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A STUDY ON THE USE OF AGRICULTURAL RESIDUES PLANTAIN PRODUCTIONS IN NICARAGUA FOR THE GENERATION OF ELECTRICITY

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Abstract.

This paper aims to present the properties of the banana pseudo stems as a possible fuel source and its economic feasibility. With ash contents and dry mass contents similar to the sugar cane already used in the sugar mill furnaces of Nicaragua during the off-season, the banana pseudo stem is a residue of the production of banana and plantain fruit, both of the Musacea family of semi perennial crops. For every ton of fruit produced, the equivalent amount of "green" residue derived from this part of the plant is 2.41 tons making it a highly "wasteful" harvest. In the case of Nicaragua, most banana plantations are located at close proximity from the major sugar mills that are already, or in the process of producing electricity not only for their internal use, but also for the nation, enabling the potential use of the residue during the off-season as a fuel source. Considering this scenario, the use of the pseudo stem is neither technically or economically feasible due to a low Net Calorific Value of 5.54 MJ/kg at 50% humidity. The high moisture content is the main factor in the low NCV and high cost of transportation that in its turn would result in an elevated leveled cost of energy of 0.114 USD/kWh with comparison to other fuels. However, a sensibility analysis of the LCOE shows that a decrease in transportation costs due to the water content could significantly augment the economic feasibility of the endeavor.

Keywords: Renewable Energy, Bagasse, Banana Pseudo Stem, LCOE, Nicaragua

1. INTRODUCTION

As a country that depends highly on agriculture, not only to supply its inner market, but to also expand economic growth through agricultural exports, Nicaragua has great amounts of unused agricultural residues. Currently, the residues of the sugar industry, one of the largest and most stable industries of the nation, are used not only for internal energy demands of the sugar mills, but also as national power generators. This being said, the sugar mills must plan and ration their energy outputs due to the seasonality of the sugar cane crop in order stretch its production schedule to the maximum. This "off-season" period makes biomass generation extremely unreliable for at least 3 months, hindering its expansion due to great idleness. In Nicaragua, according to data supplied by the National Sugar Producers Commission (CNPA 2014) the sugar cane season remains basically constant throughout the country spanning an average of 200 days from mid-November to late-May or even early June. In this scenario, other high density crop residues can come in place as not only additional fuel sources, but perhaps even as replacement fuels should the case require. The *musa* plant, or banana tree which has already played a major role in Nicaragua's history as a "Banana Republic" can regain a major relevance in the economic structure of the nation as a fuel due to the high amounts of residue left over from the harvest and the specific location of these plantations in relation to the already established sugar cane mills. The usage of a mixture of bagasse and processed banana tree pseudo stems can potentially provide enough burnable mass to allow for the generation of energy throughout the entire year. In this study a bibliographical review will provide the characterization of the banana pseudo stem as a possible fuel source. A technical analysis to determine the fuel addition rate for an already installed biomass power plant was created in order to properly calculate the projects economic feasibility. A leveled cost of energy methodology was utilized, determining the various costs of processing the banana residue in order to create a burnable fuel source.

2. CHARACTERIZATION OF THE MUSA PSEDUO STEM

The musa plant is a large perennial herb (FAO 1977). It can reach a height of up to 7 meters tall. Though it lacks a proper stem, the pseudo stem, created from the joining of many soft leaves coming from the corm, is quite sturdy and can carry fruit bunches that are produced from the inflorescence of up to 50 kg. Figure 1 is a representation of the banana tree with all of its components.

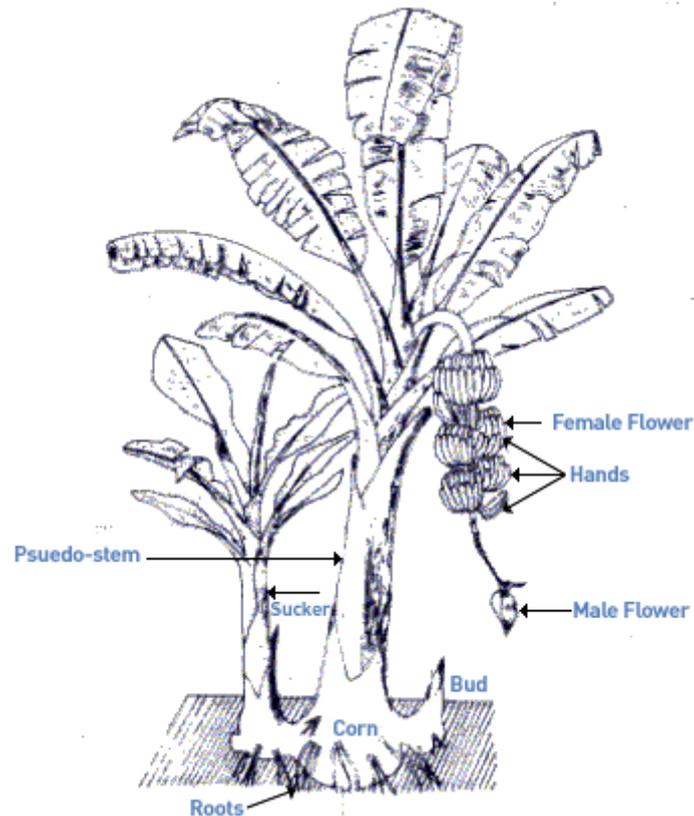


Figure 1 the Banana tree (*Musa ssp.*) (FAO 2017)

The corm is planted into the ground and leaf sprouts begin to form the pseudo stem. When the plant has reached maturity, the corm ceases to produce leaves and starts to develop the inflorescence, where the female flowers and subsequent fruit will blossom.

From plantation to flowering, the banana tree takes approximately 8 to 10 months, depending on the variety of the plant, and approximately 2 more months until harvest (Agronet 2014). When the fruit is picked, the manual laborers are required to pull on the inflorescence to secure the banana bunch and which is cut about 20 cm from the pseudo stem. However, the pseudo stem must be cut also, as it only flowers once. For larger plants, the pseudo stem must be cut in segments as a means to reach the fruit. In any case, the stem is left as a residue on the field. A study conducted by FAO 1997 demonstrated that on average the pseudo stem represents 60.5% of the total plant in wet base and that for every kilogram of fruit produced, there is approximately 2.41 kg of pseudo stem. With this weight ratio between the pseudo stem and the fruit bunch it is possible to calculate the amount of available biomass based on fruit production per hectare. The most common varieties of *musa* found in Nicaragua are the *musa sapientum* or *musa paradisiaca* (PLANTAIN) and *musa acaminata* (CAVENDISH) (INIDE 2013).

2.1 Immediate and proximate analysis

For this study, both the elemental and proximate analysis were gathered from various references. The elemental analysis comprises of the basic elements within the fuel. All of these elements are measured in percentage by weight. On the other hand, the proximate analysis determines a few characteristics of the matter that composes the fuel. In table 2, Sellin et al (2013), presents us with both analysis for the banana pseudo stem or BPS and sugar cane bagasse, demonstrating the similarities of both biomasses, which begin to hint at a possibility of the pseudo stem as a fuel despite the probable lower calorific power due to the differences in carbon and oxygen content.

Table 1 Immediate and proximate analysis of both pseudo stem and sugar-cane bagasse

	<i>BPS</i>	<i>Bagasse</i>
Carbon	38.92 %	48.6%
Hydrogen	5.92%	6.3%
Nitrogen	0.38%	0.6%
Sulfur	0.49%	0.1%
Oxygen	54.29%	45.1%
Moisture Content	10.89 %	-
Volatile Matter	73.96 %	-
Ash	8.04 %	-
Fixed Carbon	18.00 %	-

2.2 Ash content and its relevance

Ash can and generally is problematic within the whole combustion process of any fuel. Usually, high ash content in fuels means this parameter must be carefully taken into account within the whole planning of a power plant. With 8.04 percent of ash content as stated in table 2, the banana pseudo stem falls into that category.

The high ash content of all bio mass, and in this specific case, of the banana pseudo stem, presents four major issues on the surfaces of grate fired combustors at high temperatures. They are as follows:

- Excessive ash particles fusing in the fuel bed lead to poor combustion conditions as the fused particles inhibit proper aeration of the fuel. This in turn foments the further growth of the ash agglomerates that capture unburnt fuel within the bed, decreasing the overall efficiency of the furnace.
- Large agglomerates also present problems for the ash removal from the grate and of its downstream use.
- Ash deposits created through slagging and fouling of ashes also reduce the heat exchanging capabilities if the furnace. Slagging is the deposit and fusion of both fuel bed ash and large fly-ash particles on the surface of the convection surface of the furnace. Fouling is the deposit and fusion of smaller fly ash particles and ash vapors on the upper convection heat surfaces like the super heater and the economizer of the boiler.
- As ash deposits grow they can sometimes shed from the furnace walls and components, falling from the upper sections to the lower sections, damaging components of the lower furnace like the grate or ignition components.

Ash vapor can also create problems through corrosion. Elements like sulfur and chlorine are part of some inorganic volatile matter as well as contained in small portions in ash. While they are separated during the initial pyrolysis, they can mix with regular flue gases, or exhaustion gases. The alkali chlorides mixing with the flue gas react, releasing sulfates and free chlorine that when in contact with the metal tubing of the heat exchangers can begin to corrode the tubes at temperatures as low as 100°C (van Loo and Koppejan 2008). Table 3, shows us the main elements within the ash of the pseudo in grams per kilograms of fresh pseudo stem, demonstrating a relatively high potassium level that would negatively influence the ashes' fusion temperature.

Table 2 Possible ash content of the pseudo stem (Heuzé, Tran, and Archimède 2013)

Main Ash Elements	g/kg of fresh pseudo stem
Calcium	7,0
Phosphorus	0,9
Potassium	40,8
Magnesium	3,7

2.3 Gross and Net Calorific Values

To calculate both the gross caloric value (GCV) and net caloric value (NCV), van Loo and Koppejan (2008) used equations 1 and 2.

$$GCV = 0,3491X_C + 1,1783X_H + 0,1005X_S - 0,0151X_N - 0,1034X_O - 0,0211X_{ash} \quad (1)$$

Where X_i are the concentrations by weight of carbon, hydrogen, sulfur, nitrogen, oxygen and ash supplied in "tables 1 and 2".

$$NCV = GCV \left(1 - \frac{w}{100}\right) - 2,444 \left(\frac{w}{100}\right) - 2,444 \left(\frac{X_H}{100}\right) * 8,936 \left(1 - \frac{w}{100}\right) \quad (2)$$

Where w is the moisture content.

Both equations give the results in mega Joule per kilogram (MJ/kg) (van Loo and Koppejan 2008). From the information included in table 1, it was possible to determine the calorific values of the pseudo stem, resulting in a GCV (db) of 14.82 MJ/kg and a NCV (wb) of 5.54 MJ/kg at 50% humidity. The results show a fuel with a low NCV in comparison to other biomass fuels, topic that will be discussed further along.

3. CASE STUDY: THE SUGAR MILL

Seeing as how sugar mills utilize both, back-pressure and/or condensation turbines in order to generate electricity and supply vapor to the processing of the sugar/ethanol, the production scheme for an off-season generation considered a one extraction/condensation turbine of 35 MW. All primary industrial systems that are not included in the following list were cut out of the production schematics, leaving the main industrial navel functioning merely as a power generation plant:

- High Pressure and Temperature Generation Systems (Main Boilers)
- Primary Vapor Interconnection Systems (Tubing)
- Refrigeration Systems for Condensed Water
- Water Treatment Stations and Water Feed Systems
- Electric Sub-Station

In other words, any system not related to the production of energy will not be considered as during the off-season no production of sugar and molasses is possible due to the lack of raw sugar cane to processes.

The Programed Power Output Availability of the two sugar mills already providing energy to the Nicaraguan Interconnected Grid or SIN, show three months of zero production and 4 months of a limited production, this considering that the average sugar cane season in the country is 199 days or 6.7 months (INE 2014), demonstrates that already there is a rationing of full production in order to expand production to 9 months of the year. A great increase in fuel availability would allow the installed turbines and generators to work for longer durations, generating greater revenue to the sugar mill.

In order to generate 35 MW of electricity, which is the capacity of a medium sized sugar mill in Nicaragua, the amount of bagasse required is calculated using the technical specifications of the sugar mill. In order to estimate the fuel consumption rate, the proposed schematics of the Off-Season Model is shown in Fig.2. These schematics would represent a gross calculation of any and all production factors, but could give a basic idea on the validity of the model having enough fuel to operate during the off-season.

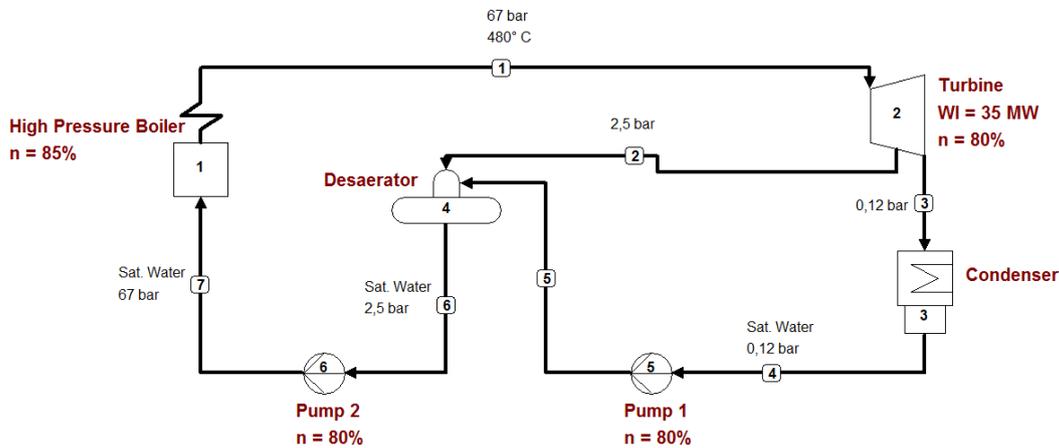


Figure 2 Idealized production schematics during Off-Season

Source: Author

Considering the operational conditions shown in the schematics of Fig. 3, the basic calculations needed to determine the fuel addition rate are the following:

$$\frac{\dot{W}_t}{\dot{m}_s} = (h_1 - h_2) + (1-y) * (h_2 - h_3) \quad (3)$$

$$\frac{\dot{W}_p}{\dot{m}_s} = (h_7 - h_6) + (1-y) * (h_5 - h_4) \quad (4)$$

$$\frac{\dot{Q}_{in}}{\dot{m}_s} = (h_1 - h_7) \quad (5)$$

$$y = \frac{h_6 - h_5}{h_2 - h_5} \quad (6)$$

$$\eta = \frac{\dot{W}_t - \dot{W}_p}{\dot{Q}_{in}} \quad (7)$$

$$\dot{m}_s = \frac{\dot{W}_{cycle}}{\dot{W}_t - \dot{W}_p} \quad (8)$$

Where,

h_i – is the value of the specific enthalpy for the specified steam/water properties in kJ/kg.

\dot{W}_t – is the power output of the turbine in Watts

\dot{W}_p – is the power consumption of both pumps in Watts.

\dot{Q}_{in} – is the Heat Intake in the boiler in Watts.

y – is the proportion of steam flow that passes through pipe number 3.

η – is the efficiency of the cogeneration system.

\dot{m}_s – is the steam flow in kg/s.

\dot{W}_{cycle} – is expected to be 35MW *(3600 s/h)*(10³ kJ/s) / 1MW.

(Moran and Shapiro 2000)

All equations considered the resulting conditions needed to produce 35 MW of power are shown in table 3.

Table 3 Resulting Operational Conditions for Off-Season Production Schematics
Data worked by author.

Factor	Unit	Value
\dot{W}_t/\dot{m}_s	kJ/kg	942.11
\dot{W}_p/\dot{m}_s	kJ/kg	12.77
\dot{Q}_{in}/\dot{m}_s	kJ/kg	2817.84
η	%	33
\dot{m}_s	kg/s	37.66

In order to produce 37.66 kg/h of steam, which would represent a consumption of approximately 136 tons of steam per hour, considering an aqua-tubular boiler working at 67 bar and having an outlet temperature of 480°C and an efficiency rate of 85%, the following equation would present the fuel consumption rate needed in order to generate that amount of steam.

$$\dot{m}_f = \frac{\dot{m}_s * \dot{Q}_{in}}{\eta_{sg} * NCV * 10^3} \quad (9)$$

Where,

\dot{m}_f – is the fuel rate consumption in kg/s.

η_{sg} – is the efficiency of the steam generator.

NCV– is the Net Calorific Value for the fuel in MJ/kg.

From, (Moran and Shapiro 2000).

Using equation 9, the resulting fuel addition rate is determined at 22.52 kg/s in order to generate the 35 MW planned.

4. LEVELIZED COST OF ENERGY

4.1 Investments, operational and maintenance Costs

In order to produce electricity from *musa* plants pseudo stems, the biomass must be initially be processed, milled and granulated from its original stem form and then the amount of humidity within the biomass must be reduced from the approximately 84% of water (FAO 1997) that it contains to a level of 50% that most furnaces in sugar mills can handle.

For this to occur, some investment would have to be made within the industrial navel. However, the main components needed to produce electricity would not be considered investments as they have already been acquired or are in the process of acquisition by the sugar mill.

4.1.1 Investment: milling and drying

In Defilippi’s 2013 masters thesis a milling central to be used in the process of preparation of sugar cane residues in the form of sugar cane straw was detailed in price. This milling center would now be used to mill the fresh banana pseudo stems, although some of the components of the original milling center could be discarded due to the differences in the biomass. The following table 4 describes the components of this center and their prices in US Dollars or USD. The plant was projected to have a work load of 15 T/h, for the purposes of processing the amount of plantain biomass required by the 35 MW generation plant.

Table 4 Components and Costs for 15 T/h Biomass Milling Center
Worked from (Amos 1998; Defilippi Filho 2013)

Biomass Milling Center 15 T/h	USD(2015)
Biomass Feeding Belt	\$152,337.33
Electromagnet Protection for Milling System	\$50,779.11
Grilled Feed belt to Eliminate Mineral Impurities	\$190,421.67
Metallic Structure for Grill/Mill	\$182,804.80
Box to Collect Impurities	\$25,389.56
Ducts and Shafts for Grill to Mill Interconnectivity	\$42,654.45
Double Barrel Mill	\$195,499.58
48" Transport belt for Milled Pseudo Stem	\$137,103.60
Civil Works	\$60,934.93
Electrical System: Control center and panels/motors	\$162,493.15
Fire Protection System	\$30,467.47
Total Investment	\$1,230,885.65

In a study from 1998 made by the National Renewable Energy Laboratory in conjunction with the US Department of Energy, discussing the process of drying biomass, the installed capital investments needed were outlined by technology and dryer type. The “Report on Biomass Drying Technology” by Wade Amos, thoroughly explained the characteristics, benefits and disadvantages of many types of dryers. However, for the water extraction from large particle biomass, a single stage rotary dryer was singled out as the most effective. Rotary dryers are less sensitive to particle size and can accept the hottest flue gases than any other type of dryer. It is relatively cheaper and has the largest capacity, yet they also pose a greater fire hazard and can allow little control of humidity percentages within the biomass in comparison to other dryers. In this study, Amos presents a table for installed capital costs of every type of dryer, and despite the fact that installation costs are very location specific; an average is given for the investment needed in kilograms of water removed per hour. The cost of removing one kilogram of water per hour from the biomass is USD176 in 1998 dollars, and adjusted for inflation represents USD 256.96/kg/h in 2015 dollars. (Amos 1998)

Table 5 Capital Investments Needed (¹Amos 1998;² Defilippi Filho 2013)

CAPEX	Unit	Cost
Milling Center ²	USD (15 T/h Cap.)	\$1,230,885.65
Rotary Dryer ¹	USD/T(GPS)/h	\$82,227.2

Apart from the investment in infrastructure and machinery needed in order to processes the GPS into an utilizable fuel source, there are operational and maintenance costs for the entire plant and the fuel itself has a specific cost. In a cost analysis study for biomass power generation, made by the International Renewable Energy Agency, or IRENA, in 2012, the major O&M costs where outlined quiet effectively. These O&M cost can be divided in fixed and variable, where fixed O&M cost depend mainly on the initial investment. These costs are primarily but not exclusively, labor, scheduled maintenance, routine component or equipment replacement (for boilers, feedstock handling equipment, etc.), and insurance. Usually, the fixed O&M have a lower specific cost per kW produced when a power generation plant is larger. Variable O&M costs depend on the output of the system and are usually expressed as a value per production unit

or USD/kWh for power plants. These costs include, any non-biomass fuel needed during the generation process, ash disposal costs, unplanned maintenance and equipment replacement and incremental servicing costs. In the study, these costs were outlined specifically by technology.

Since the Fixed O&M depends on the capital investment of a plant, considering a capital investment value for a 65 bar Condensing/Extraction Turbine at R\$1860/kW in 2008 BRL (Seabra 2008), converting that value to 2015 USD would result in a capital investment cost of 1274.3USD/kW. Considering an installed capacity of 35 MW, the total investment would finalize in approximately 44.6 million USD. So for this specific project and considering the average values for both fixed and variable O&Ms, table 6, presents the project's yearly O&M costs.

Table 6 O&M Costs for the 35 MW generation stocker boiler
Worked from (Irena 2012)

Cost	Unit	Value
Fixed O&M ¹	USD/h	188.4
Variable O&M	USD/MWh	4.25

¹ (Percentage of yearly capital investment)

The cost of the banana pseudo stem to be used as fuel basically just include the transportation of the banana pseudo stems as they currently have no value to the banana producers. As demonstrated in table 7, the costs can be separated into field work and basic transportation. As the picking of bananas is still very labor intensive, it would be the same laborer who would carry out any and all pseudo stem. The transportation costs would be of an average sugar cane transport truck bringing the wet pseudo stems to the processing plant. Since all of the extraction of the banana pseudo stems is done by hand it is not known if these costs would be relative to small scale extraction endeavors or if they could be applied on the large industrial scale extraction needed to fuel the sugar mill's boilers during the off-season.

Table 7 Cost of banana residue per Ton
Data provided by (CASUR)

Cost	Unit	Value
Transportation	USD/T	\$7.00
Field Work	USD/T	\$2.40
Total	USD/T	\$9.40

The "green" pseudo stems and the processed pseudo stem fuel would also have to be transported to and from different places and processes inside the sugar mill. Considering an average of two loader wheels and a work force of 8 laborers, table 8 shows the total costs of the internal transportation of the biomass.

Table 8 Costs of Internal Biomass Transportation
Data provided by (CASUR)

Cost	Unit	Value
Machinery (two wheel loaders)	USD/h	\$130.00
Labor (8 laborers)	USD/h	\$27.84
Total	USD/h	157.84

4.2 Determining the other economic variables

For this case study, a nominal cash flow was used, even though a real cash flow, the nominal cash flow adjusted for inflation, returns more precise information. Also, the total number of periods considered was 20 years as recommended by the Central American Bank for Economic Integration for renewable energy projects (BCIE 2009). A linear depreciation of all capital goods was considered for simplification purposes, meaning that all investments made in machinery will have a value of zero at the end of the twenty year period. Median Capital Cost of the Project can be considered as the discount rate appropriately used which is an average between the cost of acquiring debt in order to invest or K_d and the cost of utilizing the company's own capital or K_s (BCIE 2009). Although for this analysis only the company's financial capital was utilized.

However utilizing the company's own financial capital comes at a cost, where a series of risk factors reward or punish the use of that capital for any investment. The following equation was used to calculate K_s according to the Capital Asset Pricing Model, used by the BCIE in their study,

$$K_s = K_1 + \beta * (K_m - K_1) + R_p + R_{proj} \quad (3)$$

Where,

K_1 – Is the Risk Free Rate

β - Is the systematic Rate of Risk

$(K_m - K_1)$ – Is the Risk Premium

R_p - Country Risk Premium

R_{proj} - Project Risk Premium

According to the study presented by the BCIE, all risk factors are calculated with capital investment rates in the United States of America, as the investment costs would be in dollars and not in the country's official coin, the Córdoba. In the study the risk free rate is presented at 4.22% which is the average rate of return for US Treasury Bonds for the last 10 years. The " β " for these types of investments is 0.88. The risk premium is calculated for an average of 4 decades for the US market according to Standard & Poor's 500 Spread and is 4.13%. The country risk premium is calculated a ratio between a base country's credit rank and the country of investment's credit rank multiplied by the risk free rate. The base country considered was the US at rank 88 and Nicaragua at rank 22, therefore the country risk premium is 12.66%. Finally, the project risk premium was based on financial assessments made by the BCIE's consulting group and was given a 3%.

In total, K_s , given all those values, comes in at 23.5% (BCIE 2009). As the cost of capital investments is the pondered average cost of capital acquired through debt or by already existing capital. Assuming that no money would be borrowed for the acquisition of the required processing and drying plants and any other investments, the cost of capital would simply be the value of K_s , and as for Nicaragua, this value would be something similar to 23.5% meaning that K_s could be considered as the discount rate.

4.3 Result of the LCOE

Equation 3, gathered from (IEA 2010), was used to determine the levelized cost of energy in US dollars per kilowatt hour or (USD/kWh).

$$LCOE = \frac{\sum_{t=1}^n \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}} \quad (3)$$

I_t - Investment expenditures in the year t

M_t - Operations and maintenance expenditures in the year t

F_t - Fuel expenditures in the year t

E_t - Electricity generation in the year t

r - Discount Rate

t -Time in years

n - Life of the system

Table 9 presents the resulting values for the total investment need in order to process the "green" pseudo stems and also the costs generated by fixed and variable operations and maintenance, fuel costs and the expected generation prospects. All of the cost values were calculated for a 136 day off-season period considering that the average sugar cane season in Nicaragua lasts for 199 days and that at least 30 days must be left open for maintenance period (SEABRA, 2008). Apart from this, the total amount of hours in the off-season which totaled 3264 hours were multiplied by a basic capacity factor for bagasse cogeneration, leaving the amount of working hours for the off-season at 2774.4 hours. As it can be seen in table 12, the values of Fixed, Variable O&M and Fuel, were left equal on the horizon from year 1 to year 20, these estimated values do not consider inflation. In the case of the value for generation, the diminishing generating capacity of the power plants was also not included. All of these assumptions were made in order to simplify calculation as the purpose of this paper is only to provide a general idea of the costs of production.

Table 9 Costs and Generation for 136 days/Years .Source: Data worked by author.

	Years	0	1	...	20
Investment	USD	\$12,926,842.10	0	...	0
Fixed O&M	USD	0	\$960,608.26	...	\$960,608.26
Variable O&M	USD	0	\$412,692.00	...	\$412,692.00
Fuel	USD	0	\$6,606,589.60	...	\$6,606,589.60
Generation	MWh	0	97,104.00	...	97,104.00

With the data from Table 12 and equation 3 it was possible to calculate the leveled cost of energy. The resulting LCOE was a total of 0.114 USD/kWh which is elevated in comparison to other renewable fuel sources available in the country, although not as elevated as the fuel oil and diesel generation plants also present in the national energy production scheme (IEA 2010).

4.4 Sensibility of the LCOE

Out of the three cost values presented, it can be noted that the fuel cost is by far the largest one of them all. In total, the cost of fuel represents approximately 82.8% of the annual total costs making it an ideal candidate to study the sensitivity of the LCOE for the variations in the fuel costs as it can be seen in figure 3.

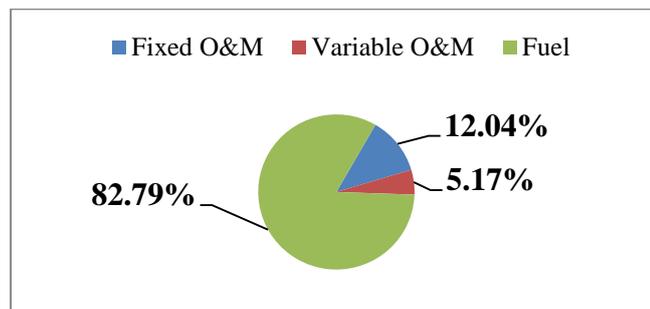


Figure 3 Percentage representation of total costs of BPS energy generation. Source: Author

Considering that, the cost calculation were merely valued considering only the transportation of the “green” banana pseudo stems, as they had no underlying value to the producers themselves, once the perception of added value from the pseudo stems reached the producing community, then they would most definitely demand some sort of pay per weight of biomass, just as it has happened with bagasse. This would definitely increase the cost of the fuel, while a better planned harvesting logistic could potentially decrease transportation costs, both scenarios were considered in studying the sensibility of the LCOE from the perspective of fuel cost. Figure 4 presents the results for this sensitivity analysis, where fuel costs were varied in positive and negative intervals of USD 2.00 from the base cost of USD9.40 per Ton.

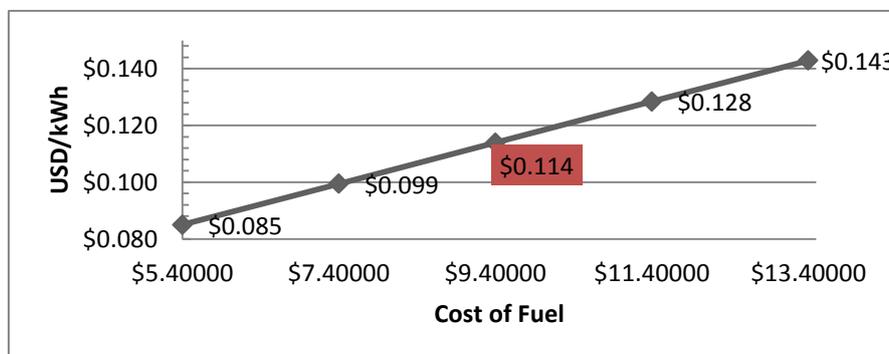


Figure 4 Sensitivity of LCOE to fuel cost variations. Source: Author

5. CONCLUSIONS

The characterization of banana pseudo stem residue as a fuel presents relatively poor burning properties. With an NCV of 5.54 MJ/kg at 50% humidity, the residue would be extremely difficult to ignite. The high moisture contents of the pseudo stem must be dealt with in a pre-combustion process, as well as the grinding of the biomass fibers in order to increase the ignitability of the mass. In technical aspects, the NCV of the pseudo stem could be brought up to a more “burnable” level but for that to happen, large amounts of humidity would have to be removed, lowering it to about 9.5% would result in a very utilizable fuel yet the removal of this humidity would come at a great cost in the form of investment and the transportation of water.

The relative ash content percentage can be compared to that of the sugar cane bagasse. However, as the pseudo stem presents higher levels of potassium, these ashes would have to be carefully monitored as not to pose a problem through ash fusion and conglomeration.

With a relatively high LCOE in comparison to other renewable fuel sources, the most cost demanding aspect of the generation is the high water content biomass, in which the set price of USD 9.40 per ton of biomass is 68% of water, turning every truck carrying the “green” pseudo stems basically into a “water truck.” A levelized cost of energy of USD 0,114/kWh considered in this paper is high enough to set the use of banana pseudo stem residues as economically unfeasible in comparison to other renewable fuel sources. If the largest contributor to this high LCOE, the fuel cost, was able to be cut in half, the resulting LCOE would have without a doubt a more interesting value in the economic sense, yet again, the whole cost of fuel is basically the cost of transporting the fuel from the production fields to the sugar mill and this cost is in great part elevated because of the elevated moisture content in the fuel. Despite the high LCOE, the use of banana residues in sugar mill cogeneration schemes would still be cheaper than the use of some petroleum derivatives like Fuel-Oil and Diesel power plants.

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