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The Electric Energy Production Models and Diversification of Brazilian Energy Matrix

Modelos de Producción de Electricidad y Diversificación de la Matriz Energética Brasileña

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Abstract: Discussions around electrical and energy matrices across the planet have been constantly growing, and along with these discussions, the diversification of the Brazilian energy matrix has also grown. In this sense, this article aims to show the models of energy production in Brazil, highlighting the main sources used in the electrical matrix in recent years, as well as the formation of the energy matrix in Brazil among the most diverse sources that compose it. This work has three sessions, the first relating to the introduction of the theme; the next section deals with the methodology of the work, and the last block deals with the characterization of the energy matrix and how they present themselves. Within this discussion, this work also brings the characteristics that define the need for diversification of the national matrix. The article brings interesting results in relation to the national matrix, such as how renewable is the electricity matrix in Brazil, how much it can expand in the most diverse sectors of energy production, and the contrast between the matrix of Brazil and the world.
Keywords: *Brazil; Electricity; Diversification; Energy matrix.*

Resumen: Las discusiones en torno a las matrices eléctricas y energéticas en todo el planeta han crecido constantemente, y junto con estas discusiones, la diversificación de la matriz energética brasileña también ha crecido. En este sentido, este trabajo tiene como objetivo mostrar los modelos de producción de energía en Brasil, destacando las principales fuentes utilizadas en la matriz eléctrica en los últimos años, así como la formación de la matriz energética brasileña entre las más diversas fuentes que la componen. Este trabajo tiene tres sesiones, la primera es una introducción al tema, la siguiente sesión es sobre la metodología del trabajo, y el último bloque es sobre la caracterización de la matriz energética y cómo se presentan. Dentro de esta discusión, este trabajo también trae las características que definen la necesidad de diversificación de la matriz nacional. El artículo trae resultados interesantes en relación a la matriz nacional, como cuán renovable es la matriz eléctrica brasileña, cuánto puede expandirse a los más diversos sectores de producción de energía, y el contraste entre la matriz de Brasil y del mundo**.**
Palabras clave: *Brasil; Energía Eléctrica; Diversificación; Matriz energética.*

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INTRODUCTION

Over the years, countries have experienced various modifications in their electrical energy production systems, from their primary origins to the ways in which they were distributed. These modifications occur constantly, and in their most profound aspects, occur both because of energy policies and economic policies; Pointing out that in many countries, their respective energy and electricity matrices are reflections of choices made in the past and present (MAUAD, FERREIRA, and TRINDADE, 2017).

The entire process involved in the choices of primary energy sources and the form of distribution and consumption is intrinsic to the lifestyle of citizens, the type of industry present in a given region, and the pertinent climatic-geographic characteristics; making the cycle of decisions made influence the methods of access to electric energy (LIMA, AMANAJÁS, et al., 2010).

Electricity production and distribution are linked to several factors such as resource supply, territorial size, exploitation capacity, and other factors (ABEEÓLICA, 2018). In Brazil, even though energy sources are varied, much of the energy produced comes from hydropower (ETENE, 2015).

The hydro source is the majority and faces resistance from the greener sectors, considering the large areas that are flooded and the need for a constant volume of water in reservoirs so that energy production does not decrease. Another part of the energy comes from non-clean and non-renewable sources, such as gas, oil, and coal, which, besides being polluting, are expensive, and another part is totally renewable, clean, and somewhat cheap, coming from wind and solar plants (ETENE, 2015).

Energy is essential to carry out the day-to-day activities of its users, so it is necessary in a context of strong economic dependence on fossil fuels (MAUAD, FERREIRA and TRINDADE, 2017), to address the significant energy challenges posed by climate change, combating pollution and the growing linkage in oil imports, the pressure exerted on energy resources, and the supply of safe energy to all consumers at affordable prices (FERREIRA JUNIOR and RODRIGUES, 2015).

Renewable energy - wind, solar (thermal and photovoltaic), hydro, geothermal, and biomass - are an essential alternative to fossil fuels (TOLMASQUIN, 2016). Their use allows reducing greenhouse gas emissions in energy production and consumption and reducing dependence on fossil fuels in a given region or country (BEZERRA, 2019).

In Brazil and in the world clean energies, also known as renewable energies, have been adopting a prominent role with regard to sustainability. Thus, energy in its most diverse forms, is indispensable for the survival of mankind, in terms of energy supply, electricity has become one of the most versatile and convenient forms of energy and represents a prominent role for economic and regional development (PINÃS et al., 2016).

Our country has a relevant advantage in the issue of renewable energy, because it has one of the cleanest energy matrices in the world, the supply of electricity in Brazil is held mainly through renewable energy sources. But it is already the consensus of most scholars that the world energy matrix will undergo changes raising this percentage of clean energy use (JACOBOWSKI et al., 2020; PINÃS et al., 2016; GEHN, 2016).

Thus, the main objective of this work is to highlight and describe the models of national electricity production, in addition to showing the diversification of the energy matrix in Brazil.

THEORETICAL FOUNDATION

Main sources of energy

The environment and energy are intrinsically linked; throughout its history, man has been able to find the most diverse sources of energy necessary for his survival (MAUAD, FERREIRA, and TRINDADE, 2017). In nature, energy in its natural form can be classified as fossil energy and non-fossil energy, where fossils are originated from all organic matter that is sedimented and deposited in certain layers of the subsoil, processes that usually last thousands of years, and whose totality is finite, i.e., its quantity is limited and liable to exhaustion (MAUAD, FERREIRA e TRINDADE, 2017).

This exhaustion as a result of the continuous exploitation of fossil resources leads to resource scarcity and increased costs (TOLMASQUIN, 2016). Further, the extraction of these materials is linked to a certain degree of constant pollution, from oil processing to coal mining.

After being collected, they undergo a transformation, combustion, which generates a significant production of carbon dioxide (CO2), the main cause of the greenhouse effect and global warming (MAUAD, FERREIRA, and TRINDADE, 2017). Widely associated with the Industrial Revolution of the 19th century, coal is historically the first fossil fuel used before oil and natural gas (SANTOS and HATAKEYAMA, 2012); and remains to this day the first used in the world for the production of electricity and, unlike other fossil fuels, is not in the process of depletion. Considered the world's first energy source since the mid-twentieth century ahead of coal, oil is everywhere in our daily lives: in fuels, electricity, in the most diverse forms of heating, but also in plastics, paints, fabrics, dyes, cosmetics, etc. Oil allows the production of electricity by combustion in thermal power plants, like other fossil fuels that also allow this production by combustion (MAUAD, FERREIRA, and TRINDADE, 2017). Natural gas is a fossil fuel consisting mainly of methane and is located in pockets underground, sometimes near oil wells, or is trapped in rock, where it is extracted through fracking. The third thermal energy source after oil and coal (BEZERRA, 2019), natural gas is exploited to produce heat and electricity and is less polluting due to lower carbon emissions in the atmosphere.

In nuclear energy production, uranium is used mainly as a raw material; it is a metal extracted from the earth's subsoil whose energy is produced by fission, producing electricity in nuclear thermoelectric plants thanks to the heat released (ETENE, 2015). To this end, there is also biogas, which unlike natural gas, is considered a renewable energy source, the name biogas indicates a gas originating from a biological process, this process is very common in nature and occurs, for example, in swamps, lake bottoms, dunghills and in the rumen of ruminant animals.

From the anaerobic decomposition of organic matter from waste deposited in landfills and wastewater treatment plants, from the presence of heterotrophic microorganisms, which oxidize organic substrates for their energy needs results in biogas. At the end of this process this expelled biogas is a mixture of 50 to 60% methane (CH4), 40 to 50% carbon dioxide (CO2) and other gases in trace concentration, i.e., less than 1%, for example, hydrogen sulfide gas (H2S), mercaptans and various volatile organic compounds (SILVESTRE, 2015).

Methane ($CH4$) has an impact twenty-one times greater than carbon dioxide on the aggravation of the greenhouse effect, but in contrast, this component present in biogas provides ample calorific power, giving it potential for energy reuse (FREITAS and MAKIYA, 2012; MELO NETO, FONTAGALLAND and LIMA, 2022). Hydraulic energy - hydroelectricity - is the energy produced by the force of water - rivers, streams, waterfalls, marine currents, etc. - and transformed into electrical energy (TOLMASQUIN, 2016).

It represents the first renewable source and the third largest source of electricity after coal and gas. It is crucial to point out that the production of energy from hydro sources also incurs problems, as there needs to be an infinite flow of water, implying the need for constant rainfall to maintain the constant flow and level of the rivers. According to the EPE (2018) about 12% of the domestic energy supply in Brazil for the year 2018 was from hydro sources, compared to 36% sourced from oil and oil products.

Energy and Electricity Matrix: Brazil and the World

The composition of the global energy matrices strongly determines the degree of search for substitution or maintenance of energy sources, whether renewable or fossil, considering that energy is an essential input consumed in the production chain of the most industrialized countries and other countries. It is still in the process of industrialization and considering that the world energy matrix predominantly uses non-renewable sources such as coal, oil, gas and uranium for nuclear energy (BARBIERI, 2007).

The energy matrices of countries are determined by natural characteristics that favor or hinder energy production. According to Mauad (2017), variations in electricity production strategies, including the sources used, and differences in national economies mean that there is great variability in the cost to

generate electricity between different countries, as in the case of Brazil, which has a significant hydro advantage but a high production cost.

According to Bezerra (2019), about 63% of the energy produced in Brazil in December 2019 came from hydroelectric sources, which reflects the fact of Brazil's hydro advantage (ETENE, 2015). However, the energy supply in our country is exposed to the fortuitous risks on the hydro sources, turning very attractive, the proposal of creating new sources of electricity generation.

Starting from the assumption of the current situation, the unstable climatic conditions that we have been facing and the problems with the incipient levels of the large hydric reservoirs, which in turn put the energy sector in check, the diversification of its energy matrix becomes a concrete action against future electric energy crises in the country (JACOBOWSKI et al., 2020).

In Table 1 are detailed the sources of electricity generation that are predominant in Brazil in the last four years, it is highlighted the largest generation that is by hydroelectric means with approximately 362,818 GWh in the year 2021, however it is observed that it has been decreasing over the years and may be the result of the insertion of new energy sources such as wind and solar energy that both have grown a lot in recent years as cleaner energy alternatives, especially solar energy generation, which jumped from 3,461GWh in 2018 to 16,752 GWh in 2021.

TABLE 01: Electricity generation by source in Brazil (GWh).

Matrix	2018	2019	2020	2021	Δ% (21/ 20)	Part. % (2021)
Hydraulics	388,971	397,877	396,381	362,818	-8.5	55.3
Natural Gas	54,295	60,188	53,515	86,861	62.3	13.2
Oil Derivatives	10,293	7,846	8,556	18,244	113.2	2.8
Coal	14,204	15,327	11,946	17,585	47.2	2.7
Nuclear	15,674	16,129	14,053	14,705	4.6	2.2
Biomass	51,876	52,111	55,613	51,711	-7.0	7.9
Wind	48,475	55,986	57,051	72,286	26.7	11.0
Solar	3,461	6,651	10,748	16,752	55.9	2.6
Other	14,147	14,210	13,387	15,146	13.1	2.3
Total	601,396	626,324	621,250	656,108	5.6	100.0

SOURCE: EPE (2021).

In the world perspective of energy matrices, it is possible to observe that there is a pattern relative to the characteristics of each country, i.e., each country's energy matrix has a peculiar and common

characteristic with other energy matrices, countries like the United States, China and Russia use a substantial amount of mineral coal and oil diesel for thermal electricity production, besides being continental countries that have well-defined seasons and harsh winters, which translates into higher energy consumption (MAUAD, FERREIRA, and TRINDADE, 2017). In the year 2018, approximately 32% of the countries' energy matrix, in an average perspective, was composed of oil and its derivatives, followed by mineral coal (27.1%), and natural gas (22.1%) (IEA, 2018), in contrast to the world matrix, Brazil's energy matrix was composed of approximately 36% of oil and derivatives, 17% of sugar cane derivatives, and 12% of hydraulic sources (EPE; MME., 2018).

In relation to the global electricity matrix, for the year 2018, just over 38% of the matrix was composed of coal, 23% by natural gas, and approximately 17% of hydraulic origin (EPE; MME., 2018), in turn, the national electricity matrix was composed of 65% of hydraulic origin, 10% from natural gas, 8% from biomass, and 6.2% of renewable origin solely solar and wind (EPE; MME., 2018). This perspective shows us how exciting and dynamic the energy and electricity matrix is in Brazil and worldwide. In December 2018, according to the Brazilian Association of Wind Energy - ABEEÓLICA - (2019), about 48,880 MW were from hydroelectric plants, representing 75% of the national energy production in the referred period, evidencing Brazil's potential for electricity production. It is in this comparative model that we see the need for new strategies for energy production, not only electricity, but all forms of energy, since everything that is produced in terms of energy is not only for electrical consumption, according to the IEA (2018) about 4.4 million Ktoe were used for energy supply in the year 2018, meaning millions of tons of CO2 in the atmosphere. Also, according to the International Energy Agency, IEA (2018) 3.8 million Ktoe of coal and 2.9 million Ktoe of natural gas was also used worldwide in energy production, which reinforces the idea that the sources of the global energy matrix are still very dependent on fossils.

The need for diversification of the energy matrix

Over time, the need for changes in specific energy sectors has proliferated due to various factors, such as depletion of sources, growth in demand, impacts on the environment, etc. With the advent of technology, energy production in the world has changed dramatically:

> [...] with the development of new technologies and the emergence of new needs, coupled with the almost constant growth of the world population, one of the great challenges encountered today is the uncertainty regarding the future availability of energy in the face of demand, mainly due to the comprehensive use of non-renewable sources and the high-scale

> exploitation of the resources provided by the planet (MAUAD, FERREIRA and TRINDADE, 2017, p. 27).

The need for advances has made a fundamental evolution also in the energy matrix. Thus, it is evident that the reduction of environmental degradation is one of the great drivers of the new energy phase, that is, the sum of the factors of technological development, new energy needs, and the scarcity of resources in the environment was, and is the primary basis to induce the development of energy strategies through renewable energy, over time.

After the periods of 1973 and 1974 (MAUAD, FERREIRA e TRINDADE, 2017), which became known as the oil shock, the search for the reduction of environmental impacts caused since the First Industrial Revolution and the replacement of oil itself as a source of energy, by other sources that were renewable and cheaper, triggered a worldwide movement that culminated in the development of goals and objectives to be met by nations, so that the existing process of environmental degradation could be reversed (SIMAS and PACCA, 2013).

The discussions around a model that could replace fossil fuels in the energy matrix were not only something of the XXI century; it can be noted that since the first world meetings held by the United Nations - UN - and the problems already presented in the past, such as oil shocks, where the search for energy security and greater independence from fuel imports has become a necessity (FERREIRA JUNIOR and RODRIGUES, 2015). These facts have stimulated the debate around reducing the impact of greenhouse gases and reducing the impact of fossil fuel exploration in the most diverse countries, such as the USA, China, and European countries (MAUAD, FERREIRA, and TRINDADE, 2017).

Today, significant development can be observed in the production of energies considered clean such as wind, solar, biomass from sugarcane bagasse and composting, and energy production in small hydroelectric plants, known as SHP (ETENE, 2015). This evolution in the production of renewable energy helped prevent the release of at least 20.58 million tons of CO2 into the atmosphere (ABEEÓLICA, 2018), which in itself would already strongly justify the adoption of renewable and clean energy in the national energy matrix.

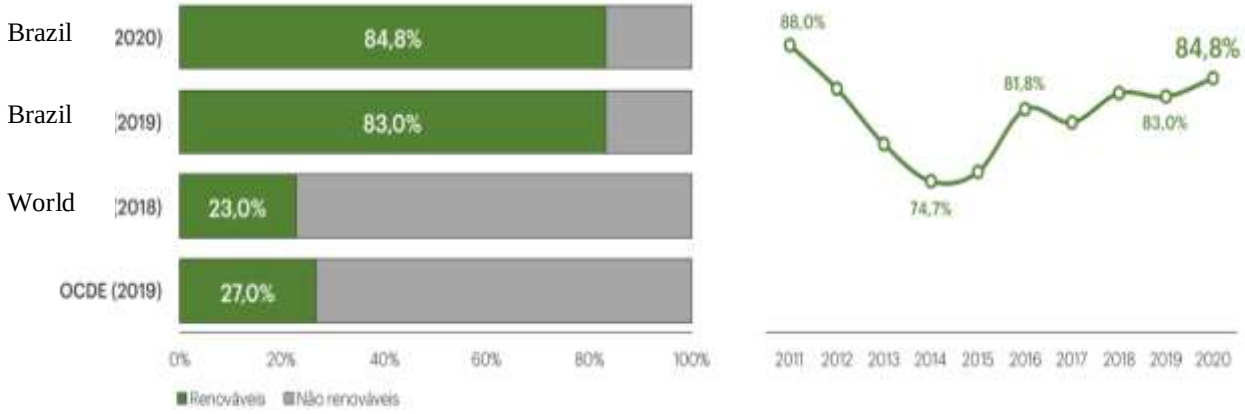
Not too long ago, debates about renewable energies were and are present in everyday life, whether because of the real need to reduce the impacts of the massive exploitation of environmental resources and environmental degradation, or just because of the interest in compensating the population for the high prices always paid by consumers of electricity. This complements the emergency character by which the development of renewable energy has occurred not only in Brazil, but also in the world, reinforcing the transformative power that renewable energy can cause.

The importance of renewable energy in Brazil

In the perspective of development evidenced by the implementation of new renewable energy sources, the adoption of energy models that diversify both the energy matrix and the electric matrix of Brazil, can lead the country to a situation of energy security and less dependence on fossil fuels, and even a reduction in the dependence on water for energy generation.

If we look at the model of electric energy production in Brazil, it is noted that this production still has links with sources that are not renewable, according to the EPE (2018) for the year 2018 electric generation from non-renewable represented 20.8% of the national total, compared to 19.6% in 2016, showing that there is still a way to go in replacing fossil sources with renewable sources. Still, it is worth noting that electricity production in Brazil is predominantly of renewable origin, as highlighted by BEN itself (2018).

FIGURE 01: Participation of renewable energy in Brazil's energy matrix.



SOURCE: EPE (2018).

After the blackout periods that hit Brazil in 2001/2002, the federal government adopted measures (BRASIL, 2001) to contain the energy crisis by reducing industrial and residential consumption through the payment of a fine in case of non-compliance with the determination (ARAÚJO et al., 2017). In turn, there was also the creation of Proeólica and Proinfa, which favored the production of renewable energy in the country, especially in relation to wind energy, when the national potentialities for such generation were observed. Being a continental country, Brazil has several ways to generate energy, mainly hydroelectric, solar, and wind power. In the southern region of Brazil, the winds from the Andes Mountains blow strongly on the pampas of the state of Rio Grande do Sul, being constant and strong enough for the installation of wind farms and power generation, already on the northeast coast, the sea

breeze that blows constantly during much of the year over much of the states in the region, favoring the constant production of wind energy (LIMA et al., 2010).

METHODOLOGY

The procedures of this research are based on the bibliographical model, where its theoretical nature is elaborated as of works, research and technical data, such as scientific articles, reports, theses and monographs (GIL, 2002). According to Lakatos and Marconi (2001), bibliographical research encompasses all the bibliography already made public in relation to the theme under study, from loose publications, bulletins, newspapers, magazines, books, surveys, monographs, theses, cartographic materials, among others. It also includes the documentary research method (GIL, 2002), considering that the approach will also focus on a series of productions that have already been analyzed or can be re-elaborated by the research objectives.

This research aims to review knowledge for scientific advancement without the need for practical application, being a qualitative and quantitative research. This work used research techniques, in the exploratory and descriptive perspectives, which will explore a theme and bring familiarity with a specific situation, characterize a phenomenon and identify the factors of these phenomena (GIL, 2002).

The bases for this research were mostly from technical papers, reports and reports from governmental institutions and autonomous institutions. In this way, the process by which all the material was treated and selected followed some criteria: The first is related to the selection and initial analysis of all the material that fit the research criteria, i.e., not all the works fit some factors such as date of publication and relevance in the environmental environment. The second point refers to the thorough analysis of the content that makes up the papers and its suitability to the sections of the article in question. Finally, the entire writing of this research followed the points deemed important to the understanding of the theme, in view of the need to understand some intrinsic factors to the research analysis, such as energy models, primary sources, among others.

RESULTS AND DISCUSSIONS

From the perspective of what was analyzed in this research, it is noted that the history of mankind is closely linked to energy development, which becomes an essential component for the most diverse activities and for the achievement of socioeconomic development. Numerous energy sources have been used during the evolution of mankind, especially fossil fuels such as oil, coal, nuclear energy, and natural gas. These sources have become indispensable in meeting the world's demand for energy.

The quality of life of a society is strongly linked to its energy consumption. Improved standards of living, especially in developing countries, lead to increased energy consumption, and therefore require better energy management that addresses the security of energy supply to meet this increased energy demand.

In international discussions and studies in several countries, the deepening of the relationship between energy consumption and the environment has been noted, since energy use implies the emission of greenhouse gasses and, consequently, global warming, both in central and peripheral countries. Great debates arise when the subject revolves around the effects of energy consumption and the conditions under which this consumption should take place. There is consensus among environmentalists that the current development model, based on the use of nature as yet another economic asset to be exploited to the maximum, is both socially unbalanced and environmentally unsustainable. Therefore, since the last decades of the 20th century, the international scientific community has mobilized, promoting events that aim to find alternatives to reduce the imbalance between human activities and the environment.

CONCLUSIONS

In light of what has been exposed throughout the work, therefore, it is clear the importance of electric power and its respective production models and needs presented throughout its course, from its origins to our present day. The history of man is closely linked to energy development, which becomes an essential component for the most diverse activities and for the achievement of socioeconomic development, taking into account the environment as a determining factor that is significantly impacted in the various forms of energy production, whether clean or not. Based on this context, the deepening of the relationship between energy consumption and the environment has been discussed in several countries, since the use of energy implies the emission of greenhouse gases and, consequently, global warming. There is a consensus among environmentalists that the current development model, based on the use of nature as yet another economic asset to be exploited to the maximum, is both socially unbalanced and environmentally unsustainable.

Brazil is a privileged country, with a significant water advantage compared to several other countries, but on the other hand it has a high production cost. It is worth mentioning that in the photovoltaic generation point of view it is also favored, because it has the northeast region that spends most of the year with constant solar radiation, providing a higher generation in this segment. It is important to invest and develop new technologies for an increasingly efficient energy generation that is less harmful to the environment, meeting the current demands and ensuring that future generations can enjoy these natural resources with the same or better quality.

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