Energy for Sustainable Development 41 (2017) 24–35

Contents lists available at ScienceDirect

Energy for Sustainable Development

The future of power generation in Brazil: An analysis of alternatives to Amazonian hydropower development

Felipe A.M. de Faria, Paulina Jaramillo *

Department of Engineering & Public Policy, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, Pennsylvania 15213, United States

ARTICLE INFO

Article history:
Received 12 January 2017
Revised 1 August 2017
Accepted 5 August 2017
Available online 23 August 2017

Keywords:
Stochastic dual dynamic programming
Brazilian power system
Impact assessment

ABSTRACT

The Brazilian government has plans to build 26 large hydropower plants in the Amazon basin between 2013 and 2028. These plants will have a total installed capacity of 44 GW, 9000 km^2 of reservoir area, and a total cost of US$ 30–70 billion. In this paper we aim to evaluate alternative generation pathways to avoid the adverse social and environmental impacts associated with reservoirs in the Amazon. Specifically we model the Brazilian electricity network under five capacity expansion scenarios. We assumed the government expansion plans as the baseline and created alternative scenarios where wind and natural gas power plants replace large Amazonian hydropower plants. We compared the scenarios using several performance indicators: greenhouse gas emissions, land use, capital and operational costs, wind curtailments, and energy storage in the hydropower reservoirs. The simulations suggest that a more aggressive policy towards wind generation than the baseline has the potential to replace Amazon hydropower providing advantages to the system operation (e.g., higher storage in hydropower reservoirs). However, when installed wind capacity reaches 24% to 28% of the total installed capacity, more thermal generation is required to balance the hydro-wind variability, increasing the operational costs and greenhouse gas emissions compared to the baseline.

Introduction

Since the middle of the 20th century, Brazil has supplied most of its electricity demand by building large hydropower plants. Currently, hydropower plants larger than 30 MW comprise 61% of the total installed system capacity of 124 GW (Agencia Nacional de Energia Eletrica (Brazilian Electricity Agency), 2015). Recently, the construction of new hydropower plants has been concentrated in the Amazon basin, where large plants like Jirau (3,750 MW), Santo Antônio (3,150 MW), and Belo Monte (11,200 MW) were recently built. Large-scale hydropower expansion has been taking place in the Amazon region because most of the hydropower potential of other regions has already been exploited. In addition to the previously listed projects, there are several projects currently under construction, such as Teles Pires (1,820 MW), São Manoel (746 MW) and Sinop (461 MW). This expansion will continue as the government indicates that most of proposed hydropower projects in the country will be built in the Amazon (e.g. São Luis do Tapajos (6,133 MW), São Simão Alto (3,509 MW)) (MME and EPE, 2014).

Although hydropower has been seen as the main supply source to meet the growing demand for electricity, projects located in the Amazon could have significant environmental and social impacts (Fearnside, 2005; Fearnside, 2001; da Silva Soito and Freitas, 2011; Latrubesse et al., 2017.). The reservoirs in recent and announced reservoirs in the Amazon would flood 9,000 km^2 (out of an area of roughly 5 million km^2 in the Legal Amazon region in Brazil), which can adversely affect flora, fauna, and ecosystem services. The dam also blocks the natural river flow, affecting the migration of aquatic species and resulting in changes in the oxygen, thermal, and sedimentary conditions in the reservoir area and downstream (Tundisi et al., 1993; Tundisi and Rocha, 1998; Friedl and Wuest, 2002). In some cases, the flooding and decay of large stocks of biomass in the reservoir area lead to greenhouse gas emissions that are comparable to those from fossil fuel power plants (de Faria et al., 2015; dos Santos et al., 2006; Fearnside, 2015). Furthermore, large hydropower projects also affect the local population through the resettlement of people living in the reservoir areas and the deterioration of social cohesion because of the high influx of workers (Jackson and Sleigh, 2000; Tilt et al., 2009), and loss of agricultural production.

In this paper we develop different capacity expansion scenarios for the Brazilian power system in order to compare the costs and benefits of power plants in the Brazilian Amazon against other alternatives for

* Corresponding author.
E-mail address: paulina@cmu.edu (P. Jaramillo).

http://dx.doi.org/10.1016/j.esd.2017.08.001
0973-0826/

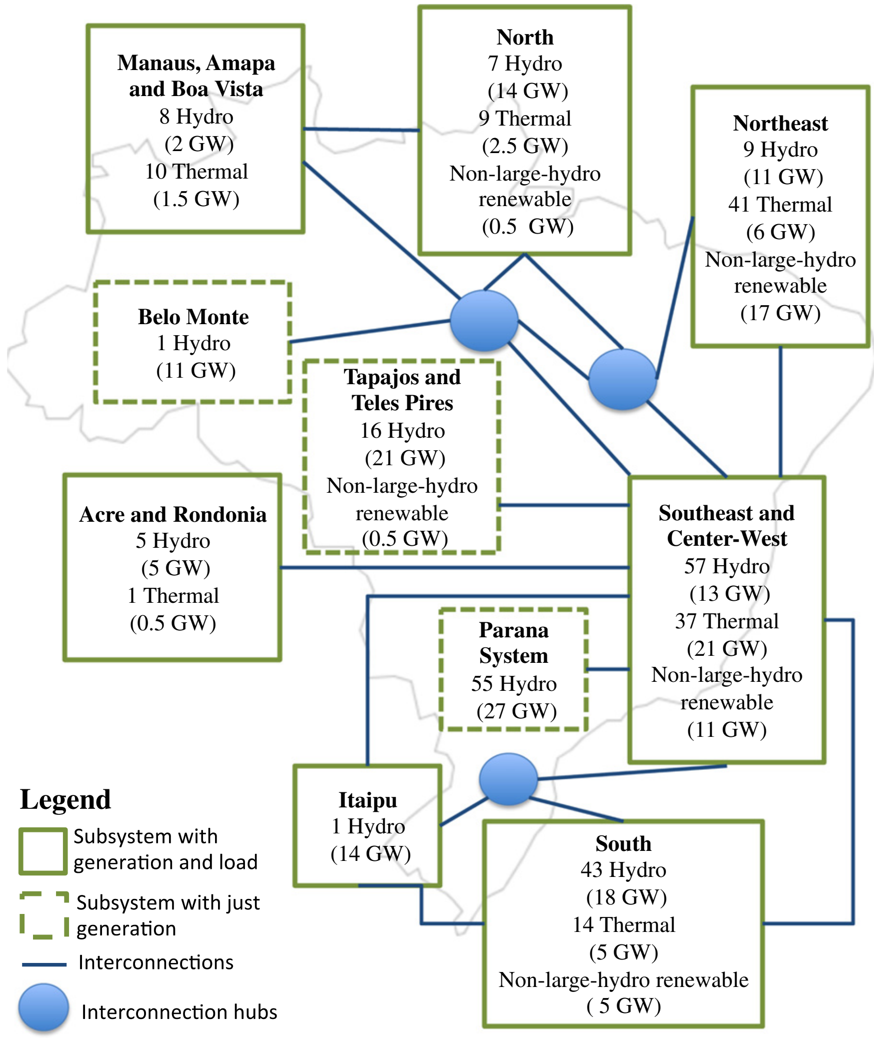

Fig. 1. Brazilian integrated system scheme with government forecasted capacity by 2028. Non-large-hydro renewables include wind, small hydropower plants (<30 MW), and biomass. Source: Authors' construction using data from EPE (EPE, 2015).

power generation. We simulate the electric system operations in order to estimate performance indicators such electricity production and operational costs, quantity of stored energy in the reservoirs, wind curtailments,[1] and greenhouse gas (GHG) emissions across the different scenarios. The alternative scenarios include replacing Amazonian hydropower capacity with wind power in the Northeast and South regions, or natural gas plants in the Southeast.

Data and methods

Current system characteristics and general description of alternative scenarios

The Brazilian electricity network is an interconnected system of 10 subs-regions: 1) North, 2) Northeast, 3) Southeast, 4) South, 5) Paraná, 6) Itaipu, 7) Teles Pires and Tapajós, 8) Belo Monte, 9) Acre and Roraima, and 10) Manaus, Amapá and Boa Vista. Some of these sub-systems contain power plants and loads (e.g. Southeast), but others contain just generation (e.g. Belo Monte). Fig. 1 describes a scheme of the sub-systems and their major interconnections.

The Empresa de Pesquisa Energetica (EPE) is the Brazilian state company responsible for creating the country's long-term energy plans (including plans for the power sector, as well as the natural gas, oil sectors). Every year EPE issues an expansion plan for the power sector (Plano Decenal de Energia, in Portuguese), which includes a set of files containing the detailed power plant characteristics used to model system operations and forecast changes in the system (EPE, 2015). As part of this expansion plan, EPE provides detailed data for each power plant, including water flows, reservoir limits, fuel types for thermal plants, minimum and maximum capacity, among others. Table S1 in the supporting information includes a full list of available variables for each power plant. In this paper, we rely on the data from the EPE report released in January 2015 (hereafter the 2015 EPE report files), which focused on modelling the system between 2013 and 2023, but provided data up to 2028. We used 2015 EPE report files as the reference scenario (baseline) to represent the electricity system between 2013 and 2028. Table 1 summarizes annual capacity additions by fuel type in the baseline. In addition, Table S5 in the supporting information includes detailed information about each hydropower plant to be constructed by 2028 in this baseline scenario. While plans for some of the power plants may be abandoned, we assume that all of them will be available following the proposed schedule included in the EPE report. Finally, we note that the EPE data include information for each hydro and thermal power plant in the fleet, while aggregate

[1] Wind curtailments are defined as "a reduction in the output of a generator from what it could otherwise produce given available resources." (Bird et al., 2014)