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Wind power feasibility analysis under uncertainty in the Brazilian electricity market

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ABSTRACT

Investors must be able to plan and analyze their investments in order to optimize decisions and turn them into profits associated with a particular project. Since electricity producers in the Brazilian electric power system are exposed to a short-term market, the goal of this paper is to propose a framework for investment analysis capable of encompassing different uncertainties and possibilities for wind power generators in a regulated market, characterized by auctions. In order to reach the proposed objective we employ a simulation technique which allows modeling cash flows considering uncertainties in variables related to project financial premises, electricity generation and producer exposure to the short-term market. For such goal, this study presents a new approach for investment analysis that allows the identification of the main uncertainty parameters and risks associated to this class of projects in the Brazilian electricity market. We also employ the Value at Risk technique to perform a risk management analysis in such context.

1. Introduction

Brazil experienced a broader policy with international repercussion directed to the renewable energy sector after 2000, with the creation of the alternative source incentive program (PROINFA). Through a strategy similar to the European *feed-in tariffs* (FIT), 3300 MW of energy was hired and built in the first phase of PROINFA. Investments were mostly directed to small hydroelectric power plants (SHPs), biomass power plants and wind farms. The second PROINFA phase began after 2009 and gradually incentivized the purchasing of renewable energy through auctions (Dutra and Szklo, 2008).

As a manner of complementing the support to the insertion of renewable energy sources (RES), special financing lines from the Brazilian national development bank BNDES along with targets for minimum participation requirement of national equipment in the hired projects created new strategies to leverage the sector. Such initiatives were relevant to motivate the sector growth, since the environment until 2001 was adverse for investments in RES in the country (Wachsmann and Tomalsquim, 2003), besides hydro.

Concerning the results of such applications, since PROINFA creation, RES, especially wind power generation has been gradually reaching more space in the Brazilian energy matrix (Juárez et al., 2014; Martins and Pereira, 2011). According to Silva et al. (2013), Brazil has more wind power plants than any other Latin American country. In August of 2012 Brazil presented around 2 GW of installed wind power capacity and in December of 2014 this value jumped to 5.9 GW, according to the Brazilian wind power association (ABEEólica, 2015), accounting for 4.4% of the country's energy matrix.

With the steady expansion of the wind power installed capacity and its production, it is important to perform analysis related to this type of investment. Several studies have emphasized in this type of analysis, such as Simons and Cheung (2016), who develop a quantitative approach focusing on the selection of wind farm projects to evaluate different parameters such as profitability and payback, energy efficiency and carbon emissions. Ayodele et al. (2016) assessed wind power potential and economic feasibility in different regions in Nigeria, the study provides guidelines on which regions of the country it is

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worthwhile to adopt incentive policies for the insertion of wind energy. Colmenar-Santos et al. (2015) analyzed whether repowering is a financially viable alternative to allow the continued integration of wind energy into the Spanish energy sector when the electricity generated is valued at the market-clearing price. The work presented in (Ramadan, 2017) evaluated the viability of the use of wind power as an alternative for generating electricity in the eastern part of Sinai. In this study the economic evaluation of a 200 MW wind farm was performed, the results show significant benefits for wind power exploration in the region.

In order to perform a more robust analysis, it is important to consider the fact that the producer gains and losses are intimately connected to generation uncertainties. Therefore, in this work, we consider the intrinsic uncertainties related to energy production of a wind farm project contracted in an auction, see more in Del Río (2014), and also the market conditions where this electricity must be traded.

Monte Carlo Simulation (MCS) techniques have rarely been used within the context of risk management of RES structures as they require considerable data processing and the definition of probability density functions for random variables (Arnold and Yildiz, 2015). In the literature there are some applications in the wind energy sector presented in (Aquila et al., 2016; Li et al., 2013; Ertürk, 2012; Montes et al., 2011; Walters and Walsh, 2011).

In this present work, we follow the consideration of the settlement of the differences in the investment analysis presented in Aquila et al. (2016). Aquila et al. (2016) analyzed the impact of incentive mechanisms and different market environments on the risk of investment in wind farms in Brazil. For this, a quantitative approach that allows an analysis of investments from the simulation of NPV values for different scenarios was used. However, the main contribution of this study is not to compare incentive mechanisms, we build in the previous work to propose the use of Value at Risk (VaR), considering the settlement of the differences, which depends on the behavior of the wind energy and the electricity prices in the spot market. This novelty approach suggests the evaluation of the wind power project under uncertainty in the Brazilian market as a mean to enhance decision-making for a potential investor.

Therefore, in general terms, this paper aims to propose a risk analysis approach, through VaR, useful to capture the impact of settlement of the differences in the short-term market for wind power generation projects contracted in auctions of alternative sources.

Besides this introductory section, this paper is divided as follows: Section 2 presents the theoretical foundations of evaluation of the energy production by wind generators and the short term market (STM) exposure for power generators in Brazil. Section 3 presents the proposed framework for investment analysis under uncertainty for wind power plant in a Brazilian energy auction, and the VaR methodology used for risk management. Section 4 presents a case study for a wind farm project to be located in Brazil along with a discussion of the main results obtained. Section 5 presents the final considerations and conclusions about this work.

2. Wind power generation and the Brazilian electricity market

Over the past decade renewable integration expanded in the Brazilian interconnected power system following global trends (Solangi et al., 2011; Pereira et al., 2012; REN 21, 2015). The main reasons for this expansion in the country are the country's on-shore (Northeast and South regions) (Martins and Pereira, 2011) and off-shore wind power potential, growth of the wind energy industry (Blanco, 2009; Islam et al., 2013), and the long-term auctions for alternative energy sources with BNDES loans support (Juárez et al., 2014).

Wind power generation has been attracting new investments and providing a sustainable path for the development of the country energy matrix (Fidelis et al., 2013). Mastropietro et al. (2014) explain that renewable energy sources can be hired through regular auctions or through energy reserve auctions, the second have been oriented towards a competition among renewables. In these auctions specific products are tailored according to the peculiarities of the wind energy source. Moreover, specific accounting mechanisms are used to allow wind farms to compensate for seasonal and inter-annual wind fluctuations in the long-run.

In the present context, where wind generation is growing along with the success of the long-term auctions, it is appropriate to evaluate new investments for this source in Brazil. Our goal is to incorporate uncertainties in terms of electricity production, electricity prices and analyze the producer exposure to the STM. In this work we consider an investment in a wind farm that will negotiate its electricity production in long-term regular auctions. In this section we present the basis to compute wind power production for a wind farm, and the circumstances where the producer can be exposed to the STM.

2.1. Electricity production from wind power plants

In order to perform statistical analysis and evaluate the energetic potential from wind sources, the Weibull distribution is broadly used in the literature. According to (Li et al., 2013; Safari and Gasore, 2010; Akdag and Guler, 2009; Custódio, 2013) the Weibull distribution is considered to be the most adequate probability density function (pdf) to represent the behavior of wind speed. According to Safari and Gasore (2010), the use of Weibull distribution is also justified due to its simplicity in estimating parameters to approximate wind speed distribution of presented wind speeds. The probability density function for a Weibull distribution with two parameters is given by Eq. (1), proposed by Justus et al. (1978).

$$f(v) = \frac{k}{C}\left(\frac{v}{C}\right)^{k-1} e^{-\left(\frac{v}{C}\right)^{k}} \quad (1)$$

where, v is an average wind speed given in [m/s], C is the Weibull scale parameter given in [m/s], k is the Weibull form parameter (dimensionless). In order to obtain both the scale and the form parameters, Custódio (2013) presents a calculation that uses Eqs. (2), (3), respectively:

$$C = \frac{v}{\Gamma\left(1 + \frac{1}{k}\right)} \quad (2)$$

where, Γ represents the gamma function.

It is worth to emphasize that the Gamma function, also called exponential integral function, is often used as a function of the Weibull k form parameter (Custódio, 2013). Eq. (3), presents the Gamma function from Eq. (2) as a function of the arguments $(1 + \frac{1}{k})$ for the k values accordingly described in (Custódio, 2013).

$$k = \left(\frac{\sigma}{V}\right)^{-1.086} \quad (3)$$

where, σ is the wind speed standard deviation in [m/s] and V is the average wind speed in [m/s].

Regarding the calculation of the wind energy potential for wind power generators, it is important to mention that a wind turbine captures a portion of the wind kinetic energy, which passes through an area swept by the rotor and transforms it into electricity. The electric power output in [W] is a function of wind speed to the cube (Amarante, 2010) as presented in Eq. (4).

$$P = \frac{1}{2}\rho A_r v^3 C_P \eta \quad (4)$$