SWITCH AND DEFER OPTION IN RENEWABLE ENERGY PROJECTS

ABSTRACT: Renewable energies (RE) are a viable alternative to keep sustainable growth and economic development of nations without an energy crisis. Since 2004, Brazilian government promotes RE to diversify national grid. RE projects has some uncertainties and flexibilities an net present value (NPV) technique can cause undervaluation analysis. Thus, this research aims to value power generation projects under the real options theory (ROT) framework capturing the existing value in uncertainties and flexibilities (switch and defer options) using binomial tree and Monte Carlo simulation. The real option valuation applied to RE adds value to the projects

Keywords: Real Options, Renewable Energy, Valuation, Investment Decision, Uncertainty.

JEL Codes: Q42, O13, C52, G11, D81.

1 INTRODUCTION

Since 2002, Brazilian government promotes the development of renewable energy (both wind and photovoltaic), in specific auctions by type and in direct competition with conventional energy, but the Brazilian electrical grid is hydraulic-thermal, where the use of hydropower and fossil fuel-fired thermoelectric plants represents almost 85% of all generated energy. (ABEEólica, 2016; Leite, Castro, & Timponi, 2013).

This high concentration in only two energy types caused an energy crisis in 2015. To reduce this concentration, the Ten-Year Energy Expansion Plan 2024 plans an increase in share of wind
and photovoltaic from 16.1% to 27.4% of Brazilian electricity grid by 2024 with an investment volume of R $ 100 billion over the next 10 years. (MME & EPE, 2015).

This amount of money is because of new power generation projects and expansions of existing projects. Thus it is important to use sophisticated economic-financial modeling to determine the competition values of generation projects in auctions and/or free-market, with fair investment return.

Despite all the tools already developed in the field of Administration, Accounting, Economics, Engineering, Statistics, Physics, Mathematics, among others, there are gaps to fill up when we go through the literature and the valuation practice of energy projects in Brazil and in the world. (Dalbem, Gomes, & Brandão, 2014; Monjas & Balibrea, 2015).

Net present value (NPV) method, coupled with other methods, is the main tool for valuation projects analysis. This occurs because of the robustness and intuition that the method gives analysts and decision makers to invest or not in a business. Despite the diffusion of the method, the conditions of uncertainties inherent in renewable energy projects are not captured by NPV, because NPV has a static and deterministic nature. (Jeon, Lee, & Shin, 2015; Shun-Chung Lee, 2011).

In this way, real options approach (ROA) is more appropriate because it allows to assess energy projects capturing uncertainties and value the project's flexibilities. Therefore, ROA aims to model the uncertainties and flexibilities of the projects and bring them to valuation environment, in order to overcome NPV weakness. (Kroniger & Madlener, 2014; Shun-Chung Lee, 2011).

Add uncertainties to project analysis makes valuation better to economic reality and makes it possible to implement different strategies throughout the project lifetime, such as: expansion at optimistic moment, abandonment or postponement in tough times, switch inputs due to the high price, speed-up building time to pick some market’s opportunities, etc. These
strategies/flexibilities add value to the project and traditional NPV have to expand for correct valuation. (Monjas & Balibrea, 2013; Trigeorgis, 1993, 1996).

Fernandes, Cunha, and Ferreira (2011) study the recent works that use real option approach in valuation process for energy generation and research projects and shown that literature is limited for renewable energy valuation with ROA.

Therefore, this research uses the modern real options approach to value wind-photovoltaic projects because uncertainties and flexibilities are inherent in each project and ROA is consistent with RE project’s reality.

Thus, this paper seeks to value renewable energy projects under real options perspective and verify the additional value of uncertainties and the options of waiting and switch (switch output) against net present value method.

The research is divided into 6 parts. In the next section we present Literature Review regarding the real options approach, its advantages and the latest work. In section 3 we describe the methodology in detail and the model assumptions. In section 4 and 5 we apply the model and show the results. Finally, we conclude the paper in section 6.

2 LITERATURE REVIEW

Corporate capital budgeting decisions are traditionally based on Net Present Value method, that first forecast project cash flow and brings to present value with a discount rate (capital cost). This method considers that investment decision should be taken like "now or never" ignoring project’s flexibilities. Then NPV has static and deterministic nature. (Boomsma, Meade, & Fleten, 2012; Shun-Chung.; Lee & Shih, 2010). While scenario analysis and simulations can help to
determine the impacts of uncertainties on project’s value, none of these approaches are capable to assess project management flexibilities.

The Real Options Approach (ROA) is suitable when the investment decision involves uncertainty and flexibility. ROA provides dynamic assessment and allows the exercise of project flexibilities according to future events. (Shun-Chung; Lee & Shih, 2010).

The term “real options” was coined by Myers (1977) and is a reference and extension of Black and Scholes (1973) work on financial options. However, the pioneer in ROA application was Tourinho (1979) and evaluate the option of exploring a natural resource reserve. McDonald and Siegel (1986) have assessed the option of deferring a given investment by choosing the optimal time to execute the project. Paddock, Siegel, and Smith (1988) were the first to value an unexploited oil reserve in Gulf of Mexico. The 1990s was an important period for Real Options, because relevant papers like Pindyck (1993) and Trigeorgis (1993), also some textbooks as Dixit and Pindyck (1994), Trigeorgis (1996), Amram and Kulatilaka (1998) and Copeland and Antikarov (2001).

All investment decisions have three main features: irreversibility, uncertainty and timing. First, the initial investment is not fully recovered if investor regrets about the investment decision. Thus, the vast majority of the initial investments are sunk costs. (Dixit & Pindyck, 1994; Kroniger & Madlener, 2014; Lin & Wesseh Jr, 2013). Second, the uncertainties are huge and affect the project’s cash flow. The uncertainties may be: (a) economic or market uncertainty; (b) technical or private uncertainty and (c) strategic uncertainty.

Economic or market uncertainties are those uncertainties exogenous to the project and are correlated to market behavior, such as: exchange rate, inflation, market price, product demand
product, interest rate, etc. These variables are usually modeled by stochastic processes. (Dias, 2014a; Dixit & Pindyck, 1994; Kroniger & Madlener, 2014).

Technical or private uncertainties are specific uncertainties, endogenous to the project and uncorrelated to market behavior. Generally, there is investment in information (learning option exercise) to knowledge the uncertainty, in other cases the simple time passage is enough to reveal all information about the uncertainty. However, the knowledge of uncertainty does not mean zero uncertainty, but a priori knowledge about uncertainty behavior. Uncertainties regarding the oil field reserve, solar radiation of a region, wind of a city, water flow of a river, etc. are some examples of technical uncertainties. Usually, probability distributions represent these types of uncertainties. (Dias, 2014a; Dixit & Pindyck, 1994; Lin & Wesseh Jr, 2013).

Strategic uncertainties are the economic agents’ behavior or preferences in economic environment. Firms behavior, auctions movements, entry costs, etc. are some examples of strategic uncertainties and are modeled like Option Games (Game Theory + ROA). (Dias, 2014a).

The third feature is timing, which deals with the possibility to defer an investment, that is, waiting for new/or more information to find the best moment to invest, expand, abandon, etc. (Dias, 2014a; Kroniger & Madlener, 2014).

Exercising waiting options, the investor runs lower risk, because will have more information about the future and wait for better conditions before invest money. In RE the waiting option is very valuable, because there are many uncertainties about the future of these energies, such as: intermittence, production costs, future prices, public policies, taxes, etc.

Boomsma et al. (2012) consider the waiting option for the best moment to invest in renewable energy projects with different capacities and different payment schemes (flat rate and green certificates).
Martinez-Cesena and Mutale (2012) value the waiting option for wind project according to wind site potential to reduce project uncertainty. Abadie and Chamorro (2014) also value the waiting option for a wind farm, but the study has different features.

Weibel and Madlener (2015) assess the economic viability and waiting option of a wind-photovoltaic project with water storage in a ring wall (Ringwall Storage Hybrid Power Plants).

Fertig et al. (2014) use ROA to analyze the timing option and the best capacity to build a pumped water storage facility for Tonstad city hydroelectric power plant in Norway southeastern. This project could be understood as an expand option, because seek to expand the facility capacity.

While waiting options occur before the investment, switch options are options that happen after exercise previous options, for example: the option to switch an input in production for another material is only possible, because at an earlier time the investment option was done.

The most common switch option is the switch-input option and it can change the inputs without changing the outputs (products/services).

Brandão, Penedo, and Bastian-Pinto (2013) value the switch-input option between two different commodities (soybean and castor bean) for a biodiesel production facility. Hu and Solana (2013) verify the value of a hybrid wind-diesel power project with a switch-input option, as well as to decide the correct number of wind turbines for the system.

The switch-output option is the opposite of a switch-input option, in other words, when the firm keeps the same raw material, but the outputs are different. Dockendorf and Paxson (2013) study the switch-output option for a fertilizer plant between ammonia and/or urea, also value the shut-down option. C. Bastian-Pinto, Brandão, and Hahn (2009) assess the switch-output option for a sugar cane facility that produces sugar and/or ethanol. Maxwell and Davison (2014) value a similar case, but the facility has an option to sell raw corn or use it in ethanol production and sell
ethanol. Oliveira, Brandao, Igrejas, and Gomes (2014) analyze the economic viability for a cogeneration unit in a large MDF plant, from forest biomass residues to generate thermal and/or electrical energy (switch-output).

Depending on the options features, we can assess option in continuous time as in Black and Scholes (1973) and Merton Merton (1973) or by dynamic programming. This pricing model is better for simple options and not for problems with multiple options and flexible decisions. (Jeon et al., 2015). However, there are many papers in real options that use this valuation technique, such as (Dockendorf & Paxson, 2013; Howell et al., 2011; Kirby & Davison, 2010; Shun-Chung Lee, 2011; Maxwell & Davison, 2014; Thompson, Davison, & Rasmussen, 2009).

Other common pricing model is the binomial model proposed by Cox, Ross, and Rubinstein (1979), because reduces the future scenario in only two possible outcomes: upside scenario or downside scenario. This model is a discrete approximation of Black-Scholes-Merton continuous-time model. In this way, the risk-free rate \((r)\) can be used in continuous-time base. (Hull, 2015; Shun-Chung.; Lee & Shih, 2010). The binomial model is successful in real options papers applied to RE such as (Dalbem et al., 2014; Gazheli & Di Corato, 2013; Isaza Cuervo & Botero Botero, 2014; Kim, Lee, & Park, 2014; Shun-Chung.; Lee & Shih, 2010; Lin & Wesseh Jr, 2013; Weibel & Madlener, 2015; Zhang, Zhou, & Zhou, 2014). However, there are other lattice forms, such as trinomial (Abadie & Chamorro, 2014; Muñoz, Contreras, Caamaño, & Correia, 2011).

Monte Carlo Simulation (MCS) solves problems with forward simulations and not backwards optimization as binomial model, that is, with mathematical equations we express a problem and generate thousands of simulations with random values that result thousands values and with these values and statistical inferences we can predict the likely result.
In real options approach, MCS can handle different stochastic processes and a large number of uncertainties, but it has a computational cost of software (in some cases) and time. (Isaza Cuervo & Botero Botero, 2014; Jeon et al., 2015; Martinez-Cesena & Mutale, 2012). Some papers use MCS to value real options for electric power assets such as (Balibrea, Sánchez-Soliño, & Lara-Galera, 2015; Boomsma et al., 2012; Fertig, Heggedal, Doorman, & Apt, 2014; Jeon et al., 2015; Kroniger & Madlener, 2014; Monjas & Balibrea, 2013, 2014, 2015), also other research fields, such as (Brandão et al., 2013; Oliveira et al., 2014; Ozório, Bastian-Pinto, Baidya, & Brandão, 2012; Rodrigues, Ozorio, Bastian -Pinto, & Brandão, 2015; Simões, Oliveira, Pinto, Klotzle, & Gomes, 2011).

All the papers referenced here have different features that make the waiting option and the switch output option of this research unique. For the waiting option, the study of Dalbem et al. (2014) has great influence, but different data and assumptions were used. The part relating to the switch-output option has direct relationship with Brazilian market features.

2.1 STOCHASTIC PROCESS

Ozório, Bastian-Pinto, and Brandao (2012) emphasize that studies under real options approach are based on two stochastic processes: (a) Geometric Brownian Motion (GBM) and (b) Mean Reversion Model (MRM).

Geometric Brownian Motion (GBM) is the most famous stochastic process, because it is the Black and Scholes (1973) process for financial option and is good to simulate stock market behavior.
The pioneering real options studies (Brennan & Schwartz, 1985; McDonald & Siegel, 1986; Paddock et al., 1988; Tourinho, 1979) also have used the GBM and continue to be the most popular stochastic process for ROA in electricity market (Boomsma et al., 2012; Haddad, 2012; Kirby & Davison, 2010; Kroniger & Madlener, 2014; Shun-Chung Lee, 2011; Shun-Chung.; Lee & Shih, 2010; Lin & Wesseh Jr, 2013; Weibel & Madlener, 2015; Zhang et al., 2014).

The GBM lognormal property is essential for assets that cannot have negative values and have exponential growth. However, this stochastic process is not always the best way to simulate random variable behavior, because of the drift term and the time horizon, the random variable could have "unreal" values. (Brandão et al., 2013; Ozório, Bastian-Pinto, & Brandao, 2012).

While GBM has a constant trend, \((\alpha > 0 \text{ or } \alpha < 0)\) over the time, in Mean Reversion Model (MRM) this trend and intensity are not constant and vary according to the value of a random variable at time \(t\). Thus, MRM values are distributed over the time around a long-term mean value associated with marginal production cost, making the movement to fall and upward randomly. Because of this property, MRM is widely used to model commodities prices and interest rates. However, its use is more suitable for long time series where can verify a MRM trend, otherwise should predominate the GBM. (Dixit & Pindyck, 1994; Ozório, Bastian-Pinto, Baidya, et al., 2012; Ozório, Bastian-Pinto, & Brandao, 2012).

Due to unavailability of access to long time series, Hull (2015) points out that most commodities are modeled following GBM. However, electricity prices in Brazil (PLD) show a clear trend of mean reversion.

Schwartz (1997) model 1 is a good representation of MRM, because it uses \(x = Ln(P)\), then the prices do not have negative values. Del Fabbro, Valentinčič, and Gubina (2016) use MRM to simulate electricity price in order to find the return rate for grid-connected photovoltaic systems.
Although MRM can represent the electricity price of Brazil, it is still necessary to verify the MRM with jumps, because some time series have spikes over the time and in a short period. In finance, one way to simulate a MRM-Jump is to join a pure MRM and a Poisson process. This is important to represent a random variable more realistic, because empirical phenomena have asymmetric returns, unexpected events and less predictable than pure MRM. (Carlos de Lamare Bastian-Pinto, Brandão, & Ozorio, 2016; Ozório, Bastian-Pinto, & Brandao, 2012).

In Fontoura, Brandão, Gomes, and Bastian-Pinto (2012), electricity prices have big volatility and present atypical behavior and is modeled as a MRM-Jump. However, the Brazilian electricity market has some features and some adaptations were done for a successful MRM-Jumps application. The authors assess a thermal plant based on elephant grass biomass and model Brazilian electricity prices with MRM-Jumps.

Oliveira et al. (2014) analyze the economic feasibility of a cogeneration project with residual forest biomass and use Fontoura et al. (2012) MRM-Jumps to model electricity prices.

In Fontoura, Brandão, and Gomes (2015), the same previous model is used for prices simulation and evaluate the economic viability of a biomass plant that has a switch option among electricity, coal and ethanol.

Monjas and Balibrea (2013) use a complex version of MRM-Jumps, because they incorporate a linear trend for the mean and the uncertainties regarding electricity price, investment costs and inflation. In different conditions, the authors replicate the same model in other two studies (Monjas and Balibrea (2014) and Monjas and Balibrea (2015)).

In general, MRM and MRM-Jumps are complex and robust to represent Brazilian electricity prices.
3 MODEL

Since 2004 Brazilian electricity market is divided into regulated market (ACR) and free market (ACL). In regulated market the retail companies buy energy through regulated auctions by governmental agency (ANEEL) in long-term contracts (20 to 30 years). In free market the producers sell energy to free consumers through contracts that have length, price, etc. in bilateral agreements. (CCEE, 2016; Leite et al., 2013).

The price \( P \) in ACR contracts is known, but contracts in the ACL do not have public price registration or at least a standardized form, because volumes, terms, prices and contractual clauses are bilaterally negotiated. However, there is PLD (Settlement Price of Differences) and it is calculated from a mathematical-computational model that uses hydrological conditions, energy demand, fuel prices, energy deficit cost, new projects and equipment availability (generation and transmission) and the optimum volume of hydraulic generation and thermal generation for each of the four submarkets that compose the Brazilian electricity market. Thus, the Brazilian electricity spot price (PLD) is function of the sector, water reservoir levels and the rainfall pattern. Thus, PLD volatility is directly related to the water cycle. (CCEE, 2016; Leite et al., 2013).

Contracts with duration of less than 2 years tend to reflect the PLD and contracts with a duration bigger than 2 years tend to reflect regulated market prices with a risk premium. (Dalbem et al., 2014). Thus, based on the last energy auctions with renewable energy projects (6th LER, 7th LER, 8th LER, 3rd LFA, 18th LEN, 19th LEN, 20th LEN and 20th LEN) and other papers, hypothetical projects were designed for Northeast submarket in Bom Jesus da Lapa city.
Table 1 – Cash flow assumptions.

<table>
<thead>
<tr>
<th></th>
<th>Wind</th>
<th>PV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment (US$)</td>
<td>32,666,932.59</td>
<td>39,856,230.00</td>
</tr>
<tr>
<td>Installed capacity (MW)</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>US$ Invest/Cap. (MW)</td>
<td>1,088,897.75</td>
<td>1,328,541.00</td>
</tr>
<tr>
<td>Total hours</td>
<td>175,200</td>
<td>175,200</td>
</tr>
<tr>
<td>Price (US$/MWh)</td>
<td>53.26</td>
<td>85.06</td>
</tr>
<tr>
<td>Operational costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land (% x Revenue):</td>
<td>1.5%*</td>
<td></td>
</tr>
<tr>
<td>Insurance (% x Investment):</td>
<td>0.6% a.r*</td>
<td></td>
</tr>
<tr>
<td>Other costs (% x Revenue):</td>
<td>0.5%*</td>
<td></td>
</tr>
<tr>
<td>Financial costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>70% of investment by BNDES*: 4% a.r. real</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30% of investment by own money *: 10% a.r. real</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WACC: 6% a.r. real</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Dalbem et al. (2014).

Other assumptions:

a) Free inflation and no tax;

b) No residual value (0) and linear depreciation;

c) Operation costs are the same for Wind and PV;

d) Projects duration = 20 years.

Projects are compared according to following strategies:
3.1.1 Strategy 1 - Projects without uncertainties (Classic NPV)

a) "Wind" project sells 100% of energy by a fixed price in ACL (free market) and wind frequency follows a typical meteorological year (TMY).

b) "PV" project sells 100% of energy by a fixed price in ACL (free market) and solar irradiation follows a typical meteorological year (TMY).

c) "Wind + PV" project sells 100% of energy by a fixed price in ACL (free market) and wind frequency and solar irradiation follow a typical meteorological year (TMY) each.

Projects of strategy 1 are valued without market uncertainty (energy price), technical uncertainties (wind frequency and solar irradiation) and operational flexibility (RO).

3.1.2 Strategy 2 - Projects without RO

a) "Wind" project sells 100% of energy by a fixed price in ACL (free market) and only wind frequency is the project’s uncertainty.

b) "PV" project sells 100% of energy by a fixed price in ACL (free market) and only solar irradiation is the project’s uncertainty.

c) "Wind + PV" project sells 100% of energy by a fixed price in ACL (free market) and wind frequency and solar irradiation are the project’s uncertainties. (technical uncertainties).
Projects of strategy 2 are valued with technical uncertainties (wind frequency and solar irradiation), but do not have market uncertainty (energy price) nor operational flexibility (RO).

### 3.1.3 Strategy 3 - Projects with switch option

a) "Wind" project sells 50% of energy by a fixed price in ACL (free market) and can sell the remaining 50% by PLD price if the investor desire. Thus, the project has a technical uncertainty (wind frequency) and a market uncertainty (energy spot price).

b) "PV" project sells 50% of energy by a fixed price in ACL (free market) and can sell the remaining 50% by PLD price if the investor desire. Thus, the project has a technical uncertainty (solar irradiation) and a market uncertainty (energy spot price).

c) "Wind + PV" project sells 50% of energy by a fixed price in ACL (free market) and can sell the remaining 50% by PLD price if the investor desire. Thus, the project has two technical uncertainties (wind frequency and solar irradiation) and a market uncertainty (energy spot price).

Projects of strategy 3 have a switch-output option, because the power facility can sell 50% of energy as an ACL product with a fixed price or as a PLD product with a floating price. Thus, the projects have the option to sell part of the energy (50%) where is economically better.

PLD price has two different stochastic processes: MRM and MRM-Jumps. Thus, strategy 3 has two different results due to stochastic process adopted in electricity prices simulation.

Note that electricity prices are in Brazilian Real (R$) and to keep the variability of time series we first simulate the prices and then convert in American dollar (US$). This conversion also focus
to keep projects and electricity prices in same currency. The exchange rate was the average weekly dollar from January 2000 to December 2016.

3.1.4 Strategy 4 - Projects with waiting option.

a) Invest or wait for a "Wind" project that sells 100% of energy by a fixed price in ACL (free market) with uncertainties like wind frequency, technology and RE public policies.

b) Invest or wait for a "PV" project that sells 100% of energy by a fixed price in ACL (free market) with uncertainties like solar irradiation, technology and RE public policies.

c) Invest or wait for a "Wind + PV" project that sells 100% of energy by a fixed price in ACL (free market) with uncertainties like wind frequency, solar irradiation, technology and RE public policies.

Strategy 4 verifies the waiting option value with binomial model of pricing option technique and GBM is the stochastic process for underlying asset (project). The GBM assumption due to the lack of knowledge about project uncertainties (technology, RE public policies wind frequency and/or solar irradiation). Hull (2015) emphasizes that when the researcher does not have access to data and/or even they are not reliable, it is better to assume that the variables follow a Geometric Brownian Motion.

The waiting option in this case is a European type and according to last auctions results and Dalbem et al. (2014), the waiting option has 3 years to expire.
4 APPLICATION

The solar irradiation hourly data were collected in SWERA's website from January 1991 to December 2001. Wind data came from a wind energy specialized software by a wind energy consultant. The wind data is from January 2006 to December 2015 with hourly and daily measurements at 120 meters height.

Electricity price is the mean PLD of Northeast submarket, on weekly basis, deflated by month inflation. The prices are from March 2002 to December 2016 as can be seen in Figure 1.

![Electricity Spot Price](image)

**Figure 1 – Electricity price.**

4.1 ANALYSIS AND PARAMETERS ESTIMATION

With unit root test it was possible to verify that Brazilian electricity prices do not follow a GBM. (Carlos de Lamare Bastian-Pinto, Brandão, & Alves, 2010; Carlos de Lamare Bastian-Pinto et al., 2016; Dias, 2014b; Ozório, Bastian-Pinto, & Brandao, 2012). Thus, we use MRM Schwartz (1997) model 1 for PLD prices in strategy 3 and the equation, under neutral risk measure and discrete time, is below:
\[ X_t = \exp \left\{ \ln[X_{t-1}] e^{-\eta \Delta t} + \left[ \ln \bar{X} - \frac{\sigma^2}{2\eta} - \frac{\mu - r}{\eta} \right] (1 - e^{-\eta \Delta t}) + \sigma \sqrt{\frac{1 - e^{-2\eta \Delta t}}{2\eta}} N(0,1) \right\} \]

\( X_t \) = price in \( t; \)
\( X_{t-1} \) = lag price;
\( \bar{X} \) = long-term mean price;
\( \frac{\mu - r}{\eta} \) = normal risk premium;
\( \eta \) = mean reversion speed;
\( \sigma \) = volatility;
\( \Delta t \) = time.

In MRM-Jumps we use Fontoura et al. (2012) and Fontoura et al. (2015) approach to filter jumps and the distribution of jumps was changed for a uniform distribution between minimum and maximum jump according to filtered jumps series. The jumps appear to be drawn for a Poisson distribution.

Thus, this paper uses Fontoura et al. (2015) MRM-Jumps with some adaptations and the equation below is under neutral risk measure and discrete time.
\[
X_t = \exp \left\{ \ln[X_{t-1}] e^{-\eta \Delta t} \right. \\
\left. + \left[ \ln \bar{X} - \frac{\sigma^2}{2\eta} - \frac{\mu - r}{\eta} \right] (1 - e^{-\eta \Delta t}) + \sigma \sqrt{\frac{1 - e^{-2\eta \Delta t}}{2\eta}} \right. \\
\left. \cdot N(0,1) \right\} \\
+ U(k, \gamma) : (u_i < \Phi \Delta t)
\]

\(X_t\) = price in \(t\);
\(X_{t-1}\) = lag price;
\(\bar{X}\) = long-term mean price;
\(\frac{\mu - r}{\eta}\) = normal risk premium;
\(\eta\) = mean reversion speed;
\(\sigma\) = volatility;
\(\Delta t\) = time
\(k\) = minimum jump;
\(\gamma\) = maximum jump;
\(\Phi\) = jump frequency;
\(u_i\) = Poisson distribution.

Table 2 provides all parameters for PLD simulation.
Table 2 – Model parameters.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Symbol</th>
<th>MRM</th>
<th>MRM-JUMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>price</td>
<td>$X_t$</td>
<td>54.06</td>
<td>54.06</td>
</tr>
<tr>
<td>long-term mean price</td>
<td>$\bar{X}$</td>
<td>163.89</td>
<td>148.72</td>
</tr>
<tr>
<td>mean reversion speed</td>
<td>$\eta$</td>
<td>1.7616</td>
<td>1.7741</td>
</tr>
<tr>
<td>volatility</td>
<td>$\sigma$</td>
<td>0.3128</td>
<td>0.3054</td>
</tr>
<tr>
<td>minimum jump</td>
<td>$k$</td>
<td>-</td>
<td>0.7689</td>
</tr>
<tr>
<td>maximum jump</td>
<td>$\gamma$</td>
<td>-</td>
<td>142.9292</td>
</tr>
<tr>
<td>jump frequency</td>
<td>$u_i$</td>
<td>-</td>
<td>0.0653</td>
</tr>
<tr>
<td>risk free rate</td>
<td>$r$</td>
<td></td>
<td>6%</td>
</tr>
</tbody>
</table>

Regarding technical uncertainty, for strategy 1, annual solar irradiation and wind frequency follow a typical meteorological year. For strategy 2, annual wind distribution follows an asymmetrical normal distribution for 10 Vesta V112 turbines with 3 MW each. In Figure 2 and Figure 3 we have the annual wind distribution and turbine power curve.

![Wind Speed Frequency](image1)

**Figure 2 – Histogram and wind distribution.**

![Turbine Power Curve](image2)

**Figure 3 – Vesta V112 power curve.**

Figure 4 shows annual photovoltaic energy production distribution with standard panels and with only one tracking axis for strategy 2.
PLD prices are weekly and for strategy 3 we found the wind distribution for each week of the year and use these to simulate the wind speed. For solar irradiation, a neural network autoregression was adopted to predict weekly solar irradiation. Nonlinear neural models to predict future solar irradiation are an optimal and sophisticated alternative, because neural networks use artificial intelligence concepts to identify patterns and simulate future values that represent the identified network patterns with a high number of interactions and accuracy. (Ahmad, Anderson, & Lie, 2015; Benmouiza & Cheknane, 2016). In Figure 5 we have ten weeks forecast for solar irradiation.
With all the parameters, we simulate ten thousand future trajectories for the projects in strategies 2 and 3 and present the results in the following sections.

For waiting option (strategy 4) the pricing method was binomial model and project cash flow follows a GBM.

Due to the impossibility of estimating technology impacts and public policies on project value, we use a conservative approach, where the annual project value volatility is equal to estimated volatility by 10 thousand simulations in strategy 3. Thus, Table 3 has the annual volatility for each project.

Table 3 – Annual volatility – strategy 4.

<table>
<thead>
<tr>
<th></th>
<th>Volatility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>0.2548280</td>
</tr>
<tr>
<td>PV</td>
<td>0.2542702</td>
</tr>
<tr>
<td>Wind + PV</td>
<td>0.2542637</td>
</tr>
</tbody>
</table>
5 RESULTS

None off the projects in strategies 1 and 2 are economically viable. However, uncertainty adds value to the projects, even so, in these two strategies are not feasible (Table 4).

<table>
<thead>
<tr>
<th>Project</th>
<th>Investment</th>
<th>Strategy 1</th>
<th>Strategy 2</th>
<th>Increase: 1 to 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NPV</td>
<td>NPV/Investment</td>
<td>NPV</td>
<td>NPV/Investment</td>
</tr>
<tr>
<td>Wind</td>
<td>32.67</td>
<td>-2.102</td>
<td>-6.43%</td>
<td>-0.307</td>
</tr>
<tr>
<td>PV</td>
<td>39.86</td>
<td>-1.376</td>
<td>-3.45%</td>
<td>-0.009</td>
</tr>
<tr>
<td>Wind + PV</td>
<td>72.52</td>
<td>-3.478</td>
<td>-4.80%</td>
<td>-0.316</td>
</tr>
</tbody>
</table>

The projects in strategy 3 (MRM and MRM-Jumps) compared with strategy 2 are economic feasible (Table 5). Switch-output option adds value to all projects and when PLD follows a MRM it is better for project “WIND” with a NPV equal to 11.02% of investments and “WIND+PV” with a NPV equal to 5.10% of investment. For “PV” project, switch-output option is better if PLD prices follow a MRM-Jumps and the NPV is 0.68% of investment.

<table>
<thead>
<tr>
<th>Project</th>
<th>Investment</th>
<th>Strategy 2</th>
<th>Strategy 3</th>
<th>Increase: 2 to 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NPV</td>
<td>NPV/Investment</td>
<td>NPV</td>
<td>NPV/Investment</td>
</tr>
<tr>
<td>Wind</td>
<td>32.67</td>
<td>-0.307</td>
<td>-0.94%</td>
<td>3.292</td>
</tr>
<tr>
<td>PV</td>
<td>39.86</td>
<td>-0.009</td>
<td>-0.02%</td>
<td>0.092</td>
</tr>
<tr>
<td>Wind + PV</td>
<td>72.52</td>
<td>-0.316</td>
<td>-0.44%</td>
<td>3.383</td>
</tr>
</tbody>
</table>
Mean Reversion Movement with Jumps

| Project | Investment | Strategy 2 | | Strategy 3 | | Increase: 2 to 3 | |
|---------|------------|------------|------------|------------|------------|------------|
|         |            | NPV        | NPV/Investment | NPV        | NPV/Investment | NPV        | NPV/Investment |
| Wind    | 32.67      | -0.307     | -0.94%      | 1.529      | 4.68%      | 1.836      | 5.62%      |
| PV      | 39.86      | -0.009     | -0.02%      | 0.260      | 0.65%      | 0.270      | 0.68%      |
| Wind + PV | 72.52     | -0.316     | -0.44%      | 1.789      | 2.47%      | 2.105      | 2.90%      |

Finally, in strategy 4 projects use binomial model to value the waiting option and this option adds value. The waiting option for “Wind” project is $3.96 million (Figure 6), for "PV" project is $5.38 million (Figure 7) and for "Wind + PV" project is 9.43 million (Figure 8).

Figure 6 – “Wind” binomial tree – waiting option.

Figure 7 – “PV” binomial tree – waiting option.
When we compare projects in strategy 4 and strategy 1 we see that for "Wind" project with a waiting option, the value increase 12.11% of investment against the same project without the option. For "PV" project, this increase is 13.51% of investment and for “Wind + PV” project this value is 13% of the investment. Thus, the waiting option increase the value of all projects in strategy 4. (Table 6).

Table 6 – Strategy 1 vs Strategy 4.

<table>
<thead>
<tr>
<th>Project</th>
<th>Investment</th>
<th>Strategy 1</th>
<th>Strategy 4</th>
<th>Increase: 1 to 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>NPV</td>
<td>NPV/Investment</td>
<td>NPV</td>
</tr>
<tr>
<td>Wind</td>
<td>32.67</td>
<td>-2.102</td>
<td>-6.43%</td>
<td>1.853</td>
</tr>
<tr>
<td>PV</td>
<td>39.86</td>
<td>-1.376</td>
<td>-3.45%</td>
<td>4.008</td>
</tr>
<tr>
<td>Wind + PV</td>
<td>72.52</td>
<td>-3.478</td>
<td>-4.80%</td>
<td>5.947</td>
</tr>
</tbody>
</table>
6 CONCLUSION

This research aims to assess the switch-output option and waiting option for RE projects according to their features and Brazilian electricity market.

The real options approach for RE projects seek to capture the value of uncertainties and flexibilities that all projects have in investor's point of view. The net present value (NPV) technique ignores these flexibilities and uncertainties, causing undervaluation in some cases.

In this way, we verify that projects in strategy 2 (projects with technical uncertainties and without option) have bigger value than the same projects in strategy 1 (without uncertainties and option). Although the value of strategy 2 projects presents an increase of value, even so these values were not enough to be economic viable.

With a switch option (strategy 3) it is clear that RO adds significant value to all projects. Regardless what type of stochastic process we have used (MRM and MRM-Jumps) for PLD prices, we see the project value increasing. The same happens when we compare strategy 1 and strategy 4 for the waiting option.

Then, when we adopt a more sophisticate approach that value flexibilities and uncertainties (ROA) for RE projects, we can see a clear increase of value if we compare to traditional investment analysis (NPV).

7 References


