

# Main Sources of Electricity Generation in Brazil

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**Abstract**— Brazil is one of the largest producers of electricity by means of hydroelectric plants; however, this generation process depends on large volumes of water directly affected by climate changes that, consequently, affect the production of electricity. Thus, the predominant production of electric energy, through hydroelectric plants in Brazil, is increasingly complemented by thermal plants to cope with the rapid growth of demand, the greater the amount of electricity generated by thermal plants, the more expensive is the cost of production and greater is the environmental impact due to the burning of fossil fuels. To combat this alternative, new renewable sources should be used in large scale. The three main sources of renewable energy for electricity generation in Brazil are: hydroelectric, wind and biomass of sugarcane, in specific the sugarcane bagasse. The aim of this study is to present how these renewable sources concentrate in a way regional, with the purpose of presenting how these sources can be complementary in the energy supply, according to the characteristics of seasonality of the same ones.

**Keywords**— Energy, Hydroelectric, Renewable, Sugarcane, Wind.

## I. INTRODUCTION

The Hydroelectric plants are still the backbone of Brazil's electricity generation sector. The use of this resource is advantageous in terms of greenhouse gas emissions, flood dampening, navigation and low cost in the generation of electric energy, however, climate changes directly affect its energy production and in times of drought; the country is forced to use thermoelectric plants that burn fossil fuels that generate more expensive and polluting energy. The severe droughts of recent years have exposed the country's huge dependence on hydroelectricity. Brazil's electricity supply system is vulnerable and has required a significant revision to meet its challenges. Renewable energy sources are not continuous as they depend on geographic location as well as climatic conditions and also require large proportions of land for their installation. Factors such as efficiency, operational facilities for power generation, infrastructure and distribution the guide public policies, so that a satisfactory reform in the sector can be achieved, as well as the social and environmental considerations that have been given priority in Brazilian energy planning [1][2].

The National Energy Balance of 2018 base 2017, developed by the Energy Research Company - EPE and the Ministry of Mines and Energy - MME, shows that the generation of electric energy in Brazil is of the order of 587,962 GWh, in the composition of this figure should be highlighted renewable sources, which represent 76.8% of electricity generation in the country, among which are: water sources, wind and biomass sources, in particular sugarcane bagasse. The representation of these renewable

sources for electricity generation is of the order of: 63% Hydroelectric, 7.20% Wind and 6.06% by sugarcane bagasse [3].

Brazil is an independent economy. In this way, the expansion of the generation of energy from renewable sources would not only increase the country's economic growth, but also reduce the environmental impact and create an opportunity for an international leadership role. In this context, it should be noted that one of the objectives of the Ministry of Environment - MMA, through the Secretariat of Climate Change and Environmental Quality - SMCQ, is to "contribute to the development of a low carbon economy through encourage energy efficiency and environmentally sound energy alternatives".

The problem to be addressed in this article is to present the concentration of these renewable energy sources per region of the federation and the amount of electric energy generated, with the purpose of presenting how the integration of these sources can be carried out, promoting the energy supply and the socioeconomic balance of the Country. The composition of the data will be through analysis of articles and documents of the national energy sector, will also be used the software QGIS® version 3.4.5 for the compilation of these data and consequently the production of maps referencing the amount of energy generated per region, for a geographic evaluation of this energy generation source.

## II. LITERATURE REVIEW

In this item will be presented the basic concepts of the three main sources of renewable energy in Brazil, used for electricity generation.

### 2.1 Hydropower

The contribution of hydropower to the country's economic development has been expressive in attendance the diverse demands of the economy or of society itself, representing an improvement in the comfort of dwellings and the quality of life of people, also plays an important role in the integration and in the development of regions distant from large urban and industrial centers. Hydroelectricity has historically been the main generation source of the Brazilian electricity system, accounting for about 63% of installed capacity in Brazil.

This significant participation in the electric matrix is due to the great hydroelectric potential of the country and the various advantages that this source of electricity generation presents in relation to the others. It is a source of renewable generation, economically competitive, and has great flexibility of operation, capable of responding to demand fluctuations almost instantaneously. Hydropower reservoirs can provide a range of non-energy services such as flood control, irrigation, water supply for human consumption, recreation and navigation services. On the other hand, it should be mentioned that the multiple uses of water can be conflicting. The main variables used in the classification of a hydroelectric plant are: height of waterfall, flow, capacity or installed power, type of turbine used, location, type of dam and reservoir. All are interdependent factors. Thus, the height of the waterfall and the flow will determine the construction site and determine the installed capacity, which in turn determines the type of turbine, dam and reservoir.

There are two types of reservoirs: accumulation and run-of-the-river. The former, usually located at the head of the rivers, in places of high waterfalls, given their large size allow the accumulation of large amount of water and function as stocks to be used in periods of drought. In addition, because they are located upstream of other hydroelectric plants, they regulate the flow of water that will flow to them, in order to allow the integrated operation of the set of plants. The run-of-the-river units generate energy with the flow of water from the river, that is, by the flow with minimal or no accumulation of the water resource.

The installed power determines whether the plant is large or medium-sized or a Small Hydroelectric Plant (SHP). The National Electric Energy Agency (Aneel) has adopted three classifications: Hydroelectric Generating Centers (CGH) (with up to 1 MW of installed capacity),

Small Hydroelectric Plants (between 1.1 MW and 30 MW of installed capacity) and Hydroelectric Power Plant (HPP, with more than 30 MW). The size of the plant also determines the size of the transmission network that will be needed to bring energy to the center of consumption.

The larger the plant, the farther it tends to be from the large centers. Thus, it requires the construction of large transmission lines in high and extra-high voltages that often cross the territory of several States. The SHPs and CGHs, installed alongside small waterfalls, generally supply small consumer centers, including industrial and commercial units, and do not require such sophisticated facilities to transport energy.

The use of hydraulic energy for electric power generation is done through the use of hydraulic turbines, properly coupled to a generator. With an efficiency that can reach 90%, hydraulic turbines are currently the most efficient forms of converting primary energy into secondary energy. Hydraulic turbines come in a variety of shapes and sizes. The most widely used model is Francis, as it adapts to both low-fall and high-fall sites. As it works totally submerged, its axis can be horizontal or vertical. Among other models of hydraulic turbines, Kaplan stands out, suitable in places of low fall (10 m to 70 m), and Pelton, more appropriate to places of high fall (200 m to 1,500 m) [4].

The construction of hydroelectric dams is clearly associated with a series of positive and negative environmental impacts. Some of them may represent real constraints to the installation of such structures, while others may act as a sustainable path to local development. Since energy is widely needed for almost all human activities, it is necessary to balance the pros and cons related to the generation of energy by a hydroelectric plant. No universal recipe can be established here, since regional peculiarities will play a significant role in the decision-making process. In the case of Brazil, the government, civil society, water users and the scientific community have for many years been deeply involved in this relevant discussion. From a broad point of view, it can be assumed that the advantages usually prevail over the limitations and a solid trend of additional power generation through the installation of dams can be identified in the country [5].

### 2.2 Wind energy

Wind energy is the kinetic energy contained in the moving air masses (wind). Its utilization occurs through the conversion of the kinetic energy of translation into kinetic energy of rotation, using wind turbines, for the generation of electricity, or through mills, for mechanical

works such as water pumping. For the generation of electricity, the first attempts appeared in the late nineteenth century, in 1970 with the international oil crisis arises the interest and investments to enable the development and application of equipment on a commercial scale.

The evaluation of wind potential in a region requires systematic data collection and analysis on wind speed and regime. In order for wind energy to be considered technically feasible, its density must be greater than or equal to  $500 \text{ W / m}^2$ , at a height of 50 m, which requires a minimum wind velocity of 7 to 8 m / s, however, according to the World Meteorological Organization, only 13% of the earth's surface presents this characteristic.

In Brazil, although there are still divergences between specialists and institutions in the estimation of Brazilian wind potential, several studies indicate extremely considerable values. Until a few years, the estimates were of the order of 20,000 MW. Today most studies indicate values greater than 60,000 MW. These divergences are mainly due to the lack of information (surface data) and the different methodologies used. Regarding the design of turbines, it can be said that at the beginning of the use of wind energy, turbines of various types arose; the wind turbine design was consolidated with the following characteristics: horizontal rotation axis, three blades, active alignment, induction generator and non-flexible structure, however, some characteristics of this project still generate controversy, such as the use or not of the control of the pitch angle of the propeller blades to limit the maximum power generated. Regarding the generation capacity in 1997, 1 MW and 1.5 MW wind turbines were introduced commercially, starting the generation of large machines. In 1999 the first wind turbines of 2MW appeared and today there are prototypes of 3.6MW and 4.5MW being tested in Spain and Germany. The average capacity of wind turbines installed in Germany in 2002 was 1.4MW and in Spain 850kW. Currently there are more than 1,000 wind turbines with a rated power of more than 1 MW in operation in the world. In recent years, the biggest technological innovations have been the use of direct drive (without gear multiplier), with synchronous generators and new control systems that allow turbines to operate at variable speed with any type of generator. As for the application, the turbines can be connected to the electrical network or intended for the supply of electricity to communities in isolated systems. Regarding the location, the installation can be done on land or offshore.

An important factor that should be highlighted in Brazil is the possibility of complementarity between hydroelectric generation and wind generation, since the greatest wind potential in the Northeast region occurs during the period of lower water availability [4]. In the Brazilian scenario, wind energy is advantageous for complementary use with hydraulic energy, source with higher generation rate in the Brazilian matrix. In addition, this complementary generation could be established in different regions of the country [6] [7] [8].

Due to this characteristic, studies have examined the possibility of installing wind turbines in reservoirs of large hydropower plants or even around small power plants [6]. The potential for generating employment due to wind energy in Brazil is 13.5 people / year for each MW between component manufacturing and the first year of the plant. The total potential is 24.5 people / year for each MW during the lifetime of the wind farm [6] [9].

Wind has become an important source of energy in Brazil, since it is the second largest renewable source in the Brazilian energy matrix. In recent years, exponential growth has been observed. The growth of this source is extremely important for the construction of a diversified, clean structure and a renewable energy matrix.

### 2.3 Biomass – Sugarcane bagasse

Sugarcane has been used as a raw material for large-scale ethanol production in Brazil for over three decades, where most sugarcane mills produce sugar, ethanol and electricity. A typical plant has processes common to the ethanol distillery and to the sugar factory composed of the following processes: reception of sugarcane, preparation of sugarcane and extraction of juice. All the energy (steam and electricity) required in this process is produced by the sugarcane bagasse as fuel in the boilers, this residue is generated in the process of extracting the juice. In many plants, the surplus energy generated is marketed to distributors [10]. Sugarcane mills currently use a co-generation system based on the Rankine cycle, the sugarcane bagasse is burned in the boiler, producing steam that is expanded in turbines coupled to electric generators, exhaust steam from the turbines is used as a source of thermal energy in the sugar and ethanol production process. This cogeneration system is installed in most of the sugar and alcohol plants in Brazil, however the steam demand in the plant is a limiting factor for the cogeneration system, that is, not all the available bagasse is often consumed [11].

Until the late 1990s, the cogeneration systems used in the mills were designed only for the thermal energy needs of the sugar and ethanol production process, burning all

the bagasse available and producing little or no electricity surplus. However, in the same period, with the elimination of certain rules and regulations of the energy sector in Brazil, conditions were created for power plants and other electricity producers to market this surplus electricity to the distributors, which enabled a modernization of cogeneration facilities existing [12]. Modern plants have replaced low pressure / low efficiency boilers with medium and high pressure boilers (42 to 90 bar) [13]. The systems with condensation-extraction steam turbines allow the maximization of the production of electricity, since the amount of steam produced does not have to correspond to that necessary to provide thermal energy for the process, since the excess steam can be condensed [10]. Approximately 25% of processed cane is processed into bagasse. According to the National Energy Balance [3], during the 2017/2018 harvest, 165.6 million tons of wet bagasse were produced. Currently, most of the sugarcane bagasse is destined to the burning of the boiler as fuel for cogeneration of energy (Steam and Electricity). The sugarcane bagasse, lignocellulosic biomass, is composed of a complex structure, composed mainly of three fractions denominated cellulose, hemicellulose and lignin. These fractions have a high energy content, being composed of cellulose (40 to 45%), hemicellulose (30 to 35%) and lignin (20 to 30%) [14]. The generation of electricity through sugarcane bagasse is a strategic source for the Brazilian electricity system due to the complementary time between the sugarcane harvest period and the period in which the reservoirs of the sugarcane plants have their lowest levels. Currently, due to the low price of electric energy in biomass energy auctions (regulated market), the investments of the sugar and ethanol sector have postponed their investments in new projects of electricity generation (bioelectricity). Another factor that is influencing the postponement of investments in bioelectricity is the latest advances in the economic-financial viability of second generation ethanol, which competes with bioelectricity using the same raw material: sugarcane bagasse [15].

### III. APPLICATION DEVELOPED

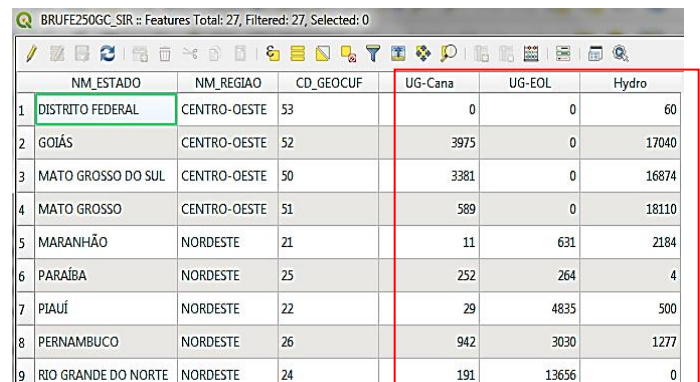
For the answer to the problem addressed in this article, the first step was to verify the generation of electricity in Brazil by source, in this way was used data available in the National Energy Balance 2018 [3], which specifies the amount of electric energy generated by source in each unit of the federation. After data collection, the second step was to allocate this amount of electric energy generated in a map for verification and visualization of

the energy generating region by source, to carry out this stage of the study the following steps were followed:

a) Obtaining the map of Brazil, detailed in units of the federation: This file is available on the IBGE website [16], the map "Brazil - Units of the 2017 Federation" was chosen, where it is possible to download the file "BRUFE250GC\_SIR" with the extensions; shx; shp; prj; dbf and cpg, for further work on QGIS® software.

b) Obtaining the software "QGIS Desktop 3.4.5": QGIS® is a licensed open source Geographic Information System (GIS). QGIS operates on a variety of operating systems and supports vectors, rasters, and databases. The use of QGIS® is necessary for the inclusion of data obtained from electric power generation by source in each geographic region [17], in this study, by region of the federation;

c) With the data obtained and the software available for use, in the file "BRUFE250GC SIR" the table of attributes was changed including three columns referring to the generation of electricity by source, hydroelectric (Hydro); wind (UG-EOL) and biomass - Sugarcane bagasse (UG-Cana), with data values in Gigawatt (GWh), as shown in Figure 1;



	NM_ESTADO	NM_REGIAO	CD_GEOCUF	UG-Cana	UG-EOL	Hydro
1	DISTRITO FEDERAL	CENTRO-OESTE	53	0	0	60
2	GOIÁS	CENTRO-OESTE	52	3975	0	17040
3	MATO GROSSO DO SUL	CENTRO-OESTE	50	3381	0	16874
4	MATO GROSSO	CENTRO-OESTE	51	589	0	18110
5	MARANHÃO	NORDESTE	21	11	631	2184
6	PARAÍBA	NORDESTE	25	252	264	4
7	PIAUI	NORDESTE	22	29	4835	500
8	PERNAMBUCO	NORDESTE	26	942	3030	1277
9	RIO GRANDE DO NORTE	NORDESTE	24	191	13656	0

Fig.1: Attribute table

d) With the inclusion of the data in the attribute table, it was possible to create three different files, for each electric power source and using the layer properties function, it was possible to identify the amount of energy generated by each region in the federation, as shown in Figure 2.



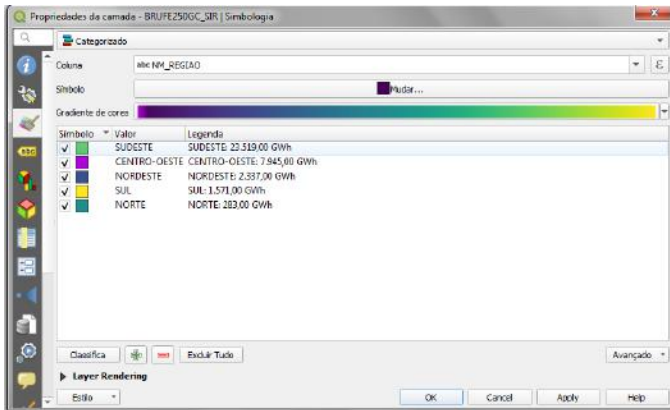


Fig.2: Layer property setting

#### IV. DISCUSSION OF RESULTS

The results presented objectively describe the concentration of these renewable energy sources and the generation of electricity through these sources per unit of the federation in Brazil.

##### 4.1 Hydroelectric

Table 1 shows the generation of electric energy for each region in Brazil, through hydroelectric plants.

Table 1: Electricity generated in Brazil - Hydroelectric

Region	Electric power generation- GWh
South	127.530,00
Southeast	87.003,00
North	86.364,00
Midwest	52.084,00
Northeast	17.927,00

Within these regions the states of Paraná, São Paulo, Pará, Minas Gerais and Rondônia stand out. The generation of electricity in Brazil generated by hydroelectric dams is carried out through two large integrated structural systems: the South-Southeast-Mid-West system and the North-Northeast system, which correspond respectively to 70% and 25% of the hydroelectric power in Brazil. Figure 3 shows the generation of electric power, through hydroelectric plants per region of the federation.

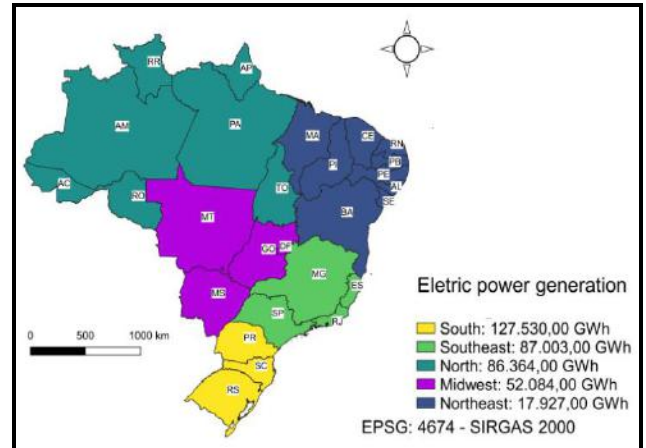


Fig. 3: Generation of electric energy by region – Hydroelectric

##### 4.2 Wind energy

Table 2 shows the generation of electricity for each region in Brazil, through wind power plants.

Table 2: Electricity generated in Brazil – Wind energy

Region	Electric power generation- GWh
Northeast	36.188,00
South	6.108,00
Southeast	78,00
Midwest	0,00
North	0,00

Within these regions stands out the states of the northeast region with the greatest amount of electric energy generated, such as Rio Grande do Norte; Bahia and Ceará, in the South region the state of Rio Grande do Sul stands out, these states are concentrated in coastal regions with a higher incidence of winds. Figure 4 shows the generation of electric power, through wind power plants per region of the federation.

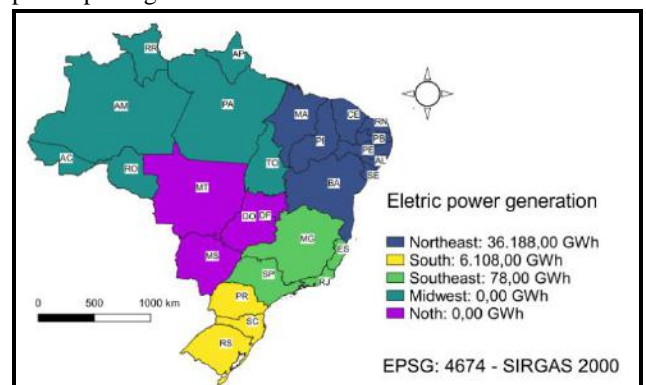


Fig. 4: Generation of electric energy by region – Wind energy

##### 4.3 Biomass – Sugarcane bagasse

Table 3 shows the generation of electric energy for each region in Brazil, through sugar and ethanol plants, using sugarcane bagasse in the cogeneration process.

Table 3: Electricity generated in Brazil – Sugarcane bagasse

Region	Electric power generation- GWh
Southeast	23.519,00
Midwest	7.945,00
Northeast	2.337,00
South	1.571,00
North	283,00

Within these regions the states of the Central South region, which are located in the Southeast and Midwest regions, stand out. The country's sugar and ethanol plants are concentrated in the Zona da Mata, in the Northeast, and in the states of São Paulo; Minas Gerais and Mato Grosso do Sul, in the Center South region (Southeast and Center West). It stands out the state of São Paulo, which produces about 52% of all the sugarcane produced in the country. Another point that stands out refers to sugarcane bagasse, sugarcane bagasse is used for power generation and there is no demand for fossil fuels in the industrial phase of sugar and ethanol production, these plants are self-sufficient. Sugarcane bagasse, the residue of the milling process, is used to produce heat and the electricity needed to produce ethanol and sugar in production plants, and in cases of excess electricity production, this becomes another item to be marketed in favor of producers. The use of sugarcane bagasse for energy cogeneration is the reason why the energy balance of ethanol production from sugarcane is highly positive, since no fossil fuel is used, except for those that are included in the production of fertilizers and pesticides, and the diesel oil used in agricultural equipment and in the transportation of sugarcane to supply the production plants.

As a result, there is a strong benefit not only in the energy balance, but also in the greenhouse gas emissions associated with sugar and ethanol production. Figure 5 shows the generation of electric energy, through sugar and ethanol plants, using sugarcane bagasse, per region of the federation.

Based on the amount of electricity generated by the three main renewable sources of energy generation in Brazil, an analysis of how these sources are to be addressed and addressed is necessary. Currently experts are beginning to question about new investments in large hydroelectric dams, considering that the development of hydroelectric dams is a global phenomenon that is affecting the most important watersheds in the world, including the Amazon, the Congo and the Mekong, creating huge disruptions, in these ecologically important regions.

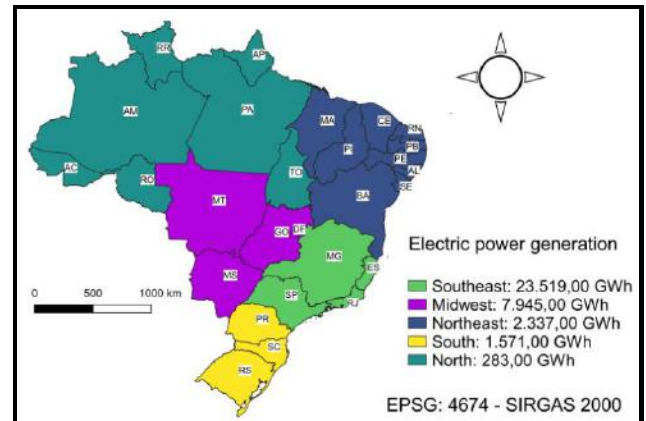


Fig. 5: Generation of electric energy by region – Sugarcane bagasse.

The financial costs of the dams are immense, and many believe that the benefits do not outweigh the costs. The hydrological consequences of large-scale dams and reservoirs are extensive; sharp declines in available fresh water due to dam construction cause seasonal changes in river flow, as well as loss of freshwater habitat downstream, floodplains and even coastal erosion and salinity changes. In the Tucuruí dam region of the Brazilian Amazon, fish catching declined by almost 60%, and more than 100,000 people living downstream were affected by loss of fishing, recession agriculture and other natural resources. The Jirau dam and the Santo Antônio dam on the Madeira River in the Brazilian Amazon, completed only 5 years ago, are expected to produce only a fraction of the 3 GW each that are designed to produce due to climate change and small storage capacity. However, it should be noted that this same author advocates the creation of small power plants, due to the lower socio-environmental impact and benefits to the community involved [18].

The bioelectricity potential of biomass through sugarcane is estimated at 62-93TW / h, which can be improved through a more adequate use of biomass from the sugar and alcohol industry, in order to balance the availability of biomass, hydroelectric power [1].

With a view to the near future, when the sugar and alcohol plants start to produce much larger surpluses of electricity, especially with more developed technology for burning straw in conjunction with sugarcane bagasse, average surplus energy values will increase substantially [13]. In relation to wind farms, Brazil has an immense coastal area with the capacity to absorb more wind farms, coinciding with the areas of greater consumption at the extreme of the transmission lines, enabling the expansion of the sector in an attractive way, [7] in particular, the peculiarities of the coastal region of the Brazilian

Northeast (NE) allow a strong penetration of wind energy, which should generate 57% of the electricity supply of the Northeast until 2020. As precipitation in the Northeast is susceptible to climate change, it is predicted that wind power may replace lost hydropower availability [1].

## V. CONCLUSION

In this article, the current condition of the electric power generation sector in Brazil is transparent, the most used source in the country is the hydroelectric plant, the share of electricity generated by projects created on the basis of renewable sources is growing; wind, biomass-sugarcane bagasse and small hydroelectric plants, with the objective of increasing energy security, reducing greenhouse gas emissions, regionalizing production, introducing new technologies, modernizing the national industrial park and valuing the respective localities. Considering the various renewable sources available, the country shows potential for integration between renewable energy sources, which would lead to an energy matrix for more distributed electricity generation, presenting socio-economic gains, technological and providing local industrial development, with a view to the power of technology absorption and learning from local industries. For the success of this integration between renewable sources, it is necessary to consider the seasonality of energy sources and that the use of these sources should be planned and functioning positively and complementing each other, it is also necessary to improve government programs to encourage the generation of electricity, in particular, the smart grid, which allows the connection of small photovoltaic and wind systems to consumers of low voltage (commerce and residences), besides allowing the perfect functioning of these systems in tune with the whole electrical system, favoring the generation of electric energy. In this context, it should be clear that there is room for other forms of generation by clean sources, such as solar energy, but these investments should always focus on the integration of generation processes, always seeking the growth of the country.

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