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COMPARATIVE EVALUATION OF INVESTMENT ANALYSIS METHODS: AN APPLICATION IN RENEWABLE ENERGY AUCTIONS BETWEEN 2011 E 2015

Avaliação Comparativa dos Métodos de Análise de Investimentos: Uma Aplicação nos Leilões de Energia Renovável Ocorridos Entre 2011 e 2015

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ABSTRACT

Purpose - This work aims to analyze the assertiveness of net present value (NPV) and real options theory (ROT), at the moment of decision making for investments in renewable energy projects, considering the 244 winning projects in the auctions of reserve energy that occurred between 2011 and 2015.
Design/methodology/approach –This is a quantitative study that used real data from 150 wind power and 94 photovoltaic projects available on ANEEL´s website. For data analysis, the confusion matrix, the area under the ROC Curve and the Kappa Index were used.
Findings – It was concluded that NPV is more effective for recommendations to invest in projects with chances to be successful, while ROT is more accurate in suggesting against investing in projects with propensity for failure. It was also found that the degree of agreement between the two techniques is substantial and determined by the level of volatility of real options.
Research limitations/implications – The limitations of this study refer to the difficulties of identifying the reasons that motivated failures in the projects.
Originality/value – Theoretically, this work contributes to identify the characteristics that effectively differentiate ROT from NPV at the time of decision making. Empirically, this work contributes to doing an ex-post analysis of the projects.

Keywords - Net present value; Real options theory; Confusion matrix.

RESUMO

Objetivo – Este estudo objetiva analisar as assertividades do valor presente líquido (VPL) e da teoria das opções reais (TOR), no momento das tomadas de decisão de investimento em projetos em energia renováveis, considerando os 244 projetos vencedores dos leilões de energia de reserva ocorridos entre 2011 e 2015.
Metodologia – Este é um estudo quantitativo que fez uso de dados de 150 projetos eólicos e 94 fotovoltaicos disponíveis no website da ANEEL. Para análise dos dados, foram usados a matriz de confusão, a área sob a curva ROC e o índice de Kappa.
Conclusão – Pôde-se concluir que o VPL é mais efetivo em recomendar o investimento em projetos com mais chances de se tornarem bem sucedidos, ao passo que a TOR tem mais acurácia em sugerir o não investimento com propensão ao fracasso. Concluiu-se também que o grau de concordância entre as duas técnicas é substancial e determinado pelo nível da volatilidade das opções reais.
Limitações - As limitações deste estudo referem-se às dificuldades de se identificar as razões que motivaram o fracasso dos projetos.
Originalidade/valor – Teoricamente, este trabalho contribui em identificar as características que efetivamente diferenciam a TOR do VPL no momento da tomada de decisão. Empiricamente, este trabalho contribui ao realizar uma análise ex-post dos projetos.

Palavras-chave: Valor presente Líquido; Teoria das opções reais; Matriz de confusão.

1 INTRODUCTION

Although Brazil has a diversity of renewable sources, 64% of its energy matrix is composed of hydroelectric plants, what enhances the risks of failures in the energy supply due to the rainfall cycles (Nascimento, 2017; Silva & Ribeiro, 2016). Thus, the importance of avoiding extreme dependence on water is increasing, which means diversifying the portfolio of electricity generation through other technologies, such as photovoltaics and wind power (Cuervo & Botero, 2016).

As a way of promoting investments in photovoltaic and wind power energy, the Brazilian government makes use of some dynamization mechanisms, such as the payment of premium tariffs (feed-in tariff), tax incentives, public financing at lower rates and reserve energy auctions. Auctions take place in a regulated contracting environment (RCE) and are promoted, directly or indirectly, by the National Electric Energy Agency (ANEEL), the Brazilian energy regulator. Through these auctions, ANEEL aims to buy energy for a more accessible price and to attract the interest of potential investors (Carmo et al., 2018; Silva, Ribeiro, & Quintella, 2018; Torinelli, Silva, & Andrade, 2018).

In addition to the long-term cash flow, Eissa and Tian (2017) point out that complexity of investments and the high uncertainty are characteristics of renewable energy projects. Uncertainty is measured differently by the main investment analysis tools, that is, the net present value (NPV) and the real options theory (ROT). NPV makes use of the discounted cash flow (DCF) principles, whose hurdle rate represents the uncertainty and is determined by the capital asset pricing model (CAPM). However, several authors, such as Abadie et al. (2017), claim that the CAPM does not have the effective capacity to capture uncertainty because it does not consider the flexibility option in decision making.

ROT´s methodology covers aspects ignored by CAPM, such as the portion of the systematic risk (Marshall, 2015; Bacelar et al., 2018). Under the ROT principles, the higher the uncertainty, the higher the value of the option, which can correct a hasty decision to consider an investment project as economically unprofitable (Pivorienė, 2017). In the particular case of power plants hired through ANEEL´s reserve energy auctions, the value of the option lies in the possibility that the investors can decide whether to participate immediately in a certain auction or to wait for a more opportune moment, that is, she/he will exercise flexibility in decision making, which is one of the indispensable conditions for assessing real options (Silva & Ribeiro, 2016).

Given this theoretical dichotomy, Mubashar and Tariq (2019) highlight the existence of a complementarity between NPV and ROT. Rambaud and Pérez (2019) state that the flexibility considered by ROT must be included in the analysis of any investment project, along with the risk covered by NPV. González and Callejo (2018) point out that it is through flexibility that ROT covers horizons not reached by NPV. As examples of the flexibility use, Liu and Ronn (2018) show the case of an entrepreneur that has decided to get further knowledge about a certain competitive scenario before making the capital expenditure, and Marfori et al. (2019), resorting to the same strategy, adopted the option of abandoning a small hydroelectric plant.

As far as our knowledge goes, the studies that deal with the investment analysis methods do not show the effective difference between NPV and ROT at the time of decision making. Thus, that is the theoretical gap which this research aims to fill up, using real data from ANEEL's auctions carried out between 2011 and 2015.

During the analyzed period, five reserve energy auctions were carried out enabling the hiring of 244 projects, 150 being of wind power, and 94 of photovoltaic (ANEEL, 2019). According to National System Operator (ONS, 2020), until August 2020, 28,00% of wind and 17,02% of photovoltaic projects were not able to enter into commercial operation, that is, they did not generate electricity, what made them unviable. It is worth mentioning that those projects were cancelled (through a reverse auction), and their licenses were either revoked or their infrastructures have been paralyzed for more than two years.

In this context, the following guiding question has been raised: considering that NPV and ROT are complementary methods of investment analysis, what does differentiate them at the moment of decision-making?

This work aims to analyze the assertiveness of net present value (NPV) and real options theory (ROT), at the moment of decision making for investments in renewable energy projects, considering the 244 winning projects of reserve energy auctions that occurred between 2011 and 2015.

This work brings about, as a theoretical contribution to the finance field, the possibility of identifying the characteristics that effectively differentiate NPV from ROT. Besides, this work contributes empirically by analyzing real data from different renewable energy projects and by carrying out an ex-post evaluation of them. The results may assist new studies in the field of investment analysis, as they will provide an improvement in decision making.

In addition to this introduction, this work is divided into four parts. The first one presents the literature review. The second, the methodological aspects. The third analyzes and discusses the data. The fourth is for conclusions and suggestions for future studies.

2 LITERATURE REVIEW

2.1 Discounted cash flow

The discounted cash flow (DCF) is an investment analysis method whose technical and conceptual rigor has enshrined it as the most used project evaluation model by companies, given that operating cash flows suffer the action of the value of money over time. This action is measured based on a minimum attractiveness rate (MAR) whose objective is to remunerate adequately the capital sources, according to the risks to which they are subject (Tubetov, 2013; Pivorienė, 2017).

Considering free cash flow, MAR can be calculated using the Capital Asset Pricing Model (CAPM), proposed by Sharpe and Lintner in the 1960s, which is still considered one of the most important theories in the finance field (Turan & Kiliç, 2018). CAPM assumes that investors have a well-diversified portfolio of assets, which allows the elimination of non-systematic risk, also called specific or idiosyncratic. Therefore, the systematic portion of the risk has yet to be considered, which is not affected by the diversification of investments and which all companies are subject to, being represented by the beta coefficient (Espinoza & Rojo, 2017). The formulation of CAPM is given by Sharpe (1964, p. 432).

$$Ke = R_F + \beta \times (R_M - R_F) \quad (1)$$

According to Sharpe (1964), Ke represents the expected rate of return on the portfolio, which is equivalent to the opportunity cost of equity. Equation 1 also includes yields on government bonds, which are considered risk-free (R_F), and the prize that the market promises to pay more than the government (R_M-R_F), which is weighted by a beta coefficient (β), also called systematic risk.

The β coefficient reflects both the operational risk, that is related to the sector in which the company operates, and the financial risk, which depends on the level of indebtedness in its capital structure. In this sense, what differentiates two organizations that operate in the same industry, and are subject to the same level of taxation, is their levels of indebtedness (Ibrahim & Haron, 2016).

Thus, the β coefficient is going to reflect the risk to which an enterprise is subject, considering that the other variables in Equation 1 are common to all other organizations that operate in the same sector (Hundal et al., 2019). Therefore, the lower the value of systematic risk, the lower the value of MAR and, consequently, the higher the value of NPV (Le et al., 2018).

It is worth noting that Normative Resolution n. 882/2020, in module 12.3, determines the guidelines for calculating the cost of capital that should be considered in power generation. It considers a maximum indebtedness of 61.37% and a cost of equity of 8.57% p.a. However, Borges and Simone (2019) warn that there is an imbalance in the expectation of tariff remuneration resulting from the methodology adopted by ANEEL. It is important to highlight that the Ministry of Mines and Energy (MME, 2019) when proposing the 10-year energy expansion plan 2029, considered a cost of equity of 13% p.a.

One of the main analysis tools of the DCF is the net present value (NPV), which represents the wealth generated by the project. For the NPV, cash inflows are brought to the present moment through MAR, forming the present value of the inflows (PV). If the PV is greater than the investment, the NPV is going to be positive, which indicates the economic viability of the investment and wealth creation by the project (Manocha & Babovic, 2018). Thus, NPV treats the project as a now or never decision: once the investment is considered economically unfeasible, the investors will have no other option than to reject the project (Gazheli & Bergh, 2018).

The problem with making an investment decision based solely on the information provided by the NPV is that CAPM is not able to capture managerial flexibility, which is understood as the investors' ability to implement a strategic decision in response to highly uncertain environments. The absence of flexibility leads the investors to consider many projects as economically unfeasible, failing to raise funds that could maximize their wealth (Tubetov, 2013; Schwartz, 2013; Čulík, 2016)

NPV also disregards the best time to make the investment, which can influence the company's profits and future opportunities, as well as the decision-making process. Under the NPV´s perspective, management is passive in the face of risks and of time. Unlike NPV, the real options theory (ROT) considers that management can react when it has more information about the uncertainties to be faced. The higher the investments and the more unlikely the chances of reversing them, the greater the usefulness of the real options (Choi et al., 2016; Perdomo et al., 2017; Morreale et al., 2017; Gazheli & Bergh, 2018).

2.2 Real options theory

ROT has full applicability in the evaluation of many types of projects, such as electric energy, due to the uncertainties which characterize that sector. ROT enables the investors to realize that there are other scenarios, besides cash inflows, which are the options arising from managerial flexibility. Thus, the investor starts understanding the investment as the risk-return-flexibility trinomial (Lee & Lee, 2015; Choi et al., 2016; Schachter & Mancarella, 2016).

The greater the uncertainties (interest and exchange rates, changes in prices, market conditions, competition etc.), the more flexibility the investors should have in their decision-making. Following this line, real options work with uncertainties and flexibility, seeking to maximize benefits (Perdomo et al., 2017).

According to Čulík (2016) there are some prerequisites that make the application of ROT possible in investment projects: the decisions are taken in an uncertain environment and the higher the uncertainties, the higher the importance of real options. However, they must be feasible and the investors must have flexibility in their decision-making.

It should also be noted that it is the flexibility that is going to determine the type of real option that the investors have at their disposal. In the particular case of investors who wish to participate in ANEEL's auctions, Silva and Ribeiro (2016) teach that flexibility lies in the possibility that they can choose between competing in a certain auction or waiting for a more opportune moment. According to Čulík (2016), flexibility is measured using models that are applicable to the valuation of financial options, such as the Black-Scholes models.

Created in 1973 by economists Fischer Black and Myron Scholes, the Black-Scholes model (BSM) became the most used methodology for assessing options and it fostered the development of the derivatives market (Del Giudice et al., 2015; Morreale et al., 2017; Bacelar et al., 2018). The idea behind BSM was a portfolio composed of two assets: the first was called the underlying asset, and the other was a risk-free asset. The cash flow of those assets was similar to the option being evaluated, and which could be solved using partial differential equations (Schwartz, 2013).

The original formulation of the Black-Scholes model was modified by Merton (1973, p. 171), when considering the existence of dividends, according to Equation 2:

$$C = S \times e^{-y \times t} \times N(d_1) - E \times e^{-r \times t} \times N(d_2) \qquad (2)$$

The variables in Equation 2 can be understood as follows:

a) S is the present value of the cash flow discounted by a rate that matches the risk;
b) y is the annual percentage of dividends to be paid over the life of the project;
c) E is the value of the investment;
d) r is the risk-free rate with continuous capitalization;
e) t is the term for exercising the option.

Black and Scholes (1973) point out that N (d_1) and N (d_2) are functions of the cumulative normal densities and that d_1 and d_2 can be calculated by the following expressions:

$$d_1 = \frac{ln\left(\frac{S}{E}\right) + \left(r + \frac{\sigma^2}{2}\right) t}{\sigma\sqrt{t}} \qquad (3)$$

$$d_2 = d_1 - \sigma\sqrt{t} \qquad (4)$$

One of the most important variables presented in Equations 3 and 4 is the volatility (σ) because it is through this variable that ROT can capture the uncertainties ignored by CAPM (Chittenden & Derregia, 2015; Marshall, 2015). Thus, volatility in real options is the result of the uncertainties to which the venture is exposed. For this reason, a company that invests in a stable business environment has less volatility in its cash flows and, consequently, its options generate a lower value (Aarle, 2013; Kim et al., 2017).

Volatility is one of the least understood issues of real options. Besides, several methodologies propose to estimate it more effectively, although there is little consensus about the approach, which ends up by generating more controversies (Choi et al., 2016; Mun, 2016). For example, Damaraju et al. (2015) understand that volatility is not constant, as determined by the Black-Scholes model, but it varies depending on the price of the underlying asset. However, Pless et al. (2016) clarify that it is not a trivial matter to associate the volatility of an investment project with the variation in price of the underlying asset, since it is not traded in the financial market. Posen et al. (2018) also point out that many methods proposed for estimating volatility end up overvaluing it to lead to a higher option value. Effectively, volatility is one of the most crucial issues in the valuation of a real option.

2.3 Methods of estimating volatility

According to Nicholls et al. (2014), the approaches proposed for calculating volatility are seen with little credibility by real options scholars, and there is not one that can be considered fully validated. Mun (2016) points out the generalized autoregressive conditional heteroskedasticity (GARCH). This method requires a significant amount of time-series data in order to find out the correct cash flow volatility.

Kim et al. (2017) and Haahtela (2013) consider the consolidated uncertainty approach, by Copeland and Antikarov (2001), as a very satisfactory measure of volatility. Copeland and Antikarov (2001) suggest that the following steps should be adopted: a) consider a fixed present value at time zero (PV_0 - the same found in the calculation of the PV); b) proceed to a Monte Carlo simulation, through which cash flow uncertainties are modeled by stochastic processes for the entire life of the project; c) estimate the present value at time one (PV_1) for each simulation; d) divide each PV_1 by PV_0; e) estimate the volatility considering it equal to the standard deviation of step “d”.

However, the method proposed by Copeland and Antikarov (2001) tends to inflate the value of volatility and, consequently, to increase the value of the option, pushing investors not to invest immediately (Smith, 2005). A possible solution to this problem was proposed by Brandão et al. (2005) when they managed to isolate the volatility within each period because, according to the authors, it can vary over the life of the project. In a later study, Brandão et al. (2012) considered the existence of fixed costs and the possibility of varying volatility from one year to another. For the authors, it is only possible to know the volatility of the first period, considering that this is where the cash flow’s unbiased value is found. Therefore, the correct volatility would be the one which equals the variance of the drift rate in the first year and which depends on the uncertainties only of that moment. Brandão et al. (2012) also consider that volatility is a function of fixed costs, becoming lower when they are diluted by increasing revenue over the life of the project. Thus, projects that are subjected to the same fixed costs and to the same uncertainties have the same volatilities.

The methodology proposed by Brandão et al. (2012) was used by several studies, as it is summarized in Table 1.

Table 1. Recent studies that use the methodology proposed by Brandão et al. (2012).

Authors	Objective
Lopes et al. (2019)	Analyze the feasibility of investing in an oil refinery.
Martinez et al. (2019)	Assess the real option of expecting an investment and expanding the operational scale of a forest-based company.
Pereira (2019)	Evaluate the use of the theory of real options in the economic-financial analysis of investments for tailings disposal that potentially generate less socio-environmental impact.
Vasseur et al. (2019)	Impact on the use of a non-biased volatility calculation method in a project in the Colombian oil and gas industry.

Source: Developed by the authors.

Table 1 shows the important theoretical advance, in the light of real options, provided by the use of the methodology proposed by Brandão et al. (2012) for the correct evaluation of an investment project.

2.4 Hypothesis development

ROT is a more sophisticated investment evaluation technique and it complements NPV by allowing the investors to make use of flexibility. Thus, under the principles of ROT, investors should not have to invest immediately in a project because of its financial viability, but they can wait until they learn more about the market or about more favorable conditions, transforming flexibility into an economic gain. However, when investing immediately, the investor ignores the option of waiting and the investment becomes irreversible, a sunk cost, and the cost of that missed option must be calculated into the project. Thus, the increase in uncertainty makes the option of waiting more valuable (Gazheli & Bergh, 2018). Some authors, as Chaudhari (2016) and Visconti (2019), advocate that ROT and NPV are complementary to each other and if they work together it will be an improvement in the decision making.

It is worth noting that NPV is implicit in the assessment of real options, serving as a basis for its valuation (Rocha, 2008). In other words, it is through the discounted cash flow that the underlying asset of real options is found. According to Pivoriené (2017), except for volatility, NPV makes use of all variables considered by the Black-Scholes model. Therefore, the results presented by the NPV have a great impact on the value of a real option (Tang et al., 2017).

Considering all of the above, the following hypotheses may be stated:

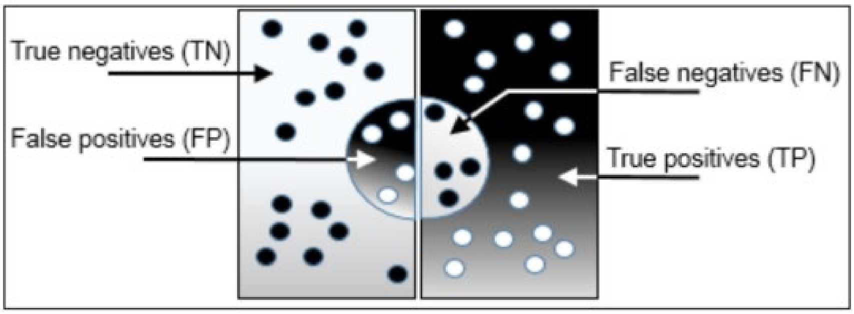
- H_1: When capturing uncertainty more effectively, ROT is more assertive than NPV in determining the feasibility of renewable energy investment, independently from the energy source;
- H_2: There is substantial agreement in decision making between those two investment analysis methods.

3 METHODOLOGY

This exploratory work uses the quantitative method of analysis to statistically validate, through a confusion matrix, the assertiveness of NPV and ROT in identifying the viability of investment projects (Dagdelenler et al., 2016; Silva, 2018).

Commonly used in machine learning, the confusion matrix is an evaluator of the accuracy of the prediction proposed by the model, concerning the data it tries to measure. The information is arranged in the rows of a square matrix, while the model forecasts are allocated in the columns (Caelen, 2017). Figure 1 shows a graphical representation of a confusion matrix.

Figure 1. Confusion matrix



Note. From "*Scala for machine learning: data processing, ML algorithms, smart analytics, and more*", by Patrick R. Nicolas, 2017, Packt Publishing Ltd, p. 72.

According to Nicolas (2017), any model must be able to classify (predict) two classes of events such as A and B. In the case of investment projects, class A can be viable and B, non-viable. When Model X can predict a project as feasible and that it truly is, there is a situation of a true positive (TP). A true negative (TN) occurs when the project is predicted to be unfeasible and the reality confirms that state. However, when the model classifies the project as feasible, but it is not effectively viable, there is the case of the false positive (FP). Finally, if the model fails to classify, stating that the project is not viable when in reality it is, there is the occurrence of a false negative (FN).

According to Gollapudi (2016), from the components of the confusion matrix (TP, TN, FP, and FN), it is possible to calculate the following indicators of a model's assertiveness:

$$\text{Accuracy} = \frac{TP+TN}{TP+TN+FP+FN} \quad (5)$$

$$\text{Sensibility} = \frac{TP}{TP+FN} \quad (6)$$

$$\text{Specificity} = \frac{TN}{TN+FP} \quad (7)$$

False Positives Rate (FPR) = 1 – Sensibility (8)

False Negatives Rate (FNR) = 1 – Specificity (9)

Accuracy can be understood as the model's overall assertiveness and sensitivity, as its ability to correctly classify the occurrence of an event X, while specificity is the correct prediction it makes of the non-occurrence of the event. FPR and FNR are the proportions of error classifiers (Caelen, 2017). It is worth mentioning that Chicco and Jurman (2020) emphasize that, if the data are not balanced, in other words, if there is an unbalanced number between positive and negative cases, accuracy cannot be considered a reliable indicator.

To complement the answer given by accuracy, this study has used the result of the area under the curve called receiver operating characteristics (ROC). The area under the ROC curve (AUC) is a measure commonly used to perform predictive model classifications, given that it offers an accurate sense of the chances of an event X being well classified by them (Camblor & Fernández, 2019). According to Park et al. (2004), for a model to have more predictive power than another, the null hypothesis of equality of the areas must be rejected, which happens when the chi-square test (Pro> chi2) is not significant at 5% level.

The confuse matrix and AUC were calculated by the statistic software Stata 16.1.

In data collection, 244 projects were selected (150 wind power and 94 photovoltaic), considering all of the winning projects of ANEEL´s auctions that occurred between 2011 and 2015. So that was the universe contemplated in this work. The period is justified because it concentrates the largest number of wind power and photovoltaic projects. From those auctions, some information was used to start the analyses: investment values, annual megawatt-hours (MWh), and regulated prices for revenue. It is important to point out that the data are not time-series because each yearly auction has its own winning projects.

During the modeling of free cash flow, some assumptions were made. Linear depreciation was considered for all projects (Pietro et al., 2016). The present value (PV) was traditionally calculated, bringing all the future free cash flow to the present through a discount rate (minimum attractiveness rate - MAR) that equals the cost of equity.

However, although the Normative Resolution no. 882/2020 considers a maximum indebtedness of 61.37%, this study has used random percentages, uniformly distributed, varying between 0% and 100%. This has caused an oscillation in the MAR value between 11.30% p.a. and 13.38% p.a., which is closer to the determination by MME (2019), that considers a MAR of 13% p.a. The use of different levels of indebtedness is also justified for a comparison with the results found by Caldas and Silva (2019), which considered that all projects were financed by 50% of debts. According to MME (2019), all projects have had a cost of debt of 7% p.a.

The hired prices were updated by the Broad Consumer Price Index (IPCA) for 20 years, as it is determined by the Normative Resolution no. 780/2017. These prices were multiplied by the annual production, which were reduced by technical losses, being 2.5% for wind power and 0.75% for photovoltaics (Lindemeyer, 2018; Silva & Ribeiro, 2016). According to Ruaro and Etges (2018) and Fontanet (2012), wind power and photovoltaic projects have maintenance costs of 2.0% and 0.5%, respectively. Based on the ICMS Agreement 109/2014, the existence of tax incidence was disregarded for both revenue and profit.

For each project, the volatilities of the real options were calculated using the approach suggested by Brandão et al. (2012). As the 150 wind power and 94 photovoltaic projects analysed in this work are subject to the same energy structures and fixed costs, the average characteristics (in terms of price, megawatts, and investment) were considered for estimating a single volatility for each type of power generation. For modeling uncertainty, Excel was used to generate a Monte Carlo Simulation (SMC).

From SMC, 10,000 scenarios were created, just for the first year of cash flow, considering the deviations determined by Ordinance no. 236/2014. Those scenarios also considered energy losses, maintenance costs, and financial expenses, as previously indicated. Besides, variations in energy sources (wind speed and solar radiation) were included in the simulations. Through the information contained in the Brazilian wind and solar energy atlases, the average variations in wind speed (14.25%) and average solar radiation (25%) were used, as stated in Amarante et al. (2010) and Pereira et al. (2006), respectively. It is important to note that in the calculation proposed by Brandão et al. (2012), the uncertainties were modeled only for year 1 and making use of equation (2).

In this way, volatilities have reached 8.48% and 6.36% for wind power and photovoltaic projects, respectively. Regarding dividends, Assaf (2019) suggests the use of a percentage of 4% p.a. Finally, data on the effective start-up of wind power and photovoltaic plants were collected from the website of the National Electric System Operator (ONS, 2020).

The investment decisions made individually by NPV (to invest or not to invest) and by ROT (to invest or to wait) were confronted with the effective entry into commercial operation of wind and photovoltaic power plants, according to ONS operation bulletins (2020). A power plant was considered viable only if it was able to enter into commercial activity until August 2020. It is important to highlight that the projects that did not enter into operation within this period were put out of contract, with the granted authorization having been revoked or paralyzed for more than two years. The decisions of each method were considered as expected values, whereas the effective entry into commercial operation was considered as observed values. Table 2 summarizes the variables used in this study.

Table 2. Variables used in the calculation of NPV and ROT

Variable	Description	Form of Collection
Cost of equity	Compensation required by investors: Fluctuating between 11.30% p.a. and 13.38% p.a.	MME (2019) and simulations
Maintenance Costs	Spent to keep the plant operating	Ruaro and Etges (2018) and Fontanet (2012)
Linear depreciation	Uniform devaluation of assets	Investment divided over 20 years
Financial Expenses	Remuneration required by creditors: 7% p.a.	MME (2019)
IPCA	Index used to update prices	Available on the *PortalBrasil* website
Investment	Capital expenditure for each project	Result of auctions 2011-2015
Annual Megawatts-Hour	Energy to be generated per hour in a year	Result of auctions 2011-2015
Technical Losses	Devaluation of the productive capacity already foreseen in the project	Lindemeyer (2018); Silva and Ribeiro (2016)
Contracted Price	Contracted Price in the RSI	Result of auctions 2011-2015
Variations in energy sources	Fluctuations in wind speed and solar radiation	Amarante et al. (2012) and Pereira et al. (2006)
Volatility	Value of uncertainty	Brandão et al. (2012)

Source: Developed by the authors.

The Kappa Index was used to verify the association between NPV and ROT. According to Mast (2007), that indicator is used when it is desired to measure the probability of agreement between the two models when they are applied to evaluate the same event X. The formulations for calculating that index are provided by Cohen (1960, p. 42).

$$K = \frac{Po - Pe}{1 - Pe} \quad (10)$$

According to Mchugh (2012), while P_o represents the actual (observed) probability that the two methods agree on about event X, P_e is a random probability between them, that is, when they randomly give the same response to event X, such as rejecting or approving a project. The author also explains that P_e is calculated by adding the products between the percentages of acceptance and rejection of event X as determined by the two methods. Depending on the value of K, the level of correlation between two different analysis methods can be inferred, as shown in Table 3.

Table 3. Interpretation of the Kappa Index

Value of K	Concordance Level
< 0	Poor
0 - 0,20	Slight
0,21 - 0,40	Fair
0,41 - 0,60	Moderate
0,61 - 0,80	Substantial
0,81 - 1,00	Almost Perfect

Note. Adapted from "The measurement of observer agreement for categorical data" de J. Richard Landis and Gary G. Koch, 1977, biometrics, pp. 159-174.

Kappa Indices (K) calculations were performed using the Stata 16.1 software.

4 ANALYSIS OF RESULTS AND DISCUSSION

Table 4 shows descriptive statistics of the analyzed projects, in terms of investment values, annual megawatt-hours (MWh) and regulated price.

Table 4. Descriptive statistics of the analyzed projects

Var.	Wind Power Projects				Photovoltaic Projects			
	Mean	**Std. Dev.**	**Min**	**Max**	**Mean**	**Std. Dev.**	**Min**	**Max**
Investment (million Reais)	93,2	28,9	28,7	145	137	35,7	20,2	208
MWh	98,173.36	30,449.5	16,655.4	146,392.2	63,544.17	15,405.6	10,519.2	82,400.4
Price (R$)	127.00	33.70	96.97	212.39	271.75	39.91	200.82	305.51

Source: Developed by the authors.

From Table 4, it can be observed that both the average investments and the average contracted prices were higher in photovoltaic projects, when comparing to wind ones, 46.99% and 113.98 %, respectively. According to Viana and Ramos (2018), those differences could be explained because prices in wind power are more able to reflect the technological advances.

In terms of MWh, it is unfair to compare these two sources of energy because the auctions of wind power analyzed in this work have occurred since 2011, whereas the first photovoltaic auction just occurred in 2014.

Table 5 presents the summary of investment decisions (expected values) in wind power and photovoltaic projects, based on suggestions from NPV and ROT.

Table 5. Summary of NPV and ROT decisions in wind power and photovoltaic projects

Decision making	Wind Power Projects		Photovoltaic Projects	
	NPV	ROT	NPV	ROT
Profitable	106	93	75	31
Unprofitable	44	57	19	63
Total	150	150	94	94

Source: Developed by the authors.

From the analysis of Table 5, it is observed that NPV has classified most projects as viable, suggesting that investments should be made in 70.67% and 79.79% of the wind power and photovoltaic projects, respectively. Considering the ROT perspective, there was a slightly more risk-averse stance, mainly in photovoltaic projects, because in 67.02% of the cases it was suggested that it was better to exercise the option of waiting instead of investing immediately.

However, Table 5 does not indicate the assertiveness of these two methods of investment analysis regarding what effectively has happened with the projects. To do so, it was necessary to compare their suggestions with the actual situations in wind power and photovoltaic plants, that is, if they effectively entered into commercial operation until August 2020 and were able to generate energy or not, as it is shown in Table 6.

Table 6. Actual situations of wind power and photovoltaic plants

Situation	Wind Power Projects		Photovoltaic Projects	
	Total	Percentage	Total	Percentage
Generated energy	108	72,00%	78	82,98%
Non generated energy	42	28,00%	16	17,02%
Total	150	100,00%	94	100,00%

Note. Source: Adapted from ONS´s monthly wind and photovoltaic generation bulletin, 2020, retrieved from http://www.ons.org.br/paginas/resultados-da-operacao/boletins-da-operacao.

The actual situations presented in Table 6, when confronted with the decisions suggested by the investment analysis methods (Table 5), originate the confusion matrices that are shown in Tables 7 and 8, concerning wind power projects.

Table 7. NPV´s confusion matrix wind power projects

Observed / Predicted	Invest	Not to Invest	FN
Invest	85	23	23
Not to Invest	21	21	21
FP	21	23	44

Source: Developed by the authors.

Table 8. ROT´s confusion matrix wind projects

Observed / Predicted	Invest	Not to Invest	FN
Invest	77	31	31
Not to Invest	16	26	16
FP	16	31	47

Source: Developed by the authors.

Tables 7 and 8 can be better understood by applying equations (5) to (9), which deal with the accuracy, sensitivity, specificity, and rates of false positives and false negatives, respectively, according to Table 9.

Table 9. The assertiveness of NPV and ROT in wind power projects

Method	Accuracy	Sensibility	Specificity	FPR	FNR
NPV	70,67%	78,70%	50,00%	50,00%	21,30%
ROT	68,67%	71,30%	61,90%	38,10%	28,70%

Source: Developed by the authors.

From Table 9, it can be seen that in global terms (accuracy), NPV has had a slightly higher assertiveness than ROT. However, both methods can have their characteristics better differentiated from the analysis of their sensitivities and specificities. In the first case, the NPV shows a better condition to identify as viable the projects that effectively have become so, having correctly suggested the investment in 78.70% of the cases. In the second case, ROT is more effective in pointing out projects with less potential for success, having succeeded in 61.90% of the situations. This led ROT to present a much lower FPR than NPV, 38.10% compared to 50% of the latter. In contrast, its FNR was higher than the one presented by NPV. In this sense, Cheng (2016) explains that there is no parameter for the FNR value; as for the FPR, the lower the value, the better. Therefore, ROT seems to be a little more cohesive than NPV. Tables 10 and 11 show the confusion matrices for photovoltaic projects.

Table 10. NPV´s confusion matrix photovoltaic projects

Observed / Predicted	Invest	Not to Invest	FN
Invest	63	15	15
Not to Invest	12	4	12
FP	12	15	27

Source: Developed by the authors.

Table 11. ROT´s confusion matrix photovoltaic projects

Observed / Predicted	Invest	Not to Invest	FN
Invest	26	52	52
Not to Invest	5	11	5
FP	5	52	57

Source: Developed by the authors.

Comparing Tables 10 and 11 with the content of Table 6, the assertiveness of the analysis methods can be evaluated, as it is shown in Table 12.

Table 12. The assertiveness of NPV and ROT in photovoltaic projects

Method	Accuracy	Sensibility	Specificity	FPR	FNR
NPV	71,28%	80,77%	25,00%	75,00%	19,23%
ROT	60,64%	66,67%	31,25%	68,75%	33,33%

Source: Developed by the authors.

The analysis of Table 12 ratifies what was shown in Table 9, that is, NPV has a better capacity to select potentially viable photovoltaic projects, due to its higher sensitivity, and ROT is more effective in identifying the ones that are least likely to become successful. However, there was a decrease in the performance of both methods concerning the identification of projects that would have a greater chance of failing, considering that there was a reduction in their specificities. This caused the FPR to be higher than those perceived in the assessment of wind power projects.

The superiority of NPV in terms of accuracy, both in wind power and photovoltaic projects, seems to lead to the rejection of the first hypothesis (H_1) of this study, that is, when capturing uncertainty with greater effectiveness, ROT is more assertive than NPV in determining the feasibility of renewable energy investments, independently from the energy source. However, both NPV and ROT have an unbalanced data classification (as it is shown in Table 5), mainly in wind power projects, confirming the assertion made by Chicco and Jurman (2020). Therefore, it was necessary to calculate the area under the ROC curve (AUC) to reject H_1. Table 13 shows the comparison of the AUC for NPV and ROT.

Table 13. Testing of areas under the ROC for NPV and ROT

Projects	Method	AUC	chi2
Wind Power	NPV	0.6435	0.4265
	ROT	0.6660	
Photovoltaics	NPV	0.5288	0.2888
	ROT	0.4896	

Source: Developed by the authors.

Table 13 shows that, for both energy sources, the null hypotheses of equality of the areas under the ROC curve were rejected at 5% significance level. Thus, it cannot be stated that there is a superiority of any of the methods in terms of global assertiveness, but rather a complementarity between them, with NPV being more able to identify projects with greater chances of success and ROT more effective prospecting the project probability of failure. Thus, H_1 was rejected. This statement confirms the results found by Caldas e Silva (2019), even though the authors made use of the approach proposed by Copeland and Antikarov (2001) to calculate volatility and a fixed discount rate on the free cash flows of the projects.

To test whether or not the H_2 of this study would have to be rejected, that is, if there was substantial correlation between the decision making of NPV and ROT, the Kappa Index was calculated, as it is shown in Table 14.

Table 14. Kappa Index Calculation

Project	Kappa	Standard Error	Z	Prob>Z
Wind Power	0.8076	0.0801	10.08	0.0000
Photovoltaic	0.6797	0.0977	6.96	0.0000

Source: Developed by the authors.

The Kappa indices shown in Table 14 have ranged from 0.8076 to 0.6797, indicating the existence of a substantial agreement between the suggestions issued by NPV and ROT, which precludes the possibility of rejecting H_2. This result differs from the one presented by Caldas and Silva (2019), who found low levels of agreement between the methods and pointed out as a justification the characteristic of the different focuses, that is, while NPV classifies more viable projects, ROT does it for the unviable. However, this explanation is not supported here, given that the same complementary reality between NPV and ROT was found in the present study, but the agreement was greater between the two methods.

It is worth noting that in the Caldas and Silva (2019) paper, variable volatilities were used, with averages of 25.61% and 12.87%, for wind power and photovoltaic projects, respectively, and a fixed discount rate of 12.34 % p.a. for all cash flows. In the present work, when using the principles presented by Brandão et al. (2012), volatilities were maintained at constant values of 8.48% and 6.36%, for wind power and photovoltaic projects, respectively, with discount rates varying, on average, from 12.38% p.a. to 12.34% p.a., for wind power and photovoltaic projects, respectively. Thus, it is clear that the variable that effectively improved the agreement between NPV and ROT was the volatility. Therefore, it can be said that by using a volatility percentage that is more in line with reality, as the model proposed by Brandão et al. (2012), NPV and ROT start showing substantial agreement in their investment suggestions.

5 FINAL CONSIDERATIONS

The proposal of this work was to analyze the assertiveness of net present value (NPV) and real options theory (ROT), at the moment of decision making for investments in renewable energy projects, considering the 244 winning projects in the auctions of reserve energy that occurred between 2011 and 2015.

The main findings showed that NPV and ROT complement each other, ratifying the literature. However, answering the research question, this work noted that NPV is more appropriate to identify projects with a propensity to be successful, whereas ROT can capture more efficiently the chances for a project to fail.

It was also noted that the level of volatility used to calculate the real option value is fundamental to guaranteeing the degree of correlation between NPV and ROT. The more volatility reflects the real uncertainties, the more the methods will come to agreement in the investment projects selection.

This work presented two contributions. Theoretically, it showed the different points of views of the investment analysis methods. NPV has a higher sensibility and ROT has a higher specificity, independently from the used discount rates. Empirically, this work brings an ex post analyzis which enabled to compare the technical suggestions of the investment methods with the realities of the analyzed projects.

The limitations of this study refer to the difficulties in identifying the reasons that motivated the 58 failed projects to have come to this situation, or even in verifying the possibility of those that have been paralyzed for more than two years to start operating again.

For future studies, it is recommended to evaluate the strategies that allow exploring the potential of the two methods, using a combined analysis of the models, in addition to seeking their application in other types of projects.

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1. Definition of research problem	√	
2. Development of hypotheses or research questions (empirical studies)	√	
3. Development of theoretical propositions (theoretical work)		
4. Theoretical foundation / Literature review	√	
5. Definition of methodological procedures	√	√
6. Data collection	√	
7. Statistical analysis	√	√
8. Analysis and interpretation of data	√	
9. Critical revision of the manuscript		√
10. Manuscript writing	√	
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