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Portfolio optimization of renewable energy assets: Hydro, wind, and photovoltaic energy in the regulated market in Brazil

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ABSTRACT

This study proposes a methodology for risk analysis and portfolio optimization of power generation assets with hydro, wind, and solar power, considering the Regulated Contracting Environment and the Mechanism for Reallocation of Energy in Brazil. Innovative stochastic models are used to generate synthetic time series for the random variables water inflow, wind speed, solar irradiance, temperature of the photovoltaic panel, and average generation capacity of the Mechanism for Reallocation of Energy. The simulation is implemented using the Monte Carlo method associated with a Cholesky decomposition. An economic approach is presented taking into account taxation and financing, as well as the Markowitz Portfolio theory. The results show that the initial correlation between the energy resources is altered by the cash flow model and mainly by the debt. In the diversification process, the complementarity between sources helps to reduce the economic risk. The increase in debt increases the correlation, decreases the return and risk and, consequently, affects the diversification process and economic results. The Mechanism for Reallocation of Energy significantly reduces the hydroelectric economic risk and increases the financial return, which directly benefits the formation of portfolios.

1. Introduction

1.1. Motivation and purpose

In Brazil, the Ten-Year Energy Expansion Plan 2023 (Brazil, Ministry of Mines and Energy, Energy Research Company, 2014) shows that the expansion of electric power generation should be done in a sustainable manner, taking into account safety criteria of the power supply and the minimization of expansion costs.

The estimated investment in new power plants for electricity generation in Brazil, in the period from 2014 to 2023, is approximately USD 47.7 billion, being 40% hydro, 49% other renewable sources (biomass + small hydro + wind + solar), and 11% thermal power (Brazil, Ministry of Mines and Energy, Energy Research Company, 2014).

In recent years, the energy market has shown major diversification in terms of generation sources, ways of trading, and contracting, exposing market agents to greater risks, both physical and financial, which complicates decision-making and business, especially in relation to investments in the sector (Escribano Francés et al., 2013; Schmidt et al., 2016; Domingues, 2003; Kashi, 2015; Pineda and Conejo, 2012). Some risks are typical of the financial sector, such as: liquidity, operational, credit, inflationary, market, and legislative changes (Escribano Francés et al., 2013). Other risks are typical of the electricity sector, such as: climate conditions, generation and transmission capacity, generation costs, supply and demand imbalance, short term price volatility, regulatory policy, and electricity commercialization (Escribano Francés et al., 2013).

To manage the electricity sector in this new scenario, it is important to know how to manage the physical and financial risks from

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the electric system operation. A company should diversify its investments in order to reduce the risk (Escribano Francés et al., 2013; Domingues, 2003; Losekann et al., 2013). To do so, investors can use the Markowitz Mean-Variance Portfolio Theory (mean-variance model) (Markowitz, 1952) to evaluate the investment and the relative risks of alternative generating portfolios which are made up of conventional and renewable energy technologies (Zhu and Fan, 2010). In this case, different generating technologies will be viewed as different assets.

1.2. Literature review and contribution

Muñoz et al. (2009) applied the mean-variance model for renewable energy in the Spanish electricity market. The internal rate of return (IRR) of the cash flow was used as an economic indicator. The authors assumed a normal probability distribution for the random variables when applying the Monte Carlo Method (MCM). Zhu and Fan (2010) applied the mean-variance portfolio theory to evaluate the generating-cost risk in China. Roques et al. (2010) presented a portfolio approach to identify cross-country portfolios in order to minimize the risk of production in wind farms. The study was conducted for five European countries. Delarue et al. (2011) presented a new portfolio theory model by combining portfolio investment and actual dispatch decisions. Bhattacharya and Kojima (2012) applied the mean-variance portfolio theory to analyze the impact of renewable energy integration in Japan's electricity sector. Escribano Francés et al. (2013) analyzed the interactions between international renewable energy and energy security using the portfolio theory. Losekann et al. (2013) estimated an efficient generation portfolio for the Brazilian electricity market, considering costs, risks, and CO_2 emissions, and compared the results with the planned portfolio in the 2020 Decennial Plan for Energy Expansion. The MCM was used to generate probability distributions for the electricity generation costs for each technology. They assumed a range of values and probability distributions (generally uniform or triangular) for each parameter and technology to be analyzed. Schmidt et al. (2016) analysed an optimal portfolio of renewable energy in Brazil, considering demand aspects and minimizing the use of thermal power production. Additionally, the authors state that a stochastic model of the historical data, considering seasonality, auto-correlation, and correlation between different sources and different production locations may generate better synthetic time-series than the simple bootstrapping procedure they used.

It is worth mentioning that none of the above studies analyzed the correlation behavior between renewable energy at the different stages of the modeling (i.e., from energy resources to final cash flow). Another aspect not analyzed is the impact of financing on the efficient frontier.

Within the context above, the contribution of this study is to propose a methodology for risk analysis and portfolio optimization of power generation assets with hydro, wind, and solar power plants, considering the regulated market in Brazil. Innovative stochastic models are used to generate synthetic time series for the random variables water inflow, wind speed, solar irradiance, and temperature of the photovoltaic panels, calculating the power generation for each source. For better modeling, a complete cash flow model is used and taxation and financing are also considered. The correlation behavior between renewable energy at the different stages of modeling is presented and analyzed, as is the impact of financing on the efficient frontier in the Markowitz model.

The combination of techniques used in this study offers a new perspective on the economic analysis of renewable energy in Brazil, which contributes greatly to the decision-making process. Thus, this study offers a comprehensive tool to encourage investment in renewable energy and to contribute to energy planning in the country.

1.3. Paper organization

The rest of this paper is organized as follows. Section 2 describes the proposed methodology, including the modeling of the random variables, the characterization of the cash flow, and the portfolio theory model. Section 3 presents and discusses the results of a case study for the northeast region in Brazil. Section 4 concludes the paper. Appendix A shows the validation of the stochastic models. Appendix B shows a sensitivity analysis considering the hydroelectric plant participating and nonparticipating in MRE.

2. Data and methods

A case study was carried out using historical data of the northeast region in Brazil. Three power plants were considered: hydroelectric of Xingó in Alagoas state, a fictitious wind power plant in Natal city of Rio Grande do Norte (RN) state, and a fictitious solar power plant in Recife city of Pernambuco (PE) state. The historical data are described in Section 2.6.

The main reason for the choice of these sites is the availability and quality of historical data. Another reason is that these sites are typical in Brazil. The northeast is one of the poorest regions in Brazil, and needs investments to promote its development.

The geographical coordinates of the fictitious solar power plant are 08° 03' S and 34° 55' W. The photovoltaic panels are inclined 8° and face north. In this study, a constant value for the albedo is used equal to 0.25.

The risk analysis is performed using the MCM applied to stochastic models. The MCM is carried out with 2000 scenarios and a period equal to 300 months (project's lifespan). The random numbers are calculated using the Cholesky decomposition, which considers the correlation between the random variables.

Stochastic models are used to generate synthetic time series of the following variables: water inflow, wind speed, solar irradiance, and photovoltaic panel temperature. The stochastic models are presented in Sections 2.1, 2.2, 2.3, and 2.4. The historical data and the procedures for parameter estimation are presented in Section 2.6.

The general flowchart of the methodology is shown in Fig. 1.

Seasonality must be removed before parameter estimation. To do so, the monthly historical data are divided by the seasonal indices of each month. Considering the historical data for a particular variable X, the monthly seasonal index expresses the ratio between the average of the historical values of a specific month $\overline{X_m}$ and the average of all historical values $\overline{X_{hist}}$, thus:

$$I_{X_m} = \frac{\overline{X_m}}{\overline{X_{hist}}} \quad ; \quad m = 1, 2, 3, \ldots, 12. \qquad (1)$$

2.1. Stochastic modeling of water inflow

The electricity generation from hydro plants depends directly on the water inflow. The inflow is a seasonal process because it is closely related to the periods of rain and drought, which alternate throughout the year. From the historical data, it can be observed that this variable shows mean reversion behavior. This suggests the use of autoregressive processes in the stochastic modeling (Dixit and Pindyck, 1994; Wooldridge, 2000).

This study extends the geometric mean-reverting model of Dixit and Pindyck (1994) by incorporating a deterministic seasonality index, as shown in Eq. (2).

$$A|S_{t+1} = \left\{ A_t \cdot e^{\left\{\left[\eta_A(\ln(\overline{A})-\ln(A))-\frac{\sigma_A^2}{2}\right]dt+\sigma_A \cdot \varepsilon_A \cdot \sqrt{dt}\right\}} \right\} \cdot I_{Am}. \qquad (2)$$