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Thermoelectric dispatch: From utopian planning to reality

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ABSTRACT

Brazil experienced an electricity crisis during 2013–2015, with some blackouts, a high risk of not having enough supply to meet the demand, and skyrocketing electricity prices. In a country in which hydropower historically accounts for more than 80% of power generation, the lack of water in the reservoirs leads to such crisis. The hypothesis of the present study is that the significant depletion of the reservoirs in Brazil from 2011 to 2015 was the result of a combination of factors: the divergence between the planning and execution of the expansion of power generation and transmission, the weakness of the NEWAVE dispatch software used by the government (a stochastic dual dynamic programming, which calculates how much thermal and hydroelectric energy should be generated to meet the current demand), and the below-average hydrology in 2014 and 2015. To avoid the issue of project planning in the projections made in this paper, the authors analyzed the projects that are under construction, study, or development and made some schedule adjustments. The NEWAVE software was also adjusted by reducing the producibility factor of dispatchable hydropower plants. As a result, in the scenario with Newave adjustments, the thermoelectric dispatch—and thus the natural gas consumption—were on average 65% higher.

1. Introduction

A prominent feature of the Brazilian power system is the participation of hydropower, with which accounts for about 66% of the installed capacity (see Fig. 1), similarly to Canada and Norway. However, unlike in these countries, most of the hydropower capacity in Brazil is associated with large reservoirs, which work as energy regulators (Tolmasquim, 2011).

Additionally, hydropower plants (as well as nuclear power plants and wind farms) work as baseload plants, which ideally run continuously all year round with a steady load, with some capable of handling load variations to add to the system stability and reserve capability. Baseload plants also have the lowest marginal cost of production and are said to be "high merit" (Harris, 2006).

Considering the electricity generation at present, the total contribution of hydropower is even bigger, having been around 86% on average in the last 16 years, or 75% on average in the last 4 years (see Fig. 2). The situation in Brazil is different from that in Europe, where the baseload plants are generally conventional gas-fired power plants, and from that in the United States, where power is mainly produced in hard coal power plants. Nuclear power generation tends to run on baseload wherever it is installed (Moreira et al., 2015).

In Brazil, oil-fired plants work as peaking plants, which usually operate at a load factor of below 15% or lower, even reaching below 0.1%. The spectrum ranges from "peak lopping," in which the plant is expected to run at certain times of the day during certain seasons, to working as a reserve power source during unexpected or unusual events, such as demand spikes or sudden outages of large generation units (Tolmasquim, 2011).

Between peaking and baseload generation is "mid-merit" or "cyclic" generation, in which the plant generally operates at load factors of between about 15% and 70% (Harris, 2006). The dispatch and economics of mid-merit plants are the most interesting in terms of market operation. In Brazil, natural gas–fired power plants provide mid-merit generation.

Although the large share of hydroelectricity in power generation has benefits, such as low variable generation costs and reduced greenhouse gas emissions, the dependence on water can lead to a severe crisis if the electrical system is not properly planned and executed. Although the country already faced electricity rationing in 2001–2002, that experience was not enough to avoid another electricity crisis during 2013–2015, with some blackouts, a high risk of not having enough supply to meet the demand, and skyrocketing electricity prices.

The lack of water in the reservoirs led to both crises. Fig. 3 shows the sharp decrease (blue curve) in the hydropower reservoir levels (measured as "stored" energy) and the ratio (orange curve) of the annual average hydrology to the historical average hydrology in southeast Brazil, which accounts for 70% of the water storage capacity

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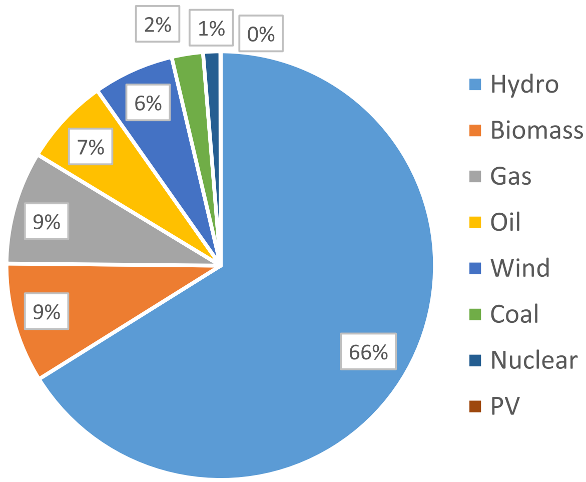

Fig. 1. Brazilian electricity matrix.
Source: ANEEL (2016).

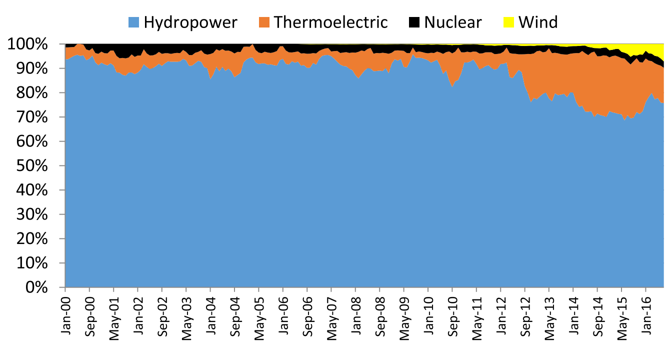

Fig. 2. Main sources of electricity generation in Brazil.
Source: ONS, 2016.

of the country.

From 2011–2013, the hydrologic conditions were above average, and yet the reservoirs were depleted. The authors considered the significant decrease in the reservoir levels in Brazil from 2011 to 2015 to be the result not only of unfavorable hydrology but also of a combination of factors: the divergence between the planning and execution of the expansion of power generation and transmission, the weakness of the NEWAVE dispatch software used by the government (stochastic dual dynamic programming, which calculates how much thermal and hydroelectric energy should be generated to meet the current demand), and the below-average hydrology in 2014 and 2015.

Therefore, this study aimed to evaluate this hypothesis and to calculate how much thermal and hydroelectric energy should be generated to meet the current demand without the same risks faced in 2013–2015, that is, to determine when is the right time to conserve water and to use fossil fuels.

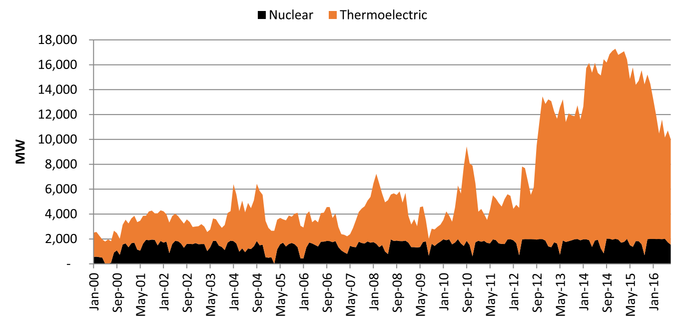

Fig. 4. Brazilian thermoelectric power generation. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)
Source: ONS, 2016.

This paper is organized as follows, after this introductory section: in Section 2, we discuss the importance of the natural gas in the electricity matrix. Operational planning of the Brazilian Electric System is described in Section 3. The dispatch model and the limitations of Newave model are presented, respectively in Sections 4 and 5. Linear regression models to forecast the electricity demand (for the several types of consumption) are developed in Section 6. Adjustments of electricity supply and natural gas- fired thermoelectric power plant dispatch are shown in Sections 7 and 8. And to close this paper, conclusions are drawn in Section 9.

2. The importance of natural gas in the electricity matrix

Fig. 4 shows the thermoelectric power generation (in megawatts) in Brazil, including nuclear power (black) and conventional thermoelectric power (orange) generation since 2000. The data indicate that coal (9%), oil (25%), bioelectricity (34%; almost all from sugarcane bagasse), and natural gas (32%) make up the national fuel matrix. Oil power plants work as peaking plants, bioelectricity plants supply baseload power, and coal and natural gas plants provide mid-merit generation.

The data in Fig. 4 indicate an increase in the thermoelectric dispatch since 2012. This was a consequence of the growth in demand for natural gas, as shown in Fig. 5, in which the monthly effective thermoelectric generation (blue line), the thermoelectric natural gas demand (orange bars), and the liquefied natural gas (LNG) consumption from thermo power (black bars) are also presented.

The relevance of natural gas power generation to the whole natural gas market is clearly indicated in Fig. 6, which shows the consumption of natural gas by sector (industrial, residential, and automotive),

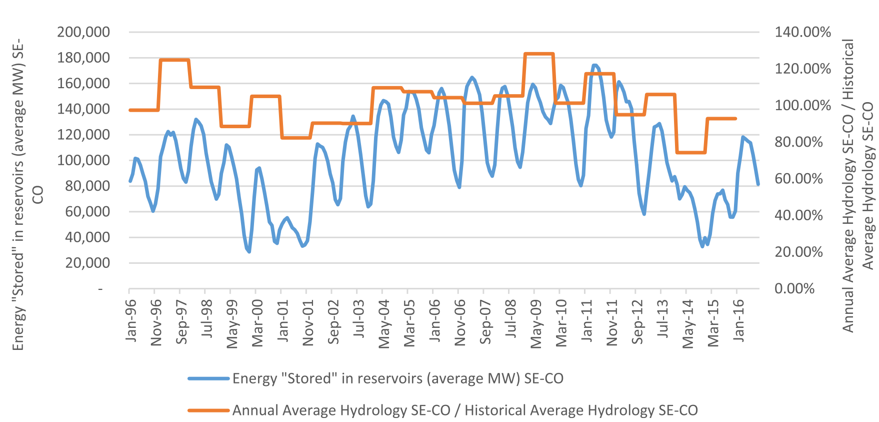

Fig. 3. Reservoir levels and hydrology. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)
Source: authors