Water Resources and the Brazilian Electricity Matrix

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The Brazilian electricity matrix, with a higher percentage of renewable sources than the world matrix, stands out in hydroelectric generation, an advantage or vulnerability depending on the rainfall regime, the volumes of the reservoirs, and the need to activate the thermoelectric plants. This work analyzes technical, economic, and the management aspects related to decisions about the composition and use of the Brazilian electricity matrix. The method was fundamentally based on the literature review. We seek answers about energy availability to meet Brazilian demand and whether government decisions can be considered the most appropriate. We analyzed the Internal Electricity Supply in Brazil since 1970, crossing it with data on population growth and GDP growth, comparing it with the evolution of the installed capacity of energy generation.

Keywords: Water Resources. Brazilian Electrical Matrix. Thermoelectric Plants. Planning.

Introduction

Energy can be understood as a fundamental means of satisfying human needs. Its use is intrinsic to the access and use of natural resources and with environmental issues, highlighting the challenges and complexity of this intertwined relationship, in contemporary times, in an energy crisis.

Access to energy resources is a crucial challenge because, despite the growing use of energy, millions of homes still need access to essential energy services. Concerning environmental issues, the increase in CO_2 emissions from fossil fuel combustion in the last thirty years (1990-2020) can be highlighted [1]. Also, the global energy demand will increase [2-4], and countries considered emerging as Brazil will play a relevant role in the energy transition process.

The challenges mentioned earlier will make choices for alternatives to traditional sources of energy production emerge, and the Sustainable Development Goals (SDGs) proposed by the United Nations will help to increase renewable energies in the global energy matrix.

The global challenges linked to the energy issue, and considering the role of hydroelectricity, this work has the main objective of presenting an overview of energy planning, analyzing technical, economic, and the management aspects of the composition and use of the Brazilian electricity matrix. We considered two questions in this paper: whether Brazil will have electricity available to meet its demand in the coming years and whether the decisions taken throughout 2021 can be evaluated as adequate considering the technical and economic aspects. This work is divided into two sections in addition to the Introduction. The first one analyzes the Brazilian energy profile and compares it with other countries. The second section analyzes data on the growth of domestic electricity supply, resident population, and gross domestic product.

Brazilian Energy Profile

Brazil was the sixth largest energy consumer in the world in 2020, with 2% of global consumption, and second in the Americas, behind only the United States, with 10%. The country produced 324 Mtoe in 2020 or about 2% of what was produced worldwide [1].

Received on 16 September 2022; revised 26 November 2022.
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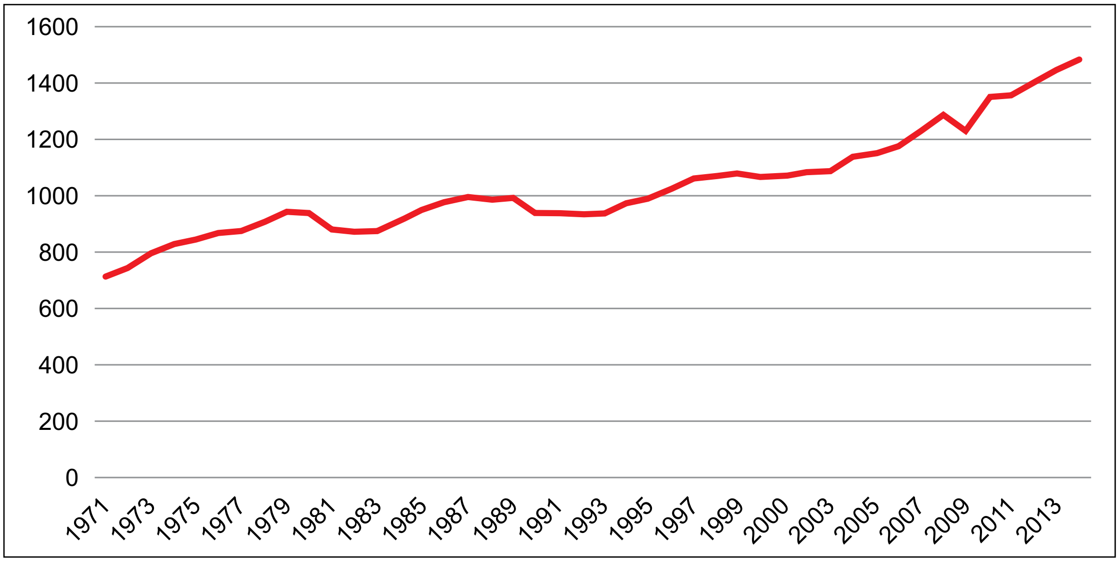
J Bioeng. Tech. Health 2022;5(4):305-310

The use of energy per capita in Brazil doubled from 1971 to 2014. However, the country suffered fluctuations in this period, especially after 1979. It increased in 1984, with a new drop in 1990. New growth occurred between 1993 and 2009 when energy use fell again and intensified the following year (Figure 1).

Fossil fuels play a leading role in the Brazilian energy matrix, with about 60% of the representation. Brazil's total energy consumption converges around oil, natural gas, and coal. In 1973, the Brazilian energy matrix showed a consumption of 82.2; in 2020, this consumption was 286 Mtoe [1].

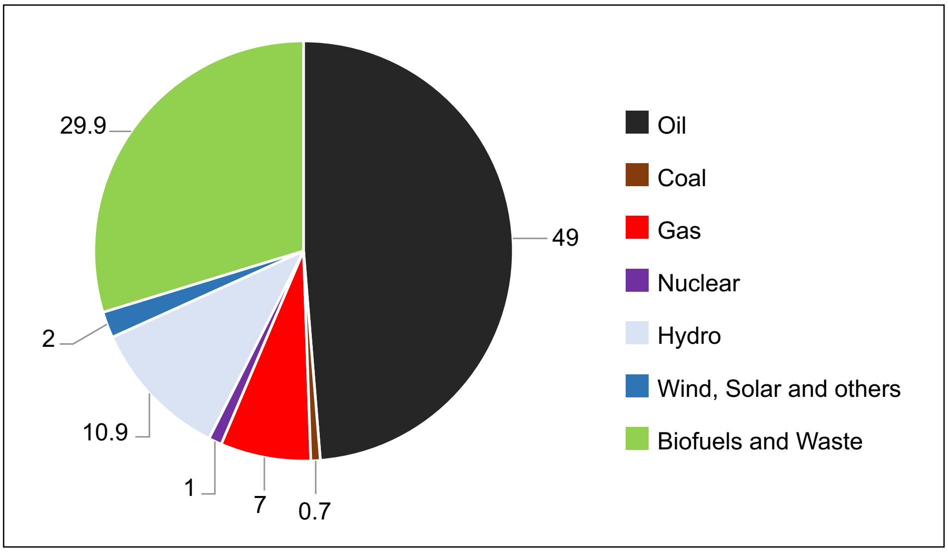
In 41 years, the Brazilian electricity matrix presented an annual growth rate of almost 6%, from consumption of 65 TWh to 624 TWh, with hydraulics being the most used source since the

Figure 1. Evolution of energy use in Brazil (kg of oil equivalent per capita) (1971-2014).



Source: World Bank, 2022 [5].

Figure 2. Brazilian energy matrix, 2020.



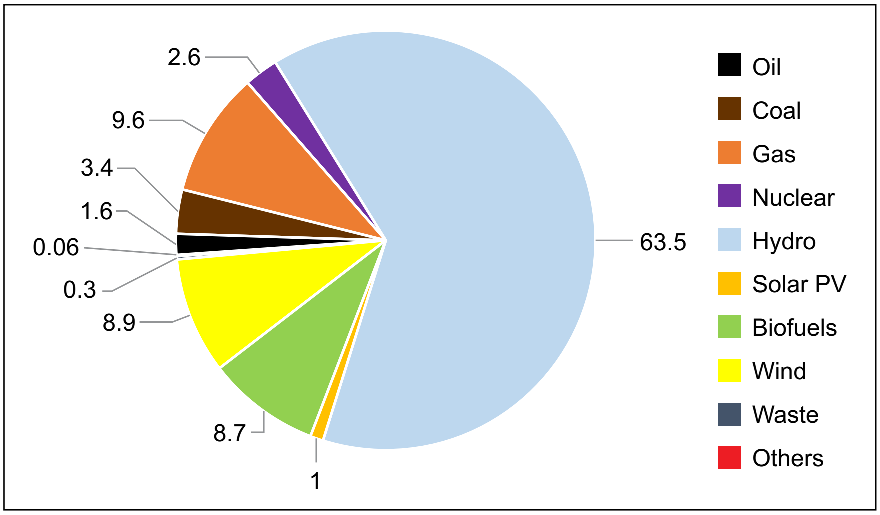
Source: IEA, 2021a [6].

1970s, before with 90% and now with 63% of Brazil's electrical matrix (Figure 3).

In the context of the production and consumption of the principal non-renewable energies, we noted that CO_2 emissions had increased consecutively for over thirty years [1] (Figure 4).

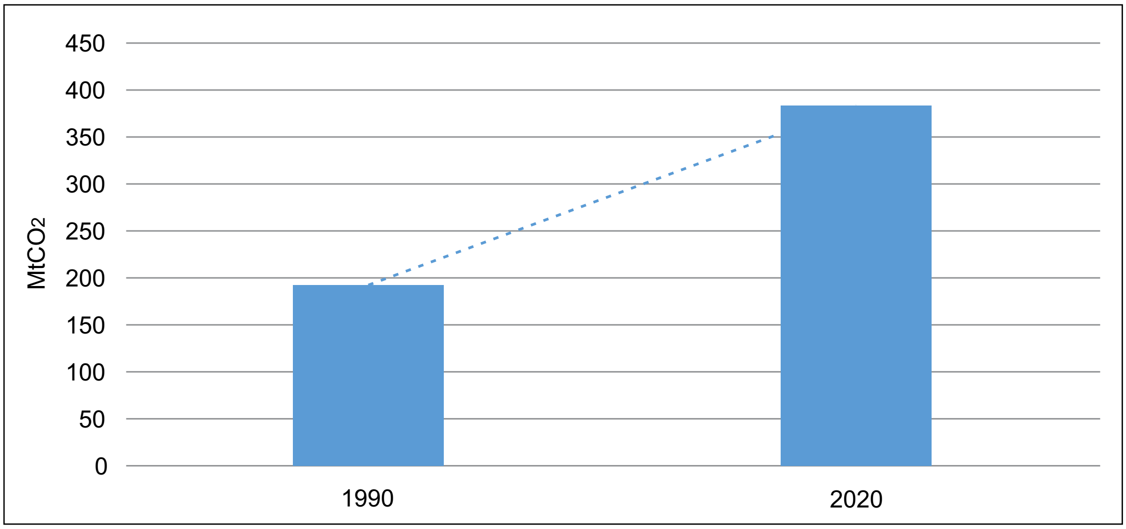
The current global hydropower generation capacity is estimated to be 1,150 GW in total, with China (326 GW), Brazil (109 GW), Canada (81 GW), the United States (80 GW), Russia (48 GW) GW) and India (45 GW) together accounted for around 60% of the world's installed capacity. Global hydropower generation in 2019 was 4,306 TWh, an increase of 2.3% over the previous year. New increases were made or incorporated into the installed capacity in several countries in 2019, among them Brazil, which stands out with the highest percentage of increase (4.9%), having gone from 76 GW in 2007 to 109 GW in 2020 [8-11]. Adding five GW to the Brazilian hydroelectric generation capacity represents almost a third of the global additions, the majority related to the

Figure 3. Brazilian electrical matrix, 2020.



Source: IEA, 2021b.

Figure 4. CO_2 emissions in Brazil (1990-2020).



Source: ENERDATA, 2021 [1].

final six turbines added to the Belo Monte plant, completing 11.2 GW. At the end of 2019, Belo Monte became the fourth largest hydroelectric plant in the world, representing 7% of Brazil's electricity generation capacity. At 418 TWh, Brazil's hydroelectric production has remained unchanged since 2018. Despite Brazil's seemingly robust market in 2019, the country's incremental hydropower development is increasingly constrained by available resources. Furthermore, only 12 GW are in areas with no ecological or social restrictions. This remaining potential is further limited by sociopolitical limitations and the environmental costs associated with development, estimated to be an order of magnitude higher than typical for wind and solar PV in Brazil [10].

According to the National Energy Balance 2021, the Brazilian electricity generation matrix is composed mainly of renewable sources (85%), at a much higher level than the world matrix (23%) [12]. The same document also informs that the hydraulic source occupies a prominent place among renewables, with 65%, followed by biomass and wind, with 9% each, and solar, with 2%.

Considering its dependence on the rainfall regime, hydroelectric power generation can be a vulnerability of our electricity matrix, especially in periods of low rainfall when the volume of reservoirs decreases.

Analysis of Growth Data (OIEE, Population, and GDP)

According to the BEN – Historical Series [13], the installed capacity for power generation increased from 33 GW in 1980 to 74 GW in 2000 and 175 GW in 2020. The population was 122 million in 1980, to 175 million in 2000, and reached 213 million in 2020 [14]. Analyzing the data on the Internal Electricity Supply – OIEE in Brazil, population growth, and GDP, it is possible to establish an OIEE / GDP / inhabitant ratio and compare it with the evolution of the installed capacity for energy generation (Table 1).

From 1980 to 2020, the Domestic Electricity Supply - OIEE grew almost five times, while the Gross Domestic Product - GDP and the Resident Population grew twice. As a result, the OIEE/Pop ratio grew almost three times over the same period, and the OIE/GDP was approximately twice. In other words, the OIEE always grew more than the indicators related to Demand, such as Population and GDP.

The demand for electric energy without significant mishaps, as demonstrated by the OIEE, can be known by planning and observing the rainfall cycles; regional characteristics; the amount of water that reaches the plants, converted

Table 1. Internal Energy Supply/GDP/Population.

	Installed Generation Capacity (GW)	**Internal Electric Energy Offer - IEEO (GWh)**	**Gross Domestic Product – GDP (10^9 US$ppc (2010))**	**Resident Population (10^6 habs)**	**IEEO/POP**	**IEEO/GDP**
1980	33.472	139.170	1.298	122	1.142	107
1990	53.050	249.358	1.517	150	1.665	164
2000	73.671	393.259	1.953	175	2.251	201
2010	113.327	550.447	2.804	196	2.812	196
2020	174.737	645.915	2.858	213	3.039	226

Source: Prepared by the authors from EPE data (BEN – Historical Series) [13].

into energy (or Affluent Natural Energy – ENA); and the various generation modalities available in the National Interconnected System – SIN, and managed by the National Electric System Operator – ONS.

However, a fact that draws attention is that, despite the increase in the OIEE, hydroelectric generation has not followed this growth, due to the unfavorable volume of rainfall, with rainfall rarely above the historical average, indicating a tendency for scarce rainfall.

The importance of planning is revealed since the models that define the dispatch of the plants to meet the demanding work with the rain projection scenarios can decide, through the Electric Sector Monitoring Committee (CMSE – *Comitê de Monitoramento do Setor Elétrico*, in Portuguese), when dispatching thermal plants to adjust supply/demand relationships.

In the Minutes at the 242nd Meeting of the CMSE held on July 12, 2020, ONS informs that "there were no significant volumes of rainfall in the main basins of interest to the SIN, from the point of view of electric energy generation" in November 2020.Moreover, continuing: "storages of 17.7%, 18.3%, 52.2%, and 28.9% were verified in the Southeast/Midwest, South, Northeast subsystems and North, respectively, evidencing the impossibility of starting the recovery of the storage of the main reservoirs of the SE/CW and South, contrary to the expected behavior for the beginning of the typically wet period" [15]. However, there was relevant information about the reservoirs' condition and the rainfall regime in the following months, which should have led to decisions that were appropriate to the gravity of the situation.

Available data from the SIN's Equivalent Volume show that the historical series from 2014 to 2021 has resulted in between 29% and 42% for December [16].

ANA – National Water Agency publishes regular and periodic monitoring of the drought situation, whose consolidated results are published through the Drought Monitor Map. In addition, monthly information on the situation of droughts is made available up to the previous month, with indicators that reflect the short-term (3, 4, and 6 months) and long-term (12, 18, and 24 months), indicating the evolution of the drought in the region [17].The Drought Monitor consolidates the technical and scientific knowledge in a different state and federal institutions in a standard document containing information on drought conditions (severity, temporal and spatial evolution) and impacts on the different sectors involved. The Monitor facilitates the translation of information into tools and products used by decision-making institutions and individuals to strengthen Monitoring, Forecasting, and Early Warning mechanisms, a valuable tool to aid the management of water resources and energy planning.

For 2021, the Drought Monitor showed that in the Northeast Region, January, February, and March had a worsening in the drought condition, a condition intensified with a worsening of the drought in May, June, July, August, September, October, and November. The same Monitor shows a worsening scenario in the Southeast Region, with a drought worsening in January, February, March, April, May, June, July, August, and September.In the South Region, rainfall below average worsened the drought in the three states in April, May, July, August, November, and December. Finally, in the Midwest, there was an advance of severe drought in January, March, April, May, June, July, August, September, and October, in addition to the persistence of the intense drought scenario, as a result of accumulated rainfall deficits in the long term. – more than 12 months.

Final Considerations

The analysis of the available data and their correlations showed that the supply of electric energy, characterized by the Internal Electricity Supply – OIEE, has always been more significant than the demand. It is inferred by the increase in the resident population and purchasing power, thus by the consumption power obtained by the evolution of the Gross Domestic Product – GDP. Even the OIEE/Resident Population and OIEE/GDP ratios show favorable rates for the growth of the OIEE. Therefore, there is no growing demand for electricity that exceeds the supply. However, the OIEE needs to be managed, as it is composed of several sources, with a predominance of hydropower. The management of water resources with an alternation between hydroelectric and thermoelectric generation can be done preventively, taking into account the indicators published by ONS, SIN, EPE, and ANA. Having ruled out the technical causes for a possible but unlikely electricity supply crisis, it remains to investigate other causes, such as decision-making and administrative ones.

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