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Analysis of the hydrological cycle and its impacts on the sustainability of the electric matrix in the state of Rio de Janeiro/Brazil

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ABSTRACT

Between 20132015 and, the state of Rio de Janeiro, which is the second most economically important state in Brazil experienced a double crisis that incurred several consequences, including a shortage of drinking water in many cities and a reduction in hydroelectric generation. Therefore, the aim of this research was to analyze the impacts of this crisis on the state's electrical matrix from socioeconomic and socio-environmental viewpoints. The work included documental research of the data and correlations among them for the generation of electricity, the volumes of the reservoirs of hydroelectric plants, and thermoelectric and thermonuclear generation during this water crisis. Thermoelectric plants (TEP) provided 61.3% of the total installed capacity in Rio de Janeiro, thermonuclear plants (NPT) provided 23.46%, and only 14.86% originated from hydroelectric plants. During the studied period, the average power generated by the TEPs was five times higher than that recorded for hydroelectric generation. This scenario has negatively impacted the sustainability of the electric matrix, as it has resulted in high energy costs and increased greenhouse gas (GHG) emissions. However, the state could diversify its matrix in a sustainable a manner of exploiting existing wind and solar potential, thus allowing the electric matrix to follow global and national initiatives to reduce GHG emissions.

1. Introduction

The use of the multiple forms of energy is vital for current society to meet its basic needs and improve quality of live. Such development involves three agents that interact: society itself, the economy, and the environment [1]. The unbalanced interaction between these factors is creating an unprecedented environmental crisis, which in turn, imposes a great challenge on 21st-century society, as the issues of sustainable energy and climate change are non-linear and multifaceted [2].

The mitigation of these conflicts could rely on transitioning the transition of a current economy into a low carbon economy and an increase in international cooperation [3–7]. As the demand for energy is increasing globally, pressures on the biophysical limits of the planet are also increasing [8,9]. These pressures do not allow the maintenance of linear economic growth as the agreement established in COP21 (21st Conference of the Parties held in Paris in 2015) needs to be fulfilled [10]. At the conference, the 195 countries that are the signatories of the 4th United Nations Framework Convention on Climate Change (UNFCCC) and the European Union agreed to maintain global warming below 2 °C and make a mutual effort to limit the temperature increase to 1.52 °C above the pre-industrial levels through the Paris agreement [11].

In 2016, the Brazilian government ratified the Paris Agreement through the National Congress. As a result, the country has committed to reduce greenhouse gas (GHG) emissions by 37% from the figures registered in 2005 by 2025, and 43% by 2030 [12].

Electricity generation is among the anthropogenic activities accountable for driving climate change. One method of mitigating the effects of GHG emissions is increasing the use of renewable sources, such as solar and wind [13–15].

In Brazil, 75% of the electrical matrix is composed of renewable sources that mostly consist of hydroelectric industries, which generate 64% of the country's power [16]. The proportion of renewable sources is expected to increase as, according to the intended nationally determined contribution (iNDC) term, Brazil has agreed to expand its use of renewable sources to include wind and solar power [12].

The significant fraction of renewable energy in the Brazilian electrical matrix is positive from the GHG emissions perspective. However, hydropower generation is susceptible to climatic variations; changes in rainfall rates have a direct impact on power generation, which causes the emergency activation of thermoelectric plants [17]. For example, during 2013–2015, Brazil underwent a severe water crisis that resulted

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Fig. 1. Localization of Brazil's southeastern region. Source: Google®.

in socioeconomic problems, such as water shortages in many cities, and decreased hydropower generation [18].

The states in southeastern Brazil include Minas Gerais, Espírito Santo, São Paulo, and Rio de Janeiro, as shown in Fig. 1. Industrial activity is high in Rio de Janeiro, providing it with the second largest GDP in the country. From an energetic viewpoint, in June 2016, the state produced 68% of Brazil's oil and 45% of the country's natural gas (NG), rendering it the largest oil producer in the country [19].

The Paraiba do Sul River basin, Fig. 2, is an important water resource in southeastern Brazil; It has a total area of about 62,074 km^2, 14,510 km^2 of which is in São Paulo, 20,713 km^2 is located in Minas Gerais, and 26,851 km^2 is in Rio de Janeiro. Espírito Santo is not part of the river's basin [20].

This basin and all its reservoirs experienced a water crisis caused by a decrease in the rainfall regime in southeastern Brazil between 2012 and 2015. In addition to the climate issues, other factors played a part in the reduction of the available water resources in the basin, such as the increases in supply due to population growth, soil occupation, productive activities, and water pollution, and the lack of measures from public and private managers in São Paulo to preserve water resources [22].

The Paraíba do Sul river basin has a great socioeconomic influence, particularly in Rio de Janeiro, and the capacity of its reservoirs has been compromised [23,24].

Hydroelectric generation has also reduced as a result of this crisis [25]. There are currently 148 hydroelectric projects in the basin, ranging from micro- (MHPS) and small hydroelectric power stations (SHPS) to hydroelectric power plants (HPP), totaling an installed electrical power of 1.82 GW. Thirty-nine of these are operational and deliver 1.41 GW. In the electrical sector, the water crises reduced hydropower generation. To overcome this shortage, thermoelectric plants (TEPs) powered by fossil fuels were activated in the continuous mode and at maximum capacity [26].

The crises also affected the water supply of the area; water rationing brought losses to the general population, agriculture, and industries reliant on the basin's water resources [27]. This is because the basin supplies 184 municipalities with potable water, 39 of which are located in São Paulo, serving 1,481,301 inhabitants; 88 are in Minas Gerais,

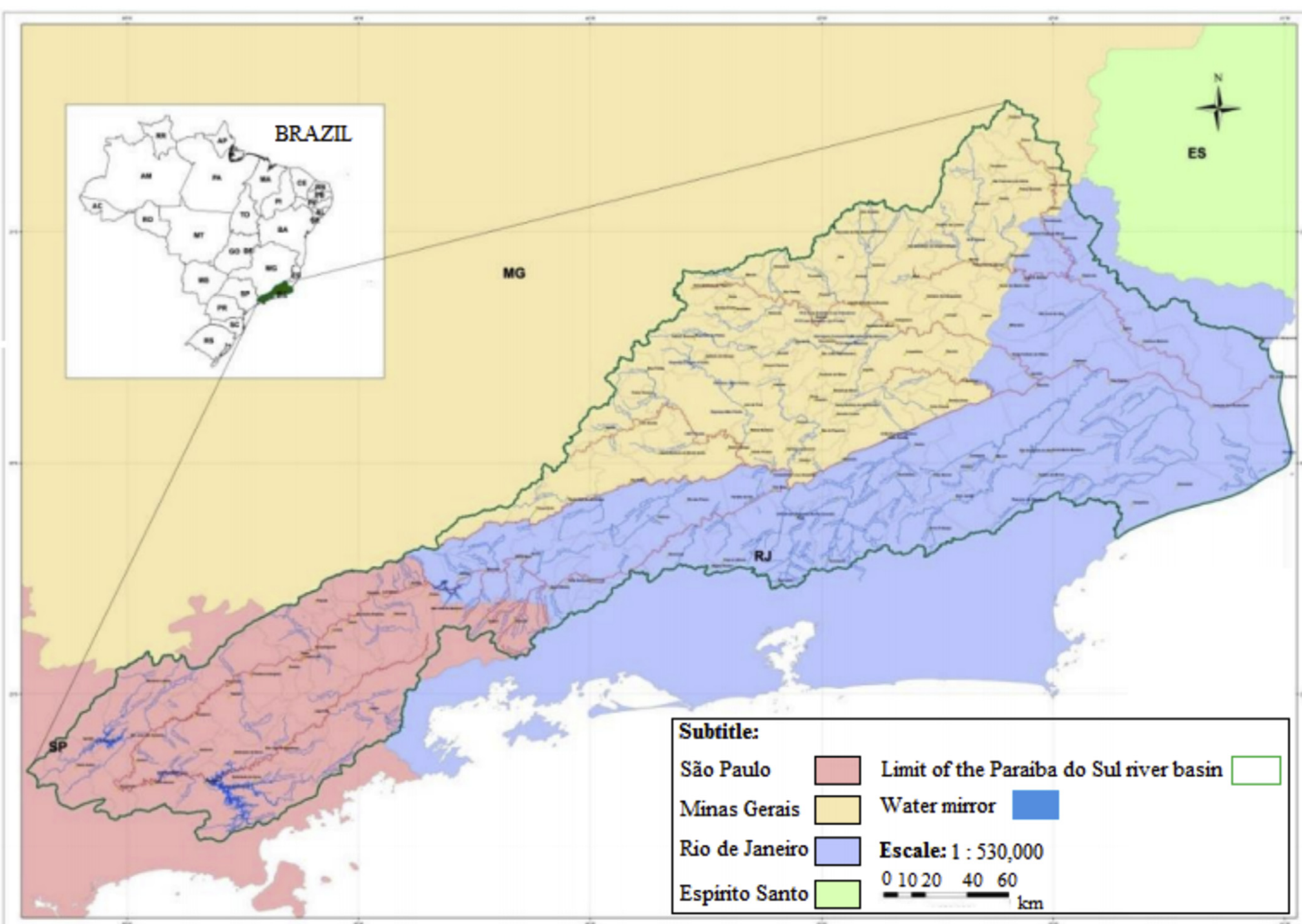

Fig. 2. Location of the Paraíba do Sul River basin in Brazil's southeast region [21].