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Real Options Analysis for Investment Decisions in Geothermal Energy

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Abstract

Geothermal renewable energy can contribute to the reduction of greenhouse gas emissions. However, difficulties have been encountered during its development. It is characterized by high-risk investment and irreversibility, whereas traditional investment analysis techniques have limited applications. As a tool for evaluating energy investments, the real options theory allows flexibility to be incorporated into project design in the face of an uncertain environment and has demonstrated the ability to add economic value to investments. Based on simulations of a geothermal project implemented in Brazil in a real-options framework specifically adapted for the analysis of geothermal investments, this study demonstrates that the tool is efficient in adding economic value to the analysis. In addition, it provides a comprehensive view of the project, identifying the managerial flexibilities and uncertainties that influence profits the most. This model is expected to encourage researchers and investors to evaluate geothermal energy projects in Brazil.

Keywords: investments, real options, geothermal, renewable energy

1. Introduction

Recent changes in the global climate are unprecedented, and all regions of the world are already affected by extreme events such as heat waves, heavy rains, droughts, and cyclones caused by global warming, making climate change a priority on the national agenda. Among mitigation and adaptation measures, the development of renewable energy (RE) has considerable potential for reducing greenhouse gas (GHG) emissions (Becker, 2022; Kim et al., 2017; Kozlova, 2017).

RE projects are often ranked among the riskiest types of investments, and managers evaluate them using more sophisticated techniques (Dranka et al., 2020). In these projects, decision-making, supported by methods of real options, has been shown to be effective in presenting a more realistic value in the evaluation, allowing value addition by using flexibility in the face of unpredictable fluctuations and certificates, which are important for the sustainable development and viability of RE (Liu & Ronn, 2020).

Among the RE sources, geothermal energy has not grown as expected, as a substantially greater effort is necessary to put it on the path of zero-carbon, requiring an increase in expansion much higher than the current one (Agência Internacional De Energia [IEA], 2021). Financing is one of the main barriers and economic analyses are limited to traditional Net Present Value (NPV) calculations (Lukavski et al., 2016). Other obstacles, such as the great need for capital and the high risks of projects, have contributed to the marginalization of geothermal resources (Barasa & Olanrewaju, 2022; Compernolle et al., 2019).

This study adapts a real options (RO) analysis framework (Kim et al., 2017) as a support for decision making, applies it to an investment evaluation in a geothermal RE project, and aims to identify the main variables that affect the economic analyses of geothermal RE projects, analyze the influence of uncertainties on project profit, and evaluate the economic viability of a geothermal plant project in Brazil, capturing the uncertainties raised.

This procedure allows researchers and investors to evaluate geothermal projects with greater precision in relation to the main associated risks in a structure that considers the macro phases of exploration, drilling, construction, and operation.

2. Theoretical Background

2.1 Real Options Theory (ROT)

Decisions in volatile investments in projects characterized by irreversibility, high risk, and uncertainty carry deficiencies if evaluated by traditional methods, as they are unable to incorporate such characteristics (Agaton et al., 2020). However, investors and managers evaluate such projects using the traditional NPV technique, which is the most used decision-making tool for these analyses (Kim et al., 2017). On the other hand, the real options theory (ROT) allows the joint evaluation of flexibility, irreversibility, and uncertainties in investments, including energy (Ditix et al., 1994).

The TOR incorporates managerial flexibility, foreseeing future uncertainties and adjusting to changes in the project, thereby increasing profitability and adding value. It is based on the methods of evaluating "financial options," and similarly, it is a right rather than an obligation (Campisi et al., 2018; Kozlova, 2017; Penizzotto et al., 2019).

The use of ROT in the economic feasibility analysis of projects under volatile conditions has grown in relation to traditional methods such as FCD, and review studies have illustrated its superiority over traditional capital budgeting techniques (Dalbem et al., 2014; Kozlova, 2017).

The types of RO can be the option to postpone the investment for more information; break up the project into phases, allowing us to choose which ones to run; abandon the project; change scale, allowing managers to reduce or expand the project; stop or restart operations, suggesting fluctuations in demand; grow, allowing gains to be improved if some factors turn out better than expected; and alternate inputs or outputs, as in bi-fuel vehicles (Trigeorgis, 1996).

Owing to these advantages, the ROT has been considered for evaluating investment projects in the energy sector in many fields of decision-making, from the evaluation of electricity generation technologies to that of policies (Fernandes, 2011).

Research has applied ROT in RE projects more generally to issues such as different support schemes (Boomsma, 2012), uncertainties, and portfolio effects (Fuss et al., 2012) in project planning (Martínez-beseña & Mutale, 2011) compared to traditional methods (Santos et al., 2014) or investment decisions in developing countries (Kim et al., 2017). Most articles dealing with specific RE sources have focused on wind energy, followed by solar and small hydropower, with few studies considering emerging RE technologies (Kozlova, 2017). No studies have analyzed investments in ROT for geothermal plants.

2.2 Geothermal Plants

Geothermal energy originates from the temperature difference between the surface and Earth's core, which drives a continuous flow of thermal energy toward the surface. It is not dependent on the climate or water levels (Wong & Tan, 2015) and is often considered a renewable and sustainable energy source (Hackstein & Madlener, 2021).

This source plays a significant role in low-carbon energy transitions owing to its ability to provide stable and flexible electricity and its low operating costs compared with thermal sources with similar characteristics (Barasa & Olanrewaju, 2022).

Since 1904, records have shown its exploitation for electricity generation. Only 29 countries currently produced electricity from geothermal resources, contributing less than 1% of the global electricity generation capacity (Barasa & Olanrewaju, 2022).

This slow development is mainly caused by obstacles related to initial investment costs and multiple sources of uncertainty, resulting in high investment risk and difficulty in mobilizing capital (Compernolle et al., 2019).

Brazil has considerable geothermal potential (Arboit et al., 2013), with studies revealing high-enthalpy resources located in the structures of Tocantins and Borborema (Lacasse et al., 2022); however, no forecast shows the implementation of geothermal plants until 2050 (Ministério de Minas e Energia, Brasil, 2020). Geothermal energy mainly serves recreation in hot spring parks such as Caldas Novas/GO, Piratuba/SC, and Araxá/MG (Arboit et al., 2013).

3. Methodology

3.1 Framework for Investment Decision in Geothermal Projects in Brazil

The structure followed in this research is based on the proposal by Kim et al. (2017), who present a process for investment decisions in RE projects with RO in developing countries, consisting of the four main steps illustrated in Figure 1:

a) Step 1 consisted of developing a scenario for an RE project considering each specific source, in this case, geothermal. The project schedule was developed and distinguished between the different phases of planning, design, construction, and operation. Each must be accompanied by managerial decisions on the option of contributing cash to the project. These phases were adapted for exploration, drilling, construction, and operation (Mart ńez et al., 2022), meeting the specific requirements for geothermal sources.

b) Step 2 involved the development of a cash flow forecast. The main variables were energy production, tariffs, the price of certified carbon emission reductions (CERs), and operation and maintenance (O&M) costs. The tariff variable was removed to use fixed feed-in tariffs to stimulate the development of new RE sources in Brazil (Dalvi et al., 2017) and energy production was replaced with net capacity, a variable directly related.

c) Step 3 involved the assessment of the ROs in each phase of the project. To calculate the volatility of a project's value, a Markov asset disclaimer (MAD) approach (Borison, 2005) was used to estimate three scenarios: optimistic, pessimistic, and most likely. A composite options model with a binomial network structure is adopted to represent the sequential nature of the projects.

d) Step 4 supports the final decision on investment in the project, allowing for a comparison of the RO value with the NPV. This step includes a sensitivity analysis via Monte Carlo simulation of the variables raised in Step 2 to quantify their impact on the project's results.

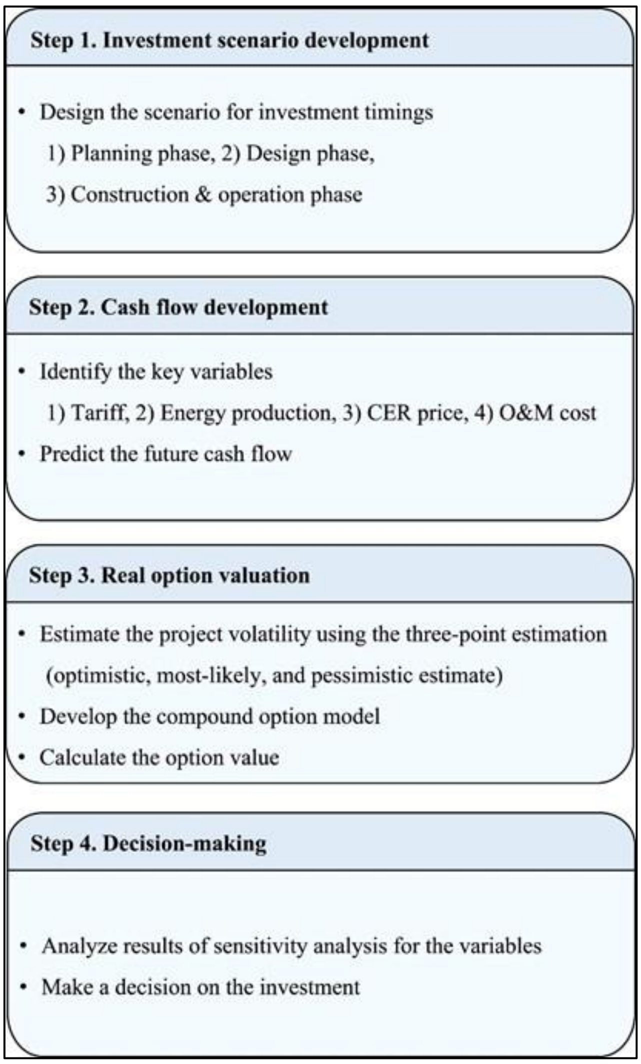

Figure 1. Investment analysis structure

Source: Kim et al. (2017).

3.2 Compound Option Model

The composite option model is based on a three-phase project life cycle: planning, design, construction, and operation, as illustrated in Figure 2 (Kim et al., 2017). The decision stages are managerial flexibilities with which investors can analyze the pertinence of continuity or abandonment of the project within the analyzed projects.

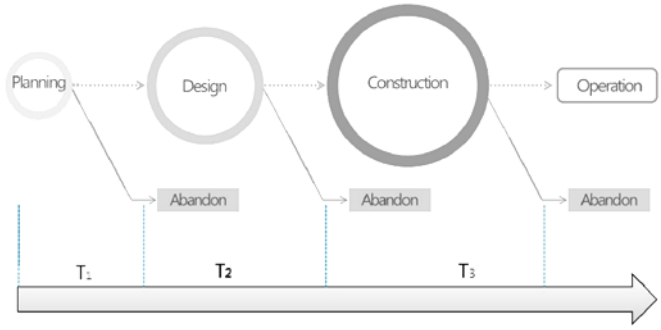

Figure 2. Compound options model

Source: Kim et al. (2017).

In the planning phase is where investors conduct financial and technical feasibility studies that consider the available information limits, study deadlines, and resources. This phase was adjusted and identified as exploration to meet the specific requirements of the geothermal sources (Mart ńez et al., 2022).

In the design phase, available information is increased and refined to clarify its scope. This phase was adjusted and identified as drilling, and is closely related to the design of the geothermal plant (Mart ńez et al., 2022).

The construction and operation phase is the longest period during which investors contribute most of their expected capital and receive returns from the operation.

3.3 Evaluation of the Option

The MAD approach and three-scenario estimation of the proposed methodology use the discounted cash flow contained in the most likely cash flow scenario as the underlying asset value. The cash flows for each of the three scenarios are obtained by combining the multiple uncertainties of the variables in Step 2, as shown in Table 1, where the most likely (moderate) scenario lies between the optimistic and pessimistic scenarios, which consider the best situations for these variables, and the pessimistic scenario, which considers the worst case.

Table 1. Input variables using covered scenarios

Variable	Best case	Moderate case	Worst case
O&M Cost	O&M Cost best	O&M Cost moderate	O&M Cost worst
Capacity factors	Capacity factors best	Capacity factors moderate	Capacity factors worst
Investiment costs	Investiment costs best	Investiment costs moderate	Investiment costs worst
CER price	CER price best	CER price moderate	CER price worst
Combined	Cash flow best	Cash flow moderate	Cash flow worst

Source: Adapted from Kim, Park, and Kim (2017).

Table 2 presents the cash flows for each period in the three scenarios.

Table 2. Cash flows according to scenarios

Period (*n*)	Best case	Moderate case	Worst case
1	Cash *flow best_1*	Cash flow *moderate_1*	Cash flow *worst_1*
2	Cash *flow best_2*	Cash flow *moderate_2*	Cash flow *worst_2*
3	Cash *flow best_3*	Cash flow *moderate_3*	Cash flow *worst_3*
:	:	:	:
n	Cash flow *best_n*	Cash flow *moderate_n*	Cash flow *worst_n*

Source: Adapted from Kim, Park, and Kim (2017).

To calculate volatility, the following equation is used (Kim et al., 2017; Kodukula & Papudesu, 2006):

$$\sigma = \frac{\ln(\frac{S_{opt}}{S_{pes}})}{4\sqrt{t}} \tag{1}$$

where Sopt is the underlying asset value in the bullish scenario, Spes is the underlying asset value in the pessimistic scenario, and t is the project period.

Values were calculated using a binomial network model. The upward movement (u), downward movement (d), risk-neutral probability (q), and option value (C) are calculated using equations (2)–(5):

$$u = e^{\sigma\sqrt{\Delta t}} \tag{2}$$

$$d = \frac{1}{u} \tag{3}$$

$$q = \frac{(e^{rt} - d)}{u - d} \tag{4}$$

$$C = e^{-rt}[qC_u + (1 - q)C_d] \tag{5}$$

In equation (5), r is the risk-free rate, and Cu and Cd are the values of the options associated with upward and downward movements, respectively.

4. Case Study for Investment Decisions with Geothermal Project Simulation in Brazil Through Rot

4.1 Description of the Case

Brazil has an interconnected electrical system of continental dimensions, with 181.6 an of installed capacity and a matrix mainly composed of hydraulic power plants, followed by thermal, wind, solar, and nuclear power plants, as shown in Figure 3 (Ministério de Minas e Energia, Brasil, 2022).

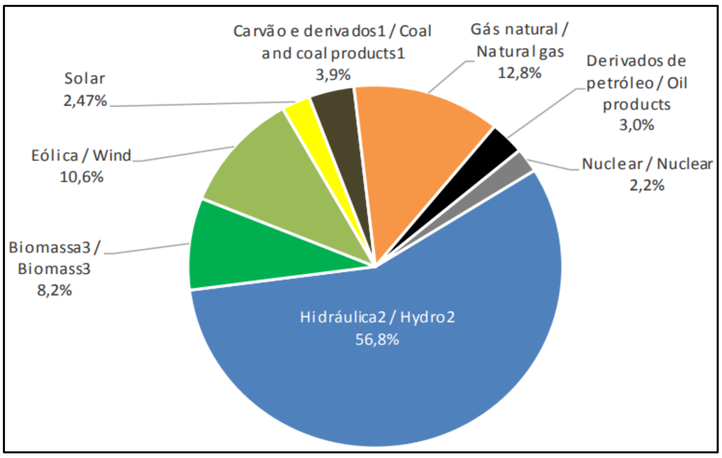

Figure 2. Supply of energy by source

Source: Brazil (2021).

Despite their substantial involvement, renewable sources are extremely dependent on climate variations; in 2021, Brazil had an increase of 113.2% in electricity generation from the use of petroleum derivatives, from 8,556 GWh in 2020 to 18,243 GWh in 2021. Its primary source, hydraulics, reduced its share from 396,381 GWh in 2020 to 362,818 GWh in 2021. The Brazilian Electrical Matrix does not include geothermal plants or perspectives for implementation until 2050 (Ministério de Minas e Energia, Brasil, 2020).

GHG emissions from electricity generation in Brazil totaled 77.8 million tons (Mt) of CO2 in 2021—about 45% higher than in 2020, as shown in Figure 3.

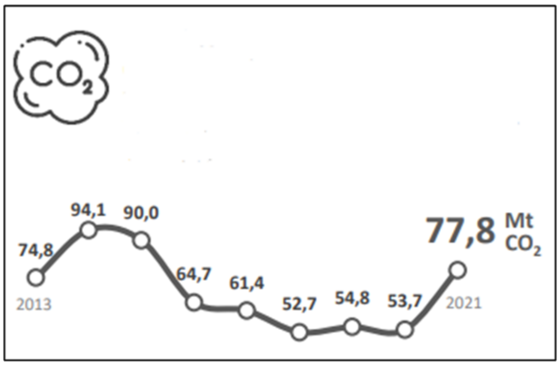

Figure 3. GHG emissions

Source: Brazil (2021).

The simulated case study project was a geothermal plant with a generation capacity of 5 MW and total investment of R$ 192 million under a moderate scenario. The main assumptions of this study are presented in Table 3.

Table 2. Project assumptions

Items	Values
Generator installed capacity	5 MW
Exploration period	1 year
Drilling period	1 year
Construction period	3 years
Period of operation/concession	20 years
Feed-in rate on Nov/22	R$787,83
TMA	9,75%
Long term interest rate	3,62%
Dollar to Real Conversion	R$5,22
Euro to Real Conversion	R$5,55
Risk free rate	6,00%

Source: own elaboration.

The exploration, drilling, construction, and operating periods are 1, 1, 3, and 20 years, respectively, and investors have three opportunities to make investment decisions, as per Section 3.2: (1) now, or year zero, about investing in the exploration phase; (2) in year 1, about continuing the drilling phase; and (3) in year 2, whether to build the geothermal project.

4.2 RO Analysis

The geothermal project was evaluated based on its RO structure. In Step 1, investment parameters are defined at their respective times. Investments in the exploration and drilling phases amounted to BRL 22,635,496.98 and BRL 28,671,629.51, corresponding to 15% and 19% of the costs of implementing geothermal plants in 2020, respectively (Irena, 2021; Mart ńez, Duque, & Ram ŕez, 2022).

Table 4 presents the evaluated variables, with the identification of their respective value references for the optimistic, moderate, and pessimistic scenarios, making it possible to calculate the cash flows and volatility of the project value. The moderate scenario cash flow illustrated in Figure 8 was also used to estimate the present value of the underlying asset. Revenue was made up of the sale of energy production—considered constant throughout the life of the project, with a fixed tariff, and annually readjusted for inflation—and the sale of CERs. The estimated cost of O&M was considered to be US$ 20 per MWh (Hackstein & Madlener, 2021), based on the generation scenarios.

Table 3. Scenarios of the evaluated variables

Variable	Best case	Moderate case	Worst case
O&M Cost	R$ 4.090 M	R$ 4441 M	R$ 4.905 M
Capacity factors	86,70%	78,50%	72,29%
Investiment costs	R$ 95.522 M	141.561	R$ 175.903 M
CER price	€ 99,22	€ 43,91	€ 14,04

Source: own elaboration.

Figure 5 shows the variations in installation costs and capacity factors of geothermal plants installed in the last 10 years worldwide. The simulations in this study considered the values and variations identified for 2020. For the capacity factor, 97% of the availability factor and 2% of the electrical losses were considered until measurement were considered (COPEL, 2007). The conventional NPV was R$119.4 million in moderate cases.

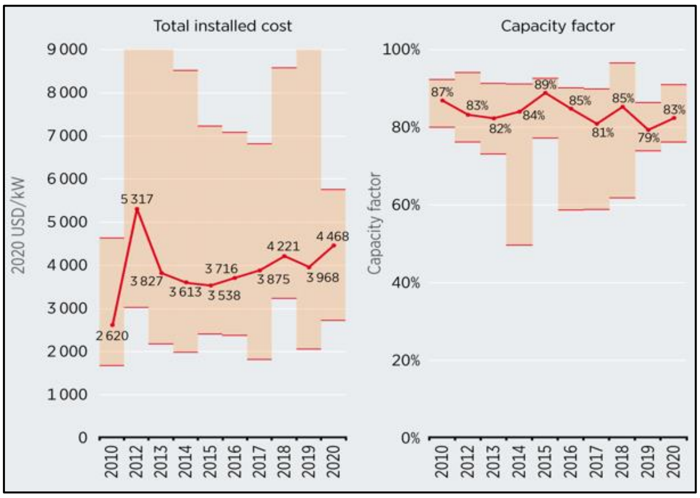

Figure 4. Historical geothermal plant deployment parameters

Source: IRENA (2021).

Considering the context and nature of the project, it was assumed to be eligible for CER under the clean development mechanism (CDM), according to the Kyoto Protocol. The ACM0002/Version 13 methodology for the energy industry and renewable resources was used as reference. As Brazil has no geothermal plant, a geothermal CDM project in Chile was used (ENEL, 2012), resulting in a credit of 0.3309 tCO_2 /MWh. The CER price was estimated based on historical data for the last 5 years, as shown in Figure 6, assuming the lowest value of the period €14.04 for the pessimistic scenario, the highest value €99.22 for the optimistic scenario, and the moderate value €43.91 as the average.

Figure 5. Future carbon credit price

Source: Investing.com (2023).

Using an MAD approach, by discounting cash flows considering the minimum attractiveness rate (MAR) of the moderate scenario, the asset value for the present time was obtained. This amount was considered the underlying asset at R$144.299 million. The annual volatility of the project's return was calculated using the cash flows generated in the optimistic and pessimistic scenarios to find the underlying assets of these scenarios and was applied in Eq. (1), which was 22%. Using equations (2)–(4), we obtain the upward movement (u), downward movement (d), and risk-neutral probability (q) as 1.2409, 0.8059, and 0.5884, respectively.

Figure 7 illustrates the multistage decision-making phases in a project's lifetime together with the values required for each stage. The composite options are calculated using a binomial network and Eq (5). The calculated option value was R$39.436 million and the cash flow with the main variables, in the moderate scenario, is presented in the Figure 8.

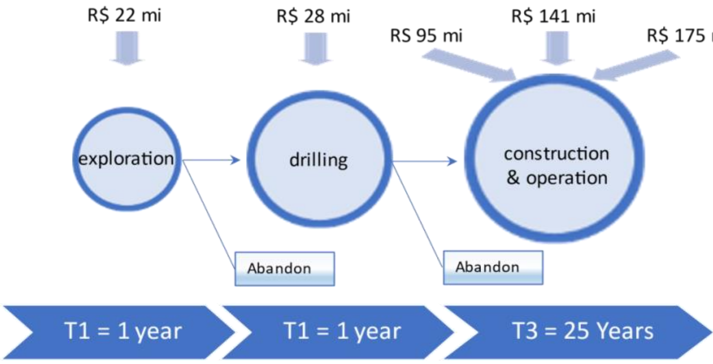

Figure 6. Compound option model case study

Source: own elaboration.

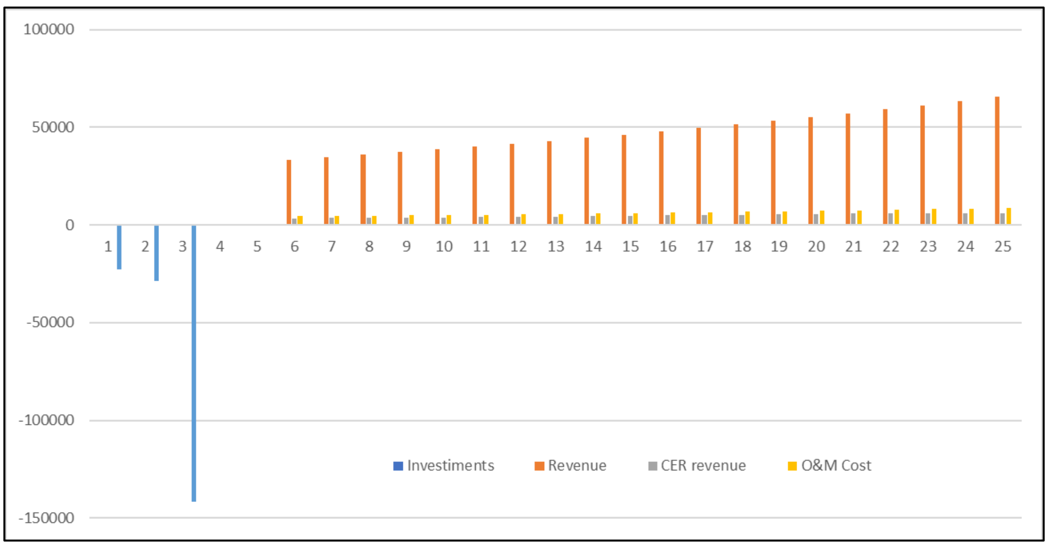

Figure 7. Cash flow with main variables

Source: own elaboration.

Investors can take advantage of the flexibility of each node in the binomial network, as shown in Figure 9. At Node 1, if the cost of the initial investment (R$22.635 million) was greater than the value of the option (R$39.436 million), the project would be abandoned, which is not the case. If uncertainties persisted until the final drilling phase, the project was considered abandoned. At node 2, executing the option at a cost of (R$28.617 million) would generate an option for the construction and operation phase in the amount of R$71.167 million. At node 3, the situation was not favorable, suggesting abandonment of the project. The final decision to build and operate the unit was made in the second year. If the project confirms its viability, establishing itself at node 4 or 5, the value of the option will be R$126.556 million for an investment of R$95.522 million and R$2.668 million for an investment of R$141.561 million. Node 6 represents the worst case, in which investment in construction is refused.

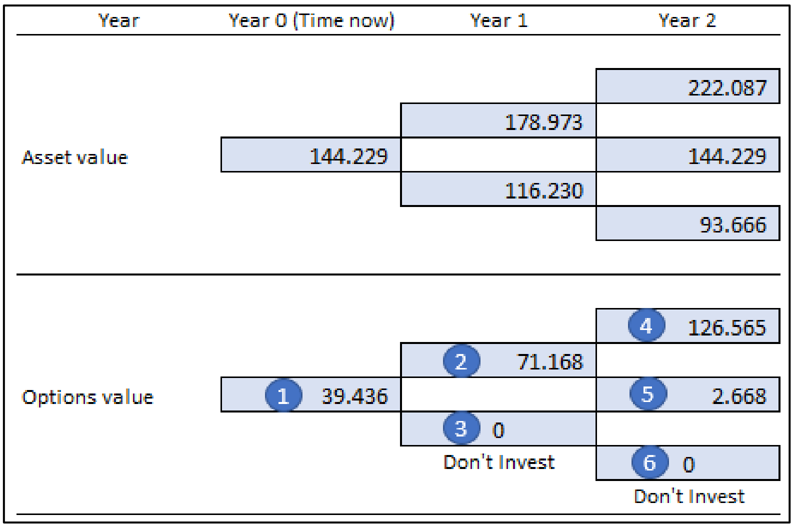

Figure 8. Binomial network for calculating the composite option

Source: own elaboration.

In Step 4, for sensitivity analysis of the four variables identified in the project, a Monte Carlo simulation was performed with 10,000 interactions. Each variable assumed a uniform distribution; that is, it had the same probability of occurrence in each interaction for any value located between the interval of the best and worst scenarios. The results were as follows: Figure 9. They show that the cost of implementing the unit represented approximately half of the influence (-45.3%) on the value of the project option in this case study, while O&M had almost no effect (-0.4%). The capacity factor exercised a 32.5% influence and the revenue from CER sales a 21.7% influence. In this scenario, the focus on the value of the investment for building the plant and the unit's capacity factor are the items that most influence the project's profitability for the investor.

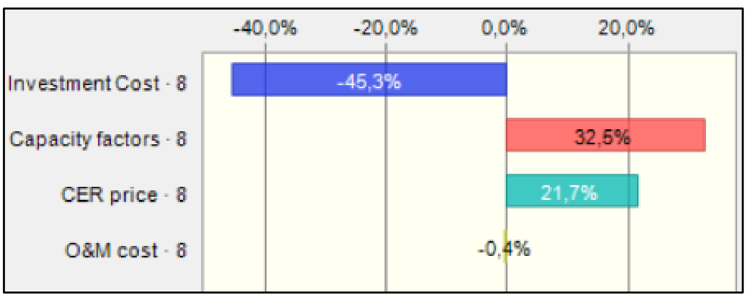

Figure 9. Sensitivity analysis

Source: prepared by the author with Oracle Crystal Ball.

5. Conclusion

Driven by the imminent need to create mechanisms to mitigate global warming, RE) sources have become fundamental tools for the planning of GHG) reduction targets. Geothermal RE is already a part of the energy matrix of many countries; however, its investment costs associated with the technical and operational uncertainties intrinsic to this source have become barriers to its implementation in Brazil, raising the need for adequate evaluation models to encourage investment in that area. Therefore, this study adopts an RO structure as a decision-making support tool and applies it to the analysis of investments in geothermal energy projects, considering managerial flexibility and four uncertain factors: investment, plant capacity, billing with CER, and O&M.

The tool proved to be efficient in helping geothermal investment decisions, presenting an economic value obtained with RO analysis that was superior to that obtained with NPV analysis because it was able to consider project flexibilities and price volatility. The case study analyzed a simulation of the implementation of a 5 MW geothermal plant in Brazil and showed an option value of R$39.44 million, which can be increased in the analysis of the traditional NPV of this unit.

The results also show that managers can optimize profits if they focus on the variables of invested capital and capacity factor of the evaluated plant, as these items influence more than 77% of the option value.

As Brazil does not have installed geothermal plants, several data were obtained from official sources and international projects, which lack accuracy when replicated in Brazil; however, the model presents itself as an adequate tool as it allows the incorporation of a reduction of uncertainties with the increase in information.

Stochastic simulations were used with reference to historical data to calculate the futures prices of CERs. A more robust prediction of the CER prices can provide important data to feed the model.

Future research may also consider other relevant technical uncertainties, such as different technology options and drilling costs, in addition to other factors considered in the decision-making process for geothermal project analyses.

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