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The role of wind power and solar PV in reducing risks in the Brazilian hydro-thermal power system

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ABSTRACT

Brazilian electricity production is subject to considerable hydrological risks due to a large share of hydropower production. A long drought has caused a crisis in the electricity system in 2014 implying high operational costs and a high amount of carbon-intensive power production. A further expansion of the Brazilian electricity system is therefore necessary to guarantee security of supply, in particular when considering the projected growth in demand. We assess how high shares of renewable electricity production can be maintained in the Brazilian system, while reducing hydrological risks. We focus on a long-term perspective and simulate 36 years of renewable power production from meteorological data, assessing the statistical characteristics of different portfolios and, using an optimization model, balancing monthly supply and demand in different technological portfolios. The uncertainty in the operation of that portfolio is compared to a hydro-only scenario. Results indicate that adding both, solar PV and wind to the system, will decrease the need for thermal power backup and the risk of loss of load, as total variability of renewable supply decreases significantly in comparison to a scenario that adds only hydropower to the system. Solar PV has a slight advantage over wind power in decreasing supply risks.

1. Introduction

Brazilian electricity production is subject to considerable hydrological risks due to a large share of production from hydropower plants [1]. The variability of hydrological resources, which has been related to the El Niño Southern Oscillation, is high, in particular in the Northeast of Brazil [2]. Droughts have been one of the causes of a crisis in the electricity system in 2001 and as recently as in 2014[1]: hydropower production fell to 90% of the average 2011–2013 production in 2014, although hydro reservoir levels in December 2014 have even fallen to 45% of the average of the Decembers in 2011–2013 [4]. As a consequence, more than double of thermal power generation had to be dispatched in 2014 compared to the average of 2011–2013 [4], implying high operational costs and high greenhouse gas emissions. A further expansion of the Brazilian electricity system is therefore necessary, in particular when considering a significant growth in projected future demand [5]. Brazil has a wide range of options for renewable energies, ranging from wind energy with highly productive locations in the North–East of the country to hydropower production in the North of Brazil, and solar PV all over the country. All of these sources cannot be dispatched on demand. This is also the case for hydropower production in the North of Brazil, where new reservoirs are not going to be built due to environmental and social restrictions [6]. They are operated as run-of-the-river plants therefore.

The purpose of our study is to assess how those different resource potentials can be optimally combined to maintain high shares of renewable electricity production in the Brazilian system, while, at the same moment, reducing hydrological risks – and thus the risk of high operational costs and high greenhouse gas emissions. We therefore focus on the long-term dynamic behaviour of a combined hydro-wind-solar system, and less on the technical details of the system. For that purpose, we simulate long-time timeseries of solar PV, wind, and hydropower production, using data from global reanalysis projects and local observations on water run-off at the most important hydropower plants. We assess how

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[1] It is stressed in the literature that the crisis in 2001 is wrongly attributed to the low rainfalls, and that the real reason were failures in regulation, as droughts were foreseeable [3]. Still, the planning of the operation of any electricity system dominated by hydropower is more complex when facing high hydrological variability.

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the long-term flexibility of the system evolves when considering different forms of renewable electricity sources, in particular we look into how different shares of renewable electricity sources affect hydrological risks in the system. We do so by generating 100 climatic scenarios for a period of 36 years and running a perfect foresight optimization model and a second „dumb“ simulation model to assess the range of uncertainty implied by (1) uncertain climatic conditions and (2) planning and operational tools used.

For the case of Brazil, a related study has been conducted using daily simulated timeseries data from the same data source [7]. While the approach is similar, the applied simulation of timeseries lacks for controlling for auto-correlation, which may make the distribution of extreme events in the generated timeseries less reliable, and there is no comparison of scenarios of different shares of renewables, thus not allowing understanding which technologies affect system availability most. Becker et al. [8] have applied a similar methodological approach as we do, i.e. they simulated renewable energies from long-term reanalysis data and used those data-sets in stripped down energy system models for the case of the United States. They assessed integration of wind and solar PV into the US system and showed that a mix of 80% windpower and 20% PV would minimize backup capacities. Huber and Weissbart [9] have assessed the future potential of renewables for the case of China, also applying reanalysis data. They use an hourly model and show that the optimal mix of wind and PV is about 70:30. However, both China and the US generation portfolio do not rely on such extensive hydropower capacities as Brazil and large-scale long-term water storage is therefore not available. Also, the time profile of renewable generation in China and the US are different from the Brazilian one. Our analysis is therefore the first to extensively assess the role of different shares of wind and PV power in a (sub)-tropical country with high shares of hydropower production.

We first put our long-term modelling approach in the context of renewable integration studies in the following section, explain our modelling approach and data subsequently in Section 3 and present results in Section 4. The paper closes with a discussion of results and some major conclusions drawn from the modelling exercise in Section 5.

2. Time horizons for the modelling of renewable integration

The integration of renewables is studied, in many cases, with high resolution hourly datasets – even if longer time periods are assessed. However, such an approach has two serious drawbacks: first, computational complexity of modelling increases and second and more importantly, a true understanding of the long-term behaviour of underlying energy generating (i.e. meteorological) processes may not be reached by those approaches. For the operation of a complex hydropowered system with extreme drought events which is buffered by hydrostorage, however, the long-term perspective is of high importance as the operation of the storage is complex and extreme events on the horizon of two or three years in the future should be considered in today's decision making [10]. We argue that in such a case, i.e. integration of intermittent renewables into a large hydrothermal system with large storage, an approach that separates the short and long-term perspective may be useful to better understand the characteristics and the value of different renewables to the system. Expensive flexibility options such as bidirectional storage (in contrast to hydrostorage) and demand side management can only provide flexibility on the very short-term due to economics: as Rathgeber et al. [11] have shown, the number of cycles of a storage device determines its costs to the system. Annual cycles of only 1 or 2 increase costs by a factor of up to 500 in comparison to a device that is used almost daily. Similar conclusions can be drawn for capital based demand side management options or integration options beyond the electricity sector [12] which are frequently proposed to lower integration costs. The installation of those flexibility options can be studied for typical situations and days throughout the seasonal cycle of resource availability, as there are economically no feasible option to deal with rare extreme events. Long lasting extreme events with periods of low rainfall, low windpower generation, and low solar radiation, however, pose a serious threat to energy systems with large shares of renewables. Determining the likeliness of those events can be better addressed with a modelling approach that focuses on modelling long-term data with less focus on the hourly or daily variations. For the case of Brazil, managing those extreme events is possible due to the availability of large, cheap hydro-storage, which is an economically feasible option for balancing extreme events even if it is used only rarely.

Obviously, short-term and long-term optimization of the system may come to different conclusions in terms of optimal portfolios. However, the two perspectives can be brought together if sets of economically similar solutions are produced (which is possible due to low computational complexity), and fit together.

3. Data & methods

Between 69% and 84% of total electricity production came from hydropower plants in the period 2004–2013 in Brazil. Huge reservoirs are used to balance seasonal and inter-annual variability of precipitation. Therefore, the planning of operation of hydropower plants needs a long-term approach to define the levels of reservoirs, as an overuse of reservoir water would increase the risk of loss of load in the future, while underusing reservoirs would increase the probability of not using future water supplies [10]. In Brazil, the long-term planning of operation of the electrical system is achieved with the dynamic stochastic optimization model NEWAVE that operates on a monthly basis for the four Brazilian subsystems SE (South–East), S (South), NE (North–East) and N (North) [13]. The model looks ahead up to 5 years. The monthly dispatch schedule derived by NEWAVE is disaggregated by other models to derive feasible hourly dispatch.

The model minimizes expected operational costs, i.e. fuel costs of thermal power production. Cascading hydropower production in combination with huge reservoirs – a total storage volume of 212 TWh is available in Brazil – is represented by an equivalent reservoir approach for each subsystem. NEWAVE uses a timeseries model for representing hydrological resources, generated from past observations of inflows into hydropower plants.

Instead of NEWAVE, we developed our own modelling approach for several reasons: first, NEWAVE is a very complex and time consuming model that does not allow to be run for several scenarios and very long periods of simulation time. Also, it does not consider electricity production from new renewables, i.e. wind and PV. In NEWAVE, wind production is currently deterministically included by calculating the residual load, i.e. demand minus wind production, for one scenario of wind power production. We, however, aim at including the uncertainty associated with wind and solar PV production explicitly in our model and thus create our own timeseries model that takes into account hydro inflows, wind speeds and solar radiation. A second reason is that we do not apply a particular stochastic model as computational complexity is huge. We rather show the range of possible results of operational models: for that purpose, operation in the system is calculated with a perfect-foresight optimization model, i.e. the best possible case, and with a „dumb“ simulation model that uses simple operational rules for operating the storage, i.e. the worst possible case with no forecast of future meteorological conditions at all. We further simplify the NEWAVE approach by aggregating the four subsystems