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A foundation for the strategic long-term planning of the renewable energy sector in Brazil: Hydroelectricity and wind energy in the face of climate change scenarios

Vera Ruffato-Ferreira[a], Renata da Costa Barreto[b], Antonio Oscar Júnior[c], Wanderson Luiz Silva[d], Daniel de Berrêdo Viana[b,*], José Antonio Sena do Nascimento[e], Marcos Aurélio Vasconcelos de Freitas[a]

[a] Federal University of Rio de Janeiro (UFRJ), Energy Planning Program (EPP/COPPE), Pedro Calmon Avenue, s/nº – Centro de Tecnologia, block C, Room 216, University City, Ilha do Fundão, Rio de Janeiro, RJ, Brazil

[b] International Virtual Institute of Global Change (IVIG/COPPE/UFRJ), Avenida Pedro Calmon, s/nº, Bloco P – P2, Cidade Universitária - Ilha do Fundão, CEP: 21941-596 Rio de Janeiro, RJ, Brazil

[c] State University of Rio de Janeiro, Institute of Geography, Avenida São Francisco Xavier, 524, 4th floor, block F, CEP: 20550-900 Rio de Janeiro, RJ, Brazil

[d] Centre of Mathematical and Nature Sciences (CCMN), Institute of Geosciences (IGEO), Department of Meteorology, Avenida Athos da Silveira Ramos, 274, Bloco A, Cidade Universitária - Ilha do Fundão, CEP: 21941-916 Rio de Janeiro, RJ, Brazil

[e] Brazilian Institute of Geography and Statistics (IBGE), Coordination of Natural Resources and Environmental Studies (CREN/DGC), República do Chile Avenue, 500, 15th floor, Downtown, Rio de Janeiro, RJ, Brazil

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ABSTRACT

The current article assesses the vulnerability of renewable energies in Brazil in the face of climate change, with hydroelectricity and wind power taken as case studies. Future climate data produced by the National Institute for Space Research were employed for three time slices (2010–2040, 2041–2070 and 2071–2100) taken from the Eta 20 km regional model using the global model HadGem2-ES of the IPCC AR5, for scenarios RCP 4.5 and 8.5. Based on these data and using indicators, it was possible to generate predictions that are useful for the evaluation of the impacts of future climate scenarios on the current energy infrastructure, enabling the proposition of recommendations for mitigation and adaptation in the energy sector, a strategic subject for Brazilian governmental programs.

1. Introduction

With the current energy scenario in Brazil and the water crisis in its South and Southeast regions [1], discussing the planning of the energy sector has never been more decisive for the energy security of the country, as it ensures the maintenance of sustainable development by providing a foundation for the planning of governmental programs. The priority water use is given to human and animal consumption, defined by the National Water Resources Policy. The lack of priority on water use by other sectors of the economy, along with increased demand, have increased the conflict of interest, especially in cases of water deficits [2].

According to the Energy Research Company [3], renewable energy have a big stake in the Brazilian energy matrix, with a predominance of hydroelectricity. Approximately 40% of the internal energy supply is from renewable sources. By 2030, 45% of all energy consumption is expected to come from renewable sources.

Under the Brazilian strategic planning, energy takes preponderant role in the interconnection with all sectors of the economy and social welfare. In this sense, the National Energy Plan (NEP), the Decennial Plan for Energy Expansion (DPE), both subsidized by the National Energy Balance (BEN) data, are instruments that embody the Brazilian energy planning. The NEP aims to provide inputs for the energy planning of the country in the long term. The last NEP fully published makes projections of energy demand and economic scenarios to 2030 [2].

The DPE is an annual basis, prepared by the Energy Research Company (EPE), under the supervision of the Ministry of Mines and

* Corresponding author.
E-mail addresses: veraruffato@ivig.coppe.ufrj.br (V. Ruffato-Ferreira), rbarreto@ivig.coppe.ufrj.br (R. da Costa Barreto), antonio.oscar@ivig.coppe.ufrj.br (A. Oscar Júnior), wanderson@ufrj.br (W.L. Silva), danberredo@ivig.coppe.ufrj.br (D. de Berrêdo Viana), joseantoniosena@gmail.com (J.A.S. do Nascimento), mfreitas@ivig.coppe.ufrj.br (M.A.V. de Freitas).

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Energy (MME) and presents the expected demand and supply of energy for the next ten years, including the disclosure annual energy matrixes [4].

Renewable energy strongly depends on climate conditions. However, the long-term energy planning in Brazil does not consider the vulnerability of renewable energy sources to global climate change [5]. The monitoring of climate variations through vulnerability analysis is important as a method to create mitigation and adaptation strategies of the Brazilian energy sector in face of these changes, with no or little impact on the socioeconomic development of the country.

The diversification of the matrix is fundamental to ensure energy security in the context of the current energy crisis and to avoid similar situations in the future. In a study aimed at long-term planning, it is necessary to consider the effects of the climate changes that will significantly affect the geographical distribution and the potential for energy generation of the country.

Several studies show the Brazilian observed trends over the past decades in climate variables, especially precipitation and air temperature. At large, these trends point to a general warming in most parts of the country, as well as an increase in the frequency and intensity of extreme precipitation events [6–8]. Still in relation to climate change research, several studies provide assessment over future projections of these variables over the twenty-first century, mainly pointing out rising temperatures, with increased events of severe rainfall and droughts in some regions [9–11].

The seven largest producers of hydroelectricity in the world are China, Canada, Brazil, the United States, Russia, India and Norway. Brazil is the second largest producer, accounting for 12% of the total, and China is the first with 19.6% of worldwide production [12]. Hydroelectric production corresponds to 11.5% of the internal energy supply in Brazil, with 65.2% of the supply of national electricity [3]. Much of the hydroelectric potential of the South, Southeast and Northeast has already been explored, concentrating 80% of installed capacity. Most of the potential to be exploited is concentrated in the Mid-West and North (Amazon). The expansion plans of the sector have turned to exploiting the potential of river basins of the Amazon region, including large projects, such as plants of Belo Monte, Santo Antônio and Jirau, in addition to the efforts in linking this region with the distribution of the National Interconnected System (NIS) [2,13].

Conditions of hydroclimatic variability, especially those extreme and/or unexpected, such as droughts and floods, can affect or even interrupt power generation in a hydroelectric power plant. As it is nearly impossible to predict these situations and therefore to adapt and respond to them, social, economic and ecological impacts can occur. A significant part of hydrological variability is stimulated by climate dynamics [14,15].

The existing regulation plans are almost entirely based on historical hydrological records, and do not consider new models neither advances in the understanding of the climate system in many time scales, including the future; a flood, for instance, can occur within hours and a drought in the period of months of years [14]. In a scenario of global climate change, which will affect the average behavior of watershed discharges, we can predict medium and long-term losses in the operation of the hydroelectric system [15]. These considerations should be taken into account in the decision-making process, for they may offer both risks and new opportunities for hydroelectric systems [14].

Milly et al. [16] analyzed the rivers streamflow of nine projection models from IPCC AR4. For the mid-twenty-first century (2041–2060), the models projected reductions in São Francisco, Parnaíba, Tocantins, Xingu rivers streamflow and others in the eastern Amazon. Lucena et al. [5] examined the interaction between future climate change and renewable energy in Brazil, including hydroelectricity. The authors used the HadCM3 global climate model precipitation data in relation to scenarios A2 and B2 of the IPCC AR4. The results indicate that the average annual streamflow (that is, the average annual amount of water that flows into the hydroelectric plants) may suffer an average decline of 8.6% in the A2 scenario and 10.8% in the B2 scenario by the end of XXI century. Bravo et al. [17] conducted hydrologic simulations using data from climate models between 1961 and 2099. The results show that in the South region and in the southern part of the Paraná River basin, there is a larger number of climate models suggesting the rise of streamflow rates [17].

Hydroelectric plants with large reservoirs are the most adopted in Brazil. Reservoirs reduce the vulnerability of the energy matrix as they have enough storage capacity to keep generating in cases of minor changes in rainfall patterns. However, with increasing consideration of environmental issues, the new plants that are being installed are based on run-of-the-river hydropower plant, with smaller reservoirs [2,5]. Thus, hydropower production becomes more vulnerable to climatic variations and the increase of extreme events resulting from global climate change.

As for wind energy, the five largest wind power generators in the world are China, the United States, Germany, Spain and India. According to BIG ANEEL database, Brazil has 336 wind farms with 8.2 GW operating and 3.5 GW under construction as on February 2016. This amount corresponds to approximately 6.07% of the electricity production capacity and 35.31% of the production capacity of projects under construction [18]. The biggest wind potential in Brazil is in the Northeast, also where most of the installed plants are located. The government has strongly encouraged the sector expansion, however, the price of the turbines also require a very high investment, limiting some projects [2].

Detailed knowledge of wind behavior is required for the analysis of wind potential, owing to the correlation between both. Speed intensity and wind direction are the main data for the determination of the wind potential of a region, and they are related to relief, soil roughness and other obstacles distributed throughout the assessed area. For wind power to be considered technically exploitable, its density needs to be higher than or equal to 500 W/m^2 at a 50-meter height, which requires a minimum wind speed of 7–8 $m\ s^{-1}$ [19].

Many studies and surveys on the topic have stimulated the commercial exploitation of the Brazilian wind potential. The first studies were carried out in the States of Ceará and Pernambuco, and the Brazilian Center of Wind Energy of the Federal University of Pernambuco published the first version of the Wind Atlas of the Northeast Region, with support from ANEEL and the Ministry of Science, Technology and Innovation. Moreover, the Overview of the Wind Potential in Brazil is a result of the continuity of this work.

The highest wind potentials were identified along the coast of the Northeast region and in the South and Southeast regions [20,21]. The annual energy potential is about 144.29 TW h/year for the Northeast region, 54.93 TW h/year for the Southeast and 41.11 TW h/year for the South [22]. The study of the variation of the country's potential for wind power production due to climate change is important due to the existing potential, to recent technological innovations that increased its competitiveness within the energy market and to the need for a more diverse energy matrix to reduce the sector's vulnerability [23,24].

Lucena et al. [24] examined some possible impacts of climate change on the Brazilian wind energy potential. According to the projections, expectations are for better conditions for wind energy generation on the coast of the Northeast region. Pereira et al. [23] projected Brazilian wind speed in the Eta-HadCM3 model. The A1B scenario simulations indicate an increase trend from 15% to 30% in wind energy density for most of the Northeast and above 100% in the northern sector of the region.

During the 21th Conference of the Parties held by the UN in November 2015 (COP 21 - Paris), Brazil presented its Intended Nationally Determined Contributions (INDCs), in which it undertook to make efforts to a “transition to renewable energy systems and decarbonizing the economy” through a 43% reduction in emissions of greenhouse gases (GHG) emissions by 2030 compared to 2005 levels