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Generation of Electricity by Plant Biomass in Villages of the Colombian Provinces: Chocó, Meta and Putumayo

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The aim of this study is to give potential solutions to supply the electricity deficit in three Colombian provinces (Choco, Meta, and Putumayo) with the maximum energy demand in Non-Interconnected Zones (ZNI, for its initials in Spanish). This was done by analysing the economic efficiency of technologies for generating electricity from biomass energy sources using the energetic planning software, Homer Energy. Different scenarios were evaluated in order to analyse how the energetic demand and subsidies from the government can contribute to properly integrate the variability of biomass plants of an economic point of view in the villages Riosucio, Alto Baudó, Puerto Concordia, La Macarena and Orito. In all cases, the results have shown, that combustion is a much more costly process than the biomass gasification.

1. Introduction

In Colombia, the ZNI are located in isolated places and cover almost 66% of the national territory including about 1,200 settlements, 16 provinces, 91 villages and 2 million people. In addition, these zones do not have appropriate access routes (transport), lack industrial and commercial development, public services are limited and undeveloped, here most of the villages are not or only partially connected to the national grid, and then the basic needs of people are unsatisfied (Narváez Rincón, 2010), which makes it impossible to perform a locally integrated energy sectors analysis, as suggested by (Kostevšek, et al, 2013).
Paradoxically, these zones have great environmental importance, which are characterized by the wealth of natural resources and biodiversity. In this regard, Colombia has an average bioenergy potentiates in a sustainable way of 366,310 km per biomass (Quijano, et al., 2012). According to the Atlas of the Energy Potential of Biomass Residual in Colombia, agro-industrial waste (UPME et al., 2010) constitutes a major source of biomass energy potential to be exploited, because it increases productivity in manufacturing plants, and simultaneously gives a solution to environmental problems through the use of agro-industrial waste from ZNI such as: plantain (31,434 t/y), rice (7,829 t/y), papaya (1,250 t/y), and banana (1,175 t/y).
On the other hand, it is noteworthy that energy solution commonly used in ZNI (diesel engines) is not the most efficient economically, since the costs necessary to supply the minimum demand is very high due to the rising costs of fuels used and the lack of technological development and skills in renewable energy systems. Nevertheless, biomass sources that are locally available in decentralized systems are an option that should be considered for assisting such isolated consumers, taking into account the availability of natural resources in the region and the advantages inherent to these sources, such as a reduction in diesel oil consumption and the possibility of developing local productive activities in these isolated communities (Zerriff, 2010).
Consequently, in order to harness the available biomass and give feasible solutions for electric generation in ZNI, this work collected data and information about biomass and villages to perform an economic analysis that assess biomass systems over a certain period time. This analysis was done with the simulation software Homer Energy, which is specially adapted to perform simulations to isolated systems (Conelly et al., 2010).

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Two options for the calculation of the economic efficiency were taken into consideration: biomass gasification, and biomass combustion. The latter proves to be the most expensive, based on the following scenarios: the Wh of electricity in the ZNI is more expensive than in the connected villages, which are connected to the network, and the Colombian government provides subsidies for the population in the ZNI, to allow electricity per kWh cheaper to purchase.

2. Case of studies: Chocó, Meta and Putumayo provinces

The case of studies were chosen from provinces and villages with the maximum energy demand, which was estimated from information about the number of households without power per village from UPME, (2011) and the average energy consumption per household (kWh/month) (UNAL, 2006) that will allow a 24-h supply in areas connected to the grid, since there are no exact data on energy consumption in ZNI (GREC, 2003), this demand was calculated for two scenarios, see Table 1:

-First scenario: the minimum demand required to supply basic appliances per household as provided by CREG: lights (bulbs), refrigerator, blender and television/radio.

-Second scenario: the maximum demand required to provide electric service in ZNI, equivalent to that provided in areas connected to the grid. With the aim of estimate maximum energy demand was included the following appliances: an iron, a fan, a water heater and a washing machine.

Table 1. Minimum and maximum demand per household

Appliances	Minimum demand [kWh/month]	Maximum demand [kWh/month]
Lighting	30.08	30.08
TV / radio	8.65	8.65
Refrigerator	47.03	47.03
Iron	_	9.20
Blender	1.45	1.45
Washing machine	_	8.60
Water heater	_	31.48
Fan	_	10.68
Total	87.20	147.15

The 10 provinces with the largest energy consumption in descendent order are: Choco, Caquetá, Putumayo, Meta, Vichada, Guainía, Amazonas, Vaupés, Guaviare, and Casanare. Caquetá department was excluded due to the armed conflict in this area and the existence of natural reserves, which could be a barrier when installing renewable energy systems.

In addition to the selection of the case of studies, the following conditions are also taken into account: Not being part of an indigenous reservation or forest reserve, no existing armed conflict problems, large population benefited, and high residential energy demand. By analysing the conditions in each department, the following cases were chosen, Table 2:

Table 2. Description of selected case studies

Province/ location	Village	Description
Chocó-in the West	Riosucio	-Lack of coverage of electric power in rural areas: 47.30 % -Number of households without power: 2,591 -Primary crop production: rice (7,829 t/y) and plantain (31,434 t/y)
	Puerto Concordia	-Lack of coverage of electric power in rural areas: 67.11 %. -Number of households without power: 1,878 -Primary crop production: palm oil (7,530 t/y) and plantain (3,573 t/y)
Meta-in the East	Alto Baudó	-Lack of coverage of electric power in rural areas: 40.17 % -Number of households without power: 1,988 -Primary crop production: plantain (21,594 t/y) and banana (1,175 t/y)
	La Macarena	-Lack of coverage of electric power in rural areas: 37.19 % -Number of households without power: 1,916 -Primary crop production: yucca (3,000 t/y) and plantain (3,500 t/y)
Putumayo-in the South	Orito	-Lack of coverage of electric power in rural areas: 32.45 % -Number of households without power: 2,542 -Primary crop production: plantain (7,000 t/y) and banana (6,500 t/y)

3. Methodology for the economic analysis

For the generation of electricity from biomass, two options were taken into consideration for the simulation in Homer Energy and the calculation of the economic efficiency: the biomass gasification, in which the synthesis gas generated feeds a generator, and biomass combustion in which the biomass is burned in a boiler and the fuel gas feeds a turbine, which in turn drives a generator.
Furthermore, in each village, two processes were simulated for the minimum and maximum energy demand. The results were assessed for cases in in which the government subsidies provide (per sold kWh) or not. It gives a total of four scenarios and eight simulations per village. The data used for each scenario are:
-Project Lifetime: 10 y
-Inflation: 4 %
-Lifetime generator: 60,000 h
-Maintenance costs of the facility: 0.5 US$/h

3.1 Definition of the primary load

Figure 1 shows the hourly behaviour of the load throughout a typical day (input in Homer Energy), for the minimum and maximum demand, which are obtained by means of the estimated load curves. Since the retrieved electric power is not always constant and varies from day to day, a random deviation of the daily values of 5 % is expected.

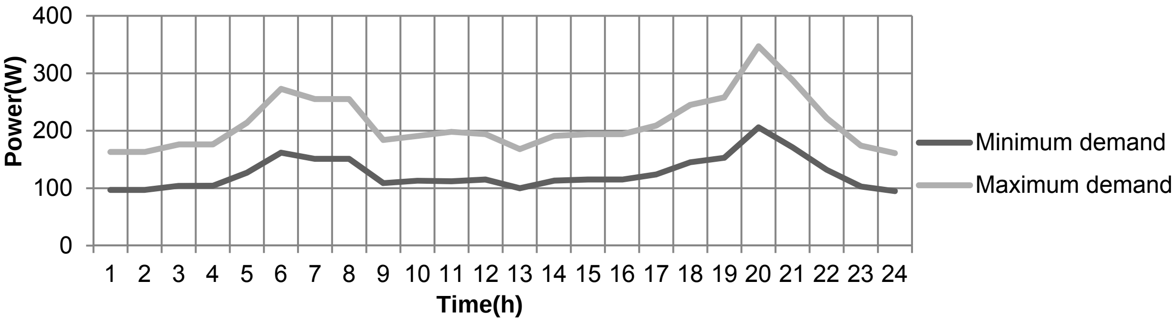

Figure 1: Daily load curve for minimum and maximum consumption per household

3.2 Characterization and selection of biomass in the studied areas

According to Atlas of the Energy Potential of Biomass Waste in Colombia (UPME et al., 2010), each village grows different crops and there will be different quantities and qualities of biomass waste. This biomass can be potentiated through the residue factor r. This factor indicates the amount of waste biomass ($m_{Biowaste}$) per the annual production of biomass in each village ($m_{Production}$). In Table 3, the residue factors and calorific values of individual crops are listed.

$$r = \frac{m_{Biowaste}}{m_{Production}} \quad (1)$$

Agro-industrial wastes with better potential for producing electricity are the sugar cane and panela with a calorific value of 18.66 MJ/kg, Table 3. However, it is not possible to use these crops in every village, because there is not enough growth in some of them, to cover the annual electricity needs. The mostly grown crop is the plantain with a calorific value of 8.51 MJ/kg and has to be used in most of the villages. The following crops are used for electricity generation in the different villages:
-Riosucio: Rice
-Alto Baudó: Plantain
-Puerto Concordia: Palm oil
-La Macarena: Plantain
-Orito: Sugar cane

Table 3 Residue factors and calorific values of biomass waste in Colombia

Crop	Type of Waste	Origin of Waste	Residue Factor ($t_{waste}/t_{production}$)	Calorific Value (MJ/kg)
Palm Oil	Fruit stone	IR	0.22	16.70
	Fibre		0.63	17.89
	Rachis		1.06	16.84
Sugar Cane	Leaf bud	CR	3.26	-
	Chaff	IR	2.68	18.66
Panela	Chaff	CR	2.53	18.66
	Leaf bud	IR	3.75	16.78
Coffee	Pulp	IR	2.13	17.83
	Husk		0.21	18.55
	Leaves	CR	3.02	18.35
Corn	Stover	CR	0.93	14.37
	Corncob		0.27	14.19
	Leaves		0.21	15.97
Rice	Chaff	CR	2.35	13.03
	Husk	IR	0.20	15.09
Banana	Rachis	CR	1.00	7.57
	Leaves		5.00	8.51
	Rejected	IR	0.15	10.42
Plantain	Rachis	CR	1.00	7.57
	Leaves		5.00	8.51
	Rejected	IR	0.15	-

IR: Industrial residues; CR: Crop residues

3.3 Selection of the equipment

In this stage, the selection of equipment necessary for the operation of each systems was based on information about developed projects by governmental institutions and according to efficiency and used in the market. In the Table 4, different systems for electricity generation from biomass are specified.

G600/Bx15/C12 abbreviation means that a generator with 600 kW, 15 Trojan L16P Batteries and a converter with 12 kW is used. The words “minimum” and “maximum”, behind each tows stands for the minimum and maximum energy demand.

Table 4. Biomass systems per village

Gasification system	Combustion system	Village
G600/Bx15/C12	G600/Bx15/C12	Riosucio (minimum)
G1,100	G1100	Riosucio (maximum)
G500	G450/Bx25/C20	Alto Baudó (minimum)
G850	G800/Bx30/C22	Alto Baudó (maximum)
G450	G450	Puerto Concordia (minimum)
G800	G750/Bx35/C26	Puerto Concordia (maximum)
G550	G500/Bx35/C28	La Macarena (minimum)
G950	G900/Bx30/C22	La Macarena (maximum)
G600	G600	Orito (minimum)
G1,100	G1000/Bx65/C50	Orito (maximum)

3.4 Costs of technologies

The costs considered for the technologies, are: pre-investment, investment, management, operation, maintenance and replacement. The biomass of each village is free and does not have to be imported or purchased, and then the transport costs are incurred.

In the generation of electricity with gasification, the cost per ton of biomass provided is assumed to be 10 US$ and the investment cost (IG) in US$/kW of such a system (carburettor, generator and gas purification system) can be described with the following function:

$$\mathrm{IG} = 4437.2\, \mathrm{P_i}^{-0.211} \quad (2)$$

Where P_i is the installed power in kW.

In the process of biomass combustion, the costs of the biomass is assumed to be 0.09 US$/kg and the investment costs (IG) in US$/kW of such a system total investment costs of such a system can be described with the following function:

$$IG = 4126.5\ MW^{-0.2052} \tag{3}$$

Where MW is the installed power in MW.

3.5 Assessment of results and economic evaluation

The last step of the methodology includes the analysis of simulation results and the economic evaluation.

The project lifespan of the simulations is 10 y, and is used to calculate the annualized replacement cost and the annualized capital cost of each equipment, as well as the current value of future cash flow, called net present value (NPV) of the system. The total NPV is the main economic output obtained with Homer Energy and it is calculated by using the following expression:

$$NPV = -INV + \sum_{t=1}^{n} \frac{V_t}{(1+r)^t} \tag{4}$$

Where INV is the value of the initial investment, t is the time between present and future, r is the discount rate and V_t: are the cash flows in each period t.

4. Result and discusion

4.1 Maximum and minimum demand-unsubsidized scenarios

The Table 5 shows a comparison between economic parameter for maximum and minimum demand-unsubsidized scenarios in each village. According to the VPN, biomass combustion is not feasible due to the high-energy cost and the investment cost. However, in the case of Riosucio, the investment is recovered at least in 10 y, since this village has great biomass potential.

On the other hand, biomass gasification has very low energy costs, and regardless of whether the demand is maximum or minimum, the recovery times of these processes in all cases are very short, between 1 and 2 y.

Table 5. Economic results of maximum and minimum demand -unsubsidized biomass-scenarios

Village	Parameters	Minimum demand		Maximum demand	
		Gasification	Combustion	Gasification	Combustion
Riosucio	NPV (US$) EC (US$/kWh) RT (y)	3,929,149 0.05 1	-3,346,829 0.36 10	7,117,637 0.05 1	-5,265,665 0.35 10
Alto Baudó	NPV (US$) EC (US$/kWh) RT (y)	2,785,752 0.06 2	-3,724,365 0.44 NR	5,172,857 0.05 1	-5,531,380 0.41 NR
Puerto Concordia	NPV (US$) EC (US$/kWh) RT (y)	2,163,446 0.06 2	-3,312,347 0.37 NR	3,996,805 0.05 2	-4,407,964 0.33 NR
La Macarena	NPV (US$) EC (US$/kWh) RT (y)	2,423,907 0.06 2	-4,754,470 0.43 NR	4,533,722 0.05 2	-7,320,552 0.41 NR
Orito	NPV (US$) EC (US$/kWh) RT (y)	2,289,960 0.06 2	-4,646,062 0.35 NR	4,215,361 0.05 2	-6,404,859 0.31 NR

EC: Energy Cost RT: Recovery Time NR: Not recovery

4.2 Maximum and minimum demand-subsidized scenarios

The Table 6 shows a comparison between economic parameter for maximum and minimum demand-subsidized scenarios in each village. Similarly to the above scenarios, the recovery time of biomass gasification is very short, but the biomass combustion is not feasible, and in no case it is able to recover the investment in less than 10 y. The subsidies that the government gives to the cost of kW of energy causes the selling price to be lower, and consequently the recovery time becomes greater.

Table 6. Economic results of maximum and minimum demand -subsidized biomass-scenarios

Village	Parameters	Minimum demand		Maximum demand	
		Gasification	Combustion	Gasification	Combustion
Riosucio	NPV (US$) EC (US$/kWh) RT (y)	1,393,165 0.05 2	-5,882,813 0.36 NR	2,678,737 0.05 2	-9,704,565 0.35 NR
Alto Baudó	NPV (US$) EC (US$/kWh) RT (y)	839,595 0.06 2	-5,670,522 0.44 NR	1,766,998 0.05 2	-8,937,240 0.41 NR
Puerto Concordia	NPV (US$) EC (US$/kWh) RT (y)	619,985 0.06 3	-4,855,808 0.37 NR	1,296,103 0.05 2	-7,108,667 0.33 NR
La Macarena	NPV (US$) EC (US$/kWh) RT (y)	588,087 0.06 3	-6,590,289 0.43 NR	1,320,895 0.05 3	-10,533,377 0.41 NR
Orito	INPV (US$) EC (US$/kWh) RT (y)	546,060 0.06 3	-6,389,961 0.35 NR	1,163,597 0.05 3	-9,456,622 0.31 NR

5. Conclusion

The costs thereby incurred to build a system of biomass gasification and a system for biomass combustion, fall out very differently. By comparing the two systems with the simulation software Homer Energy, it becomes clear that biomass combustion is a much more costly process than the biomass gasification; especially for small plants (<10MW). For 1 MW, the investment costs of biomass gasification is 1,033,021 US$ and for biomass combustion 5,364,450 US$, which is about five times more. Thus it is important to highlight the operating costs incurred by the biomass in combustion, 0.09 $/kg, which is significant in individual villages, where thousand tons of biomass are required per year.

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