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Potential of electric energy generation from vegetable biomass in different regions of Brazil: mapping and analysis

Luís Oscar Silva Martins
luisoscar@ufrb.edu.br
Universidade Federal do Recôncavo da Bahia / Universidade Federal da Bahia

Roberto Antônio Fortuna Carneiro
roberto.carneiro@ufba.br
Universidade Federal da Bahia (UFBA), Salvador, Bahia
Faculdade de Tecnologia e Ciências (FTC), Salvador, Bahia, Brasil.

Marcelo Santana Silva
profmarceloifba@gmail.com
Instituto Federal de Educação da Bahia (IFBA), Santo Amaro, Bahia, Brasil.
Universidade Federal da Bahia (UFBA), Salvador, Bahia, Brasil.

Ednildo Andrade Torres
ednildo@ufba.br
Universidade Federal da Bahia (UFBA), Salvador, Bahia

ABSTRACT

This study presents a preliminary analysis of the potential of electric energy generation from vegetal biomass coming from different Brazilian regions. The residues derived from sugar cane, silviculture, rice, cashew nuts, bay coconut and elephant grass were analysed. Based on the values of their harvests (referring to 2017/2018), with the exception of elephant grass', the most updated mapping of which was in 2015, and also on the values of the lower calorific powers researched in the pertinent literature, thematic maps were constructed, which demonstrated the potential of electricity generation of crops. The results showed that, for cane and forestry, whose stage of development and use are already consolidated, there is still room for exploration. Rice bark and elephant grass presented high potential and growth capacity, while cashew nuts and coconut shells may be an energetic alternative, especially for the Northeast, despite the problems related to humidity of the latter.

KEYWORDS: Biomass. Waste. Energy. Electricity.

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INTRODUCTION

Renewable energy sources play a key role in current global strategies to reduce greenhouse gas emissions and partially replace fossil fuels. The reserves of these fuels, such as oil, gas and coal, are the main sources of energy scattered across a small number of countries. In this way, they form a fragile energy supply that must reach its limit in the foreseeable future.

In this sense, energy sources point the way chosen by the nations in terms of economic development, since choices are guided by the world's production, energy security and consumption standards of every society. Although the energy matrix has undergone changes over time, it is still possible to state that one is located in an era of fossil energy sources. Even with clean and renewable energy introduction processes, the world continues to invest in the search for new reserves of oil and other inputs of non-renewable origin.

According to estimates given by the International Energy Agency (IEA) (2017), although oil is still the most heavily involved in the world energy matrix, 32%, oil will be losing ground over the years, with an estimated share of 27.8% in 2035.

Current energy supply issues associated with climate change awareness have motivated the academy to research renewable fuel sources and devote more effort to the study of its energy efficiency and environmental impacts (RAJBAHANDARI; ZHANG, 2018).

Amid the energy sources of renewable origin, biomass presents itself in a promising way. It includes, among others, vegetation, energy crops, as well as biosolids, animal, forest and agricultural residues, the organic fraction of urban waste and certain types of industrial waste. Its appeal is due to its potential worldwide availability, its conversion efficiency and its ability to be produced and consumed in a neutral carbon dioxide (CO_2) basis (IAKOVOU et al., 2010).

Brazil, in particular, holds a great potential for biomass production. It is one of the countries that has the largest abundance of renewable energy in the world and, unlike other nations, has some advantages to lead energy agriculture. It stands out because of its ability to incorporate new areas into energy agriculture without competing with food production, because of its possibility of multiple crops throughout the year, and because it receives an intense solar radiation, has a diverse climate and a biodiversity exuberance (BORGES et al., 2016). However, the risks of socio-environmental damage, characteristic of the activity, cannot be discard.

Regarding the generation of electricity, according to data from the National Energy Balance (BEN) of the Energy Research Company of Brazil (EPE) (2018b), public service and self-producers reached a magnitude of 588 TWh in 2017. The public power plants accounted for 83.5% of this total, being the main source of hydroelectric generation, which represented 65.3% of the total energy produced. This demonstrates that the national electricity matrix is composed, for the most part, of renewable sources.

Renewable sources account for 80.2% of the domestic electricity supply, with biomass accounting for 8.2% of the energy produced, representing 47.47 TWh. This is almost enough to supply the Metropolitan Region of São Paulo, which in 2016 consumed 53.4 TWh, according to the Statistical Yearbook of Energy by

Municipality in the State of São Paulo (SÃO PAULO, 2017). When the analysis is performed on the participation of the sources on the installed capacity, the biomass happens to correspond to 9.4%, or approximately 14,132 MW (EPE, 2018b).

Given the advantages mentioned above for the country as a whole, it is important to highlight regional particularities. Due to the vast territorial dimension of Brazil, as well as the climatic differences between regions, the incidence of different crops conducive to the production of bioelectricity is a reality. In the states of São Paulo, Minas Gerais, Bahia and Rio Grande do Sul, according to the Brazilian Association of Planted Forest Producers (ABRAF) (2013), forest residues (silviculture) stand out, representing 87.1% of the planted area. In the sugar and alcohol industry, São Paulo accounted for approximately 55% of the total area planted, also stand out the states of Paraná and Goiás and the Zona da Mata Northeastern Region (Brazilian Institute of Geography and Statistics [IBGE], 2017a).

Concerning other crops and plant residues used to generate electricity, there is rice husk in Mato Grosso, Maranhão and Rio Grande do Sul (MAYER; GALLON; HOFFMANN, 2018). The cashew nut shell has higher production in the Northeast and Pará, as well as the coconut shell of the bay. In addition, there is also the potential for elephant grass, produced in large scale, mainly in the western region of Bahia.

Thus, the main objective of this work was to map and analyse the potential of electric power generation, and the surplus potential, as the case may be, from the aforementioned residues and crops, identifying the specialties of the different regions of Brazil. Specifically, it was intended to: a) evaluate the current scenario of biomass in the world and in Brazil and its use for bioelectricity generation; b) identify the current and more efficient technological routes to convert plant residues into electric energy; c) map and measure the potential of electricity generation, exposing the results from thematic maps.

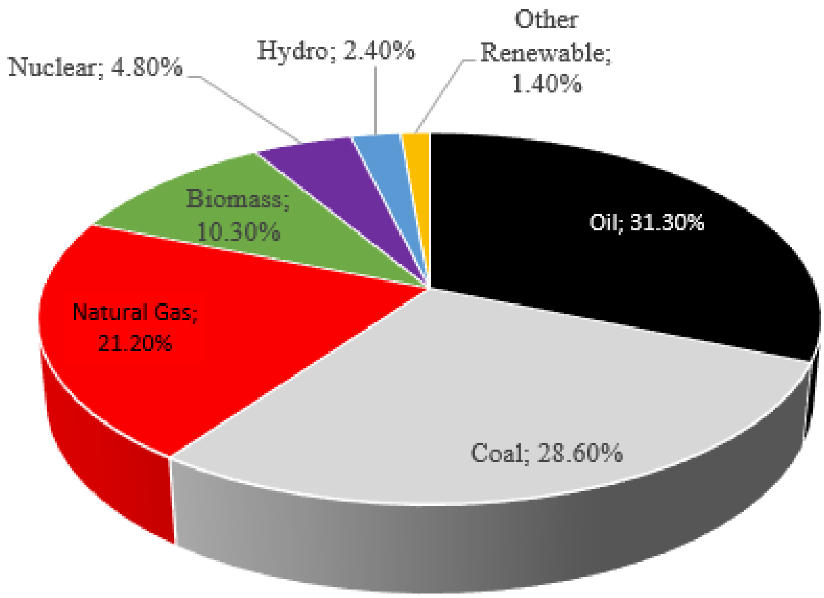
In this sense, this article is divided into four sections, besides this Introduction. Chapter two is about the state of the art, exposing scenarios for the use of biomass for electricity generation in the world and in Brazil, as well as demonstrating the conversion technologies. In chapter three, there is an explanation of the methodological process of this research construction, which used thematic cartographic techniques to organize the maps. In chapter four, the results found are exposed and discussed. Finally, in chapter five, there are inferred final considerations and proposals for project development and new studies.

THE USE OF BIOMASS AS A GENERATING SOURCE OF ELECTRICAL ENERGY IN THE WORLD AND IN BRAZIL

Biomass is the oldest form of primary energy used by humankind. For millennia, and even in a relatively recent past, it has differentiated itself as the main source of energy used in the world. In its vegetable form, it is characterized as a device of nature to store solar energy. This means that plants, through the process of photosynthesis, combine the carbon dioxide (CO_2) found in air and groundwater to produce carbohydrates of various types, constituents of the vegetal tissues, which in turn, possess considerable energetic value.

Only in the last 25 years of the 19th century, biomass was surpassed by coal and, only at the beginning of the 20th century, by oil. Despite its pioneering and of being considered as one of the sources of greater growth potential for the coming years (given its diversity in obtaining electricity and biofuels) (PUROHIT; CHATURVEDI, 2018), it represents only 10.3% of the world energy matrix, according to the IEA (2017). It is still composed mainly of fossil fuels such as oil, coal and natural gas (Figure 1).

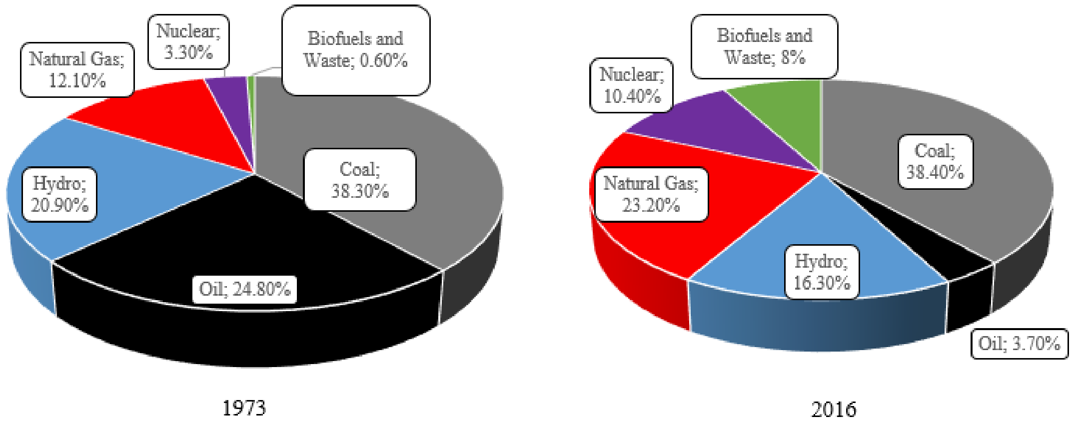
Figure 1 - World Energy Matrix



Source: IEA (2017).

Concerning the production of electricity, the world's dependence on fossil fuels is also high. Figure 2 summarizes the world electricity matrix, with the supply of electricity and the participation of different sources for the years 1973 and 2016. The offer increased from 6,131 TWh to 24.97 TWh, that is an increase of approximately 307% in this period. The most used sources were coal, which practically maintained the same percentage of use in the last 43 years, and natural gas, which doubled its participation in the matrix. Renewable energies (with the exception of hydroelectric power) also grew significantly in the order of 800%, increasing their share from 0.6% in 1973 to 8% in 2017

Figure 2 - Generation of electricity by source (1973 and 2016)

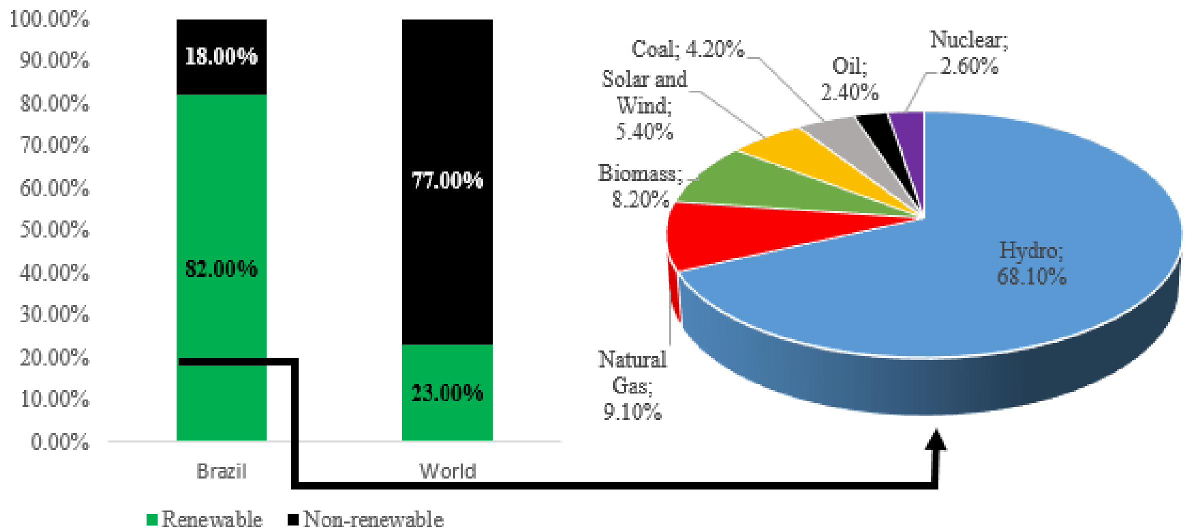


Source: IEA (2018).

Brazil occupies a prominent position in the world energy scenario because it has the most renewable energy matrix in the industrialized world, with 43.5% of the energy consumption from renewable sources (AGUIRRE; IBIKUNLE, 2014; IEA, 2017). The global leadership in renewable energies is likely to continue as renewable energy production will double in 2035, maintaining an average of 43% of the Brazilian energy matrix (IEA, 2017).

The same occurs with the electric matrix, where 82% of the electricity generated come from renewable sources, against 23% of the world's electrical matrix (Figure 3). This shows that the Brazilian electricity sector has one of the lowest carbon intensities in the world, despite the greater availability and use of the hydroelectric source (LAM et al., 2016). This means that in spite of being considered a renewable and clean energy, it can generate environmental impacts and, in times of rainfall, causes a decrease of energy production (LAM et al., 2016). This is a worrying fact, since electricity consumption will reach 971 TWh in 2030 and 1,605 TWh in 2050 (EPE, 2018b).

Figure 3 - Electricity generation in Brazil in 2017 by source



Source: Adapted from BEN (EPE, 2018b).

In the biomass field, Brazil holds a great potential to produce various crops. It is one of the countries with the largest abundance of renewable energy in the world and, unlike other nations, has some advantages to lead energy agriculture. Among these advantages, it stands out: the ability to incorporate new areas into agriculture for energy generation without competing with food production, environmental impacts limited to what is socially accepted, the possibility of multiple crops throughout the year, the intense solar radiation received and the diversity of the climate and exuberance of biodiversity (PRATES; SCHAITZA, 2018).

Another advantage of biomass as an energy source is the possibility of expanding, decentralizing and distributing the energy supply, meeting the needs of regions that have a generation deficit. This would allow distant sites to become less dependent on fossil fuels to move fleets or as a source primary power. In these cases, rural producers would gain because, in addition to producing food, they could become important suppliers of energy beyond the rural area.

Bioelectricity represented 9% of the Brazilian power matrix or 14,763 MW of power granted in 2018, according to data from the National Electric Energy Agency (ANEEL) (2018), with sugarcane (77%) as the most important source, forests (21%) and other sources of biomass (2%). Currently, 556 registered independent producers produce electricity to meet their energy demands, with the surplus marketed in auctions or in the free and short-term markets (FERREIRA; PATAH, 2017). As a result, the country ranks as the world's fourth largest producer of biomass energy alongside the United States, China and Germany (RENEWABLE ENERGY POLICY NETWORK FOR THE 21st CENTURY [REN21], 2016). The maintenance and possible extension of this advantage will depend on the sources of biomass used, as well as on the conversion technologies, which are the target of the next section of the research.

PRODUCTION OF ELECTRICITY FROM BIOMASS

The technological alternatives for the production of electric energy from forest biomass and agricultural residues consist of their conversion into intermediate inputs, later transformed into mechanical energy in driving machines, triggering an electric power generator. Considering this study focuses on the mapping and analysis of the potential of electric energy production from forest biomass and agroindustrial residues, two technological routes were described, according to the study contemplated in the National Energy Plan 2030 and summarized by ANEEL (2008), defined as follows:

a) Steam cycle with backpressure turbines: used in an integrated way in productive processes by cogeneration. In this process, the biomass is burned directly in boilers, resulting in thermal energy used in the production of steam. This steam can be used to drive turbines used in the required mechanical work in industrial production units and turbines for electric power generation.

b) Steam cycle with condensation and extraction turbines: in this cycle, the steam at the end of the work on the turbine is totally or partially condensed to meet the mechanical or thermal activities of the production. This condensed energy, when integrated in the cogeneration process, is extracted at an intermediate point in the steam expansion that will drive the turbines. The fundamental differences of this cycle and the steam cycle with backpressure turbines are the existence of a condenser in the exhaust of the turbine and the occurrence of certain levels for heating the water that will supply the boiler. The first difference provides greater flexibility of the thermoelectric generation, while the second generates an increase in the overall efficiency of energy production. According to Zhao, Minett and Harris (2013), a disadvantage of this system is its high installation cost, especially when compared to the investments required to implement the simple condensation system.

c) Combined cycle integrated with biomass gasification: combined cycles integrate heat recovery and steam turbines that use the thermal energy of the gas turbine exhaust gases to generate steam and reuse it in the production of electricity in a turbine the overall efficiency of the cycle. In the present work, the use of biomass gasification technology in a combined cycle has shown to be efficient in the development of biomass gasification, of thermoelectric generation from 14% to 22% higher when compared to the conventional condensing steam turbine cycle.

Despite all the technology available for the generation of electric energy from agricultural biomass, the thermoelectric generation of this source is concentrated in the sugar cane bagasse. Therefore, it is important to develop studies that point out the potential gains of energy generation from other biomass sources, as well as their location.

METHODOLOGY

In relation to the objectives, this research is characterized as descriptive, since it aims to describe the characteristics of the main vegetable origin biomass sources for electric power generation in Brazil, highlighting the regional particularities, as well as their availability. The study design was bibliographical and documentary.

The objective of this study was to map and calculate the potential for electricity generation from different sources of biomass: sugar cane bagasse, forest residues, rice hulls, bay shells, cashew nuts and elephant grass. Their respective harvests were consulted (2017/2018). The availability of the crops was collected together with the Municipal Agricultural Research (PAM) of the IBGE (2017b), and the report of the Production of Plant Extraction and Silviculture (PEVS), of the IBGE as well, in the case of forest residues. The exception was the elephant grass, which the Institute does not carry out separately from other forage crops. Thus, the data collected from the Laboratory of Image Processing and Geoprocessing (LAPIG), from the Federal University of Goiás, were used to perform systematic and periodic mapping on pastures. For the grass it was used the production of 2015.

The calculation methodology of energy conversion was based on the publication "Methodologies of calculation of energy conversion of selected biomasses" of the Bioenergy Atlas of Brazil, whose last edition was published in 2012 by the National Reference in Biomass (CENBIO), linked to the Institute of Electrotechnics and Energy (IEE) of the University of São Paulo (USP). Currently, due to internal restructuring of the IEE, since 2015, CENBIO has become a research group called Bioenergy Research Group (Gbio).

To perform the calculations, the production of each biomass was collected from IBGE various bases in the 2017/2018 crop, with the exception of elephant grass that used data from 2015 and the Lower Calorific Power (CPI) of the inputs that was consulted with pertinent literature. From these results, the thematic maps shown in section four were constructed. In this way, the methodologies for calculating the electric power generation potential for each type of biomass analysed in this study are presented below.

SUGAR CANE

The cogeneration of electric energy through the residues of sugar cane has already been widely studied. Proof of this is that currently, according to data from BEN (EPE, 2018b), the domestic supply of renewable energy in Brazil reached 42.9%, with cane residues accounting for 17%. The production of electricity through bagasse cogeneration is an effective undertaking established in several countries beyond Brazil, such as India and Mauritius (MUHAMMAD; AHMED, 2016).

The electric power generation potential is calculated by multiplying the efficiency of the process given in kilowatts by the amount of sugar cane harvested in each Brazilian municipality in the 2017/2018 crop, which was provided by the PAM of IBGE (2017b). (Equation 1). The process efficiency scenario was established at 30 kWh/tons of sugar cane (Tc) based on a study by Trombeta and Caixeta Filho (2017). In the referred study, searching for agroindustrial indicators for the sugar cane industry, they found that more than 60 % of the boilers in the industries analysed present a low-pressure technology (up to 48 bar) and 69% of the turbines are of the single backpressure type. It was also established that the system only operates during the harvest (April to November), with 95% of the annual hours, totaling 5,563 hours.

$$MW/year = \frac{(Tc * 30kWh/t)}{1{,}000 * 5{,}563}$$

(Equation 1)

RICE HUSK

Studies for electricity generation from rice husk are widespread. The main conversion technology used is gasification. A study by Darmawan et al. (2018), showed that processing 200 t of the grain can generate surplus electricity of about 3.4 MW with a production efficiency of about 32%.

For the calculation of the electric power generation potential, the value of the 2017/2018 crop was used, which is provided by IBGE in tons of rice produced. Thus, it is necessary to consider only the husk as residue. For this estimate, the study of Oliveira et al. (2015) was used, which states that approximately 22% of

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the rice is husk. The CPI used was 3,300 kcal / kg (OLIVEIRA et al., 2015). The calculation of the potential was done according to Equation 2:

$$MW/year = \frac{[(t\ rice\ husk * 0.22) * (CPI\ \ kcal/kg * 0.15)]}{860 * 8{,}322}$$

(Equation 2)

The efficiency considered in the process was 15% and it is assumed that the system will operate in 95% of the annual hours, resulting in 8,322 operating hours per year. In addition, to convert kcal / kg to kWh / kg, it is necessary a division by 860.

BAY COCONUT SHELL

Coconut palm is a plant of great socioeconomic importance for Brazil. Besides producing food, the productive chain of this culture generates a large amount of waste, among them the bark, which, if discarded incorrectly, contributes to the spread of diseases, to the procreation of venomous animals and to the pollution of the environment. (MARCELINO; MELO; TORRES, 2017).

The PAM of the IBGE (2017b) informs the quantity in a thousand fruits, therefore, it is necessary to establish an average weight for each fruit. The established value (0.5 kg) was selected according to Atlas of Bioenergy of Brazil (CENBIO, 2012). Then the IBGE values were divided by a thousand. However, it is necessary to consider only the husk of the fruit as an agricultural residue that can be used for the generation of bioelectricity. According to Marcelino, Melo and Torres (2017), the husk represents on average 57% of the fruit. The CPI considered was 3,413.10 kcal/kg (MONIR et al., 2018). Thus, the calculation was arranged according to Equation 3. The parameters of efficiency, application and conversion were the same as those used for rice husk.

$$MW/year = \frac{\{[(thous.fruits * 500g)/(1000) * 0.57] * (CPIkcal/kg * 0.15)\}}{860 * 8{,}322}$$

(Equation 3)

CASHEW NUT SHELL

Cashew cultivation is practiced in several regions of Brazil, with emphasis on the Northeast Region, where, according to IBGE (2017a), 502.98 hectares are cultivated. Cashew nut is formed of three elements: shell, layer and almond. The shell is not used for commercialization, but it can be used for several purposes. Among these there are the productions of liquid biofuel (extraction of cashew nut liquid), solid fuel (by briquetting the shell) or electricity generation by pyrolysis (converting the shell into energetic gas by means of partial oxidation at elevated temperatures) (AGYEMANG; ZHU; TIAN, 2016).

To calculate the bioelectricity production potential, it is necessary to know the percentage of the shell on the chestnut. According to Morais (2009) and Paiva, Garutti and Silva Neto (2000), the shell represents 45% to 50% of the weight of the nut. For this research it is was used the most conservative value of 45%. The CPI considered was 4,184.58 kcal / kg (FIGUEREDO, 2011). The efficiency of the process was of 15%, assuming that it works in 95% of the annual hours, totaling 8,322 hours. For conversion from kcal / kg to kWh / kg, the equation is divided by 860, according to Equation 4 below:

$$\mathrm{MW/year} = \frac{[(\mathrm{t\ cashew\ nut} * 0.45) * (\mathrm{CPIkcal/kg} * 0.15)]}{860 * 8{,}322}$$

(Equation 4)

ELEPHANT GRASS

Elephant grass (Pennisetum purpureum), also known as napiê grass, is a plant species native to Africa with growth rates of up to 40 tons of dry biomass per hectare per year (FONTOURA; BRANDÃO; GOMES, 2015). For more than a century, the plant was also introduced in South America and Australia as fodder for livestock. It requires few additional nutrients for growth and can be harvested up to four times a year, which makes this plant prospective for energy use (LI et al., 2016; OLIVEIRA et al., 2015; WOODARD; PRINE, 1993).

According to Marafon et al. (2016) and Saraiva and Konig (2013), the average CPI of the grass in its various diversities is 4,129.89 kcal/kg. The technique used for its conversion is similar to that used by sugar cane, that is: multiplying the efficiency of the process given in a kilowatt, by the amount of elephant grass produced in Brazil in 2015 (Equation 5). The estimated efficiency scenario was 30 kWh/t and it was assumed that elephant grass is productive throughout the year. In addition, the system operates at 95% of the annual hours, totaling 8,322 hours.

$$MW/year = \frac{(Dry\ biomass\ ton * 30kWh/t)}{1{,}000 * 8{,}322}$$

(Equation 5)

FORESTRY

When it comes to planted forests, wood is the most sought-after raw material, with other parts of the tree (bark, branches, leaves and roots) often being treated as waste. All material left behind during harvesting is considered as forest residue, both in natural forests and in reforestation. It consists of leaves, branches, part of the bark and part of the wood that is not used, such as the tips (wood with smaller diameter than the commercial one). The remainder of wasted material is generated after harvesting the trees, due to the cutting process (CASTRO et al., 2017).

For this research, the information provided by the IBGE (2017b) of the already processed wood was considered, based on the wood Eucalyptos Benthamii, a species from Australia and that is the most common in Brazil. Only the residue resulting from its processing, ie 40%, was considered (BLOIS et al., 2017). The data provided by IBGE is in cubic meters (m3) and these values must be converted in a ratio of 1 m3 to 0.61 tons (BRAZILIAN SOCIETY OF FORESTRY [SBS], 2008). The percentage of generated waste (40%) and the CPI of 4,379.1 kcal / kg (SILVA et al., 2015), as well as efficiency of 15%, operating at 95% of annual is Equation 6:

$$MW/ano = \frac{[(wood * 0.4\, resíduo) * (PCIkcal/kg * 0.15)]}{860 * 8{,}322}$$

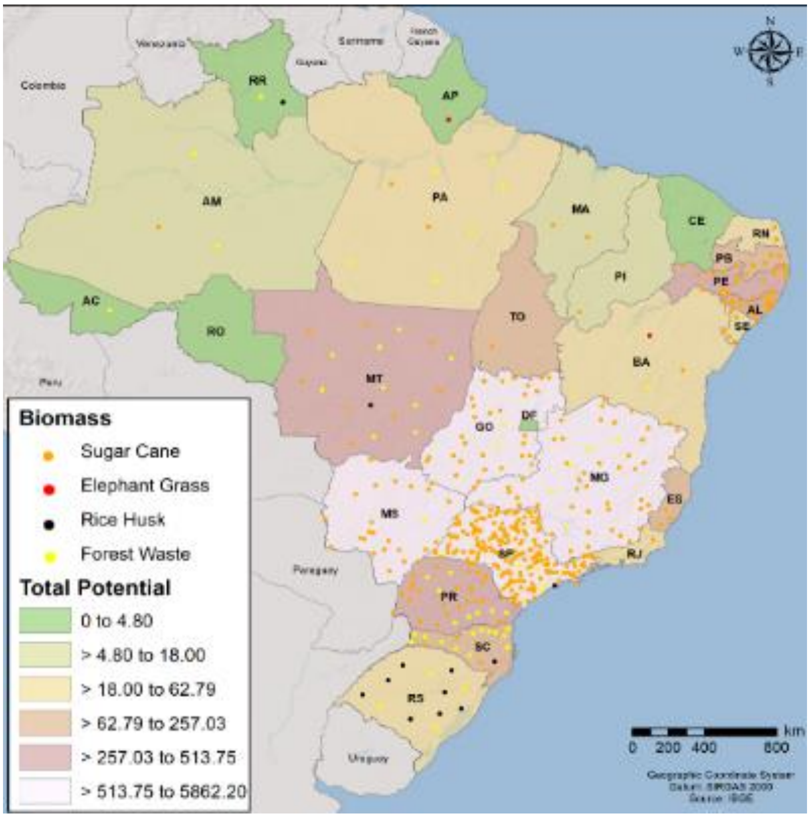
(Equation 6)

The data were collected, and the conversions made according to the equation above, using the free software with open source QGIS, version 3.0.1, for the construction of the thematic maps exposed in section four of this article. The analysis of the maps allowed a better visualization of Brazilian potentialities in terms of vegetal biomass for electric power generation.

RESOURCES AVAILABILITY, BIOMASS CONSUMPTION AND ELECTRICAL ENERGY GENERATION POTENTIAL

After presenting the technologies and calculations of biomass conversion of plant origin, this section aimed to demonstrate, through thematic maps, the potential of electric energy generation of each of them. It is important to note that some Brazilian states have projects that already produce electricity from some of the crops selected by this research, mainly by cogeneration. Thus, it has become necessary to reduce from the theoretical potential calculated what is already produced. Figure 4 summarizes this information, also showing the distribution, by state, of companies producing electric energy from biomass of plant origin.

Figure 4 - Total potential of electricity production from vegetal biomass and distribution of the producing enterprises in Brazil (MW)



Source: Authors (2019)

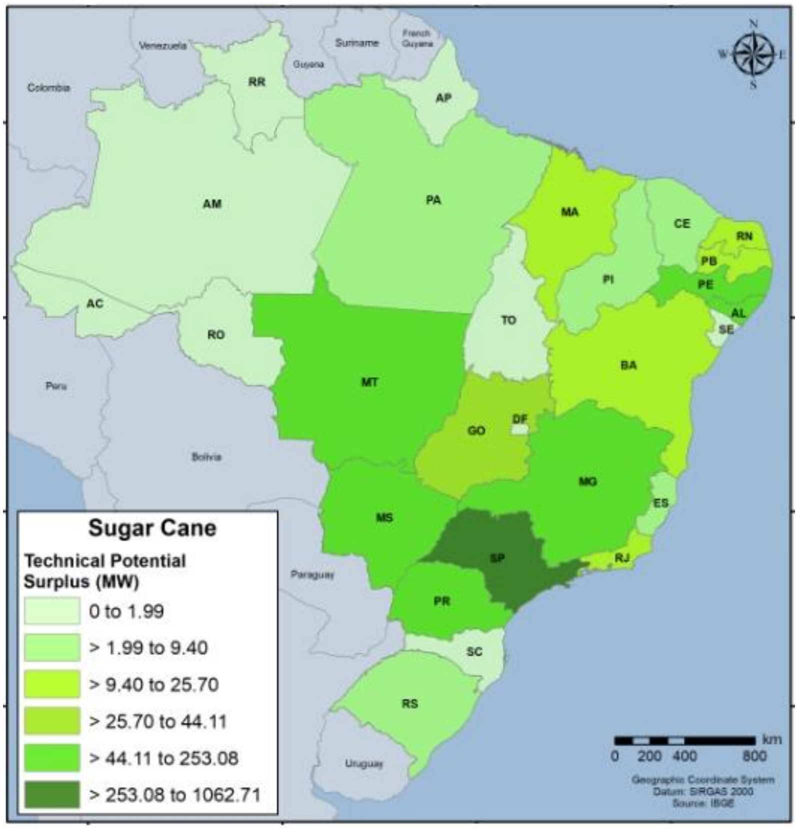
Currently, Brazil has 474 enterprises that produce energy from sugarcane bagasse (404), forest residues (56), rice husk (12) and elephant grass (2) (ANEEL, 2019). The energy generated in 2018 from these biomasses was 20,944.98 GWh/year. This represents approximately 4% of Brazil's total domestic electric energy consumption in 2017, which was 526,200 GWh/year (EPE, 2018b). If all potential were used, this figure would rise to 67,141.98 GWh/year, or approximately 13% of consumption. Considering that the country imported 36,400 GWh in 2017 (EPE, 2018b) to meet its electricity demand, only the surplus theoretical value would be enough to meet this shortage, with a positive impact on the trade balance.

It is important to highlight that ANEEL's aggregate data do not show the existence of projects that use the other vegetal biomasses analysed in this research, i.e., cashew nut shells and coconut shells which, together, have the potential of producing electric energy in the order of 37.11 MW, considering the 2017/2018 crop.

Sugar cane is one of the crops most used for the production of electricity in a cogeneration system. The largest producer is the state of São Paulo, with a power output of 5,799.5 MW (ANEEL, 2019), effective production of 1,366.32 MW (Union of the Sugar Cane Industry [UNICA], 2017) and a technical surplus of 1,062.71 MW. According to the National Center for the Industries of the Energy and Biofuels Sector (CEISE BR) (DE SOUZA, 2017), the state imports approximately 60% of the electricity needed to meet its demand or 80,000 GWh. If the potential technical surplus was used and, considering that a plant operates in all hours of the year (8,760 hours), it could produce up to 9,309.34 GWh/year, helping to reduce this economic impact.

Other states that stand out in terms of potential are Mato Grosso do Sul (253.08 MW), Minas Gerais (77.15 MW), Mato Grosso (76.42 MW), Goiás (44.11 MW) and Bahia (25.70 MW). Figure 5 illustrates the surplus power generation potential for all Brazilian states.

Figure 5 - Potential for generating surplus electricity from sugarcane bagasse

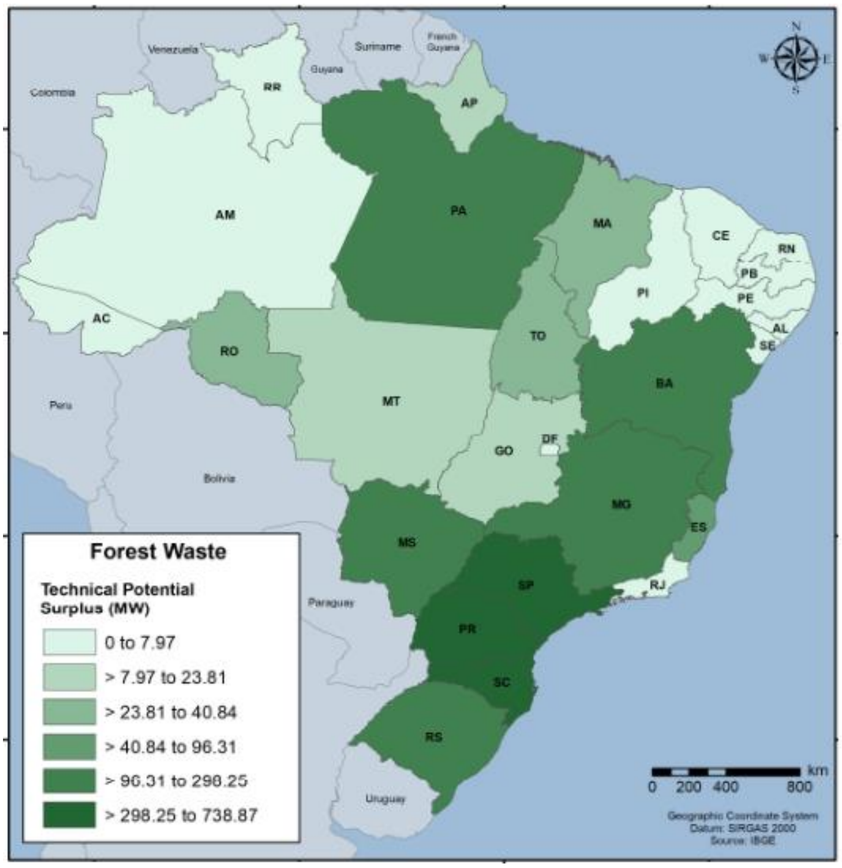


Source: Authors (2019)

The production of wood in the form of logs, firewood or charcoal also generates a large amount of waste that can be used to produce electricity. As shown in Figure 6, the Brazilian states with the highest potential for utilization of forest residues are Paraná (738.87 MW), Santa Catarina (449.67 MW) and São Paulo (439.54 MW), followed by Bahia (298.25 MW) and Mato Grosso do Sul (295.44 MW).

It is important to note that the type of wood production (reforestation, extractive or dedicated cultivation) directly influences the distribution of generated waste. In cases of selective extraction and decentralized processing, the use of forest residue may become economically unviable, given the environmental impacts they can cause, despite advanced management techniques and reduced impacts.

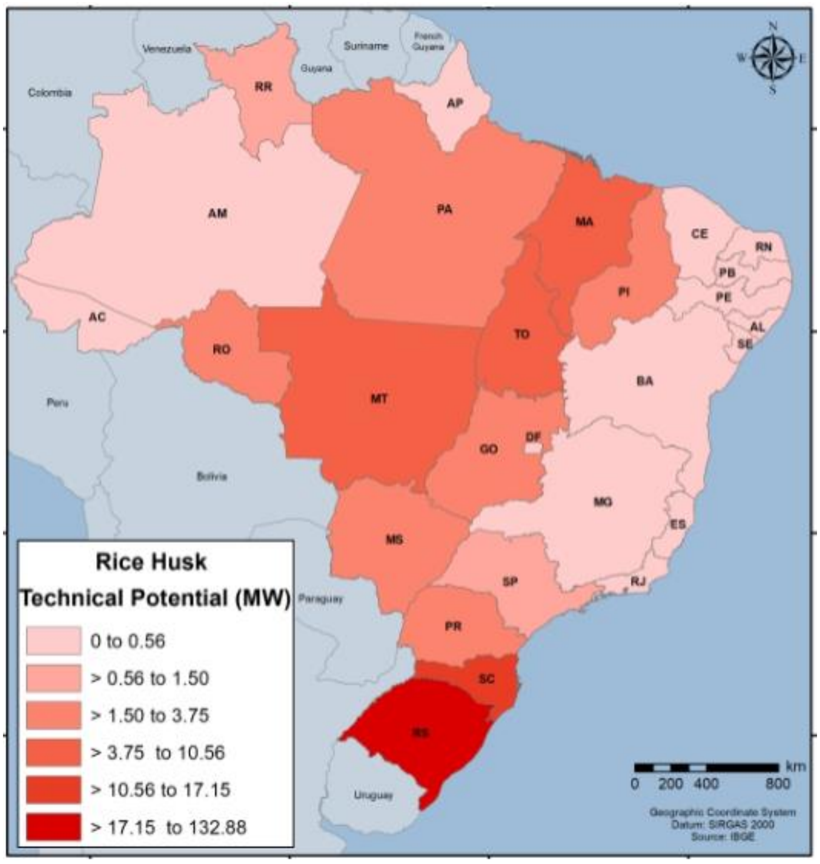
Figure 6 - Potential to generate surplus electricity from forest residues



Source: Authors (2019)

An unexplored residue for electricity generation in Brazil is rice husk. The 2017/2018 crop was 12,469,516 million tons, resulting in an overall potential of 189.74 MW. Rio Grande do Sul was the largest producer and, consequently, the state with the highest potential (132.88 MW) followed by Santa Catarina (17.15 MW) and Tocantins (10.56 MW). As an example, the 12 companies authorized to produce electricity from rice husk in the country (eight of them are in Rio Grande do Sul), have a power granted of 45.33 MW (ANEEL, 2019) that means, approximately, only approximately 24% of the theoretical potential. This shows, at least in terms of input supply, that some regions of Brazil, especially the South region, have the capacity to increase their electrical capacity from rice husk.

Figure 7 - Electric power generation potential from rice husk



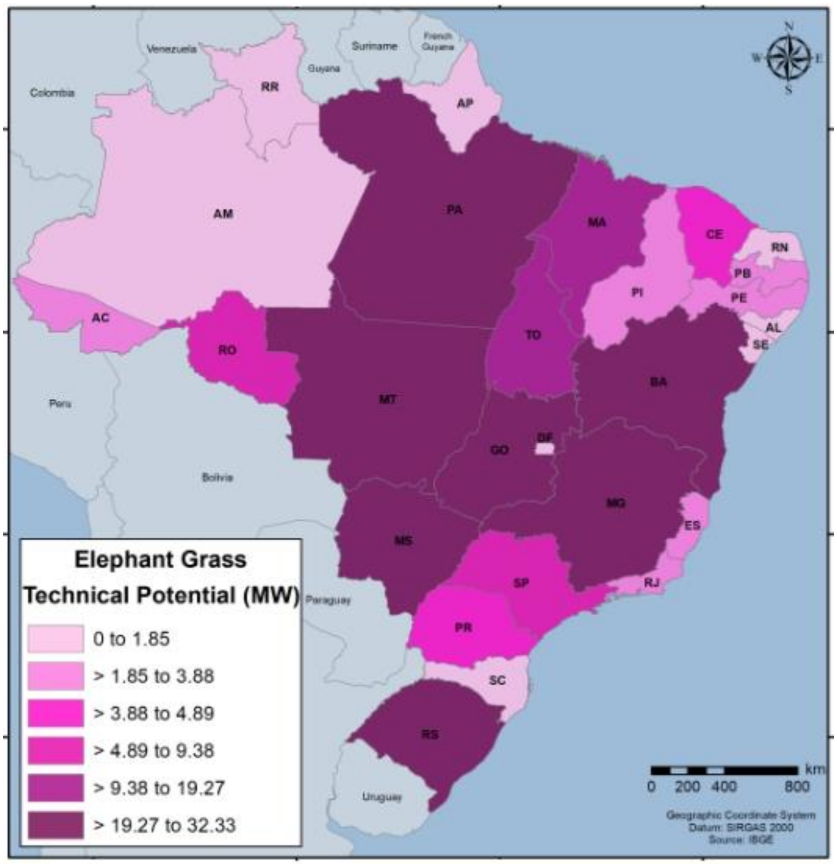
Source: Authors (2019)

Among the forage grasses, elephant grass is, admittedly, the one with the greatest productive potential, adapting very well to the climate and soil conditions of practically the whole of Brazil. While eucalyptus, the most exploited species in the country for cellulose and charcoal production, produces up to 20 t of dry biomass per hectare per year, elephant grass is capable of producing at least 30 to 40 t/ha/year (MARAFON et al., 2016). However, just like rice husk, investors of the electric sector have neglected this potential. Proof of this is there are only two companies that turn elephant grass into electricity. One of them is located in the state of Bahia, with a power of 30 MW and the other one in Amapá, authorized to operate at 1.7 MW (ANEEL, 2019).

The authorized 31.7 MW, therefore, represent only 12.53% of the calculated theoretical potential (252.86 MW). The states with the greatest skills are Minas Gerais (32.33 MW), Mato Grosso (31.86 MW) and Bahia itself, which already owns its industrial unit with capacity to generate 24.59 MW of power. Figure 8 illustrates the technical potential for electricity generation in Brazil by state.

MARTINS, L. O. S.; CARNEIRO, R. A. F.; SILVA, M. S.; TORRES, E. A. Potencial of eletric energy generation from vegetable biomass in diferente regions of Brazil: mapping and analysis. Análise bibliométrica em publicações relacionadas a logística e mobilidade urbana no contexto de smart city. **R. Tecnol. Soc.,** Curitiba, v. 15, n. 37, p. 332-359, jul./set. 2019.

Figure 8 - Potential of electric power generation from elephant grass



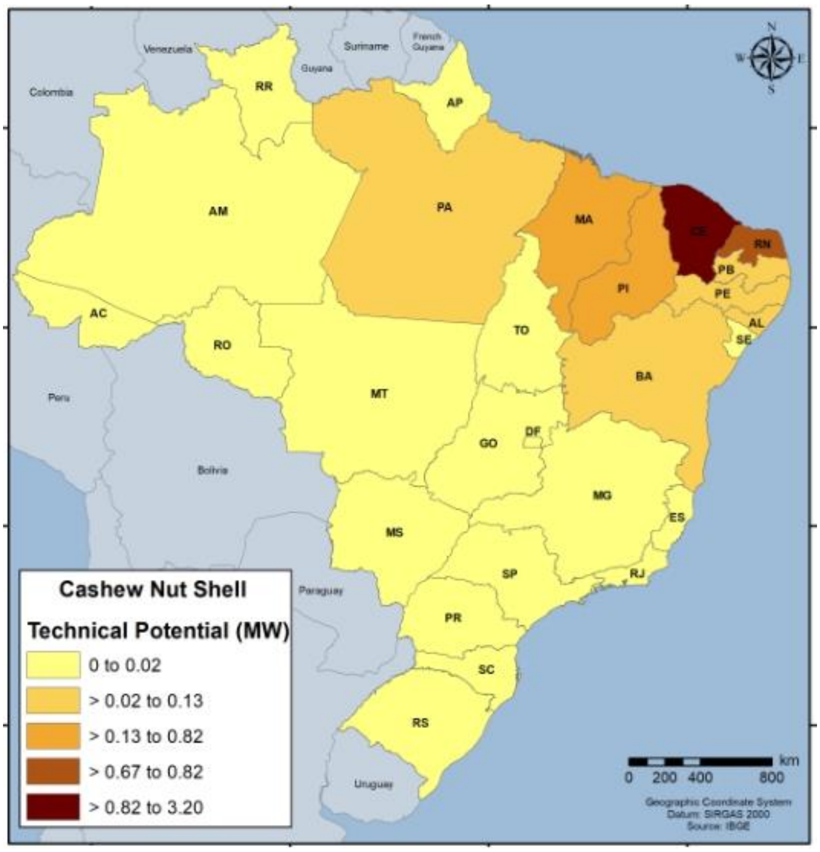
Source: Authors (2019)

The last two biomasses studied in this research, cashew nut shells and coconut shells, despite having high potential, especially the coconut, do not have dedicated projects or a cogeneration system for the production of electricity, according to information from ANEEL (2019).

Cashew nut is produced basically in the Northeast of Brazil, being the fifth largest producer in the world. Production in 2017/2018 was approximately 267 thousand tons, with Ceará state being the largest producer, with 81 thousand tons. From this total, it is estimated that the value of the residue (the shell of the nut) represents 45% of the fruit, from which energy can be obtained in several ways: briquetting the shell, biodiesel by means of cashew nut liquid and, in the specific case of this study, pyrolysis, using water vapor as a gaseous agent for electricity production, as performed in India – currently the largest producer in the world.

In addition to Ceará, the states of Rio Grande do Norte (0.82 MW) and Maranhão (0.67 MW) are the ones with the highest potential for bioelectricity production. If the system operates uninterruptedly for one year, Rio Grande do Norte would generate 7,183.2 GWh/year, which would be enough to supply 45% of the state's total electricity generation. In the other hand, Maranhão supplied 41% in 2017 according to information from Statistical Yearbook of Electrical Energy (EPE, 2018a). Figure 9 shows the production potential of each Brazilian state, with emphasis on the Northeast region and the state of Pará.

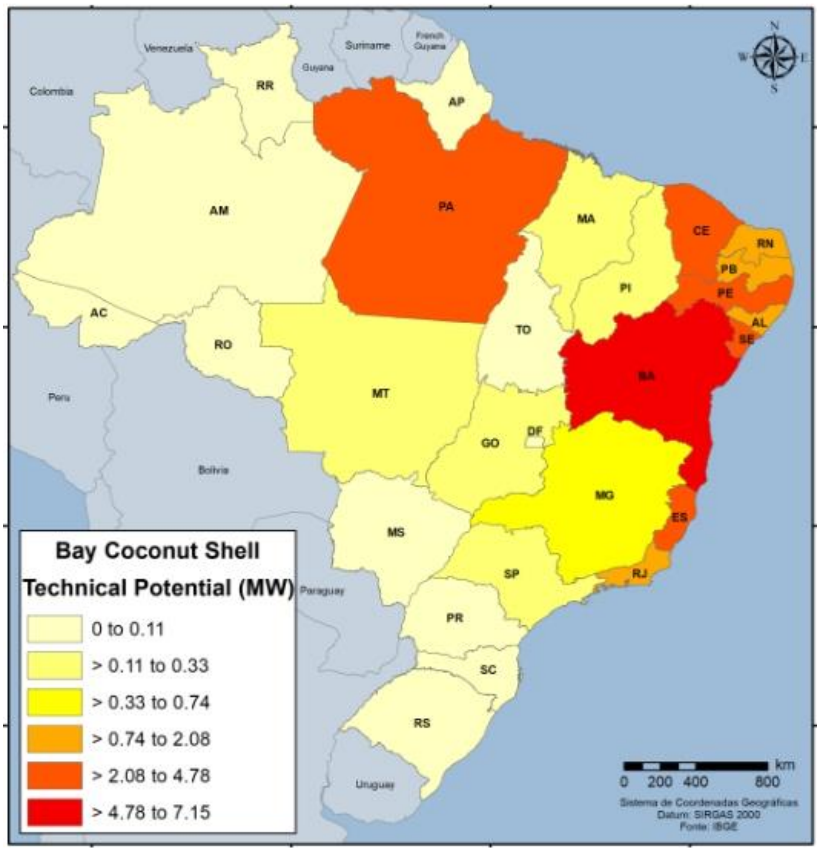
Figure 9 - Potential of electricity generation from cashew nuts



Source: Authors (2019)

Bay coconut production in 2017/2018 was approximately 781 thousand tons (IBGE, 2017b), considering the average weight of 500 grams for each fruit. This total has a technical potential of 31.84 MW. The state with the highest potential is Bahia, 7.15 MW, followed by Sergipe, 4.78 and Ceará, 3.81. Apart from the Northeast, the states of Pará (3.45 MW) and Espírito Santo (2.42 MW) stand out. Figure 10 illustrates the potential of each Brazilian state.

Figure 10 - Potential of electric power generation from bay coconut shell



Source: Authors (2019)

According to Carmo (2013), the high productivity of the crop, and consequent potential for electricity production, is an inconvenience of coconut shells, with a high moisture content around 80%. According to the author, contents of 40% to 50% are acceptable in thermoelectric to the molds of the sugar and alcohol mills, therefore, a drying process is necessary before the conversion, which would increase the costs.

FINAL CONSIDERATIONS

The research showed that Brazil has significant potential for electric power generation from biomass sources of different types and in different regions. Hence, the potential for sugar cane bagasse and silviculture, which are already widely developed, are still unexploited crops, such as rice husk and elephant grass, as well as coconut shells and chestnut shell, which do not even have ventures granted by ANEEL.

The country's regional characteristics have also demonstrated the possibility of diversifying the production of electricity from biomass in different states. Due to this fact, beyond improving environmental sustainability by reducing CO2 emissions and the final destination of waste, it can help in the economic context through the generation of employment and income.

The data presented evidence that Brazil has significant potential for the production of electricity from the residues researched. According to the applied methodology, the potential is around 5,421.26 MW, capable of generating 47,490.23 GWh/year, in a situation in which the units would operate in all annual hours. Considering a value of only 60% of operation, the generation capacity would be 28,494.15 GWh/year, corresponding to approximately 5% of the total electricity generated in 2017 in Brazil.

The sugar cane bagasse and forest residues, which were considered only surplus potential, have a capacity of 1,810.21 MW and 3,131.33 MW, respectively, capable of generating, together, 43,287.89 GWh/year, if they operate in 100% of the annual hours.

Although the remaining residues (rice husk, cashew nut shell, bay coconut shell, as well as elephant grass) are little explored from an energy point of view, they have a combined potential of 479.72 MW. In addition, their advantage, in particular the elephant grass', is to be able to be produced in disparate regions of Brazil, and, consequently, to be used for conversion into bioelectricity, significantly reducing the Brazilian energy deficit and reducing its historical dependence on hydroelectricity.

As future studies, the calorific powers of samples of these residues for each region should be investigated, defining the best technological routes and economic and locational particular analyses. It should be done in order to implant and expand projects aimed at the production of electricity in a sustainable way, especially in less developed regions, such as the North and Northeast – nevertheless, both with broad potential for the development of renewable energies.

Finally, other sources of biomass, for example municipal solid waste, liquid effluents and oilseeds, such as palm oil, should have potential evaluated, since the diversification of the biomass used to generate various agroenergy products is essential to increase the supply of electricity in Brazil.

Potencial da geração de energia elétrica da biomassa vegetal em diferentes regiões do Brasil: mapeamento e análise

RESUMO

Este estudo apresenta uma análise preliminar do potencial de geração de energia elétrica a partir de biomassa vegetal proveniente de diferentes regiões brasileiras. Foram analisados os resíduos derivados da cana-de-açúcar, silvicultura, arroz, castanha de caju, coco-da-baía e a gramínea capim elefante. A partir dos valores de suas safras, referentes à 2017/2018, com exceção do capim elefante, cujo mapeamento mais atualizado foi de 2015, juntamente com os valores dos poderes caloríficos inferiores pesquisados junto à literatura pertinente, foram construídos mapas temáticos, que demonstraram o potencial teórico de geração de eletricidade das culturas. Os resultados demonstraram que, para a cana e a silvicultura, cujo estágio de desenvolvimento e utilização já estão consolidados, ainda existe espaço para exploração. A casca de arroz e o capim elefante apresentaram alto potencial e capacidade de crescimento, enquanto que a casca da castanha de caju e a casca de coco-da-baía podem ser uma alternativa energética, especialmente para o Nordeste, apesar dos problemas relacionados a umidade deste último.

PALAVRAS-CHAVE: Biomassa. Resíduos. Energia Elétrica.

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REFERENCES

AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA (Brasil). **Atlas de Energia Elétrica do Brasil.** 3. ed. Brasília, DF: ANEEL, 2008.

AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA (Brasil). **Capacidade de Geração do Brasil.** Brasília, DF: ANEEL, 2019. Disponível em: http://www2.aneel.gov.br/aplicacoes/capacidadebrasil/capacidadebrasil.cfm. Acesso em: 15 jan. 2019.

AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA (Brasil). **Dados abertos:** Geração. Brasília, DF: ANEEL, 2018. Disponível em: http://www.aneel.gov.br/dados/geracao. Acesso em: 6 nov. 2018.

AGUIRRE, M.; IBIKUNLE, G. Determinants of renewable energy growth: A global sample analysis. **Energy Policy**, v. 69, p. 374-384, June 2014. DOI: https://doi.org/10.1016/j.enpol.2014.02.036.

AGYEMANG, M.; ZHU, Q.; TIAN, Y. Analysis of opportunities for greenhouse emission reduction in the global supply chains of cashew industry in West Africa. **Journal Cleaner of Production**, v. 115, p. 149-161, 1 Mar. 2016. DOI: https://doi.org/10.1016/j.jclepro.2015.12.059.

ASSOCIAÇÃO BRASILEIRA DE PRODUTORES DE FLORESTAS PLANTADAS (Brasil). **Anuário Estatístico ABRAF 2013 ano base 2012.** Brasília, DF: ABRAF, 2013. Disponível em: https://www.ipef.br/estatisticas/relatorios/anuario-ABRAF13-BR.pdf. Acesso em: 01/12/2018.

BLOIS, H. D.; PARIS, E.; CARVALHO, M. P.; NUNES, B. B. Silvicultura: Cenários Prospectivos para Geração de Energia Elétrica. **Revista de Gestão Ambiental e Sustentabilidade,** São Paulo, v. 6, n. 1, p. 140-159, jan./abr. 2017. DOI: https://doi.org/10.5585/geas.v6i1.488.

BORGES, A. C. P.; SILVA, M. S.; ALVES, C. T.; TORRES, E. A. Energias renováveis: uma contextualização da Biomassa como fonte de energia. **Rede – Revista eletrônica do PRODEMA,** Fortaleza, v. 10, n. 2, p. 23-36, jul./dez. 2016.

CARMO, V. B. **Avaliação da eficiência energética renovável de biomassas alternativas para geração de eletricidade.** 2013. Tese (Doutorado em Engenharia Química) – Faculdade de Engenharia Química, Universidade Estadual de Campinas, São Paulo, 2013.

CASTILLO, L. F. M. (2017). Renewable energy and energy efficiency in Latin America: a regulatory vision. **Journal of Energy & Natural Resources Law**, v. 35, n. 4, p. 405-416, 12 oct. 2017. DOI: https://doi.org/10.1080/02646811.2017.1370175.

CASTRO, A. F. N. M.; CASTRO, R. V. O.; CARNEIRO, A. de C. O.; CARVALHO, A. M. M. L.; DA SILVA, C. H. F.; CÂNDIDO, W. L.; DOS SANTOS, R. C. Quantification of forestry and carbonization waste. **Renewable Energy**, v. 103, p. 432-438, Apr. 2017. DOI: https://doi.org/10.1016/j.renene.2016.11.050.

CENTRO NACIONAL DE REFERÊNCIA EM BIOMASSA. **Atlas de Bioenergia do Brasil**: Metodologias de cálculo da conversão energética das biomassas selecionadas. São Paulo: CENBIO, 2012.

CHATTERJEE, C.; PONG, F.; SEN, A. Chemical conversion pathways for carbohydrates. **Green Chemistry**, v. 17, n. 1, p. 40-71, 2015. DOI: http://dx.doi.org/10.1039/C4GC01062K.

COELHO, S. T.; GARCILASSO, V. P.; ESCOBAR, J. F.; COLUNA, N.; DO AMARAL, A. C. Geração de Eletricidade a partir de biomassa no Brasil. Situação atual, perspectivas e barreiras. *In*: MOREIRA, J. R. S. (Org.). **Energias renováveis, geração distribuída e eficiência energética,** 1. ed. Rio de Janeiro: LTC, 2017. cap. 11, p. 235-255.

DARMAWAN, A.; FITRIANTO, A. C.; AZIZ, M.; KOJI, T. Integrated system of rice production and electricity generation. **Applied Energy**, v. 220, p. 672-680, 15 June 2018. DOI: https://doi.org/10.1016/j.apenergy.2018.03.098.

DE SOUZA, Z. J. O estado de São Paulo importa mais de 60% da energia que consome. **CENTRO NACIONAL DAS INDÚSTRIAS DO SETOR SUCROENERGÉTICO E BIOCOMBUSTÍVEIS – CEISE BR,** 16 out. 2017.

EMPRESA DE PESQUISA ENERGÉTICA (Brasil). **Anuário Estatístico De Energia Elétrica 2018 (ano base 2017).** Rio de Janeiro: EPE, 2018a. Disponível em: http://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-160/topico-168/Anuario2018vf.pdf. Acesso em: 12 dez. 2018.

EMPRESA DE PESQUISA ENERGÉTICA (Brasil). **Balanço Energético Nacional 2018: Relatório Síntese (ano base 2017).** Rio de Janeiro: EPE, 2018b. Disponível em: http://epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-303/topico-397/Relat%C3%B3rio%20S%C3%ADntese%202018-ab%202017vff.pdf. Acesso em: 22/11/2018.

FERREIRA, H. L.; PATAH, L. A. Renewable energy: the role of the auctions of energy in Brazil and the acting of the sources of biomass. **Revista Gestão & Tecnologia,** v. 17, n. 2, p. 51-65, maio/ago. 2017. DOI: https://doi.org/10.20397/2177-6652/2017.v17i2.1147.

FIGUEIREDO, R. A. **Caracterização dos produtos da pirólise da casca de castanha de caju = influência da taxa de aquecimento e da temperatura.** 2011. Tese (Doutorado em Engenharia Mecânica) – Faculdade de Engenharia Mecânica, Universidade Estadual de Campinas, São Paulo, 2011.

FONTOURA, C. F.; BRANDÃO, L. E.; GOMES, L. L. Elephant grass biorefineries: towards a cleaner Brazilian energy matrix? **Journal of Cleaner Production**, v. 96, p. 85-93, 1 June 2015. DOI: https://doi.org/10.1016/j.jclepro.2014.02.062.

HAMELINCK, C. N.; VAN HOOIJDONK, G.; FAAIJ, A. P. C. Ethanol from lignocellulosic biomass: techno-economic performance in short-, middle- and long-term. **Biomass and Bioenergy**, v. 28, n. 4, p. 384-410, Apr. 2005. DOI: https://doi.org/10.1016/j.biombioe.2004.09.002.

IAKOVOU, E.; KARAGIANNIDIS, A.; VLACHOS, D.; TOKA, A.; MALAMAKIS, A. Waste biomass-to-energy supply chain management: A critical synthesis. **Waste Management**, v. 30, n. 10, p. 1860-1870, Oct. 2010.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (Brasil). **Levantamento Sistemático da Produção Agrícola (LSPA).** Rio de Janeiro: IBGE, 2017a. Disponível em: https://sidra.ibge.gov.br/home/lspa/brasil. Acesso em: 20/12/2018.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (Brasil). **Produção Agrícola Municipal (PAM).** Rio de Janeiro: IBGE, 2017b. Disponível em: https://sidra.ibge.gov.br/pesquisa/pam/tabelas. Acesso em: 10 out. 2018.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (Brasil). **Produção da Extração Vegetal e da Silvicultura (PEVS).** Rio de Janeiro: IBGE, 2017c. Disponível em: https://sidra.ibge.gov.br/pesquisa/pevs/quadros/brasil/2017. Acesso em: 20 dez. 2018.

INTERNATIONAL ENERGY AGENCY. **Key World Energy Statistics 2018**. Paris, France: IEA, 2018.

INTERNATIONAL ENERGY AGENCY. **World Energy Outlook 2017.** Paris, France: IEA, 2017.

KNOTHE, G.; VAN GERPEN, J. H.; KRAHL, J. **The Biodiesel Handbook.** Champaign, Illinois: AOCS Press, 2005.

LAM, K. L.; LANT, P. A.; O'BRIEN, K. R.; KENWAY, S. J. Comparison of water-energy trajectories of two major regions experiencing water shortage. **Journal of Environmental Management**, v. 181, p. 403-412, 1 Oct. 2016. DOI: https://doi.org/10.1016/j.jenvman.2016.06.068.

LABORATÓRIO DE PROCESSAMENTO DE IMAGENS E GEOPROCESSAMENTO. Atlas digital das pastagens brasileiras. Diposnível em: https://www.lapig.iesa.ufg.br/lapig/index.php/produtos/atlas-digital-das-pastagens-brasileiras. Goiânia – GO, 2015. Acesso em: 12/12/2018.

LI, X.; GENG, X.; XIE, R.; FU, L.; JIANG, J.; GAO, L.; SUN, J. The endophytic bacteria isolated from elephant grass (Pennisetum purpureum Schumach) promote plant growth and enhance salt tolerance of Hybrid Pennisetum. **Biotechnology for Biofuels**, v. 9, n. 190, p. 1-12, 2016. DOI: 10.1186/s13068-016-0592-0.

MARAFON, A. C.; SANTIAGO, A. D.; AMARAL, A. F. C.; BIERHALS, A. N.; PAIVA, H. L.; GUIMARÃES, V. dos S. **Poder Calorífico do Capim-Elefante para a Geração de Energia Térmica.** Aracaju: Embrapa Tabuleiros Costeiros, 2016.

MARCELINO, M. M.; MELO, S. A. B. V. de; TORRES, E. A. Caracterização da biomassa da casca de coco para obtenção de energia. **Bahia Análise & Dados**, v. 27, n. 1, p. 337-355, jan./jun. 2017.

MAYER, F. D.; GALLON, R.; HOFFMANN, R. Economical sensitivity analysis of rice husk utilization in a 300 kWel Micro Thermal Power Plant. **Environment, Development and Sustainability**, v. 20, n. 1, p. 75-88, Feb. 2018.

MONIR, M. U.; AZIZ, A. A.; KRISTANTI, R. A.; YOUSUF, A. Gasification of lignocellulosic biomass to produce syngas in a 50 kW downdraft reactor. **Biomass and Bioenergy,** v. 119, p. 335-345, Dec. 2018. DOI: https://doi.org/10.1016/j.biombioe.2018.10.006.

MORAIS, A. C. da S. Desenvolvimento, otimização e aceitabilidade de extrato hidrossolúvel da amêndoa de castanha de caju. (Anacardium occidentale L.). 2009. Dissertação (Mestrado em Ciência e Tecnologia de Alimentos) – Universidade Federal do Ceará, Ceará, 2009.

MUHAMMAD, A.; AHMED S. Cogeneration through bagasse: A renewable strategy to meet the future energy needs. **Renewable and Sustainable Energy Reviews**, v. 54, p. 732-737, Feb. 2016. DOI: https://doi.org/10.1016/j.rser.2015.10.145.

MUNASINGHE, P. C.; KHANAL, S. K. Biomass-derived syngas fermentation into biofuels: Opportunities and challenges. (2010). **Bioresource Technology**, v. 101, n. 13, p. 5013-5022, July 2010. DOI: https://doi.org/10.1016/j.biortech.2009.12.098.

OLIVEIRA, T. L.; ASSIS, P. S.; LEAL; E. M.; ILÍDIO, J. R. Study of biomass applied to a cogeneration system: A steelmaking industry case. **Applied Thermal Engineering**, v. 80, p. 269-278, Apr. 2015. DOI: https://doi.org/10.1016/j.applthermaleng.2015.01.002.

PAIVA, F. F. de A.; GARRUTI, D. dos S.; SILVA NETO, R. M. da. **Aproveitamento Industrial do caju.** Fortaleza: Embrapa-CNPAT: SEBRAE/CE, 2000.

PEDROSO, D. T.; MACHIN, E. B.; PÉREZ, N. P.; BRAGA, L. B.; SILVEIRA, J. L. Technical assessment of the Biomass Integrated Gasification/Gas Turbine Combined Cycle (BIG/GTCC) incorporation in the sugarcane industry. **Renewable Energy**, v. 114, part B, p. 464-479, Dec. 2017. DOI: https://doi.org/10.1016/j.renene.2017.07.038.

PRATES, G. A.; SCHAITZA, E. G. Wood gasification energy micro-generation system in Brazil- a Monte Carlo viability simulation. **Independent Journal of Management & Production,** v. 9, n. 1, p. 140-152, Jan./Mar. 2018. DOI: https://doi.org/10.14807/ijmp.v9i1.678.

PUROHIT, P.; CHATURVEDI, V. Biomass pellets for power generation in India: a techno-economic evaluation. **Environmental Science and Pollution Research**, v. 25, n. 29, p. 29614-29632, Oct. 2018.

RAJBAHANDARI, A.; ZHANG, F. Does energy efficiency promot economic growth? Evidence from a multicountry and multisectorial panel dataset. Energy Economics, v. 69, p. 128-139, Jan. 2018.

RENEWABLE ENERGY POLICY NETWORK FOR THE 21st CENTURY. **Annual Report 2016**. Paris, France: REN21, 2016. Disponível em: http://www.ren21.net/wp-content/uploads/2016/12/REN21_AnnualReport_2016_low.pdf. Acesso em: 27 nov. 2018.

RUIZ, J. A.; JUÁREZ, M. C.; MORALES, M. P.; MUÑOZ, P.; MENDÍVIL, M. A. Biomass gasification for electricity generation: Review of current technology barriers. **Renewable and Sustainable Energy Reviews**, v. 18, p. 174-183, Feb. 2013. DOI: https://doi.org/10.1016/j.rser.2012.10.021.

SÃO PAULO (Estado). Secretaria de Energia e Mineração. **Anuário de energéticos por município no Estado de São Paulo - 2017 ano base 2016**. São Paulo: Secretaria de Energia e Mineração, 2017.

SARAIVA, V. M.; KONIG, A. Produtividade do capim-elefante-roxo irrigado com efluente doméstico tratado no seminário potiguar e suas utilidades. **Holos**, ano 29, v. 1, p. 28-46, 2013.

SILVA, D. A.; MULLER, B. V.; KUJASKI, E. C.; ELOY, E.; BEHLING, A.; COLAÇO, C. M. Propriedades da madeira de Eucalyptus benthamii para produção de energia. **Pesquisa Florestal Brasileira**, v. 35, n. 84, p. 481-485, 2015. DOI: https://doi.org/10.4336/2015.pfb.35.84.677.

SOCIEDADE BRASILEIRA DE SILVICULTURA. **Fatos e Números do Brasil Florestal.** São Paulo: SBS, 2008. Disponível em: http://www.sbs.org.br/FatoseNumerosdoBrasilFlorestal.pdf. Acesso em: 10/12/2018.

SUTTLES, S. A.; TYNER, W. E.; SHIVELY, G.; SANDS, R. D.; SOHNGEN, B. Economic effects of bioenergy policy in the United States and Europe: A general equilibrium approach focusing on forest biomass. **Renewable Energy**, v. 69, p. 428-436, Sept. 2014.

TROMBETA, N. C.; CAIXETA FILHO, J. C. Potencial e disponibilidade de biomassa de cana-de-açúcar na Região Centro-Sul do Brasil: indicadores agroindustriais. **Revista de Economia e Sociologia Rural**, v. 55, n.3, p. 479-496, 2017.

UNIÃO DA INDÚSTRIA DE CANA-DE-AÇÚCAR. BOLETIM/UNICA: A Bioeletricidade da Cana em Números – Dezembro de 2017. São Paulo: UNICA, 2017. Disponível em: http://unica.com.br/noticia/40257742920325965233/bioeletricidade-bate-recordes-por-cento2C-mas-continuidade-da-expansao-preocupa/. Acesso em:15/12/2018.

VILELA, A. de D.; LORA, E. S.; QUINTERO, Q. R.; VICINTIN, R. A.; DA SILVA E SOUZA, T. P. A new technology for the combined production of charcoal and electricity through cogeneration. **Biomass and Bioenergy**, v. 69, p. 222-240, Oct.2014. DOI: https://doi.org/10.1016/j.biombioe.2014.06.019.

WEILAND, P. Biomass Digestion in Agriculture: A Successful Pathway for the Energy Production and Waste Treatment in Germany. **Engineering in Life Sciences**, v. 6, n. 3, p. 302-309, June 2006. DOI: https://doi.org/10.1002/elsc.200620128.

WITTY, K. J.; ZHANG, H. R.; EDDINGS, E. G. Emissions from Syngas Combustion. **Combustion Science and Technology**, v. 180, n. 6, p. 1117-1136, 2008. DOI: https://doi.org/10.1080/00102200801963326.

WOODARD, K. R.; PRINE G. M. Dry Matter Accumulation of Elephant Grass, Energycane, and Elephant Millet in a Subtropical Climate. **Crop Science Society of America**, v. 33, n. 4, p. 818–824, 1993. DOI: 10.2135/cropsci1993.0011183X003300040038x.

XU, S.; UZOEJINWA, B. B.; WANG, S.; HU, Y.; QIAN, L.; LIU, L.; LI, B.; WANG, Q.; ABOMOHRA, A. El-F.; CHUNHOU, L.; ZHANG, B. Study on co-pyrolysis synergistic mechanism of seaweed and rice husk by investigation of the characteristics of char/coke. **Renewable Energy,** v. 132, p. 527-542, Mar. 2019. DOI: https://doi.org/10.1016/j.renene.2018.08.025.

YIN, F.; SHAH, K.; ZHOU, C.; TREMAIN, P.; YU, J.; DOROODCHI, E.; MOGHTADERI, B. Novel Calcium-Looping-Based Biomass-Integrated Gasification Combined Cycle: Thermodynamic Modeling and Experimental Study. **Energy Fuels**, v. 30, n. 3, p. 1730-1740, 2016. DOI: https:// 10.1021/acs.energyfuels.5b02266.

ZHAO, M.; MINETT, A. I.; HARRIS, A. T. A review of techno-economic models for the retrofitting of conventional pulverised-coal power plants for post-combustion capture (PCC) of CO2. **Energy & Environmental Science**, v. 6, n. 1, p. 25-40, 01 Jan. 2013. DOI: http://dx.doi.org/10.1039/C2EE22890D.

ZHU, J. Y.; PAN, X. J.; WANG, G. S.; GLEISNER, R. Sulfite pretreatment (SPORL) for robust enzymatic saccharification of spruce and red pine. **Bioresource Technology**, v. 100, n. 8, p. 2411-2418, Apr. 2009. DOI: https://doi.org/10.1016/j.biortech.2008.10.057.

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Correspondência:
Roberto Antônio Fortuna Carneiro
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