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Climate change and electricity demand in Brazil: A stochastic approach

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ABSTRACT

We present a framework for incorporating weather uncertainty into electricity demand forecasting when weather patterns cannot be assumed to be stable, such as in climate change scenarios. This is done by first calibrating an econometric model for electricity demand on historical data, and subsequently applying the model to a large number of simulated weather paths, together with projections for the remaining determinants. Simulated weather paths are generated based on output from a global circulation model, using a method that preserves the trend and annual seasonality of the first and second moments, as well as the spatial and serial correlations. The application of the framework is demonstrated by creating long-term, probabilistic electricity demand forecasts for Brazil for the period 2016–2100 that incorporates weather uncertainty for three climate change scenarios. All three scenarios indicate steady growth in annual average electricity demand until reaching a peak of approximately 1071–1200 TWh in 2060, then subsequently a decline, largely reflecting the trajectory of the population projections. The weather uncertainty in all scenarios is significant, with up to 400 TWh separating the 10th and the 90th percentiles, or approximately ±17% relative to the mean.

1. Introduction

Changes in the Earth's climatic system over the next several decades could have large direct and indirect consequences for electricity demand in many regions [18]. At the same time, effective energy planning requires projections with a long time horizon, high temporal resolution and a clear indication of the uncertainty of the projections – especially considering the long lead times and lifetimes of energy infrastructure, as well as the increasing proliferation of intermittent energy sources (e.g. wind and photovoltaic power generation).

Weather variables have been used regularly for electricity demand forecasts since Dryar [6] first noted that electric system load was influenced by weather conditions and "events of unusual attraction". Electric system planning, production scheduling and daily operations of the power system now depend heavily on load forecasts that take consideration to weather conditions. Since its inception, load forecasting has been such a prolific topic that a thorough review of the literature is beyond the scope of this paper. However, a handful of studies have specifically addressed the subject of probabilistic, long-term and high-resolution load forecasts. We focus on a few works that can be considered the primary intellectual progenitors of this study. Although many earlier studies estimated certain parameters of the probability distribution of electricity demand (normally first and second moments), Veall [39] first estimated the full probability distribution of future annual peak electricity demand using a nonparametric bootstrapping approach. Building on this approach, Adams et al. [1] included weather variables and investigated the probability distribution at a weekly and daily temporal resolution. To estimate the full probability density function of the peak load forecast, Belzer and Kellogg [3] explored a Monte Carlo approach for fitting an extreme value distribution to the load forecasts, and Charytoniuk and Niebrzydowski [4] used a product kernel to estimate the conditional multivariate probability density function of load.

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In a move to replace historical weather observations with forecasted weather, Taylor and Buizza [34] incorporated weather uncertainty in load forecasts for the next ten days by using weather prediction ensembles. Using a simple multiple regression model calibrated on historical data, McSharry et al. [22] generated weather simulations by the method of surrogates to estimate the probability density function of peak electricity demand one year ahead. In a similar fashion, Pezzulli et al. [28] employed a climatological weather generator calibrated on historical weather to calculate density forecasts using a hierarchical Bayesian model. Acknowledging that future weather patterns may differ from historical patterns, Hor et al. [13] used the output from a global circulation model to create daily load forecasts for the period from 2011 to 2100, and in addition incorporated model uncertainty by residual simulation. Hyndman and Fan [14] developed a framework for forecasting the probability density of long-term peak electricity demand, based on calibrating a semi-parametric additive demand model on historical data and subsequently generating a large number of simulated realisations using temperature simulations, assumed future socio-economic variables and residual bootstrapping. Similarly, Ziser et al. [41] used a large number of synthetic weather scenarios generated by surrogate methods in order to incorporate weather uncertainty in demand forecasts, although the demand models were calibrated using machine learning techniques. In a less complicated approach, Hong et al. [12] used 30 years of historical weather data and three socio-economic scenarios to create an ensemble of load forecasts from a multiple linear regression model for hourly load. Attempting to improve load forecasting by using weather forecasts rather than historical weather, De Felice et al. [5] examined the use of seasonal ensemble weather forecasts for creating probabilistic load forecasts up to four months ahead.

Common for nearly all of these earlier studies is that their period of interest is sufficiently short to allow them to legitimately disregard changes in the climate and assume that weather patterns will remain relatively stable over the forecast horizon. The exception is Hor et al. [13]; who incorporate the output from a global circulation model and create forecasts up to year 2100, although they incorporate uncertainty only by residual simulation rather than considering uncertainty in the input variables. For the explicit purpose of examining weather risk due to climate change, it is not correct to assume that the weather patterns are stable, nor only incorporate uncertainty by means of residual simulation.

Therefore, this study presents a framework for incorporating weather uncertainty in high-resolution electric system load forecasts by combining an econometric demand model and a large number of weather simulations. The weather simulations are based on the output from a GCM (global circulation model) and are designed to preserve the trend and seasonality of the first and second moments of the weather variables, as well as spatial and serial correlations present in the GCM output. This is useful for evaluating the electricity demand subject to weather risk under climate change scenarios. We demonstrate the application of this framework by creating a probabilistic forecast for Brazilian electricity demand for the period 2016–2100, with daily resolution and subject to weather uncertainty under climate change scenarios.

The method is presented in the context of a quantitative thought experiment on Brazilian electricity demand under climate change scenarios, and there are several reasons for this choice. In a review of the literature on the impacts of climate change on the electricity market, Mideksa and Kallbekken [23] noted specifically that more research was needed on the demand-side impacts in Latin America. Although Schaeffer et al. [30] have previously studied the demand-side impacts of climate change on Brazilian electricity demand, our study improves upon this earlier study in two important ways. Firstly, it employs a stochastic approach that emphasises weather uncertainty and will provide an estimate of the probability distribution of demand, whereas Schaeffer et al. [30] chose a deterministic approach. This is a very important aspect, as shown by Ferreira et al. [9]; who have called for more research on stochastic modelling of the Brazilian Electric Power Sector. Secondly, this study takes advantage of more recent data – updated observations, models and discoveries – that were unavailable at the time of the earlier study. In light of recent advances in this research area, an updated assessment of the impact of climate change on the Brazilian electricity demand is sorely needed.

The main contributions of this study are therefore twofold. Firstly, we propose a new method for incorporating weather uncertainty in electricity demand forecasts when weather patterns cannot be assumed stable. This topic is presumably of great interest to a number of energy and climate change researchers worldwide. Secondly, the study satisfies an acute need for an updated appraisal of the impacts of climate change on Brazilian electricity demand in light of recent advances in this field of research. This is a topic of interest to policy makers, energy market participants and researchers with a particular interest in Brazil.

The remainder of this article is organised as follows: Section 2 describes the calibration of an electricity demand model for Brazil with daily resolution. Section 3 demonstrates how the model is used for forecasting electricity demand, including how weather simulations are generated for creating probabilistic forecasts that incorporate weather uncertainty. The subsequent section, Section 4, provides an overview of the main results and a detailed discussion. Finally, Section 5 summarises the main findings of this study and suggests directions for future research.

2. Calibrating an electricity demand model

2.1. Drivers of electricity demand and modelling framework

In order to create an econometric model for aggregated electricity demand, it is first necessary to identify the relevant variables that affect electricity demand and select an appropriate modelling framework. Fortunately, we need not start *ab initio*: we can rather draw heavily on the rich literature concerning this topic.

Two main considerations led to the choice of a daily temporal resolution for the electricity demand model, which is the highest temporal resolution afforded by the publicly available Brazilian electricity demand statistics. The first argument is that a higher resolution may offer a greater degree of accuracy for the model. Consider, for example, the possibility that high temperatures during the weekend have a slightly different impact on demand than high temperatures during working days. A model aggregated to monthly or annual scale might make it difficult to distinguish between these two cases, or similar interaction effects that might exist. Secondly, the highest possible temporal resolution is most useful for planning purposes. For instance, the peak instantaneous demand is often used as an important point of reference for supply planning purposes, since planners often want to ensure that maximum generation capacity is greater than peak instantaneous demand. The increasing share of renewable non-dispatchable energy sources also means that the timing of demand changes can have a great impact on expansion and dispatch planning, that is, whether high-demand periods coincide or not with high generation from non-dispatchable energy sources. In electric systems where the supply is dominated by hydroelectric generation, the order of events can also be of great importance to supply planning, for instance if a high-demand period precedes or succeeds a period