Eucalyptus sp. WOODCHIP POTENTIAL FOR INDUSTRIAL THERMAL ENERGY PRODUCTION[1]

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ABSTRACT – The main objective of this work was to identify and analyze the potential of forest biomass of *Eucalyptus* sp. such as thermal energy source for industrial use in place of fossil fuels. Two cases were analyzed: the first one estimated the total demand for forest biomass to replace the main fossil fuels in Brazilian industrial sector, with scenarios of 100, 75 and 50% replacement; in the second, it was calculated the cost of each fuel for producing ton of industrial steam (thermal energy) for a dairy industry, in order to verify the competitiveness of forest biomass compared to fossil fuels. The results showed that the areas demanded to replace 100, 75 and 50% of the analyzed fossil fuels were, respectively, 2.9, 2.2 and 1.5 million planted forests hectares, and the steam ton cost ratio using the woodchips was at least 34% lower than with other fuels, which corroborates the substitution potential in this sector.

Keywords: Planted forests; Energy potential; Industrial steam.

POTENCIAL DO CAVACO DA MADEIRA DE **Eucalyptus** *sp. PARA PRODUÇÃO DE ENERGIA TÉRMICA INDUSTRIAL*

RESUMO – O objetivo central deste trabalho foi identificar e analisar o potencial da madeira de espécies do gênero **Eucalyptus** *como fonte de energia térmica para uso industrial em substituição aos combustíveis fósseis. Foram analisados dois casos: no primeiro foi estimada a demanda total dessa biomassa florestal para substituição dos principais combustíveis fósseis no setor industrial do Brasil, com cenários de 100, 75 e 50% de substituição; e no segundo foi calculado o custo com cada combustível para produção de uma tonelada de vapor industrial (energia térmica) para uma indústria de laticínios, de forma a verificar a competitividade da biomassa florestal frente aos combustíveis fósseis. Os resultados encontrados demonstraram que as áreas demandadas para substituição de 100, 75 e 50% dos combustíveis fósseis analisados foram respectivamente, 2,9, 2,2 e 1,5 milhões de hectares de florestas plantadas de eucalipto, e o custo da tonelada de vapor utilizando o cavaco de eucalipto foi no mínimo 34% menor do que com os demais combustíveis, o que corrobora o potencial de substituição nesse setor.*

Palavras-Chave: Florestas plantadas; Potencial energético; Vapor industrial.

1. INTRODUCTION

The use of wood as an energy source has taken place since the early days of mankind, and to this day it has been an important fuel for many regions, especially in developing and underdeveloped countries. Over the years, however, the development of the oil industry has made it, as it is more efficient, the main fuel of the energy mix of most countries (Bentsen and Felby, 2012; Dobie and Sharma, 2015). Currently, with the development of high production planted forests of the genera *Eucalyptus* and *Pinus* together with the increase in modern energy conversion technologies, the consumption of forest biomass for energy production has increased. This bioenergy can generate potential benefits to forest producers and for the industrial sector and reduce their dependence on fossil fuels (Eisentraut and Brown, 2012; Iiyama et al., 2014).

In the Brazilian case, forest biomass has always played an important role in the energy mix, with charcoal and firewood being the main use. According to the National Energy Balance (BEN), wood accounted for 8.1% of primary energy production in 2014. In addition, according to the Brazilian Tree Industry (2016), the wood consumption for industrial use in the year 2015 was 194 million cubic meters, mainly of *Eucalyptus* genus species (EPE, 2015; IBÁ, 2016).

The growth of the demand for wood as a thermoenergy fuel for industrial use is already a reality in much of the world (Albani et al., 2014; Berndes et al., 2003; Gonzalez-Salazar et al., 2016). However, it is a market that still needs to be consolidated in Brazil, including the large availability of idle or underutilized pasture lands, which has forestry as a good option for use and income generation (Couto et al., 2002; Payn et al., 2015).

In Brazil, firewood and its derivatives (such as woodchip) are on the sixth place in the primary energy production for the industrial sector, with a tendency to grow. In some sectors such as food and beverages, it occupies the third place in the energy matrix (EPE, 2015). In addition to firewood in its commercial form, wood waste has been widely used in recent years in power generation. In this way, waste is no longer an environmental problem and becomes a renewable and low-cost energy source (Dal Farra and Esperancini, 2014).

One of the main uses of forest biomass for energy is the woodchip, which consists of mincing firewood or residues in small fragments of more or less homogeneous sizes (Nascimento and Baggion, 2010). Using the woodchip it is possible to reduce the thermal energy cost compared to the use of firewood because the chip allows a greater process mechanization and a lower cost with labor, which directly impacts the energy final cost. Several sectors such as the dairy, refrigeration, paper, fertilizer and agroindustry in general are opting for eucalyptus woodchips for the thermal energy (steam) production in detriment of fossil fuels, with economic and environmental returns (Ribeiro and Valverde, 2016).

In this way, this research was conceived and carried out after several unknown findings about the eucalyptus woodchip feasibility for industrial thermal energy production, given the expectation of this biomass great potential. In this way, it is necessary to know and analyze the eucalyptus wood potential as raw material for the thermal energy production in substitution of fossil fuels, their properties, their costs and their potentialities and obstacles, in order to contribute to this sector expansion.

2. MATERIALAND METHODS

2.1. Forest biomass properties for energy

For the best use of forest biomass in energy production, it is important to be aware of several factors, the main being the physical, chemical and thermal properties of the biomass used. From these properties, one must know this biomass fundamental characteristics, which are the elemental composition, immediate composition and calorific value (Cortez and Lora; Gómes, 2008).

The direct wood burning for the thermal energy production is called combustion, a complex process involving chemical reactions and simultaneous heat and mass transfer (Vital et al., 2013). According to the scientific and technical literature review, the main characteristics and indexes that affect the woodchip quality for the direct burning are: calorific value, basic density, moisture content and elemental chemical composition analysis. Thus, the greater the wood calorific value is, the better it is for using in direct burning (Vale et al., 2000; Vital et al., 2013).

Moisture content is also a very important variable for the biomass energy utilization, because the water presence in the wood causes the calorific value reduction, since part of the heat generated is consumed in the water evaporation (Carneiro et al., 2014).

The main tree species used in the country for energy purposes are of the genus *Eucalyptus*, due to its high productivity indexes, adaptation to different ecological conditions, uses for the most varied purposes, and especially, energy characteristics (wood density and calorific value), allied to the silvicultural and genetic knowledge acquired in the last decades (Brito, 2007; Couto and Müller, 2013; Torres et al., 2016).

In this way, this work will take into account the woodchip calorific value, density and moisture content to evaluate the eucalyptus woodchip potential.

2.2. Forest biomass demand estimation for thermal energy production

From the industrial sector energy matrix, obtained in the National Energy Balance 2015, base year 2014 (BEN), the fuels to be replaced by the forest biomass were extracted, being: natural gas, liquefied petroleum gas (LPG), fuel oil and diesel oil, because they are the most used in the thermal energy production by the industrial sector. After this identification, these fuels replacement scenarios by forest biomass were established in 100, 75 and 50%.

For energy conversion, the BEN data is presented in the ton of oil equivalent unit (toe). Thus, the conversion factor for wood presented by the same BEN was used, in which one ton of wood corresponds to 0.31 toe, with an efficiency of 80%, corresponding to the thermal energy production yield.

From the thermal energy demanded values obtained from the fossil fuel substitution simulations by the forest biomass, the forest area required to supply the wood demand was calculated.

For the conversion of the wood mass to the cubic meter, a wood density of 0.5 t./m³ was used. Finally, to estimate the equivalent forest area demanded for energy production, an average forest productivity of 40m³/ha.year was considered. The equations for ton of oil equivalent equivalence in wood mass and forest area are presented below.

$$t.mad. = \frac{D_c}{0{,}31} * 1{,}25 \quad \text{(Eq. 1)}$$

Where:

t. mad. = Wood demand in tons;

D_c = Energy demand in ton oil equivalent.

$$D_m = \frac{D_t}{0{,}5} \quad \text{(Eq. 2)}$$

Where:

D_m = Wood demand in m³;

D_t = Wood demand in tons.

$$AF = \frac{D_m}{40} \quad \text{(Eq. 3)}$$

Where:

AF = Demanded forest area in hectares

D_m = Wood demand in m³

2.3. Thermal energy generation fuel cost

In order to demonstrate the forest biomass competitiveness against the fossil fuels used in the thermal energy production by the national industry, it was estimated each fuel cost for one steam ton production and the comparison between them.

In order to compose the steam demand and to exemplify the cost calculations, production data from the dairy industry were used with the respective steam consumption coefficients for each product, found by Silva (2011), (Tabela 1). The produced quantities were taken from the survey on brazilian industrial production carried out by the Brazilian Institute of Geography and Statistics (IBGE), base year 2011 (Silva, 2011).

The fuel amount required to generate thermal energy was estimated according to Nascimento and Biaggioni (2010).

$$Q_c = \frac{Q_v(h_v - h_a)}{\eta(PCU)} \quad \text{(Eq. 4)}$$

Where:

Q_c = fuel amount (kg)

Q_v = steam amount (kg)

h_v = steam enthalpy depending on pressure and temperature (kcal/kg)

h_a = water enthalpy depending on temperature (kcal/kg)

η = yield (%)

PCU = Net Calorific Value (kcal/kg)

The steam enthalpy value used in the calculations was 663.9 kcal/kg and the water enthalpy of 185.6 kcal/kg. These values may vary depending on the working pressure and temperature of the boiler. Due to the moisture influence on the forest biomass calorific value, the following expression was used to calculate the PCU (Vale et al., 2011).

$$PCU = [PCI * (1 - U)] - 600 * U \quad \text{(Eq. 5)}$$

Where:

PCU = Net Calorific Value;

PCI = Calorific value less than 0% of humidity (PCI = PCS - 324);

U = Moisture content on wet basis (%)

Thus, in order to calculate the cost of generating one ton of thermal energy (steam) and the comparison between them, it was necessary to obtain: the production process incomes by the boiler in the thermal energy conversion to each of the fuels; the net calorific value (PCU) of the different fuels used, by which the firewood and woodchip calculated values were made based on wood with humidity of 35% (wet basis); fuel densities - to convert the calculated values to the commercial units of each fuel; and fuel prices used in the study. All data are summarized in Table 2.

3. RESULTS

3.1. Replacement of non-renewable fuels with forest biomass

For the substitution scenarios evaluation, Table 3 shows the consumption of non-renewable fuels by the industrial sector in the year 2012, which may be replaced by forest biomass for thermal energy production. From this consumption, it was estimated the equivalence of these fuels in ton and cubic meter of forest biomass, with the results presented in Table 3.

At Table 4 is presented the forest area demanded for partial or total replacement of fossil fuels by forest biomass, according to stipulated replacement percentages.

According to IBÁ (2015) the forest plantations area in Brazil is 7.6 million hectares. Considering a replacement of 100% of the mentioned fuels, the forest area needed to meet the industrial sector would be around 38% of the total forest plantations area existing in the country at present, that is, 2.9 million hectares.

Table 1 – Total Brazilian production and coefficient of energy consumption of some products of the dairy industry.
***Tabela 1** – Produção total brasileira e coeficiente de consumo energético de alguns produtos da indústria de laticínios.*

Products description	Produced amount (Annual total)	Unit	Energy consumption coefficient (steam/unit ton.)
Pasteurized milk, including skimmed milk	1,278,497	1,000 L	0.05
Dairy beverages	852,113	1,000 L	0.06
Curd cheese (cream, light, hard or northern)	177,161	ton.	0.72
Minas frescal cheese	83,929	ton.	0.31
Mozzarella cheese	385,462	ton.	0.71

Source: Adapted from Silva (2011) and IBGE.

Table 2 – Characteristics of the different fuels.
***Tabela 2** – Características dos diferentes combustíveis.*

Fuel	Yield (%)	PCU (Kcal/kg)	Density (Kg/m³)	Price
Fuel oil	80	9,550	980	R$ 1.57/liter
Diesel oil	90	10,100	840	R$ 2.25/liter
Natural gas	90	9,000	0.74	R$ 0.50/m³
Liquefied petroleum gas (LPG)	90	11,200	552	R$ 2,615.00/t.
Firewood	60	2,711	500	R$ 75.00/m³
Woodchip	80	2,711	333	R$ 45.00/m³

Sources: Yield: BIRTH; BAGIONI (2010); PCU = Net Calorific Value: EPE (2015) and ARAUTERM; Density: EPE (2015); Prices: ANP, IBP, INDEX MUNDI, CIFLORESTAS (base December, 2014).

Table 3 – Fuel consumption by the industrial sector and forest biomass equivalence.
Tabela 3 – *Consumo de combustíveis pelo setor industrial e equivalência em biomassa florestal.*

Sources	Consumption (10^3 toe)	Equivalence	
		t. wood (10^3)	m³ wood (10^3)
Natural gas	9,849	39,712.4	79,424.8
Diesel oil	1,038	4,183.6	8,367.2
Fuel oil	2,587	10,430.0	20,859.9
Liquefied petroleum gas	1,005	4,050.6	8,101.2
Total	14,477	58,376.6	116,753.1

Table 4 – Forest area, in hectares, demanded for replacement.
Tabela 4 – *Área de floresta, em hectare, demandada para substituição.*

Fuel	Replacement percentages		
	50%	75%	100%
Liquefied petroleum gas	101,265	151,898	202,531
Diesel oil	104,590	156,886	209,181
Fuel oil	260,749	391,123	521,497
Natural gas	992,810	1,489,215	1,985,619
Total	1,459,414	2,189,121	2,918,828

Source: Own elaboration

Admitting a replacement of 75%, the area needed to supply the demand would be approximately 2.2 million hectares, corresponding to 29% of the entire planted forests area in Brazil. The forest area demanded for the replacement of 50% is 1.46 million hectares, which corresponds to 19.2% of the planted forests total area of the country.

3.2. Thermal energy cost – Case Study: Dairy industry

As mentioned, a dairy industry case study was used to calculate the cost of generating one ton of thermal energy (steam). Costs were considered equal for any industry given the same technological conditions and boiler efficiency. The Table 5 presents the producing steam costs with different fuels. It should be noted that the presented costs only include the raw material (fuel) for the steam production, not including, therefore, the equipment operating and labor costs.

Among the evaluated fuels, the woodchip is the one that produces the steam at the lowest cost, even in comparison to the firewood, due to its greater yield in the boiler and due to its greater specific area and stability in the steam flow, as already observed in some studies (Nascimento and Biaggioni, 2010; Buchmayr et al., 2015). The other fuels derived from petroleum allow high boiler efficiency and ease system mechanization and automation, however they have a higher cost.

4. DISCUSSION

As shown in item 3.1, it is observed that the forest biomass amount in relation to the ton of oil equivalent increases considerably, since the calorific value of the wood is lower compared to oil and its derivatives. This leads to some implications such as the handling of larger fuel quantities, thus requiring a more complex logistics for biomass in relation to fossil fuels (Pinto

Table 5 – Steam production comparative cost.
Tabela 5 – *Custo comparativo de produção do vapor.*

Fuel sources	Density(Kg/m³)	Demand (m³)	Unit	Price(R$)	Steam cost (R$/t.)
Firewood	500	315,096	m³	75.00	44.11
Woodchip	333	354,837	m³	45.00	29.81
Fuel oil	980	34,223,588	Lt	1.57	100.30
Diesel oil	840	33,558,443	Lt	2.25	140.94
Natural gas	0.74	42,749,224	m³	0.50	39.90
LPG	552	46,051	t.	2,615.00	224.79

Source: Own elaboration

Jr et al., 2007; Pelkonen et al., 2014).

Although only 50% of fuel consumption would be replaced by forest biomass, new business opportunities, economic, social and environmental benefits would be generated, as well as greater participation of small producers in the forest market, in addition to making it possible to destine the wood of numerous plantations which are without market.

In the case of the dairy industry study (item 3.2), in addition to produce the industrial steam with lower cost, the woodchip has some operational advantages in relation to firewood, such as: i) fuel supply mechanization - the woodchip allows greater burner feed mechanization, which contributes to steam flow system automation and stability; ii) moisture control - the woodchip has homogeneous granulometry, which facilitates drying and a better moisture control; iii) logistics - it is possible to mechanize all woodchip production and transport operations, from loading to unloading at the final destination; and iv) steam quality - because it allows more uniform burning and flow, the woodchip produces a better quality steam.

Among the petroleum derived fuels, natural gas is the one that presents the lowest cost for steam production, but its cost is 34% higher than the woodchip cost. Although with higher production costs, petroleum derivates are still widely used because of the logistical and operational ease, as well as the lower bureaucratic requirement in relation to forest biomass.

The main strengths about the forest biomass use in thermal energy generation are the fact that it is a renewable fuel, has a competitive cost, high forest productivity in Brazil, job creation, regional scope and land for forest implantation availability. However, there are still proven disadvantages, such as the intrinsic wood characteristics (low energy concentration per volume unit), its volume-based marketing form, which penalizes wood with higher density and higher calorific value, and organizational representativeness lack. The growth of the forest biomass participation in the energy market depends on the effective participation of all productive chain *stakeholders,* of public policies greater incentive and sector organizational improvements, which are considered important points for a qualitative study on this sector.

Similar results confirming the greater feasibility of thermal energy production using forest biomass compared to petroleum products can be confirmed in Ribeiro and Vicari (2005), Lima et al. (2006), Caetano and Duarte Junior (2004) and Nascimento and Baggioni (2010). Another important international study of AEBIOM (*European Biomass Association*), called Basis Bioenergy (2016), shows that there are around 4,000 bioenergy plants with a power of more than one megawatt (MW) in the European Union, using woodchips as an energy source for heat generation, industrial steam and electricity.

Therefore, although logistical difficulties may limit the substitution of petroleum derivatives for forest biomass, if some effort is made to stimulate energy matrix alteration through public policies, it is believed that it is possible to reach higher percentages of forest biomass consumption.

5. CONCLUSION

From the results of this work, we conclude that:

There is a space to be conquered by forest biomass (eucalyptus woodchip) in the thermal energy market for industrial use by replacing fossil fuels such as natural gas, fuel oil, diesel oil and LPG. As shown, replacing half of the petroleum derivatives consumption cited by forest biomass, would already be sufficient to promote the demand of 116.8 million m^3 of wood per year, which would represent a great generation of direct and indirect jobs for the sector.

In addition, it was observed that the thermal energy cost generated with fossil fuels is at least 34% higher than with forest biomass, where the eucalyptus woodchip stood out at a lower cost and competitive advantages compared to other energy sources.

It is important to note that the main limitations of this work are in the cost comparison generalization using only the dairy industry demand, and without evaluating changes in fuel prices. Future works evaluating these energy sources comparative cost should take into account other industrial sectors, as well as make price sensitivity and variable cost analysis.

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