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Uma abordagem logística e econômica para coordenar uma cadeia de suprimentos de biomassa, incluindo características de energia

A logistical and economical approach to coordinating a biomass supply chain, including energy characteristics

Un enfoque logístico y económico para coordinar una cadena de suministro de biomasa, incluidas las características de energía

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Resumo

O aproveitamento energético da biomassa é cada vez mais difundido pelas indústrias. Existe uma demanda crescente para compra de biomassa visando a geração de energia térmica e elétrica, como no caso dos setores sucroenergético, papel e celulose e painéis de madeira. O objetivo deste artigo é analisar uma cadeia de suprimentos de biomassa considerando as características de oferta, distância e energia de biomassa. A demanda por biocombustível teve como referência uma indústria de painéis localizada na Região Metropolitana de Sorocaba. O custo final foi calculado com base em cotações de preços, fretes e propriedades de energia de

cada biomassa. As biomassas escolhidas para análise foram: serragem, cavaco de madeira, briquete, lenha, floresta de eucalipto em pé (tora) e casca de arroz. Verificou-se que o maior suprimento de biomassa ao menor custo está nas distâncias entre 50 km e 250 km. Concluiu-se que o cavaco e a tora apresentaram vantagens para diferentes distâncias.
Palavras-chave: Bioenergia; Custo; Logística; Resíduos; Biomassa.

Abstract

The use of biomass energy is increasingly widespread among industries. There is a growing demand for the purchase of biomass aiming at the generation of thermal and electric energy, as in the case of the sugar and energy sectors, pulp and paper and wood panels. The aim of this article is to analyze a biomass supply chain considering the offer, distance and energy characteristics of biomass. The demand for biofuel is from a panel industry located in the Metropolitan Region of Sorocaba. The final cost was calculated based on price quotes, freights and energy properties of each biomass. The biomasses chosen for analysis were: sawdust, wood chips, briquettes, firewood, standing eucalyptus forest (log) and rice husks. It was found that the largest supply of biomass at the lowest cost is in the distances between 50 km and 250 km. The best materials were wood chips and eucalyptus log. Freight was not a determining factor in the final cost of biomass, even for the longest distances. It was concluded that the chip and the log had advantages for different distances.
Keywords: Bioenergy; Cost; Logistics; Residues; Biomass.

Resumen

El uso energético de la biomasa está cada vez más extendido entre las industrias. Existe una creciente demanda de compra de biomasa destinada a la generación de energía térmica y eléctrica, como en el caso de los sectores de azúcar y energía, celulosa y papel y paneles de madera. El objetivo de este artículo es analizar una cadena de suministro de biomasa considerando las características de oferta, distancia y energía de la biomasa. La demanda de biocombustibles proviene de una industria de paneles ubicada en la Región Metropolitana de Sorocaba. El costo final se calculó en base a cotizaciones de precios, fletes y propiedades energéticas de cada biomasa. Las biomasas elegidas para el análisis fueron: aserrín, astillas de madera, briquetas, leña, bosque de eucaliptos (tronco) y cáscaras de arroz. Se descubrió que el mayor suministro de biomasa al menor costo se encuentra en las distancias entre 50 km y 250 km. Los mejores materiales fueron astillas de madera y troncos de eucalipto. El flete no fue un factor determinante en el costo final de la biomasa, incluso para las distancias más largas. Se concluyó que el chip y el registro tenían ventajas para diferentes distancias.

Palabras clave: Bioenergía; Costo; Logística; Residuos; Biomasa.

1. Introduction

According to Proskurina et al. (2017), large industrial plants demand biomass to reduce fossil fuel costs, generating energy in a sustainable manner and also reducing greenhouse gas emissions. Silva et al. (2017) stated that the applicability of biomass for energy purposes are diverse. Biomass has a variety of sources involving agricultural, industrial, urban waste and several technologies for conversion into energy, such as pyrolysis, gasification and combustion.

The use of biomass by the industries depends on the factors, such as the location of suppliers, the seasonality of supply, quality and price. The location of suppliers will determine the cost of biomass transport, in addition to the capacity to supply a quantity that meets the daily demand by the industry (Malladi, Quirion-Blais & Sowlati, 2018).

According to Nunes, Causer and Ciolkosz (2020), several variables are related to the cost of biomass acquisition, they are: the monthly production of raw material by the suppliers, the period of time required for production, the storage period and the distance from each supplier. In addition, the use of different sources of biomass (from a number of suppliers) is a feasible solution to meet different demand volumes.

Regarding the supply seasonality, many biomasses depend on the harvest period, weather conditions and the replanting of trees for availability (Nunes, Causer & Ciolkosz, 2020). Many residues, such as those originating from the planting of sugar cane, orange and rice, are only supplied in some months of the year and are offered in larger amount in some regions of Brazil. It makes an aggravating factor for the industry dependence of these energy sources throughout the year.

Quality is a pivotal factor in choosing which biomass to use. The quality of the biomass includes its energetic properties and also the suitability factor for usage in equipment. For example, although some biomasses have the right calorific value, they can be abrasive, which reduces the lifespan of grids (Shabani & Sowlati, 2015; Niu, Tan & Hui, 2016). However, it is still considered by the industries a secondary factor when compared to the price of biomass.

As per Figueiró et al. (2019), Brazil has great potential in the production of forest biomass, due to its high productivity. According to the authors, woody biomass can consist of whole trees, roots, branches and forest management residues.

Regarding forest residues, they are basically the materials that are left behind in the harvesting process. Large quantities of these residues are produced in Brazil every year. Approximately 41 million tons of wood residues from the forestry processing and harvesting industry, with an equivalent capacity of 1.7 GW / year (Ferreira et al., 2018).

Swithenbank et al. (2011) stated that using raw wood for energy production may not be an efficient way, since it can contain more than 50% moisture, which reduces the calorific value and makes transportation more expensive. A reduction from 50% to 30% in the moisture content would contribute, according to the authors, to a 50% increase in the calorific value of the material.

As specified by Fisher et al. (2017), the use of wood in a sustainable way for energy production depends on methods that maximize operational efficiency, consider costs and be resistant to biotic and abiotic environmental stresses.

In addition to the generation of bioenergy from the direct use of wood for burning, biomass from agricultural and forest residues are also used, as in the case of rice husks, coffee husks, eucalyptus husks, sawdust, sugarcane bagasse, etc. According to Han, Gao and Qi (2019), there are several disadvantages in direct combustion of biomass. Among them, the problems caused by the high content of alkali metals that cause fouling, sintering, agglomeration and corrosion by overheating. According to the authors, burning and transporting non-compacted biomass generates low efficiency and pollution. Thus, biomass briquetting emerges as a solution to these problems.

The rice husk, obtained from the rice processing, is usually used for energy generation. As per Abaide (2019), it corresponds to about 23% of the weight of rice and its annual production is around 149 million tons, worldwide, approximately 70% of this is used for energy production.

Thus, all factors must be considered, as some materials, despite having lower prices, it can have high costs for usage, as in transportation costs. The objective was to analyze the economic viability of different types of biomass for energy (solid fuel), considering the logistics, supply and energy properties of biomass. Biomasses with different physical characteristics (granulometry, moisture and density) and from different sources were chosen. The number of suppliers in the area and the seasonality of each type of biomass were considered. The materials selected for analysis were: sawdust, wood chips, briquettes, firewood, standing eucalyptus forest (bark) and rice bark.

The wood of *Eucalyptus* sp. was the main biomass, given its importance in the region forest scenario and also for its various forms used for energy purposes (Fernándes, et al. 2018;

Ferreira, et al. 2017; Pighinelli, Schaffer & Boateng, 2018). In this way, price for sawdust, briquette, firewood, wood chips and log (standing forest) from eucalyptus wood and rice husk (offered in the region), were quoted.

2. Material and Methods

Company approached in the case study

The company is located in MRS and it has a demand of biomass for burning and it uses a boiler system for direct steam consumption. A large company in the wood panel market, located in the MRS, was used as a reference to estimate the daily consumption of biomass, which requires a daily amount of 200 tons of wood chips for energy generation. Therefore, the demand for other types of biomass was calculated based on the amount of chips.

Study Region

The MRS is composed of 27 counties and it has a population of more than 2.1 million people, which represents 4.65% of the total population in the state of São Paulo (EMPLASA, 2019). In addition, this region is located on the axis of the metropolitan regions of São Paulo and Curitiba, and remains close to the metropolitan region of Campinas, which means an advantage for commercial and logistics relations.

Regarding industrial activity, this region stands out for the production of ores, such as cement, limestone, among others and also in agricultural production. According to data from the Municipal Agricultural Production (PAM), the area destined for agricultural harvest in the MRS reached a total of 4,758 hectares in 2017, generating more than R$ 100 million in the same year (IBGE, 2017). For the forestry production, 27,573 hectares are allocated for planting in the region, with eucalyptus being responsible for 99% of this value, which represents 3% of eucalyptus planting in the State of São Paulo (CNAE, 2016).

Data Collection

The case study was used as methodology. Through this methodology, data surveys are carried out that will serve as a basis for qualitative and quantitative analyzes (Pereira, et al., 2018). Websites were used to get primary data regarding price quotations of biomasses between 2018 and 2019 and also the direct procurement of price quotations from suppliers.

In relation to the eucalyptus standing forest, plantations between 6 to 13 years were considered, given that there was no great price difference in the quotations for plantations up to 13 years. To calculate the annual productivity of planting, the Mean Annual Increment (MAI) of 35 m^3 /ha/year was considered (Cordeiro, et al., 2018).

The quotation of firewood, rice husk, sawdust and wood chips was considered bulk materials, without any treatment process (such as carbonization, sterilization, drying process). These criteria were used in order to find products aimed at generating energy in industries. The biomass market is, also, focused on small companies (such as in pizzerias and bakeries) at different prices.

To start the market research the logistics, biomass supply capacity, and availability of suppliers were considered It was included biomass suppliers located at a maximum distance of 500 kilometers from the MRS. Thus, suppliers were found in the states of São Paulo, Minas Gerais, Paraná and Santa Catarina.

Energy characterization

The data related to calorific value, density on a dry basis, bulk density and moisture content was obtained through a bibliographic survey and are reported in Table 1.

Table 1 - Higher calorific value (HCV), Basic Density (BcD), Bulk Density (BkD) and moisture content on wet basis (Mwb) of the materials.

Properties	Briquette	Wood chip	Sawdust	Firewood	Wood	Rice Husk
Mwb (%)	12[1]	35*	44[5]	30[1]	40*	15*
HCV (MJ/Kg)	18.95[2]	17.96[3]	19.49[6]	17.30[7]	19.37[9]	12.92[11]
BkD (kg/m³)	780[1]	186[4]	167[5]	-	-	114[11]
BcD (kg/m³)	-	-	-	440[8]	490[10]	-

* Information obtained by suppliers.
Source: [1] Biomax (ND); [2] Quirino et al. (2012); [3] Borges (2015); [4] Pedrazzi et al. (2010); [5] Calegari et al. (2005); [6] Costa et al. (2017); [7] Oliveira (2010); [8] Gatto et al. (2003); [9] Quirino et al. (2005); [10] Silva Oliveira, Hellmeister, Filho (2005) ; [11] Morais et al. (2006).

For calculations of transport and energy costs, it was necessary to recalculate the values in Table 1 referring to the HCV, bulk and basic density and energy density considering the moisture content on wet basis. To convert energy into ton of oil equivalent (toe), data from the National Energy Balance (NEB) were used. In this way, to calculate the toe, the ratio between the calorific value of each biomass and the calorific value of oil was used, which is 10,800 kcal / kg (EPE, 2018), according to Equation 1.

$$toe = \frac{HCV}{10{,}800} \qquad (1)$$

Where:
HCV: means Higher calorific value (kcal.kg^{-1})

Delivery logistics

For biomass transportation, it was considered two possibilities: delivery by the suppliers or removal of material by the company itself. In the case of removal, the freight cost was simulated on the National Land Transport Agency - ANTT website (2019), where the distance between 50 km and 500 km was considered for the cost calculation. The values quoted for freight do not include the tax costs with loading and unloading of the goods, fees such as toll and the cost with empty truck back. Included in the freight charges are the national taxes (PIS/COFINS), a profit margin of 8% and costs with inputs in the São Paulo region.

Regarding the delivery rate, the suppliers companies considered outsourcing. For the transportation of firewood and eucalyptus wood, the platform truck with a coupled trailer (called “Romeo and Juliet”) with a volume of 90 m³ of the cargo box and with 7 axles, with a cargo capacity of 51 tons, were considered. For the transportation of bulk materials, such as rice husks, chips, briquettes and sawdust, the truck with a 5-axle semi-trailer (movable bottom) was considered, with a load capacity of 32 tons and a volume of 110 m³ of the cargo box.

Harvest cost of eucalyptus forest

The harvest cost was based on Bendlin et al. (2014). A mechanized system was considered, where the Feller Buncher was used. Bendlin et al. (2014) found R$ 18 per stere (1 cubic m of firewood stacked) for eucalyptus logs. It was considered the costs in the felling by the Feller Buncher, dragging by Skidder and the stacking of the logs. The harvest cost was converted into m^3 and adjusted by the IGP-M (General Market Price Index), resulting in R$ 32.10 per m^3 for the year 2019.

This system is the most used today in case of planting for energy, since the diameter at breast height (DBH) is smaller than in other plantations for paper and celluloses. From this, it is possible to increase the productivity of the harvest, since the Feller Buncher manages to catch several logs to later unload.

Economic analysis

Offer prices were analyzed for each distance, in which average quotation values were considered. It was used Equation 2 to calculate the energy cost of each biomass, including freight. The Equation 3 was used with and without the freight offered by the supplier, the price per m^3, freight service cost per m^3, the material price per m^3 with the delivery by the supplier and the energy density (ED) were used, according to equations 2 and 3.

$$\text{Energy cost} = (\text{Price} + \text{freight}) \div \text{ED} \qquad (2)$$

$$\text{Energy cost with supplier delivery} = \text{Price} \div \text{ED} \qquad (3)$$

To obtain the energy density, Equation 4 was used:

$$\text{ED} = \text{HCV} \times \text{DMwb}\ (\text{MJ.m}^{-3}) \qquad (4)$$

Where:

HCV: means Higher calorific value ($MJ.kg^{-1}$)

DMwb: means Density with moisture content on wet basis ($kg.m^{-3}$)

The HCV used to calculate the energy density and the daily amount of each biomass was calculated with the moisture content on wet basis (Mwb). The new values of the HCV with Mwb were obtained from Equation 5:

$$\text{HCV (Mwb)} = \text{HCV} \times (100\ \% - \text{Mwb}) \qquad (5)$$

Regarding the daily amount of biomass, it was obtained based on the daily amount of 200 tons of chips, in which each biomass would meet the daily energy demand of the industry in isolation. Thus, to determine the quantity of each biomass, the energy density of the chip, the daily amount of chip and the HCV (Mwb) of each biomass were used.

To make the prices standardized, a single unit of measurement, the cubic meter, was used for all materials. For this purpose, the price quotations that were obtained in tons (in the case of briquettes and in some cases for chips, rice husks and sawdust), in cubic meters (chips, sawdust and rice husks) and in stereo meter (firewood and logs).

Regarding the transport cost, the number of trucks needed for each material was calculated, taking into account the density of the material with moisture content on wet basis. To obtain the transport cost per m³, the ratio between the costs of transporting the truck for each distance by the daily amount of material in m³ was used.

3. Results and Discussion

In Table 2 are portrayed the new values of the HCV, BkD, according to Equation 5 in the previous section. It is noticed that the new values of the PCS are lower than the values of Table 1, since the HCV has a negative correlation with the moisture content, in addition to decreasing the efficiency for usage in boilers (Cavalcanti, Carvalho & Azevedo, 2019; Ferreira, et al. 2016).

Table 2 - HCV, BkD, BcD and ED, using Mwb.

Properties	Briquette	Wood chip	Sawdust	Firewood	Wood	Rice Husk
HCV (MJ/Kg)	16.68	11.67	10.77	12.11	11.62	10.98
BkD (kg/m³)	900	536	298	-	-	264
BcD (kg/m³)	-	-	-	700	890	-
ED (MJ/m³)	15,008.40	6,257.26	3,205.33	8,477.00	10,343.58	2,900.35

Source: Own elaboration.

In Tables 3, 4, 5, 6 and 7 are provided detailed information on freight costs for each type of truck, price, impact of the cost of transportation and the type of truck for each type of material, taking into account all distance rays analyzed. For all the graphs, charts and tables in this section, the standing forest (log) was considered with the cost of cutting already embedded. Only the standing forest had costs with the harvest of eucalyptus, which is already included in the price described in the tables for the log (R$ 32.10 per m³).

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Table 3 - Average price per m³ of biomass for each distance (R$).

	Briquette	Wood chip	Rice Husk	Sawdust	Firewood	Log
50 km	-	56.74	-	-	78.00	93.60
100 km	-	29.05	29.05	61.69	-	-
150 km	-	16.00	41.50	53.00	130.00	78.10
200 km	-	54.25	51.50	35.00	76.00	70.67
250 km	306.00	32.50	32.00	35.31	135.50	61.10
300 km	378.00	-	21.13	-	64.00	69.10
350 km	355.50	-	58.10	27.50	58.50	75.10
400 km	-	39.50	20.00	75.00	-	87.60
450 km	-	73.47	-	15.00	-	73.43
500 km	540.00	95.28	-	-	65.00	71.85
Average Price	394.88	49.60	36.18	43.21	86.71	75.62

Source: Own elaboration.

Table 4 - Freight cost for each distance (R$).

	Cost per truck - Mobile botton with 5 axes	Cost per truck - Romeo and Juliet 7 axles
50 km	566.61	766.50
100 km	770.60	945.00
150 km	974.60	1,417.50
200 km	1,178.60	1,890.00
250 km	1,382.59	2,065.00
300 km	1,586.59	2,478.00
350 km	1,790.59	2,719.50
400 km	1,994.58	3,108.00
450 km	2,402.58	3,370.50
500 km	2,810.57	3,775.00

Source: Own elaboration based on ANTT data (2019).

To calculate the daily cost of transport per km (Table 5), the freight cost per type of truck was multiplied by the number of trucks needed to transport daily each type of biomass, obtaining the total cost of transport per day. This cost was then divided by each distance. Note that costs per km are higher for shorter distances. This is because fixed costs are high and are not compensated for over longer distances.

Table 5 - Daily cost of transportation per km (R$).

	Briquette	Wood chip	Rice Husk	Sawdust	Firewood	Log
50 km	56.66	79.33	90.66	79.33	61.32	61.32
100 km	38.53	53.94	61.65	53.94	37.80	37.80
150 km	32.49	45.48	51.98	45.48	37.80	37.80
200 km	29.47	41.25	47.14	41.25	37.80	37.80
250 km	27.65	38.71	44.24	38.71	33.04	33.04
300 km	26.44	37.02	42.31	37.02	33.04	33.04
350 km	25.58	35.81	40.93	35.81	31.08	31.08
400 km	24.93	34.91	39.89	34.91	31.08	31.08
450 km	26.70	37.37	42.71	37.37	29.96	29.96
500 km	28.11	39.35	44.97	39.35	30.20	30.20

Source: Own elaboration based on ANTT data (2019).

To calculate freight per m³ (Table 6), the total cost of transportation per day was divided by the daily amount of material in m³.

Table 6 - Freight cost per m³ (R$).

	Briquette	Wood chip	Rice Husk	Sawdust	Firewood	Log
50 km	18.21	10.63	5.63	5.45	11.13	13.58
100 km	24.77	14.46	7.66	7.41	13.72	16.75
150 km	31.32	18.28	9.69	9.37	20.59	25.12
200 km	37.88	22.11	11.71	11.33	27.45	33.49
250 km	44.44	25.94	13.74	13.29	29.99	36.59
300 km	50.99	29.76	15.77	15.25	35.99	43.91
350 km	57.55	33.59	17.79	17.21	39.49	48.19
400 km	64.11	37.42	19.82	19.17	45.14	55.08
450 km	77.22	45.07	23.88	23.09	48.95	59.73
500 km	90.33	52.73	27.93	27.01	54.82	66.90

Source: Own elaboration.

In Table 7, the impact of the cost of transportation was obtained from the cost of transportation per m³ divided by the average price of biomass. In this way, the impact of the transport cost was obtained without taking into account the price variations of biomasses for the different distance.

Table 7 - Impact of transportation costs (%).

	Briquette	Wood chip	Rice Husk	Sawdust	Firewood	Log
50 km	5	20	16	13	13	18
100 km	6	28	21	17	16	22
150 km	8	35	27	22	24	33
200 km	10	43	32	26	32	44
250 km	11	50	38	31	35	48
300 km	13	57	44	35	42	58
350 km	15	65	49	40	46	64
400 km	16	72	55	44	52	73
450 km	20	87	66	53	56	79
500 km	23	102	77	63	63	88

Source: Own elaboration.

Based on Table 7, the impact of transport costs on the final cost of some materials is perceived, as the distance of the industry increases. Among the materials that had the greatest impact, considering a distance of up to 300 km, one can highlight the chip, the firewood and the log. From 400 km, for all materials, the cost of transportation approaches or exceeds the cost of the product (except for the briquette). It can be said that the cost of transportation had a low impact on the cost of the briquette, due to its high density. Unlike the other materials in which the limiting factor to take advantage of the truck's load capacity was the volume, in the case of the briquette, it was its weight.

In Table 8 are provided information about the density and quantity of biomass to be used daily and per truck, which were used to obtain the number of trucks.

Table 8 - Quantities of biomass and trucks.

	DMwb	Quantity of biomass per truck (t)	Volume of transport of the truck (t)	Daily quantity of biomass (t)	Number of trucks per day
Sawdust	0.30	32.75	32	216.88	7
Wood chips	0.54	58.96	32	200.00	7
Rice Husk	0.26	29.05	29	212.60	8
Briquette	0.90	45.00	32	140.01	5
Firewood	0.70	63.00	51	192.80	4
Log	0.89	80.10	51	200.89	4

Source: Own elaboration.

In Table 9, it is observed that the materials that have more supply are the chip and the log. It should be noted that the briquette is still produced, in general, on a small scale in Brazil,

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being more demanded for commercial than industrial use. As reported by suppliers, the husk and sawdust have little offer for sale in the market and are difficult to be transported. Regarding firewood, many suppliers did not provide information about the quantity available for sale, but it is assumed that they have a similar offer to the standing forest. Among the biomasses analyzed, only the rice husk has a seasonal production, being harvested between the months of March and June.

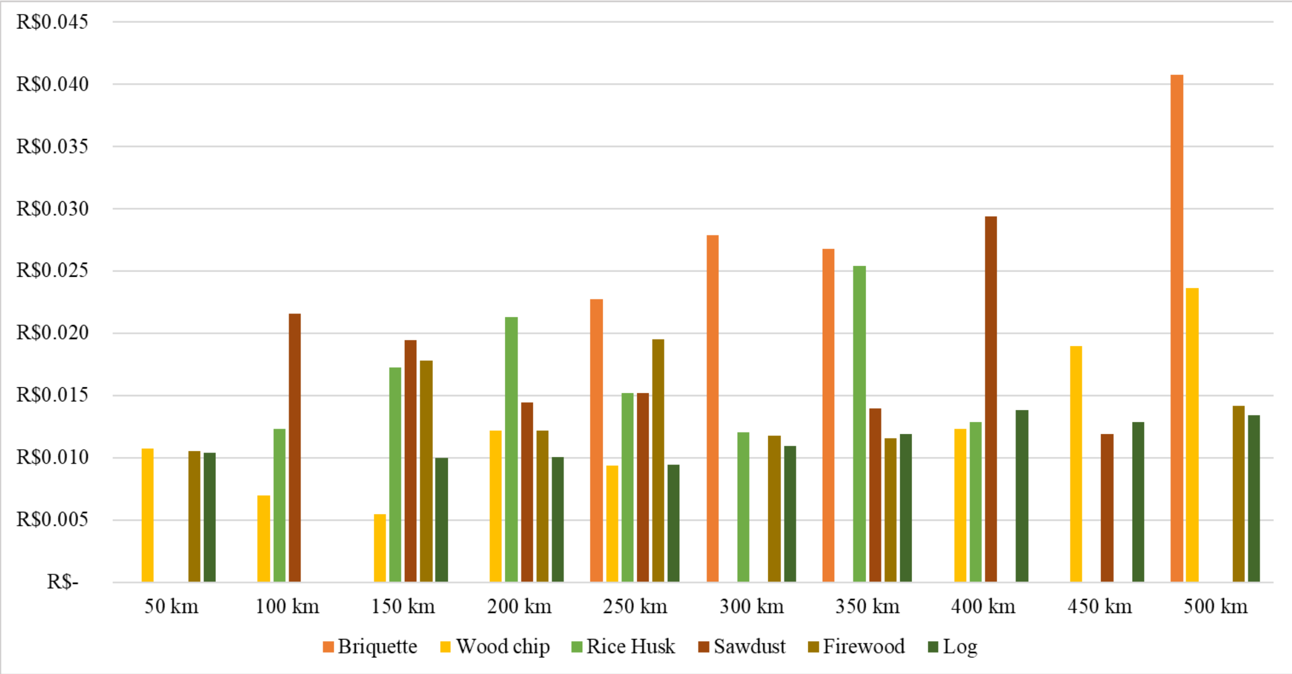
Table 9 - Daily Quantity Offered of each material (ton.).

	Briquette	Wood chip	Rice Husk	Sawdust	Firewood	Log
50 km	-	264	12	-	-	60,615
100 km	-	467	-	96	-	-
150 km	-	200	19	-	-	4,806
200 km	10	211	-	73	6,860	26,704
250 km	-	348	-	-	-	17,222
300 km	14	-	-	-	-	13,408
350 km	-	-	-	-	-	10,814
400 km	-	96	-	-	-	4,575
450 km	-	2,087	-	-	-	39,534
500 km	-	601	-	-	-	13,279

Source: Own elaboration.

It can be seen in Figure 1 that the biomass that has the lowest energy cost is the chip, within a distance of 150 km. In addition, for this distance, the chip is able to meet a daily demand of 200 tons, as shown in Table 9. As a second option, it should be noted that the chip at a distance of 100 km has a lower cost and has availability of supply and, as a third option, the log at 250 km.

Figure 1 - Energy cost (R$ / MJ).



Source: Own elaboration.

In Table 10 are listed the five materials with the lowest energy cost, based on Figure 1.

Table 10 - Energy cost ranking.

Position	Biomass	Energy cost (R$ / MJ)	Radius of distance (km)	Supply (ton)
1	Wood chips	0.005	150	200
2	Wood chips	0.007	100	467
3	Log	0.008	250	17,222
4	Log	0.009	150	4,806
5	Log	0.009	300	13,408

Source: Own elaboration.

Figure 2 provides information on the cost of energy with the freight service provided by the suppliers. It is noticed that the chip and the firewood have lower energy costs for different distance radii.

Figure 2 - Energy cost with freight service by the supplier (R$ / MJ).

Source: Own elaboration.

In Table 11 are listed the five materials with the lowest energy costs, considering the freight service performed by the supplier. As previously described in relation to Table 9, firewood does not have information about the supply for most distance radii. However, it is assumed that its production is in the same proportion as that of the standing forest.

Table 11 - Ranking of energy cost with freight service by the supplier.

Position	Biomass	Energy cost (R$ / MJ)	Radius of distance (km)	Supply (ton)
1	Wood chips	0.006	250	348
2	Firewood	0.010	50	
3	Firewood	0.010	100	
4	Wood chips	0.012	100	467
5	Wood chips	0.012	50	264

Source: Own elaboration.

Based on Tables 10 and 11, it can be seen that it is feasible to buy biomass without the supplier's freight service, with the exception of the chip, which is sold within a distance of 250 km. In this way, the ranking in Table 10 is maintained, with the replacement of the chip that is sold at a distance of 100 km by the chip that is sold with freight by the supplier at a distance of 250 km (Table 11), in second place.

According to Table 12, among the biomasses that produce the most energy are briquette, wood chips, firewood and eucalyptus logs. As analyzed in Figures 1 and 2 and, from an analysis of Tables 3, 7 and 12, the briquette, even though it is the biomass that produces the most energy and has the lowest transport cost in relation to its price, as it is a material that has a high price and has little supply, results in the highest final cost, making it difficult to use it for energy production in industries.

Table 12 - Energy production.

Materials	TOE
Briquette	0.369
Firewood	0.268
Wood Chip	0.258
Log	0.257
Rice Husk	0.243
Sawdust	0.238

Source: Own elaboration.

According to the analysis of Figures 1 and 2 and Tables 10 and 11, they were feasible to be used in scale for energy production in industries in the MRS, the chip and the eucalyptus log. In addition, according to Silva Miranda et al. (2017), the use of the chip reduces the energy cost, when compared to the use of firewood, since the chip allows the mechanization of the boiler feeding process, which decreases the labor cost. Still, according to the authors, the reduction in the cost of energy with the use of the chip has led industries in several sectors, such as dairy, refrigeration, paper, fertilizers and the agribusiness to reduce the use of fossil fuels.

Petrol derived fuels are still widely used by the industry because of logistics advantages, ease of operational use and bureaucracy in relation to forest biomass. Among the limitations that interfere with the use of forest biomass for energy production are availability, high production cost, conversion techniques, logistics and their physical and chemical characteristics. However, such limitations in the use of forest biomass can be reduced through incentives made by public policies (Silva Miranda, et al., 2017; Deboni et al., 2019).

It should be noted that the use of biomass of forest origin in Brazil has advantages when compared to the use of fossil fuels, such as competitive cost, being renewable, high productivity, job creation and availability of land for planting (SILVA MIRANDA, et al., 2017).

The industry used as a reference in this work daily demands 200 tons of chips for energy generation. Therefore, from the analyzes carried out in this work, it was found, in the Metropolitan Region of Sorocaba, that the eucalyptus chip is the most viable to be used for energy generation in an automated boiler system. The briquette, due to its high price, is not feasible to be used in industries in the region. In relation to rice husks and sawdust, they have high costs due to the cost of freight. Rice husk and sawdust are feasible to be used in the industries that generate these biomasses or in the regions that produce them the most. Eucalyptus firewood was viable when sold with freight by suppliers. The eucalyptus log has reduced costs in relation to other biomasses, being an alternative for the industry that does not have automated boilers and also to supplement a demand that is higher than estimated for daily consumption.

4. Final Considerations

From the analysis, it is concluded that the chip and the eucalyptus log have advantages that depend on the application and the distance that are offered. The distance rays that presented biomasses with greater supply and lower cost were those of 50 km to 250 km. In addition, the cost of freight for longer distance was not a factor that made biomass more expensive in some cases, as the price offered was lower than for smaller distance radii, as in the case of the chip, where lower energy cost for 100 km and 150 km radii than for 50 km.

It should be noted, based on these conclusions, that depending on the usage the chip is more viable when compared to the log, as it is a bulk material that has favorable particle size to be used in an automated boiler feed process.

As a suggestion for future work, an additional analysis is proposed that addresses the economic feasibility of implementing a briquette production to reduce the cost of the briquettes. Also, a study related to the cost (including equipment and maintenance) of using mix of biomass in the industrial boilers.

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