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Agroenergy from Residual Biomass: Energy Perspective

*Cintia de Faria Ferreira Carraro, André Celestino Martins,
Ana Carolina da Silva Faria and
Carla Cristina Almeida Loures*

Abstract

The search for energy alternatives from renewable and clean sources has been gaining prominence at the international level, due to the increased demand for energy and the future depletion of fossil fuels, coupled with the concern with environmental issues. The generation of electricity distributed from the use of biomass can contribute to the conservation of the environment, the diversification of the energy matrix, the national economic development, the generation of jobs in the agro-industry and in the distribution of clean energy, as a sustainable alternative. This chapter aims to present information related to the use of different residual biomass as an energy alternative for Brazil, with a focus on electricity generation, based on a bibliographic survey, where it is highlighted as the best sources of biomass for electricity generation in the country, observing the profitability and viability for logistics and national economy.

Keywords: biomass residues, power generation, energy efficiency, environment, sustainable

1. Introduction

The constant growth of the world population and the economy and social development are the main drivers of the increase global energy demand that is currently supported by fossil fuels. The global energy market depends heavily on fossil fuel energy sources such as coal, oil, and natural gas. Currently, oil is the main source of energy, although its reserves are considered finite, since it takes millions of years for these fuels to be formed on earth, they are soon subject to depletion as they are consumed. In addition to the production processes in the oil fields, they are recognized as polluting and harmful to the environment and the climate. Many efforts have been made to find alternative ways of obtaining energy through cleaner and more sustainable processes. The only natural and renewable resource based on carbon that is vast enough to be used as a replacement for fossil fuels it is biomass [1–5].

Biomass is all organic matter, of vegetable or animal origin, used in the production of energy. It is obtained through the decomposition of a variety of renewable resources, such as plants, wood, food scraps, excrement, garbage, and agricultural waste. The advantages of biomass energy over other energy sources may explain the growing interest in its consumption. First, biomass energy can be used for many different purposes, such as cooking, heating, electricity generation, and

transportation. Among the types of renewable energy, biomass conversion process can generate solid, liquid or gaseous fuels, the biomass energy being the only one that can be converted into liquid fuel. Second, biomass energy is renewable energy, abundant, and easily produced source. The use of biomass energy will help countries to reduce their dependence on fossil energy resources and ensure national energy security. Third, biomass energy production contributes to creating more job opportunities, thereby increasing income and reducing poverty among the rural labor force. Finally, and most importantly, biomass energy is a “carbon neutral” source. Compared with fossil energy, biomass energy is less polluting and environmentally safer. Using biomass energy can help to mitigate greenhouse gas emissions and tackle climate change [6–9].

In Brazil, different forms of agro-industrial production work are in parallel with agricultural production. Most processing is directly conditioned to the generation of products and, consequently, the generation large amounts of waste. The production of waste from agro-industrial works is originally derived from the processing of sugar and alcohol industries, biodiesel, cassava, citrus, beers, pulp, and paper, participate expressively in the production of waste. Inadequate disposal of residual biomass can cause soil contamination, compromise the quality of water resources, and cause environmental disturbance among species. Several other factors are related to the disposal of biomass, including many associated with public health problems. Brazil has vast reserves of residual biomass energy from agricultural activities, such as sugarcane bagasse, cassava, and soybeans, which has been gaining interest as a source of energy resources, due to the energetic potential. It is possible to verify that these species together have in Brazil an energy potential of 2615,360 GWh/year [10–15].

2. Biomass agricultural origin

Biomass is one of the most environmentally friendly fuels, since bagasse offers the advantage of being a cheap, abundant, and low-polluting fuel [16]. Biomass has been considered a promising and “environmentally friendly” energy source about energy production. One reason for this renewed interest is due to the way they spread, their sustainable character, and their potential to reduce global emissions of greenhouse gases [17]. World biomass amount is estimated at 1.8 Tt on a dry basis, with a potential thermal yield close to 138 EJ [18–20].

Biomass has been widely recognized as a source of renewable energy with increasing potential to replace conventional fossil fuels in the energy market. Furthermore, using biomass for energy production, another part of a problem is solved, which is waste disposal.

2.1 Bagasse sugar cane

As Brazil is the largest producer of sugarcane, accounting for 36% of global production [21–23], great importance to mention this biomass. In addition, the cultivation of sugarcane has the potential to increase environmental benefits, increasing carbon sequestration, optimizing the agricultural production chain, and thus moderating local environmental impacts [21].

When compared to other agricultural residues, the bagasse has a high yield in terms of the solar energy reservoir and the capture of chemical energy. The sugarcane combustion/gasification produces the same amount of CO₂ that it consumes during its growth; therefore it has a carbon neutral [24].

Edreis et al. [16] studied the effect of the gasification heating rate and the thermal kinetic behavior of sugarcane bagasse coals prepared at 500, 800, and

900°C during CO₂ gasification, and they found that the sugar cane coal gasification occurred in a one stage and that the maximum mass loss rate and its corresponding temperature are directly proportional to the high pyrolysis temperature and the gasification heating rate. In thermal analysis, the activation energy mainly affects the temperature sensitivity of the reaction rate.

2.2 Cassava

The cassava starch produces a significant quantity of residues, which must be rationally used for minimizing the environmental impact of the agricultural activities.

Cassava is widely grown in the tropical and subtropical regions of Asia, Africa, and South America. Brazil occupies a prominent position in world cassava production, alongside only Nigeria and Thailand [25]. Serious attempts have been carried out by the industrial and agro-industrial sectors aiming at the use of this waste profitably [26], but still further opportunities are yet to be developed mainly due to the variety of biomasses and bi-products obtained during the processing steps. The cassava bagasse can be considered as the remaining fraction of the processing of cassava for starch production and consists of 75% of starch, on average, on a dry basis [25].

2.3 Corn stalk

The behavior of corn stalk pyrolysis was studied by Sun et al. [27]. Their research showed that hydrogen-rich gas could be generated by decomposing of the pyrolysis gas at a higher temperature. They concluded that the residual charcoal produced—consisting of fixed carbon and ash—is a good fuel with higher activity and heat value [28].

Corn stands out among agricultural species with the potential to provide biomass for energy production, as it has a large planted area of approximately 177 million acres worldwide [29] and grain production of almost 900 million hectares. Tons [30] resulting in approximately the same amount of residual biomass [31]. This biomass has a high calorific value, ranging from 15.6 to 18.3 MJ Kg⁻¹, like the values of species cultivated exclusively for energy production, such as Eucalyptus sp. [32–33]. Due to the different energy content and amounts of biomass produced by different parts of the corn plant, its potential for energy generation varies significantly [34–37].

3. Process of energy conversion of biomass

High moisture content biomass, such as the herbaceous plant sugarcane, lends itself to a “wet/aqueous” conversion process, involving biologically mediated reactions, such as fermentation, while a “dry” biomass such as cassava and corn stalks, is more economically suited to gasification, pyrolysis. Aqueous processing is used when the moisture content of the material is such that the energy required for drying would be inordinately large compared to the energy content of the product formed. It is the inherent properties of the biomass source that determines both the choice of conversion process and any subsequent processing difficulties that may arise. Equally, the choice of biomass source is influenced by the form in which the energy is required, and it is the interplay between these two aspects that enables flexibility to be introduced into the use of biomass as an energy source.

The World Energy Council defines bioenergy to include traditional biomass (example forestry and agricultural residues), modern biomass and biofuels [38].

The typical biomass materials used for power generation are bagasse, cotton stalk, straw, rice husk, soya husk, saw dust, de-oiled cakes, coconut shells, coffee waste, groundnut shells, Neem, *Jatropha curcas*, Mahua, and Jute wastes, [39]. These biomass materials are being converted into energy via two major energy conversion routes, that is, thermochemical and biochemical. The possible ways in thermochemical route are illustrated in **Figure 1** [40].

The main material properties of interest, during subsequent processing as an energy source, relate to:

- moisture content (intrinsic and extrinsic),
- calorific value,
- proportions of fixed carbon and volatiles,
- ash/residue content,
- alkali metal content,
- cellulose/lignin ratio.

For dry biomass conversion processes, the first five properties are of interest, while for wet biomass conversion processes, the first and last properties are of prime concern.

In biomass the moisture content is presented as intrinsic (without the influence of climate effects) and extrinsic (the influence of climate in the moisture content).

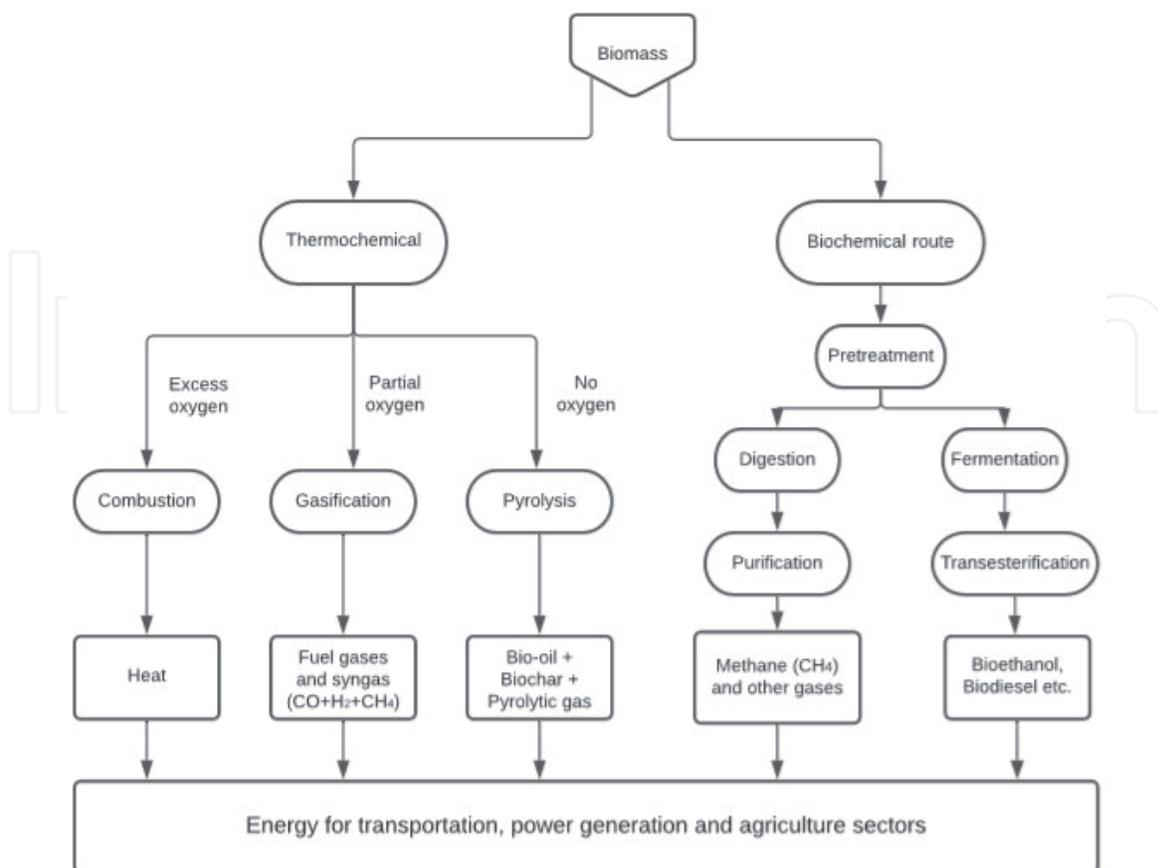


Figure 1. Thermochemical and biochemical routes for conversion of biomass to energy [40].

In practical terms, it is only concerned with the extrinsic moisture content because the intrinsic moisture content is usually only achieved, or applicable, in a laboratory setting.

The calorific value (CV) of a material is an expression of the energy content, or heat value, released when burnt in air. The CV is usually measured in terms of the energy content per unit mass, or volume; hence MJ/kg for solids, MJ/l for liquids, or MJ/Nm³ for gases. The CV of a fuel can be expressed in two forms, the gross CV (GCV), or higher heating value (HHV) and the net CV (NCV), or lower heating value (LHV). In practical terms, the latent heat contained in the water vapor cannot be used effectively and therefore, the LHV is the appropriate value to use for the energy available for subsequent use. In **Table 1** is shown the immediate analysis of some biomass feedstocks.

Fuel analysis has been developed based on solid fuels, such as coal, which consists of chemical energy stored in two forms, fixed carbon and volatiles:

- the volatiles content, or volatile matter (VM) of a solid fuel, is that portion driven-off as a gas (including moisture) by heating (to 950 C for 7 min).
- the fixed carbon content (FC), is the mass remaining after the releases of volatiles, excluding the ash and moisture contents.

Elemental analysis of a fuel, presented as C, N, H, O and S together with the ash content, is termed the ultimate analysis of a fuel. **Table 2** gives the ultimate analyses for some biomass materials.

The significance of the VM and FC contents is that they provide a measure of the ease with which the biomass can be ignited and subsequently gasified, or oxidized, depending on how the biomass is to be utilized as an energy source.

The chemical breakdown of a biomass fuel, by either thermo-chemical or bio-chemical processes, produces a solid residue. When produced by combustion in air, this solid residue is called “ash” and forms a standard measurement parameter for solid and liquid fuels. The ash content of biomass affects both the handling and processing costs of the overall, biomass energy conversion cost. During biochemical conversion, the percentage of solid residue will be greater than the ash content formed during combustion of the same material.

Dependent on the magnitude of the ash content, the available energy of the fuel is reduced proportionately. In a thermo-chemical conversion process, the

Biomass	VM (%)	FC (%)	Ash (%)	HHV (MJ/Kg)
Sugar cane [41, 42]	85.49	12.39	2.12	18.73
Cassava [43, 44]	79.89	13.40	5.43	15.39
Corn stalk [45]	75.38	17.95	6.67	16.59

Table 1.
 Immediate analysis of some biomass feedstocks (wt%).

Material	C	H	O	N	S
Sugar cane [41]	49.8	6.00	43.90	0.20	0.06
Cassava [42]	49.4	6.10	44.60	0.17	0.10
Corn stalk [43]	42.53	6.17	43.59	0.93	0.11

Table 2.
 Ultimate analyses for typical biomass materials (wt%).

chemical composition of the ash can present significant operational problems. This is especially true for combustion processes, where the ash can react to form a “slag,” a liquid phase formed at elevated temperatures, which can reduce plant throughput and result in increased operating costs.

4. Methods of generating electricity using biomass

4.1 Biomass in the Brazilian energy matrix

Global energy demand is still largely satisfied by non-renewable energy sources. According to the International Energy Agency [46], in the world, of the nearly 14 million toe (tons of oil equivalent) of the total primary energy supply in 2019, oil, coal, and natural gas together represented more than 80% of this demand, where each one corresponded to 32, 27, and 22% respectively, on the other hand, biomass-derived energy supplied only 10% of this amount [46].

The domestic energy supply in Brazil in 2019 reached 294 million toes, corresponding to a total of approximately 1.4 tons per inhabitant, an increase of 1.4% over the previous year [47].

Of this total, renewable sources corresponded to 46.1% of the total energy generation in the country, divided into biomass from sugarcane (18%), hydraulic (12.4%), firewood, and charcoal (8.7%) and other renewables (7%) [47]. Only biomass from sugarcane and firewood with charcoal were responsible for 26.7% of the domestic energy supply, however, it is known that among others renewables there are more biomass-derived energy sources such as leachate, biogas, biodiesel, and others, which still increase the share of biomass in the Brazilian energy matrix [47].

The current Brazilian electric scenario is even more centered on renewable energies, since of the domestic supply of electric energy in the country, approximately 651.3 TWh, during 2019, 83% was composed of renewable energy sources, with the generation of electricity through hydroelectric (64.9%), wind (8.6%), biomass (8.4) and solar (1%) [47].

4.2 Electricity production and cogeneration using biomass

The power production by biomass can be carried out through different technological routes, commonly the process consists of converting the feedstock into an intermediate product, which will be used for the operation of generating mechanical energy in a machine to drive an electric generator, which will produce electricity [48].

Traditionally, the industrial sectors that generate electricity by biomass also choose to have a cogeneration system, where two or more energy forms are produced from a single process for generating energy, such as heat and electricity [48].

Among the main technological routes, stands out the steam cycle with back pressure turbines, steam cycle with extraction condensing turbines, and the biomass integrated gasification combined cycle [48].

4.3 Steam cycle with back pressure turbines

In this process for generating power, the steam produced by the direct burning of biomass in the boilers is used in turbines coupled with generators, for the production of electrical energy or in turbines for the production of mechanical work and also the fraction that would be released into the atmosphere can be reused directly to meet the thermal needs of the process [48]. In general, the back-pressure steam turbines provide not only electricity but also steam to be used in the plant facilities [49].

The advantage of this process is that the back pressure turbines have few stages with simple structure and small exhaust parts, which results in low cost of the equipment [49], currently this route is the most used and is already well developed commercially, having in Brazil several producers for most equipment [48].

4.4 Steam cycle with extraction condensing turbines

This process is similar to the previous one, however, the steam is totally or partially condensed, after its use in the production process, therefore, its main difference is found in the presence of a condenser in the exhaust of the turbine and specific levels for heating the feedwater boiler supply [48].

In addition, extraction condensing turbines can independently change the production of electricity and process steam, through the control of valves [49], thus, this type of cycle has greater operational flexibility for power generation, concerning with the back pressure turbines [48, 49], also having higher global energy efficiency, allowing obtaining a larger volume of power produced [48].

However, the disadvantage of this type of process is the higher investments for its implementation in relation to the use of back pressure turbines [49] and simple condensing systems [48].

4.5 Biomass integrated gasification combined cycle

By biomass gasification, the fuel gas is obtained and can be used in thermoelectric plants operating on gas for power generation, and applied on a large scale, transforms biomass into an important feedstock for the large thermoelectric plants and through the use of combined cycles of gas and steam, increases the system efficiency [48].

However, it is still a technological route that is not yet commercially competitive, since its greatest difficulty for its application is the production of quality fuel gas, with reliability and safety, adapted to the parameters of biomass and operation [48].

4.6 Biomass thermoelectric plants in Brazil

The participation of thermoelectric plants operating on biomass plays an increasingly important role for the national panorama concerning the supply of electricity. The immense Brazilian land surface located mainly in tropical and rainy regions favors the production and energy use of biomass on a large scale [50].

Sugarcane bagasse is the most widely used biomass as fuel in Brazil for the production of electricity, corresponding to 82% of the electricity exported to the National Interconnected System (in Portuguese, Sistema Interligado Nacional or SIN), this is only possible, because its plants can be energetically self-sufficient [51]. As a result, the power generation costs are competitive with the conventional supply system, which makes the plants through cogeneration being energetic self-sufficient [50].

Sugarcane stands out among biomasses because its high productivity crops together with the gains from the transformation processes of sugar-alcohol biomass, make available an enormous amount of organic matter, mainly in the form of bagasse in the plants and distilleries, also, there is still an interesting complementary relationship between the electricity generated through sugarcane bagasse biomass and hydroelectric power plants, since the sugarcane harvest season coincides exactly in the dry months, thus, the generation of electricity through biomass acts to complement the electrical demand, **Figure 2** [50, 51].

The share of electricity generated through sugarcane in Brazil's energy matrix in 2019 was 3.8%, of which, out of 366 sugar-energy plants in operation in 2019, 220 exported to the network about in mean 2.6 GW [51].

Recently, there has been a significant increase in the export of power to the electrical system generated through other biomasses, especially black liquor, biogas, forest residues, rice husk and others, being important for energy security and reliability, given the seasonality of sugarcane biomass [51]. **Figure 3** shows the biomass thermoelectric plants in operation in Brazil and the potential installed by states in September 2003.

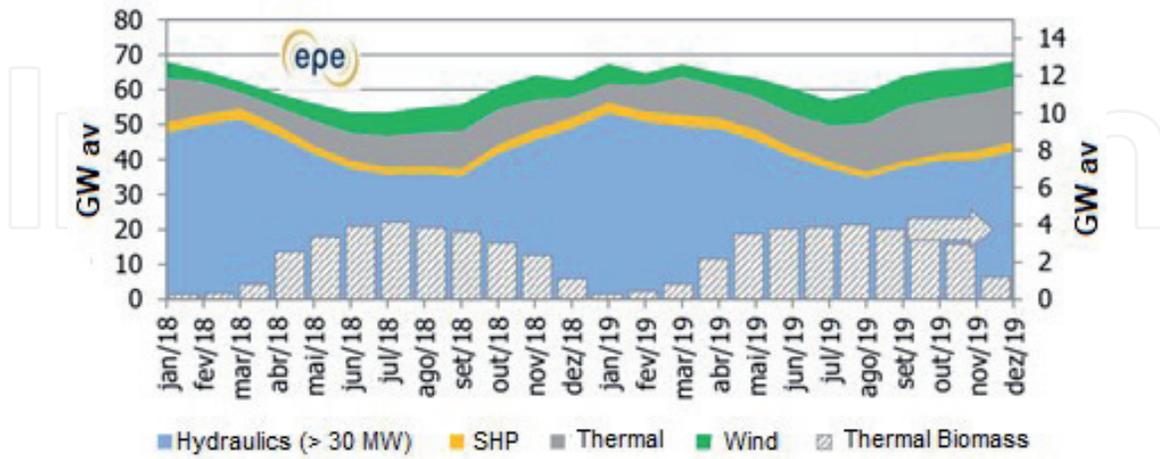


Figure 2. Participation of sugarcane biomass in electricity generation from January 2018 to December 2019 [51].

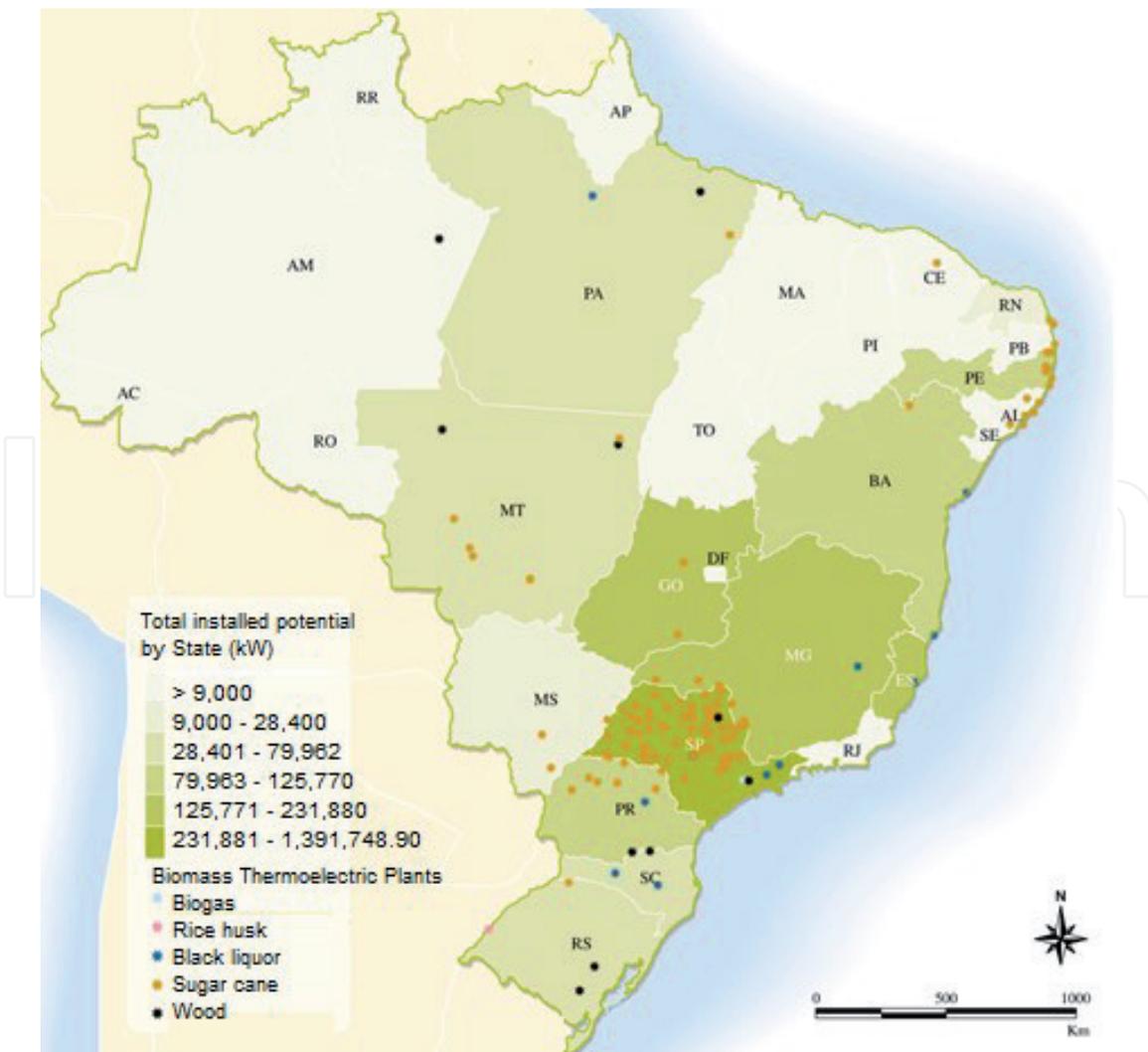


Figure 3. Biomass thermoelectric plants in operation in Brazil by states in September 2003 [51].

5. Conclusions

The global energy market's dependence on fossil fuel energy sources such as coal, oil, and natural gas needs to give way to alternative and sustainable ways to meet this demand. One of the most promising alternatives is the use of biomass, the only natural and renewable resource based on carbon that is vast enough to be used as a substitute for fossil fuels

The biomass conversion process can generate solid, liquid, or gaseous fuels, the biomass energy being one of the renewable energies, the only one that can be converted into liquid fuel. In addition, biomass energy is renewable energy, an abundant and easily produced source. The use of biomass energy is an important ally in mitigating greenhouse gas emissions.

Brazil occupies a prominent position in the world production of cassava, alongside countries in subtropical regions. Cassava starch produces a significant amount of waste, which must be used rationally to minimize the environmental impact of agricultural activities. Brazil is also the largest producer of sugarcane. In addition, the cultivation of sugarcane has the potential to increase environmental benefits, increasing carbon sequestration and optimizing the agricultural production chain. Corn stands out among agricultural species with the potential to provide biomass for energy production, as it has a large acreage worldwide and is a biomass with high calorific value.

The inherent properties of the biomass source are that determine the choice of the conversion process and the possible processing difficulties. In this way, the choice of the biomass source is influenced by the way in which energy is needed, and it is the interaction between these two aspects that allows flexibility to be introduced in the use of biomass as an energy source. Biomass is converted into energy through two main energy conversion routes, namely, thermochemistry and biochemistry.

Due to its vast territory, Brazil has high potential or effective rates of waste from agro-industrial products, making the use of biomass a great possibility for increasing energy production in the Brazilian energy matrix. The results achieved in the year 2019, by 220 sugar-energy plants in operation, exported about 2.6 average GW to the network, showing that the participation of biomass thermoelectric plants assumes an increasingly important role for the national panorama about electricity supply. Sugarcane bagasse is the biomass most used as fuel in Brazil to produce electric energy, due to the high productivity of sugarcane in its crops to serve the sugar and alcohol sector. The energy generated by this biomass stands out, and due to the sugarcane harvest exactly coincides with the dry months, the generation of electricity from biomass acts as a complement to the electric demand produced by hydroelectric plants; there was also a significant increase in energy exports for the electrical system generated by other biomasses.

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Author details

Cintia de Faria Ferreira Carraro^{1,2*}, André Celestino Martins¹,
Ana Carolina da Silva Faria¹ and Carla Cristina Almeida Loures¹

1 The Federal Center for Technological Education Celso Suckow da Fonseca
(Cefet/RJ), Angra dos Reis, RJ, Brazil

2 Federal University Fluminense, Volta Redonda, RJ, Brazil

*Address all correspondence to: cintia.carraro@cefet-rj.br

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