute 58 % and 23 % respectively. This indicates that the plantain in Chocó is the most representative crop, in terms of amount residue and energy potential annually, with a contribution of 566 t/y and 231 GJ/y, respectively as shown in Table 3. Regarding the leaves and buds of sugarcane and pruning Borojó the lowest energy potential with a value of 1.9 GJ/y and 2.7 GJ/y is observed.

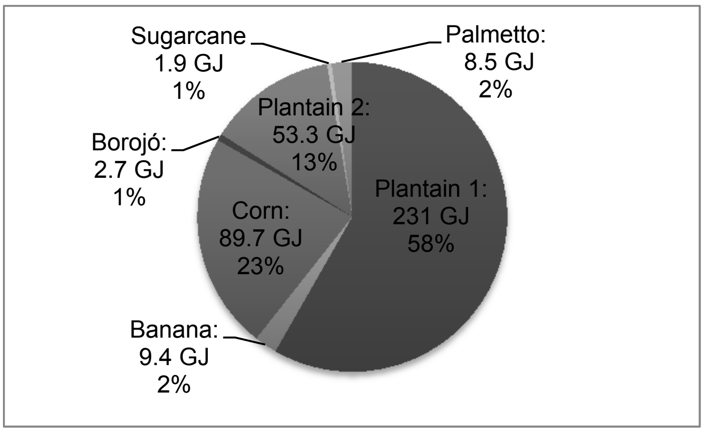

Figure 2: Energy potential of the crop residues selected.

Table 3: Technical energy potential of crop residues by department.

Village	Crop	Crop residue	Area[a] (ha)	RPR (t residue/ t product)	Residue generated (t/y)	Dry residue fraction	LVH (GJ/t)	Energy Potential (GJ)
Alto Baudó (Chocó)	Plantain	Leaves	16,134	0.35	45.0	0,20	12.12	53.0
		Stem		3.91	521.1	0,06	10.91	178.0
	Banana	Leaves	807	0.35	1.9	0,17	11.37	1.8
		Stem		5.6	31.0	0,04	11.66	7.5
	Corn	Stover	15,518	2.32	43.2	0,29	14.12	89.7
	Borojó	Pruning	1,464	0.12	0.8	0,56	12.75	2.7
Orito (Putumayo)	Plantain	Leaves	5,294	0.33	13.2	0,20	10.47	13.8
		Stem		4.16	165.2	0,04	10.87	39.5
	Sugarcane	Leaves and buds	2,238	0.18	1.4	0,22	12.85	1.9
	Palmetto	Leaves	351	5.07	2.5	0,27	12.01	4.0
		Stem		8.66	4.3	0,17	12.68	4.5

Source: Own calculations, except *a*: Statistical Yearbook of the Agricultural Sector 2012 (MINAGRICULTURA, 2013).

4. Conclusions

The energy potential of agricultural residues in two departments of ZNI in Colombia was estimated. Most of RPR values calculated in this research are close to other comparative studies. The results show that 829 t /y of agricultural residues generated in 2012 offer 397 GJ/y of energy. This amount of residues currently not being utilized and can be collected without compromising agricultural and environmental biomass requirements and competitive uses. Of the two departments of study, Chocó produces the largest volume of residue from the plantain crop, which generates an energy potential of 231 GJ/y equivalents to 41.4 MWh. The plantain is the most representative crop in terms of tonnes of residue and annual energy potential.

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