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Evaluation of the electrical energy potential of woody biomass of an isolated community in the Northern of Brazil

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ABSTRACT

The objective of this work was to evaluate the potential of electric energy from biomass residues available in an Amazonian community, currently with a maximum demand of 56 kW. The chosen community is called Santo Antônio. A 200 kW plant with biomass residues from the sawmill was installed in that community as part of a government program called Light for All (Progama Luz para Todos). The chosen community has working sawmills, which generate wood residues. The plant was designed according to the volume of waste available. An extensive mass and volume balance of the residue from the sawmill activity was conducted. For the evaluation of the energy potential, the overall efficiency of the power plant was estimated using the specific consumption of the steam turbine and the boiler efficiency. The study showed that at the highest production period 66% of the wood log processed by the Santo Antonio's sawmill turns into waste resulting in 104 kW of potential electrical power. The study also concluded that there is a 12% decrease in the volume of wood processed in periods of lower production. Even so, the amount of biomass available would be sufficient to provide the electric power to the community. The study demonstrates that a biomass plant is feasible for the supply of Electric Energy to small Amazonian communities, avoiding the construction of energy subtransmission systems in regions of native forest. The work can be replicated to other rural communities, in regions still without access to electricity but with availability of biomass.

INTRODUCTION

It has been estimated that approximately 70% of more than 5,000 thousands Brazilian Amazon remotes villages do not have electricity access neither from the National Interconnected System nor from decentralized local diesel power plants (Coelho & Goldemberg, 2013). Typically, the only alternative for these populations is to generate their own electricity using diesel generator sets. Price and long distances to buy diesel are additional difficulties that they have to deal with; according to Schmid and Hoffmann (2004) diesel oil supplied to small communities in the Amazon can cost much more than in the urban cities.

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Studying and developing technologies suitable to the characteristics of these communities, as a replacement to the generator sets, became an enormous concern among Brazilian government and academic institutions. A government’s program called Light to All (Luz Para Todos) subsidized development projects on technologies based on renewable energy to bring electricity to households at isolated areas (Andrade *et al*., 2011; Gómez & Silveira, 2015; Maham Hussain, 2015). A group of researchers at the University of Para (UFPA) had their project, construction and installation of a steam cycle biomass-fueled power plant, funded by the Program (Rendeiro & Nogueira, 2008). The project mentioned above generated the raw data used in the present study.

The chosen Amazonian community was Santo Antonio, one of the islands of the Marajo´s archipelago that fitted two criteria: a) isolation; and b) use of generator set to supply houses. The biomass considered was wood residues due to its frequent availability in Amazonian communities. According to Brazilian Institute of Geography and Statistics (IBGE) the northern region of Brazil detains 71% of the log production of the country (IBGE, 2009). This economical activity is predominant in the south bank of Amazon River estuary, accounting for approximately 10% of the total Brazilian production. Typically, the local communities are characterized by having small sawmills ranked as micro enterprises responsible for an annual average production bellow four thousands cubic meters (Veríssimo et al., 2002). Residues from such production become biomass waste and are estimated to be 58% to 62% of the log volume (Lentini *et al*., 2005). Mostly the wood production is conducted without overexploiting the forest. The logs delivered are from floodplain forests; the least expensive method of extraction of wood, and the transport is done via log rafts (Barro & Uhl, 1995). However the down side of this method is the seasonality influx of logs imposed by the distinguished flood and dry season in the region.

In the project, the researchers additionally included the construction and installation of a vegetable oil extraction plant (Duván Martínez, 2016), a cooling chamber and an ice factory. Considering the houses, the sawmill and the three extra apparatus, a 200 kW thermal plant was selected.

Since quantity of residues is dependent on the lumber produced, it was an important concern to verify whether the woody waste would be sufficient to run the thermal plant or not, during the entire year. This verification was fundamental because documented data of wood residues potential in Brazil are not easy to be found and have a high level of uncertainty since there are reliant on each specific region (Brasil, 2007; Lora & Andrade, 2009).

In order to estimate the amount of the woody biomass waste, measurements of mass and volume were taken. Sawn yield was also an important piece of information resulted from the measurement procedures, allowing comparisons with data from others studies for that region.

Thus, the main purpose of this work is to show and discuss how the energy potential was evaluated at Santo Antonio, how was done the gathering and the data analysis from the amount of woody biomass residues. Data was collected in January, period of the year with the most lumber production, to guarantee, as results, the maximum amount of biomass available to electric power generation. Also, an analysis of the residual biomass properties, boiler efficiency, and turbine specific steam consumption were performed to verify whether the power plant of 200 kW was adequate.

It is important to mention that concerns about the carbon balance, the economical and the social evaluation of the wood activity were all beyond the scope of the present work.

MATERIAL AND METHODS

1.1. Details of the study site – the community:

Positioned in the geographic coordinates of 01º 47.658’S and 50º 19.343’W, indicated in Figure 1 with a pinned star symbol, Santo Antonio is one of the smallest communities located at Siriri Island, which is part of the Marajo Archipelago in the state of Para, Brazil. The archipelago is constituted of more than 2,500 small islands being the largest one called Marajo Island. Figure 1 also brings the map of the electricity grid of Brazil to illustrate how isolated the community is from the national access electric energy (ONS, 2016).

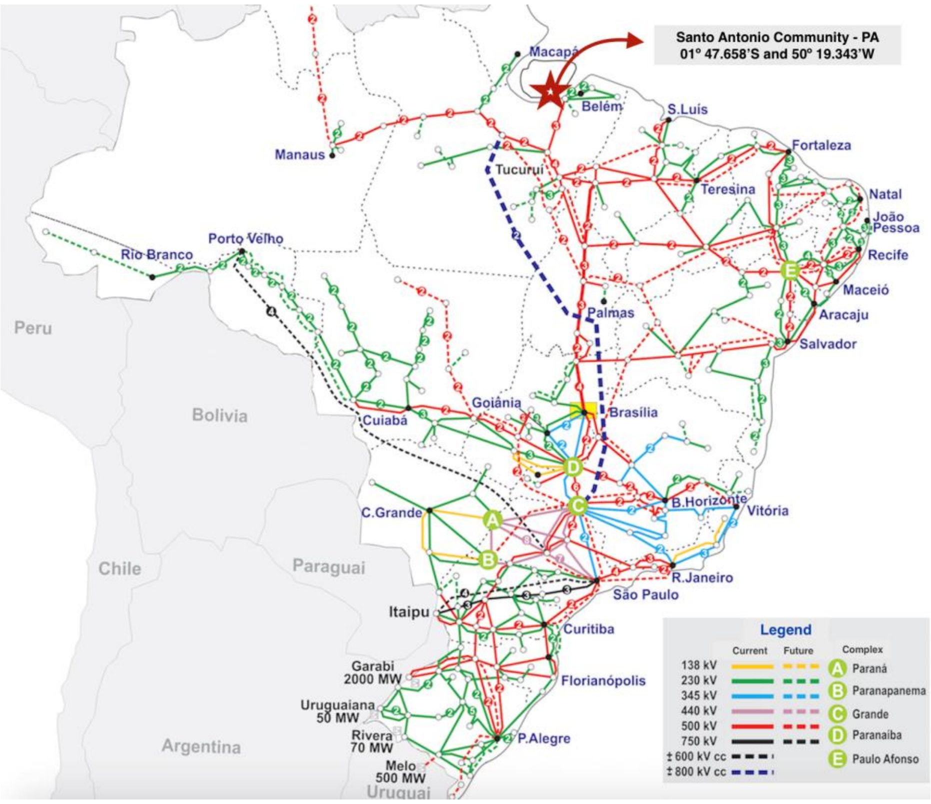

Fig. 1: Brazilian electric grid and geographic position of the studied isolated community (ONS, 2016)

Santo Antonio has currently less than 100 inhabitants and all the electrical devices or equipment in use at the island summed 56 kW. The community is excluded region from the national electricity grid, uses diesel generator set, and dependent basically in three economic activities: timber cut, agriculture and fishing.

The installed apparatus - vegetable oil extraction plant, cooling chamber, ice factory, and thermal power plant – was placed into a warehouse-style building besides the sawmill located at the river bank to facilitate the logistics of all inputs and goods. At the region, the trade logistics consists of delivering and picking up, i.e.: a) the incoming logs are left at the river bank, as it can be seen in Figure 2; and b) the out coming lumber is left at the river bank, ready to be picked up by the buyers, as illustrated in Figure 3.

Fig. 2: Incoming log left at the bank of the river.

Fig. 3: Outgoing lumber left at the bank of the river.

1.2. Evaluation of the biomass residues:

The data collected for conducting this research were originated from a shipment of thirty three logs comprised two different species – twenty were *Virola surinamensis* and thirteen were *Symphonia globulifera* - which thermo-physical properties were determined. Samples of the core wood and the bark of the log were taken for measurements of density and higher heating value (*HHV*). Once the *HHV* was determined, the lower heating value (*LHV*) was obtained as well, as shown in Table 1.

Table 1: The two species thermo-physical properties for bark and wood.

BIOMASS	HHV Higher heat value (kJ/kg)	LHV Lower heat value (kJ/kg)		DENSITY (kg/m^3)
Bark of *symphonia globulifera*	17,827.4	16,603.1		562.6
Bark of *virola surinamensis*	17,831.6	16,607.3		841.3
Bark weighted mean – two species			16,605.1	
Wood of *symphonia globulifera*	18,945.3	17,721.0		700.0
Wood of *virola surinamensis*	18,338.2	17,113,9		520.0
Wood weighted mean – two species			17,484.9	

Calculations of the density and weighted mean of the lower heating value ($\overline{LHV}$), for the bark and wood, were both fundamental parameters to determine the mass balance and the potential energy. The LHV for the bark and wood were obtained using Eq. 1, considering for each log of each specie (twenty logs of *Virola surinamensis* and thirteen logs of *Symphonia globulifera*) its volume, density, *LHV* and calculated mass. Since logs were not weighed, the calculated mass of the bark and the wood were obtained from multiplying the volume by the density.

$$\overline{LHV}_B = \sum\nolimits_{(B)_{i,specie}} \left(V_{(B)_{i,specie}}.D_{(B)_{i,specie}}.LHV_{(B)_{i,specie}}\right) / \sum\nolimits_{(B)_{i,specie}} m_{(B)_{i,specie}} \tag{1}$$

where bark or wood are identified by the index *B*, *V* stands for volume, *D* is density, *LHV* is lower heating value, *m* is mass, the index *specie* is *Virola surinamensis* or *Symphonia globulifera* and *i* is for log index; 1 to 20 for *Virola surinamensis;* 21 to 33 for *Symphonia globulifera.*

It is inaccurate to assume that the biomass residue, useful as fuel for a fixed grate power plant, is entirely derived from the mass difference between the income log and outcome lumber. This assumption guides to inexactness in the results because: i) parts of the tree, such as bark and heartwood, have different thermal-physical properties; ii) sawdust residue cannot be used as fuel for fixed grate furnace.

Just to avoid such faults in the results, a rigorously procedure was followed during the performance of the measurement, where each different part of the log had its mass determined direct or indirectly. Direct method to weigh the biomass pieces is applied when feasible, i.e. smaller pieces. On the other hand, an indirect method was used for large pieces due to the impossibility of weighing pieces such as income logs; the method is called indirect because instead of a mass balance, it is common to conduct a volumetric balance. Once the volume was obtained, the mass was calculated using density data. The results of the mass and the volumetric balance are presented in Table 2 for both situations, measured and calculated.

Table 2: Data of the volumetric and mass balance.

Material	Measured volume (m^3)	Measured mass (kg)	Calculated mass (kg)	Equivalent volume (%)
Income log	9.2	-	5666.9	100
Heartwood	8.3	-	5094.3	90.7
Outcome lumber	2.8	-	1713.0	30.3
Bark	0.9	-	572.5	9.3
Sawdust		1094.0		
Offcuts		2290.8		

Volume of each income log was calculated based on Smalian´s formula (Yavuz *et al.*, 1999). For this purpose the perimeters at both ends and the length of the logs were measured. The total income volume measured for both species resulted in 9.2 m^3.

Outcome lumber (or boards), a well-defined dimensional lumber ready to the market, also had its volume measured and resulted in a total of 2.8 m^3.

The sawdust deriving from the sawmill activity was weighed and resulted in a total mass of 1,093.0 kg. However, its volume cannot be estimated due to the lack of density data.

Bark and offcuts residues could only be weighed together, yielding to a total of 2,863.3 kg. Bark and offcuts have different thermal properties, thus it was necessary to calculate the split between bark and offcuts masses of the total above. Bark is the part of the log which volume could be determined using data of the measurements from the thickness at each end of the log, and resulted in a volume of 0.9 m^3. Then, knowing data of the density, the mass for bark was found to be 572.5 kg.

Consequently, the offcuts mass of 2,290.0 kg was obtained by subtracting the mass bark from 2,863.3 kg of the offcuts/bark.

Thus, each different part of the log had the mass established direct and indirectly. The total mass of the available biomass residue, bark and offcuts, from the sawmill activity for the shipment of 33 logs totalized 2,863.3 kg.

Parameter such as sawn yield, the relation between the income and outcome volume, is useful to indicate the efficiency of sawmill, helping to point whether or not there is a misused during the operation. It was identified that sawmill total income volume was 9.2 m^3 corresponding to 5,666.9 kg for a typical day of production. At the same way, a volumetric balance of 2.8 m^3 related to the total outcome volume resulted in a sawn yield of 30.3%. For a small Amazonian community, this value is in accordance to the data for the same region, suggesting a satisfactory operation (Verissimo *et al.*, 1992; Gardingena *et al.*, 2003).

RESULTS AND DISCUSSION

1.3. Estimative of energy potential:

In order to calculate the electrical energy potential of the woody biomass waste of the community, the first step was to know how much of steam mass flow ($\dot{m}_s$) the boiler generates when biomass waste ($\dot{m}_{bio}$) was burned. For this purpose it was applied the formula shown in Eq. 2, derived from thermodynamics basics theory (Moran et al., 2008), that establishes the boiler energy balance; being η_c the boiler efficiency, LHV is the lower heating value, biomass consumption is the $\dot{m}_{bio}$, □H is the enthalpy variation of the water vapor and the steam consumption is given by $\dot{m}_s$. Also, for the calculation it was indispensable the knowledge of the technical specifications of the turbine and the boiler, showed in Table 3.

$$\dot{m}_s = \eta_c.[(LHV.\dot{m}_{bio})_{bark} + (LHV.\dot{m}_{bio})_{wood}]/\Delta \mathrm{H} \tag{2}$$

The result revealed a steam consumption of 2,314.0 kg/h, which was obtained as follows.

The boiler efficiency used was the 80% given by the manufacturer.

The LHV weighted mean was used for both bark and offcuts, showed in Table 1, to account for the two different species in different quantities. Thus, it was used for bark and wood (offcuts), respectively, 16,605.1 kJ/kg and 17,484.9 kJ/kg.

Table 3: The power plant devices technical specifications.

TURBINE
Manufacturer: TGM Turbines
Mod: TG 320
Nominal speed: 10,000 rpm
Power: 220 kW
Input Steam Pressure: 18 kgf/cm^2
Steam Temperature: 208.8°C

BOILER
Fixed grate furnace: 18 kgf/cm^2
Heat transfer surface area: 178 m^2
Category: B
Capacity: 4,000 kg/h
Efficiency: 80%

Data of biomass consumption, $\dot{m}_{bio}$, of bark and offcuts (wood) was obtained by an simple division of the available mass by 9 hours, that is a typical day's work in the region. The results were 63,6 kg/h for bark and 254.5 kg/h for offcuts.

Enthalpy of 1923.1 kJ/kg was calculated assuming Rankine cycle in such way that the vapor condition at the boiler input was saturated liquid at temperature of 206.2°C and the output condition was superheated water vapor with pressure and temperature at 18 kgf/cm^2 and 208.8°C, respectively.

Subsequent procedure was to evaluate the energy generated in the turbine. The plot presented in Figure 4, built with data from the turbine manufacturer, shows the water vapor consumption, in kilogram per hour, as a function of the power at the electric borne of the power plant generator. Notice that for the maximum power output of 200 kW, the power plant requires a mass flux of 3,736.6 kg/h of water vapor, while for a minimum of 50 kW it requires 1,504.2 kg/h. Consequently, when the calculated consumption of 2,314.0 kg/h (Eq. 1) is plotted in the graph it corresponds to an electrical potential of 104.6 kW, confirming that the amount of biomass waste generated by the studied community is sufficient to run the power plant.

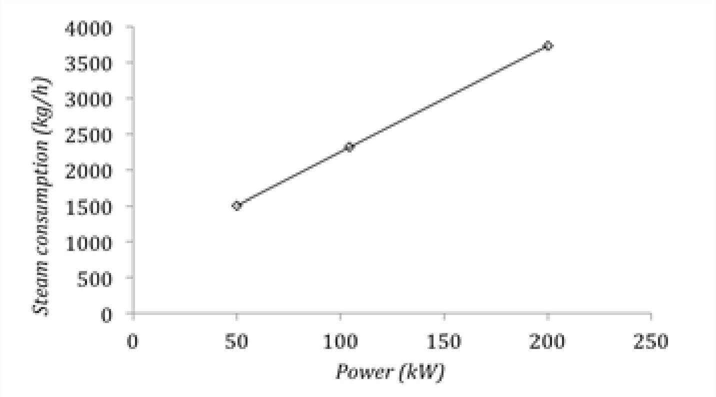

Fig. 4: Power plant steam consumption as function of the generated power.

However, the data was collected in January, the month with the highest lumber production, meaning that for the next months there will be a decrease in the sawmill activity thus a decrease in the biomass waste and power output. A seasonality analysis to verify how the climate affects the production throughout the year was conducted.

A month-to-month wood production oscillation due to the climate and tides changes was verified plotting, from 2002 to 2009 (IBGE, 2013), the average data of the lumber production of the Amazon region versus months of the year, keeping January as month of reference. It is seen in the graph presented in Figure 5 that between May and July, referred to as dry or low season, the decreasing in production reaches 12% down from the reference month. If the lumber production at this particular community suffers this 12% impact, the same reduction in the power output potential is to be expected, thus 92.0 kW for the low season would be produced, instead of 104.6 kW for January. Such value still guarantees the operation of the power plant, that requires a minimum of 50kW, and also covers the estimated maximum power of 56 kW demanded by the community households.

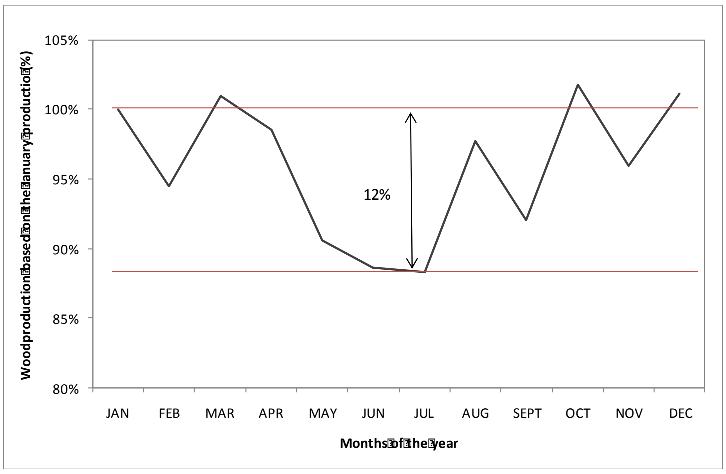

Fig. 5: Wood cutting production in the Amazon basin.

Comments:

The community current power demand of 56 kW is only 60% of the low season 92 kW power output, thus the community could grow 64% its power demand by either growing its population or growing its per capita consumption.

Beyond that power demand growth, additional biomass waste would be required. Potentially there are two alternatives: i) raising the lumber production, or ii) getting available waste from sawmills in nearby communities. The nearest biomass power plant is 100 km away, thus there are many communities to acquire biomass waste. Obviously that would require proper means of transportation and logistics.

Jointly with the studies to determine the electrical potential, it was identified, for the analyzed shipment, a sawn yield of 30.2%. It is worth to mention that improvement in the sawn yield parameter causes an economical gain to the community because increases the amount of final product, in the case more lumber to be sold but, on the other hand, it causes a decrease in the available residual biomass to generate electrical energy. To which path to take will be a decision manage by the community.

Therefore, as long as there is equilibrium between the sawn yield and generated electrical power, the increase of lumber production and economical development must be accompanied by energy consumption of the community.

More details about organization and dynamics of the community and power plant feasibility and costs were presented, respectively, in two studies cases: a) sustainable management model for rural electrification (Pinheiro *et al*., 2012), and b) economic, regulatory and market aspects (Rendeiro *et al*., 2011).

Conclusion:

The work showed that the production of electricity from biomass in rural communities in the Amazon forest is viable. With financing from the governmental program called ‘Light for All’ (Progama Luz para Todos), it was possible to build a 200kW thermal plant. This mill used wood waste as an energy source. Importantly, this is an abundant raw material throughout the Amazon.

As part of the main task of the present work a cautiously mass balance was performed and the results showed that at the highest production period, which happens during the flood season, 66% of the wood log processed by the Santo Antonio's sawmill becomes waste, resulting in 104 kW of potential electrical power. After analyzing the climate fluctuation at the Amazon region, it was revealed that for the period of the lowest production occurs a decline of 12% compared with the highest. Despite of the decrease caused by the seasonality influx of logs, the amount of residues from the sawmill activity was demonstrated to be enough to supply the electrical energy demand of the community and it will not compromise the 200 kW power plant performance.

These conclusions were possible after the calculation of the electrical energy potential of the woody biomass residues of the community. To do so, it was calculated that the steam flow generated by the boiler generates when the biomass residues are burned. From there, the energy generated in the turbine was evaluated from the manufacturer's data, which provided the water vapor consumption curve as a function of the electric power generated.

The implanted system also allows the community to increase its energy consumption by 60%, which may take a few years. Even if this margin is exhausted, there is the possibility of obtaining more woody material in adjacent communities or even by increasing own production. The energy demand can also be optimized by controlling the energy efficiency of the loads.

Thus, it was demonstrated that the supply of electricity to isolated communities through own plants can have several advantages. It avoids the construction of energy subtransmission systems over long distances, in the middle of forests. Systems of this type, besides having a high cost, demand constant maintenance, due to the risk of touching vegetation to the energized circuits. A plant installed in the community also generates employment and income associated with the operation of the equipment, maintenance of the system and the purchase of wood residues. This favors the development of the local economy.

The work described here allows replicability to any rural community in different parts of the world. The existence of biomass for power generation is the only necessary condition. The presented energy potential models can be adapted and harnessed according to the characteristics of the different projects studied.

Contributions of this subject to knowledge:

The work is relevant to the scientific community because it describes in detail how to evaluate the biomass potential of small rural communities for electricity generation.

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