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The effect of windpower on long-term variability of combined hydro-wind resources: The case of Brazil

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ABSTRACT

A high share of Brazilian power generation comes from hydropower sources and a further expansion of power generation is necessary due to high growth rates in electricity demand. As an alternative to the expansion of hydropower which shows high seasonal and annual variability with risks of load shedding due to droughts, windpower production may be increased. We assess the variability of potential windpower plants in the four most important windpower producing states Ceará (CE), Rio Grande do Norte (RN), Bahia (BA) and Rio Grande do Sul (RS) in comparison to adding new hydropower capacities in the North region. We assess seasonality and long-term deviations from seasonal production patterns. For that purpose, time series of windpower production from wind speeds derived from measurements and two global climate reanalysis models (NCAR and ECMWF) are generated and validated. Our results show that seasonal variability of windpower generation in the North-Eastern states is anticyclical to hydrological seasonality in the South-East, North-East, and North region of Brazil. Deviations of simulated windpower production from the monthly means are less correlated with current hydropower production than deviations of potential new hydropower projects. Adding windpower instead of hydropower to the system decreases significantly the risk of long periods of very low resource availability. The states Bahia and Rio Grande do Sul perform best with respect to that measure. Our validation procedure shows that ECMWF data may be the best source of long-term wind time series as it better reproduces ground measurements than NCAR.

Contents

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1. Introduction

Electricity consumption in Brazil has risen by around 4% annually in the decade 2004–2013 and is projected to increase continuously by around 4.7% annually, driven by population and economic growth [1]. Therefore an expansion of the Brazilian electricity generation capacity is of importance, even in case that rigorous energy efficiency measures will take place [1]. Historically, Brazil relies on a very high share of hydropower production: in the decade 2004–2013 between 69% and 84% of electricity production came from hydropower sources, depending on hydrological conditions [2]. Recently, windpower capacities have increased significantly, in particular in the North-East and South Region of the country. While a total of 20 GW of new hydropower capacity has been contracted and is partly under construction in the North of Brazil, a further expansion of 17 GW of hydropower is planned up to 2022. However, relying on power generation from hydro production increases operational complexity as seasonality of rainfall is very high in Brazil, and as most new projects in the North of Brazil will not include storage opportunities [1]. The risk of loss of load or the need for the expensive dispatching of backup thermal power plants would therefore increase. The electricity crisis in Brazil in the years 2014–2015, driven by rainfalls far below the average, shows that long-term variability is a serious issue. It not only causes high costs to the system due to the dispatch of thermal power capacities but may also eventually lead to load shedding.

An alternative to this expansion path is to focus on new, intermittent renewable sources of electricity. In particular windpower production has seen high growth rates in recent years due to good wind production conditions in several parts of the country and thus is able to economically compete with thermal power production [1]. Windpower may add a positive portfolio effect to the current hydropower dominated power regime, thus reducing the risk of loss of load. However, intermittent production obviously has drawbacks as it cannot be dispatched on demand and, unlike hydropower, lacks of any cheap storage possibilities. The very short-term intermittency in terms of minutely or hourly ramping in production due to changes in wind speed is the focus of most of the research that deals with integration of renewables [3–7]. This kind of intermittency causes problems in the transmission grid and increases the need for quickly ramping backup capacities. Nevertheless, there are also longer-term issues that have to be investigated: first, wind regimes may have the same or a different seasonality than hydropower inflows. Second, deviations from the long-term mean of windpower resources may be positively or negatively correlated with deviations of hydropower inflows. Third, as the time-profile of production regimes may vary significantly from location to location for windpower in a large country as Brazil, those effects may also vary significantly between the regions.

Research on these issues has been conducted in Brazil before, particularly on the seasonality of wind resources. Lopes and Borges [8] have shown that the electricity grid imposes significant restrictions on the amount of windpower that can be integrated into the system of the Southern Brazilian state of Rio Grande do Sul. Others, using simulated windpower production data, have shown that wind- and hydropower production are seasonally complementary, in particular hydropower production in the North and Southeast regions and windpower production in the North-East region is seasonally complementary [9–11,15–17]: While hydroinflows are higher in the first half of the year for most rivers in the North and North-East region, windpower production is higher in the second half of the year in the North-East region [9–11]. However, there is only weak evidence on how windpower production may be correlated with hydropower inflows when excluding seasonality. Chade Ricosti and Sauer [12]. used modelled time series of windpower production derived from the National Center of Atmospheric Research/National Centers for Environmental Protection reanalysis project (NCAR) reanalysis project [13]. to assess how wind from the North-East region and hydrological regimes in the North-East region are associated. They show that windpower production seems to be higher in years of low precipitation in the relevant river basins. However, the authors do not apply thorough statistical analyses for this purpose. Bezerra et al. [11]. use the same dataset to investigate inter-annual complementarity. They find no evidence for a systematic relationship between hydro inflows and availability of wind. They do not use statistical testing in their analysis and only assess annual sums of the respective variables. Additionally, globally modelled data-sets may not contain a very good representation of some of the estimated parameters, and validation of the data set is therefore of high importance. Data quality issues, however, were neither addressed by Chade Ricosti and Sauer [12], nor by Bezerra et al. [11].

The aim of this article is to assess the effect of adding windpower to the Brazilian production portfolio on the variability of joint wind- and hydropower resources. For that purpose, we combine different data sets from ground measurements, and globally modelled time series from two climate reanalysis projects – the NCAR reanalysis [13] and the European Centre for Medium-Range Weather Forecasts (ECMWF) interim reanalysis [14]. We simulate time series of windpower production, as the timeseries of observed windpower production are too short to be used in statistical analysis. The data sets are compared with respect to their seasonality and residuals when removing seasonality. Also, the long-term correlation with hydropower production is derived. Additionally, we assess how the probabilities of very low combined resource availability of wind and hydropower evolve assuming different shares of windpower in the production matrix. We focus on the four most important windpower producing states in Brazil, i.e. Bahia (BA), Ceará (CE), Rio Grande do Norte (RN), and Rio Grande do Sul (RS).

In the following section, we present data sets being used for the simulation of windpower production and how these have been validated against each other. Furthermore, we discuss how they were used to assess the effect on long-term variability of joint output of hydropower and windpower system. Results, including the validation process, are presented in Section 3. We compare our results with other publications and discuss the limitations of our study in Section 4. Finally we conclude in the very last section of the paper.

2. Materials and methods

An overview over the methodological approach is shown in Fig. 1. We first model windpower timeseries on the basis of meteorological data from different geographical locations. By using a simple optimisation process we choose those locations that best fit observed windspeeds. We model monthly time series of windpower production for a multi-annual period to be able to calculate seasonality and deviations from seasonality for windpower sources. The simulation of synthetic time series is necessary as long-term data from real windpower production sites is not available. Official statistics report data on windpower generation since 2004. The data shows that annual production surpassed 100 GWh as recently as 2006 [2]. All data sets we use are publicly available for download and comprise either measured or modelled wind speeds.

Afterwards, we compare the timeseries derived from the different datasets and choose the dataset which shows the best fit