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Solar and wind energy production in relation to the electricity load curve and hydroelectricity in the northeast region of Brazil

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ABSTRACT

The objective of this research is to analyze the effectiveness of wind power and solar energy to supply electricity to the grid during peak demand periods in the Northeast of Brazil. To achieve this objective, a comparative analysis is performed between the electricity load curve for a typical year and a typical day and statistical data for wind speed and solar irradiation. The results obtained indicate that correlations exist and renewable energy can help support regional temporal demand in the existing electricity grid in an efficient and more environmentally friendly manner than fossil fuel power plants. Another interesting finding was the complementarity between hydroelectricity (the region's main energy resource) and wind and solar energy. That is, in the months of the dry season (when the cost of energy is more expensive) there is a greater availability of wind and solar energy. This makes investments in these two renewable sources more economically viable and also helps to diversify the electricity grid power supply, securing it against the effects of droughts.

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1. Introduction

The Northeast (NE) region represents almost one fifth of Brazil's geographic area and is the homeland of 53.6 million people, as well as being the most arid part of the country. While Brazil overall has the world's largest water resources, this particular region suffers from occasional droughts, which can also affect the power supply, as the majority of the energy matrix is supplied by hydroelectricity. The region is privileged with huge solar and wind resources, while at the same time it imports a significant percentage of electricity from the North and Southeast regions [1], as shown in Fig. 1.

Forecasts for coming years, for the studied region, indicate an increase of around 4% in the Gross Domestic Product and an equivalent rise in the electricity demand [2,3]. This continuous rise of electricity demand is being addressed by increasing the capacity of existing fossil fuel power stations and by planning and constructing new ones [4]. The region's hydroelectric potential is almost saturated, and new tenders are only for small hydro plants. The main river of the region is the São Francisco River, which is responsible for 65% of the region's power supply [5]. With already five dams and several hydroelectric plants along its course, it is no longer possible to build big hydroelectric facilities as was done in the past. Additionally, there is a controversial project by the

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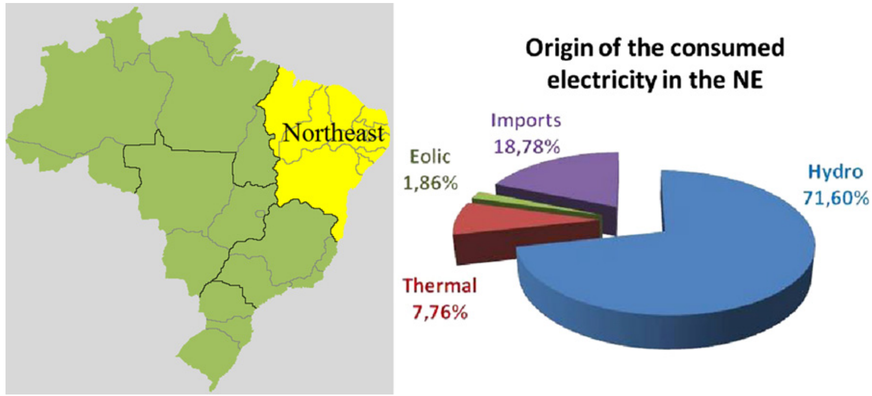

Fig. 1. Left: The Northeast (NE) region of Brazil. Right: Origin of the electricity consumed in the region, from Jan 2011 to Feb 2012. (Currently in the NE, "Thermal" electricity generation comes purely from fossil fuels. "Imports" consists mostly of hydro from other regions).

Brazilian government, already under construction, which aims to divert part of the river's water flow in order to irrigate arid territories. The completion of this project would further deteriorate the actual situation of hydroelectricity stagnation, resulting in a reduction of electricity production in the context of constantly rising electricity demand. The construction of the huge Belo Monte hydroelectric plant, in the northern state of Pará, once completed, will allow for an increase of imported electricity from the North region, but with significant amounts of energy loss due to the lengthy transmission lines. Additionally, large hydroelectric dams, such as Belo Monte, planned for the Amazon basin region have limited power output during the dry season and cause significant environmental conflicts.

In this context, the debate concerning the installation of nuclear power plants in the Northeast arises, fueled by the existence of uranium deposits in the region and by the government's wish to further develop the national nuclear industry. The "Plano Nacional de Energia- PNE 2030" (Brazilian National Energy Program) [6] which reflects the government strategy for expansion of the Brazilian electricity generation infrastructure, forecasts the need for an additional 4000 MW from nuclear power by 2025. This will mean the construction of two nuclear power plants in the Northeast and two more in the Southeast. According to this plan, the Brazilian Generation Matrix will see at least a 10% increase in the proportion of thermal electricity generation (including nuclear power) by 2030.

Whatever solution is adopted for electricity generation in the coming years, there is undoubtedly a need for planning, because the period of execution for large projects, such as a nuclear power plant or a big hydroelectric plant is in the order of 5–10 years. At the present moment Brazil is located at an interesting point in terms of energy planning, and current wind and solar technologies could play an important role in the near future. In this context, wind power has already taken off in the Northeast. In particularly the states of Bahia, Ceará and Rio Grande do Norte, have experienced a rapid growth in wind farm development due to their favorable conditions in terms of wind speed, frequency, distribution and turbulence.

By studying the correlation between the monthly variation of the load curve in a typical year and some characteristic parameters taken as representatives of renewable energy availability, this study aims to show the advantage of increasing the proportion of solar and wind power in the electrical grid in the Northeast. It will be shown that wind and solar power can support temporal demand variations in the electricity grid load curves (during a typical day and year) in a reasonably efficient manner.

Likewise, by studying the reverse correlation between the monthly availability of water in the São Francisco reservoirs and the availability of wind and solar power during a typical year, the benefits of solar and in particular wind power can be realized.

There have been a number of studies examining solar and wind resource complementarity and to what extent these resources correlate to peak load demand when connected to the electricity grid. Almeida [7] used a simple multivariable weather model for the simulation of a combined wind-solar-hydro power system in Portugal, using wind speed (m/s) at a height of 50 m, global radiation (kWh/m^2) and rainfall (l/m^2) data. The study calculated both simple and partial correlation coefficients between these three parameters.

Moura [8] in the article entitled "Multi-objective optimization of a mixed renewable system with demand-side management" studied the correlation between wind, solar and hydro resources in Portugal by presenting the yearly variation curves of their capacity factors.

A study by Hoicka and Rowlands [9] found that combining renewable energy sources such as wind and solar power in Ontario, Canada, smoothed out power production in terms of reducing instances of high and low values. Additionally, increasing the number of locations geographically of both wind and solar resources further smoothed out power generation and produced less variability. The study did not consider the correlation of wind and solar resources data with variations in the region's electricity load.

Li et al. [10] examines the correlation of wind and solar resources data against the electricity load curve in NSW, Australia for an entire year. The normalized results showed a strong complementarity between the combined resources of wind and solar source, which also cross correlated to the electricity demand.

Mai et al. [11] simulated hourly production of electricity in the USA for 2050 with nearly 80% of electricity from renewable resources, including nearly 50% from variable renewable generation. The simulations predicted that there would be no hours of unserved load during peak load hours in summer (July) or during any other hour of the year.

Similarly, Elliston et al. [12] demonstrated simulations for a 100% renewable energy systems to meet actual hourly demand in the Australian National Electricity Market (NEM) in 2010. They found that various renewable configuration were technically feasible and could meet the NEM supply-demand reliability standard. Technologies included in the simulations were concentrated solar thermal (CST) power with storage, wind, PV, existing hydro and biogas turbines.

Sayeef et al. [13] examined various international studies on the intermittency of wind and solar energy and their correlation with hourly load profiles. Similarly, Burger [14] shows daily weekly, monthly and annual graphs of planned versus actual production of photovoltaic, wind and conventional energies in Germany.