Energy and Power Engineering, 2023, 15, 241-263
https://www.scirp.org/journal/epe
ISSN Online: 1947-3818
ISSN Print: 1949-243X

Investment in Generation of Photovoltaic Solar Energy: A Fezsibility Study with Flexibility and Uncertainty

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How to cite this paper: da Silva, L.C. and Baidya, T.K.N. (2023) Investment in Generation of Photovoltaic Solar Energy: A Fezsibility Study with Flexibility and Uncertainty. *Energy and Power Engineering*, **15**, 241-263.
https://doi.org/10.4236/epe.2023.157012

Received: June 16, 2023
Accepted: July 28, 2023
Published: July 31, 2023

Abstract

The objective of this research will be to calculate the feasibility of investing in a solar energy generation project through the development of a methodology that allows the capture of environmental uncertainties by improving decision making. The article presents a comparative study of the feasibility analysis of investment in a solar mini solar energy for a Shopping, considering a regime of certainty and uncertainty. The assumed stochastic variables were energy tariff and price of solar panels. The trajectories were simulated with the binomial approach that combined resulted in a quadratic diagram. The applied methodology presented the best recommendation and the option to wait was the most valuable. The exchange of the energy obtained from LIGHT by own generation of energy with solar photovoltaic source will be viable for the manager since it observes the behavior of the variables over time and follows the rules of optimal decision.

Keywords

Real Options, Self-Generation, Decision Making, Solar Energy, Feasibility of Investment

1. Introduction

Technological advancement influences the growth of energy demand in the world, which provides an incessant search for exploration of new sources of alternative energy that do not pose risks of polluting the environment or causing major environmental catastrophes such as Fukushima, in Japan [1].

Photovoltaic solar energy is one of these alternative sources and according to data available on the website of the Renewable Energy Agency—IRENA [2], in 2000 photovoltaic solar energy represented 0.15% of the total installed capacity of renewable energies. This percentage, in 2016, came to represent 14.67% and in 2017 there was a net addition of 3% of installed capacity in the world, which resulted in a proportion of 17.88% and in 2022 31.04%. The country that stood out the most with the highest installed capacity is China.

In Brazil, according to IRENA e CPI (2023, p.9) [3], to boost solar energy generation, the highlight is the energy auctions for solar plants and the net-metering compensation system encouraged by Normative Resolution 482/2012, which established criteria for distributed generation through the micro and mini-generation system. Other regulations and laws have been implemented over the years. These policies adopted over the years, according to the Energy Research Company—EPE (2023) [4], contributed to the fact that the electricity generated through the solar source in 2019, which represented a percentage of 1% in the Brazilian electricity matrix, in the year 2021 increased to 2.5%. Although Brazil's electricity matrix is composed of 82.9% electricity generated from renewable sources, energy consumption in the country is still mostly from non-renewable sources (51.6% in 2021).

The authors, Carvalho *et al.* (2017) [5], studied the mechanisms of government incentives for tax exemptions and other more attractive lines of financing adopted by the Brazilian government and the State of Ceará, for which they carried out financing simulations and analyzed the feasibility of investment using the Net Present Value methodology. The authors identified the need to make law more flexible and the influence of the energy tariff as one of the main items that could boost or slow down advances in the use of photovoltaic solar technology in Brazilian homes and in the State of Ceará, where the case study was carried out. Therefore, in view of the above, the viability of any solar energy project is related to the cost of generating the technology and the energy tariff adopted by the distributors. It is important to highlight that the authors Carvalho *et al.* (2017) [5], developed their studies and simulations for residences.

The investigations of this study will be directed to medium voltage businesses that operate in the free energy market. The problem of this scientific research will be: how should a medium voltage business calculate the viability of a solar energy project in the face of environmental uncertainties that require flexibility in decision-making from the manager?

In view of the above research problem, the objective of this article will be to capture these uncertainties and contribute to the manager to provide the improvement of his decision on carrying out investments in photovoltaic solar energy.

To achieve the proposed objective, it is necessary to develop an investment analysis methodology that can capture the environmental uncertainties that are reflected in the technology used for energy generation and in energy tariffs. For the development of a tool that provides the best investment recommendation in a volatile environment, this study will present a solution through recursive dynamic programming for Real Options.

The business selected for the application of the methodology was a shopping center located in the city of Volta Redonda. Electric energy, according to data provided by the project's administrator, represents a significant weight in the composition of the total cost (33.64% of the total cost). According to Shopping Centers magazine (2015, p.12) [6], energy costs reach 60% of all costs in a shopping mall. Therefore, the development and experimentation of the developed tool will contribute to make possible the valuation of existing options in the future, capturing the impact of uncertainty on the value of the project.

The innovation and justification of this research are because it is a medium voltage consumer, classified as a special consumer in the free energy market, and contributes to investment decision-making with the use of photovoltaic solar energy technology in the resolution with Real Options recursive dynamic programming extending the binomial model to Real Options.

The structure of this article is as follows: section 2 will present the main strategies adopted to boost solar power generation in Brazil, highlighting auctions and regulations. Sections 3 and 4 will describe the methodological procedures for feasibility analysis without and with uncertainty considering two stochastic variables (energy tariff and the price of solar panels). The results of this investigation will be demonstrated in section 5. In section 6 the conclusions will be presented answering the initial objective of this investigation.

2. Solar Energy in Brazil

The Brazilian government has been concerned about increasing the share of solar energy in the electricity matrix over the years. In 2017, the share of electricity generation produced from solar and wind energy represented 8.5%. The expansion of installed electric energy capacity with the use of solar energy in Brazil is the result of the evolution of strong regulation in the sector and incentive policies adopted over the years. In the year 2022, Brazil became the third position in the world in the use of renewable energy to generate energy of 175,261.9 MW. (EPE, 2017, p.18 [7]; Country Ranking, 2023 [2]).

Incentives for the use of photovoltaic solar energy in Brazil started with the "Luz para Todos" program in 2003 (IRENA, OECD/IEA & REN 21, 2018) [8].

Auctions emerged in 2004, according to Tolmasquim (2015, p.62) [9] because of the regulation of the electricity market with Laws 10,847 and 10,848. Law 10,848 created two types of energy markets: the Regulated Contracting Market and the Free Contracting Market. These markets allowed short, medium, and long-term electricity acquisition contracts to be carried out through auctions. According to data from IRENA, OECD/IEA & REN 21, (2018) [6], the first Auction to contract additional wind and solar photovoltaic energy capacity was in 2009 (IRENA, OECD/IEA & REN 21, 2018) [8].

In 2012, to encourage the generation of energy in homes, the net-metering system was created, through Resolution 482 [10], of the National Electric Energy Agency—ANEEL, which introduced a compensation system with net metering of energy generation from renewable sources small scale, connected to the network. Resolution 482 [10] allowed the surplus electricity produced by low and medium voltage generators to be injected back into the electricity grid, in exchange for electricity billing credits to be recovered within an established period of 60 months.

Resolution 482 (this resolution and resolution 687 are repealed and superseded by resolution 1059/2023, as described in the following paragraph) [10] was amended in 2015 by Resolution 687/15 (repealed and extended by resolution 1059/2023) [11] and aimed to expand incentives for distributed generation of photovoltaic solar energy. The changes regulated three things: shared generation; power generation in condominiums; remote self-consumption that encourages the production of energy in locations (example land) with compensation for credits in the electricity bill of the consumer's home (generator) in the same city. In that year, 2015, the 7th and 8th Reserve Auctions took place in August and November, which were responsible for contracting 33 solar plants equivalent to 929.3 MW (REN 687/2015 [11]; CENÁRIOS SOLAR, 2016, pp. 25, 63 [12]).

Currently, Normative Resolution 1059 (2023) [13] refines the regulation of the net-metering system for micro and mini-generation of energy and the standardization in relation to the billing of micro-generation and distributed mini-generation plants. Large power generating plants are prevented from dividing into smaller units to fit within the installed power limits of distributed microgeneration or mini generation. The resolution ensures the rights of consumers and procedures for gaining access to distributed generation as well as establishing rules for the billing of distributed generation by energy distributors.

The Ten-Year Expansion Plan, by the Ministry of Mines and Energy and the Energy Research Company, foresees an expansion of 9641 MW by 2026, resulting from a source of Photovoltaic Solar Energy (MME/EPE, 2017) [14]. This goal was reached in 2021 when Brazil now has an electrical capacity of 13,055 MW. In 2022, Brazil increased its electrical capacity with photovoltaic solar technology generating 24,078.9 MW (COUNTRY RANKING, 2023) [2]. Auctions were mainly responsible for the increase in installed solar capacity in Brazil with a growth of 248% from 2015 to 2016 and 1271% from 2016 to 2017. This sporadic increase was the result of the operation of 32 solar plants of independent solar energy production in 2017. From 2017 to 2018 a total of 45 plants came into operation. In later years (2019 to 2022), the plants started supplying energy from various sources, mainly from solar photovoltaics. For the years 2023, 2024 and 2025, the impact will be greater as the contracted plants will start operating, in 2023, the energy contracted in the 2018 auctions will start operating with a generation potential of 203.7 MW, for 2025, plants that won the 2019 auctions are contracted to supply 502 MW with solar photovoltaic technology. The auctions that took place in 2021 will ensure that Solar Plants deliver the contracted energy in 2025 of 169.30 MW and in 2026, 236.40 MW. In 2022 the energy contracted through the auctions was 106.6 MW to start operations in 2026 (ANEEL, 2023) [15]. According to the magazine Scenarios Solar 2016-2017 (2017, p. 26-31) [12], the investors who stand out in the solar energy sector and who are responsible for large-scale solar plants in Brazil participating in the 2014 and 2015 auctions are: Enel, Canadian Solar, Cobra, Solaire Direct, SunEdison, FRV, Kroma, Renova, Gestamp, SER, Steelcon/Soliker, Gransolar, Rio Alto, European Energy and others. These investors have plants in operation and under contract, totaling 128 projects.

This research was developed with data from a Shopping Mall and the premise considered was that it will have the option of investing in a mini solar plant, becoming a self-producer agent to meet its contracted demand of 1.35 MW, if the Shopping Mall produces surplus in a given period, its sale is ensured by article 19 (nineteen) of Normative Resolution—REN ANEEL 676 (2015) [16]. It will be analyzed, through the methodology presented in the next section, the feasibility of the investment without flexibility and uncertainty through the sizing of the system to calculate the cost of the investment and the cash flow to calculate the static Net Present Value and the other moment will be the analysis of the feasibility considering the flexibility and uncertainty in relation to the energy tariff and the value of the investment in the project with the resolution through recursive dynamic programming in Real Options.

3. Methodological Procedures without Uncertainty

The assumption considered for estimating the operation of the electricity generation system is 25 years with an efficiency loss of 0.576%. The Investment will be a function of the price of the solar panels (I) and the Present Value of the cash flows will be a function of the energy tariff (P). The discount rate to be considered will be risk free at 4% to ensure that the project is not arbitraged.

To calculate the Present Value the mathematical representation will be:

$$PV(P) = \sum_{i=1}^{25} \frac{P_i Q_i - a_i I_0}{(1+rf)^i} \tag{1}$$

where:

$PV(P)$ = Present Value of discounted cash flows as a function of the energy tariff.

P_i = Energy tariff in each period.

Q_i = Quantity of energy generated by the system considering the efficiency loss.

a_i = Operating and administrative expenses which, following Peraza, D. G., Gasparin, F. P., & Krenzinger, A. (2015) [17] and Ribeiro, R., Brito, N., Medeiros, M., Simões, M., & Oliveira, S. (2017) [18], will correspond to 1% of the investment cost.

I_0 (I) = Total investment costs as a function of the price of solar panels.

rf = Risk-free rate.

i = Period.

Q_i will be denoted by:

$$Q_i = Q \times (1 - efic)^{i-1} \tag{2}$$

where:

Q = Amount of energy generated by the system.

efic = System efficiency loss factor. The efficiency loss of the solar modules will be 0.576%/year, following the studies of and Ribeiro, R., Brito, N., Medeiros, M., Simões, M., & Oliveira, S. (2017) [18], who developed a methodology for analyzing the economic viability of a photovoltaic plant.

The investment value will be obtained through the following representation:

$$I_0(I) = I_a(\text{panels}) + I_b(\text{inverters}) + I_c(\text{cables} + \text{others}) + R \tag{3}$$

where:

I_0 = Represents the value in Reais of the total investment cost as a function of the price of the solar panels.

I_a = Represents the value in Reais of the solar panels.

I_b = Represents the value in Reais of the inverters.

I_c = Represents the value in Reais of the cables and others. The proportion considered of this cost will be 40% of the total cost (ABINEE, 2012, p. 160) [19].

R - Represents the value in Reais of reinvestment. Following Ribeiro, R., Brito, N., Medeiros, M., Simões, M., & Oliveira, S. (2017) [18], the value of reinvestment will not be considered to obtain the estimate of the value of cables and others.

Note: The costs (I_c) were called by the Brazilian Association of Electrical and Electronic Industry—ABINEE [19] as BoS (Balance of System). For ABINEE [19], the costs of the plates with the inverters represent between 50% and 60% of the total cost of the photovoltaic system. The R represents the reinvestment related to the replacement of inverters and depreciated cables, which will not be considered to calculate the BoS (ABINEE, 2012, p. 160) [19].

Therefore:

$$I_c = 0.40(I_0 - R) \tag{4}$$

The total amount of the investment cost will be:

$$I_0 = \left(\frac{I_a + I_b}{0.6}\right) + R \tag{5}$$

The Net Present Value (NPV) will be:

$$NPV(P, I) = -I_0(I) + PV(P) \tag{6}$$

where:

$NPV(P,I)$ = Net present value as a function of energy tariff and price of boards.

I_0 = Total cost of investment.

PV = Present value of discounted cash flows.

4. Methodological Procedures Considering Uncertainty and Flexibility

The uncertainty variables identified as those that influence the project cost are the energy tariff and the price of solar panels. To represent the different paths that can be followed by the energy tariff and the price of solar panels, each variable will adopt a binomial random path from Cox, Ross & Rubinstein (1979) [20] to approximate the Brownian motion process.

The combination of the two variables will generate a quadratic diagram, with four possible states, making the solution of uncertainty more complex.

The representation I_0 will be applied to the price of solar PV plates in the present time and P_0 to the energy tariff in the present time. The ramp-up factor will be represented by u_1 for asset P_0 and u_2 for asset I_0. With the variables described the representation results in a four-asset model shown in **Figure 1** with the two variables and four branches.

The Net Present Value (NPV) will be a function of the energy tariff and the price of the solar energy plates, *i.e.* $NPV_t\,(P_t,I_t)$.

To seek to resolve the uncertainty and provide a recommendation for the best path, the diagram presents the four possible combinations: the first combination considers the possibility that the tariff and the price of the solar panels will rise (Pu_1Iu_2), the notation could be simply Pu_1Iu_2, the second considers that the tariff will rise and the price of the solar panels will fall (Pu_1Id_2), the third combination considers that the energy tariff will fall and the price of the solar panels will rise (Pd_1Iu_2) and the fourth combination considers that the energy tariff and the solar panels will fall simultaneously (Pd_1Id_2). Therefore, four NPV values will be obtained considering the movement of variables P and I.

"Pa" is the state where the energy tariff rises to P_0u_1 and the solar panel price rises to I_0u_2. "Pb" is the state where the energy tariff rises to P_0u_1 and the solar panel price falls to I_0d_2. "Pc" is the state where the energy tariff falls to P_0d_1 and the solar panel price rises to I_0u_2. "Pd" is the state where the energy tariff falls to P_0d_1 and the solar panel price falls to I_0d_2. The probabilities are defined by calculating the risk sizing.

For the solution and calculation of the risk dimensioning resulting from the combination of these two uncertainty variables, represented by φ, the methodology will be developed that will extend the preferential state-time approach of Arrow & Debreu (1954) [21] and binomial of Cox, Ross & Rubinstein (1979) [20].

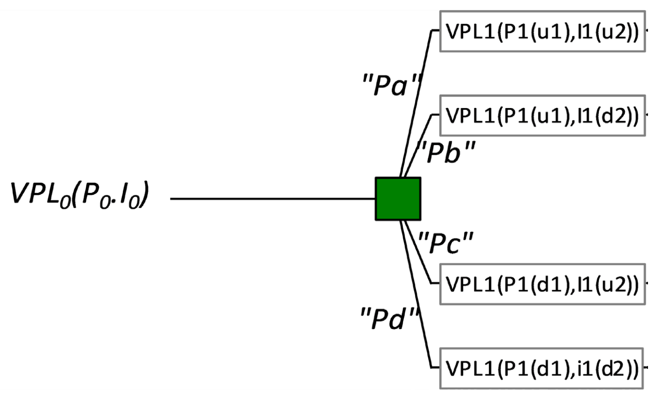

Figure 1. Combination of the four variable states.

By combining the states and probabilities of the two stochastic variables, in a risk-free environment, the probabilities are defined as follows:

$$p_a = \phi_a (1 + rf)$$

$$p_b = \phi_b (1 + rf)$$

$$p_c = \phi_c (1 + rf)$$

$$p_d = \phi_d (1 + rf)$$

To define φ, the studies started from the research of Arrow & Debreu (1954) [21] for the solution of uncertainties.

The methodological approach presented in this section will result in the construction of the quadratic balance sheet by extending the binomial model, developed by Cox, Ross & Rubinstein apud Hull (2016, p.293) [22], considering two variables of uncertainties. It is important to emphasize that the model developed in this study can be applied in any business to contribute to decision making in relation to the investment feasibility analysis with more than one uncertainty variable.

One can create an asset that pays $1 in state "a" and pays nothing in the other states. This asset can be bought on the market today for a price φ_a. In other words, φ_a is the price of the asset that pays $1 in state "a", and nothing in the other states. Similarly, φ_b is the price of the asset that pays $1 in state b and nothing in the other states. The same will occur with φ_c and φ_d.

So, for the portfolio to be risk-free and for the investor to receive $1 in any state, he will have to pay $\varphi_a + \varphi_b + \varphi_c + \varphi_d$ as shown in **Figure 2**.

Therefore,

$$\phi_a + \phi_b + \phi_c + \phi_d = \frac{1}{1 + rf} \tag{7}$$

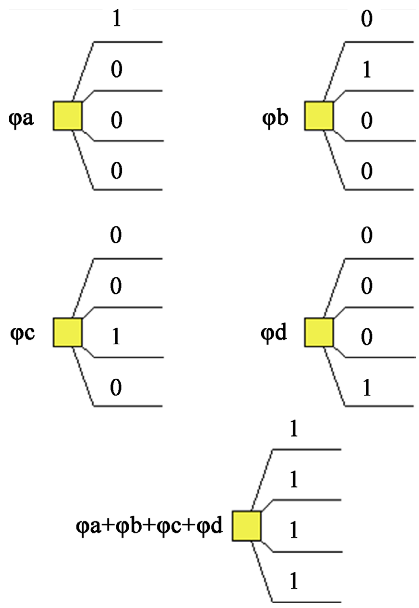

Figure 2. Risk-free portfolio.

The possibilities of occurrence will be described below in **Figure 3**, considering four states for each variable.

Diagrams a, b, c and d in the above representation (**Figure 3**) show the four possible states for the price of the plates and the price of energy. The ratio between the energy tariff and the price of the plates shows how much energy I must pay to obtain the solar plates.

By dividing by the variables, themselves the following equations are obtained:

Equation a:

$$\phi_a u_1 + \phi_b u_1 + \phi_c d_1 + \phi_d d_1 = 1$$

Assumption: $u_1 d_1 = 1$ then: $d_1 = \frac{1}{u_1}$

Substituting into the above equation, Equation (1) will be obtained as follows:

$$\phi_a u_1^2 + \phi_b u_1^2 + \phi_c + \phi_d = u_1 \tag{8a}$$

Equation b:

$$\phi_a u_2 + \phi_b d_2 + \phi_c u_2 + \phi_d d_2 = 1$$

Substituting d_2 into the equation will give us:

$$\phi_a u_2^2 + \phi_b + \phi_c u_2^2 + \phi_d = u_2 \tag{9b}$$

Equation c:

$$\phi_a \frac{u_1}{u_2} + \phi_b \frac{u_1}{d_2} + \phi_c \frac{d_1}{u_2} + \phi_d \frac{d_1}{d_2} = 1$$

Substituting d_1 and d_2 into the equation we get:

$$\phi_a u_1^2 + \phi_b u_1^2 u_2^2 + \phi_c + \phi_d u_2^2 = u_1 u_2 \tag{10c}$$

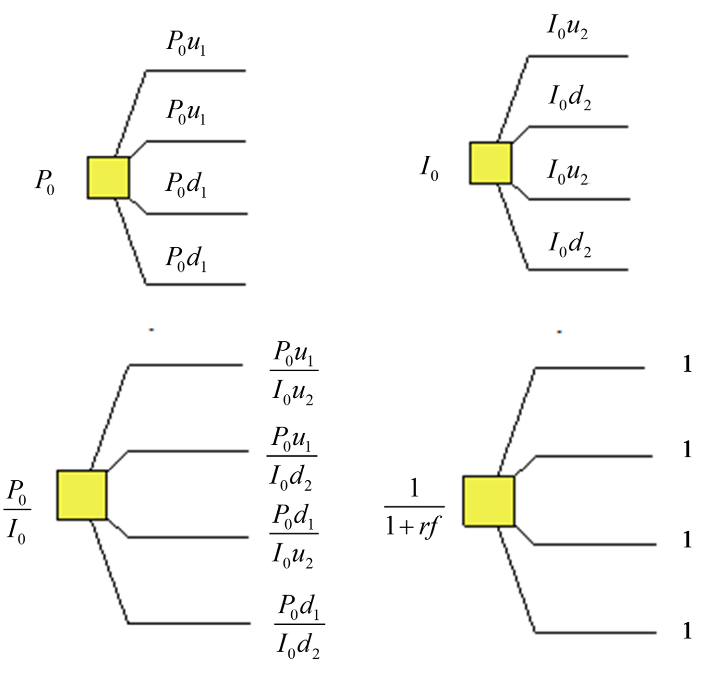

Figure 3. Diagrams of possible occurrences in four states.

Equation d:

It has already been demonstrated earlier in Equation (7).

$$\phi_a + \phi_b + \phi_c + \phi_d = \frac{1}{1+rf}$$

Therefore, the matrix for calculating φ will be as follows:

$$\underbrace{\begin{bmatrix} u_1^2 & u_1^2 & 1 & 1 \\ u_2^2 & 1 & u_2^2 & 1 \\ u_1^2 & u_1^2 u_2^2 & 1 & u_2^2 \\ 1 & 1 & 1 & 1 \end{bmatrix}}_{\text{Matriz } U} \underbrace{\begin{bmatrix} \phi_a \\ \phi_b \\ \phi_c \\ \phi_d \end{bmatrix}}_{\text{Vetor } \varphi} = \underbrace{\begin{bmatrix} u_1 \\ u_2 \\ u_1 u_2 \\ VP \end{bmatrix}}_{\text{Vetor } c} \quad (11d)$$

The representation for the operation between the matrices will be:

$$U_{4\times4} \cdot \phi_{4\times1} = c_{4\times1} \quad (12d)$$

Therefore, to find φ we calculate the inverse of the matrix "U":

$$\phi_{4\times1} = U_{4\times4}^{-1} c_{4\times1} \quad (13d)$$

The expected value in the present time of the estimated value for period one will be shown as follows:

$$E_0(V_1 | P_0, I_0) = \phi_a V_1(P_1 u, I_1 u) + \phi_b V_1(P_1 u, I_1 d) + \phi_c V_1(P_1 d, I_1 u) + \phi_d V_1(P_1 d, I_1 d)$$

$$E_0(V_1 | P_0, I_0) = \frac{1}{1+rf}\left[p_a V_1(P_1 u, I_1 u) + p_b V_1(P_1 u, I_1 d) + p_c V_1(P_1 d, I_1 u) + p_d V_1(P_1 d, I_1 d)\right]$$

Figure 4 shows the general form of recursive dynamic programming where w represents the upward (u) or downward (d) movement in period i of the P or I variable.

5. Results and Discussions

Initially, the results found with the calculation of the static Net Present Value will be presented, that is, in a regime of certainty and without flexibility. Soon after, the proposed methodology will be applied to assist the manager in decision making in a volatile environment.

5.1. Feasibility Analysis with Traditional Model

To analyze the feasibility of investment without considering the uncertainty and

General form:

$$VPL_i(P_i w_i, I_i w_i) = \sum_{i=1}^{N} \left\{ \frac{\left[P_i w_i \times \left(Q \times (1 - 00576)^{i-1}\right)\right] - 0{,}01 \times I_i w_i}{(1+rf)^i} \right\} - I_i w_i$$

$$E_i(V_{i+1} / P_i w_i, I_i w_i) = \frac{E_{i+1}(V_{i+1} / P_i w_i, I_i w_i)}{1+rf}$$

$$V_i(P_i w_i, I_i w_i) = Máx\left(VPL_i(P_i w_i, I_i w_i); E_i(V_{i+1} / P_i w_i, I_i w_i)\right)$$

Where w represents the upward (u) or downward (d) movement in period i of the variable P or I.

Figure 4. General form of the Recursive Dynamic Programming representation.

flexibility in an investment of photovoltaic solar power generation, the first step is to raise the costs of the investment and then build the projected cash flows for the next twenty-five years (duration of the solar panels).

To raise the investment costs, it is necessary to size the system resulting from the energy demand of the Shopping Center, then an estimate of the energy tariff is made based on the survey of monthly costs identified later. The value of the average tariff and the estimated monthly consumption are entered for the system sizing in the PVSOL premium 2017 software [23].

When migrating to the free energy market, the Shopping Center contracted from LIGHT Serviços de Eletricidade S.A. a pre-established peak and off-peak demand of 1350 kW. In the free contracting environment, the costs accounted for by the Shopping Center are:

1˚. Charges on the transportation of electricity on the wire composed of TUSD (Tarifa de Utilização do Sistema de Distribuição or Tariff for Use of the Distribution System) and the provision of services by LIGHT.

2˚. Energy tariff with charges levied by LIGHT and multiplied by consumption.

3˚. Compensation and adjustment of differences—the settlement of differences is calculated by comparing the measured energy with the contracted one, the result of this difference is valued by the Price of Settlement of Differences—PLD.

The average tariff found based on the total costs described above and provided by Shopping was R$0.5426kWh (Brazilian currency).

Table 1 below shows the average energy tariffs paid by the Shopping Centre on the free energy market.

Table 1. Estimation of the value of the average energy tariff.

2017	Total Costs	Consumption	Tariff
Jan	243.993,28	483.597	0.5045
Feb	276.330,29	459.867	0.6009
Mar	162.687,21	392.138	0.4149
Apr	220.169,95	452.191	0.4869
June	175.669,44	400.248	0.4389
July	225.405,16	385.616	0.5845
Aug	181.294,07	373.855	0.4849
Sept	231.973,76	366.071	0.6337
Oct	274.669,56	382.539	0.7180
Dec	229.851,39	411.170	0.5590
Total	2.222.044,11	4.516.788	-
Average	222.204,41	410.617	0.5426

Source: spreadsheet adapted from data provided by the operational manager of the Shopping Center and made available for the development of this research. Sample of a Table footnote (*table footnote is dispensable*).

It is important to note that the operation of the shopping center takes place from 9 am to 9 pm. The mini solar plant will be able to sell the surplus energy generated on the free market and buy it during the time of absence of solar radiation in the periods, for example, from 6 pm to 9 pm. As this is a barter process, these values will not be considered for the construction of the cash flow.

5.1.1. Sizing of the Solar Power Generation System to Self-Generation

For the sizing of the energy generation system to self-generation, the PV*SOL premium [23] software will be used, which is a tool adapted to the Brazilian reality. The software provides the number of plates and inverters needed to meet the demand of 420,000 kWh/month.

The model of the plates and inverters was defined based on the Environmental Control Plan of the Solar Photovoltaic Plant of Pirapora, in Minas Gerais, carried out by Solatio Brasil Gestão de Projetos Solares LTDA-ME [24]. The panels will be Canadian Solar, model CS6X 310P, and the inverters, ABB PVS800-57-1000 kW. The prices of the products were purchased on the internet.

Table 2 shows the prices and quantities of modules (panels) and inverters needed to meet the demand of the Shopping Centre.

The assumptions established for calculating the investment are set out below:

- Considering the values of the solar panels of R$ 16,666,363.71, the inverters R$ 900,000.00 and the value of the reinvestment of R$ 13,725,896.79, the value of the cost of the cables and others found will be R$ 11,710,909.14 and the cost of the investment will be R$ 43,003,169.63. These values are shown in **Table 3** (Cox, Ross, & Rubinstein, 1979) [20].

Table 2. Prices and quantities of modules and inverters.

Description	Size and price	
	Sizing	Price/unit (R$)
CS6X 310P solar panel	9.788	1.702,74
Inversor ABB PVS800-57-1000 kW	3	300.000,00
Land	18.781 m^2	231,48/m^2

Source: developed by the authors.

Table 3. Prices and quantities of modules and inverters.

Investment	R$	Time in years of replacement
Solar Panels	16.666.363,71	25
Inverters	900.000,00	10
Cables and others	11.710,909,14	10
Reinvestment (inverters and others)	13.725.896,79	
TOTAL	43.003.169.63	

Source: developed by the authors.

Table 3 shows the prices, the quantities of panels needed and other investments required for the implementation of the mini solar power plant for self-generation.

- The amount generated by the PV system, multiplied by the average tariff shown in Table 1, will be considered as revenue.

- The risk-free rate will be 4%.

- In the 11th and 21st periods, the reinvestment values related to the replacement of inverters, cables and others that have a depreciation term of 10 years will be considered.

- In the 25th year the project term will end, and half of the values of the inverters, cables and others will be included in the gross cash flow. This cash inflow will represent the revenue from the sale of scrap metal.

- Considering that the land is a strategic and permanent investment and may in the future be used for different investments that may cause an increase in its value, it will not be considered for the feasibility analysis and construction of the asset tree. It will be at the discretion of the mall's managers to decide whether to invest in the land or rent it to invest in solar energy.

5.1.2. Operating and Administrative Costs ("*ai*" Model Variable)

The costs to be considered for the operation of the mini self-generation plant and construction of the cash flow are maintenance costs (Holdermann, C., Kessel, J., & Beigel, J. (2014), p.614) [25] and sector-specific fees and contributions.

Considering that the Shopping is classified in group A4 (2.3 to 25 kV) and that it will use the grid distribution system to make the generated energy reach it, the fees to be considered are listed below:

1) TUSD (Tariff for the Use of the Distribution System)—follows ANEEL Normative Resolution—REN no. 481 of 2012, which regulates the 50% discount for solar generation from projects that entered commercial operation after 12/31/2017. The value of the TUSD established by ANEEL Homologate Resolution—REH No. 2375 of March 13, 2018, for the A4 voltage group for power generation was R$ 4.20 R$/kW/month, totaling R$ 68,040.00 (result referring to the contracted demand per month of 1350 × 12 months × R$ 4.20/kW).

2) TFSEE (Electric Energy Services Inspection Fee)—according to ANEEL Technical Note No. 005/2016, the TFSEE rate will be 0.4% and ANEEL Order No. 4402 of 12/29/2017 established the annual Unit Economic Benefit for the year 2018 in the amount of R$ 640.42/kW. Based on this information, the inspection fee of R$ 2.56/kW/month is calculated, totaling the fee amount of R$ 41,499.22/kW.

Peraza *et al.* (2015) [17] and Ribeiro, R., Brito, N., Medeiros, M., Simões, M., & Oliveira, S. (2017) [18] estimated Operating and Administrative Costs at 1% of the initial investment.

In view of the above, the Operating and Administrative costs are presented in Table 4.

For the construction of the discounted cash flow, the following assumptions already mentioned above and summarized in Table 5 below will be considered.

Table 4. Operational and administrative costs.

Costs	R$
Maintenance	215.015,85
TUSD	68.040,00
TFSEE	41.499,22
Other costs	105.476,63
TOTAL	430.031,70

Source: developed by the authors.

Table 5. Summary of the assumptions adopted..

	Assumptions
Risk Free Rate	4%/year
Energy Tariff	R$ 0,5426
Loss of board efficiency	0.576%/year
Operational and Administrative Costs	1% of I0
Replacement of Inverters and Cables	11^{th} and 21^{st} year
Sale of Scrap	25^{th} year

Source: developed by the authors.

5.1.3. Calculation of Net Present Value

Considering all the above assumptions, the Net Present Value was calculated.

$$NPV = \sum_{i=1}^{25} \frac{0.5426\left[5040000(1-0.00576)^{i-1}\right] - 0.01 \times 43003169.63}{(1+0.04)^{i}}$$

By making this amount available for reinvestment and removing it from the cash flow in the referred periods, the present value of the discounted cash flows totals R$36,006,058.41. The Net Present Value will be calculated as below:

$$NPV = -I_0 + VP$$

$$NPV = -43003169.63 + 36006058.41 = -6997111.22$$

The Net Present Value found, using the proposed model without considering uncertainty, was negative −6,997,111.22. In view of these results, the manager will refuse to invest in the construction of the mini solar plant, as the initial investment amount is much higher than the return on investment.

When relating the return of the discounted cash flows (Present Value) with the total energy that the photovoltaic system will generate during the 25 years, the result obtained was R$ 0.53, that is, for each 1 kWh of photovoltaic solar energy generated the plant will give a cash return of fifty-three cents and a cost of R$ 0.63. It is observed that the cost per generation is higher than the return obtained. The results found will lead the manager to refuse the investment.

5.2. Analysis of Investment Possibility up to One Year with Uncertainty

The Net Present Value found earlier was negative, however, if the decision maker chooses to postpone the project considering the uncertainty, the diagram can indicate the best way forward through the trigger rules.

For the calculation of the up and down factors of the investment, the values considered will be based on the volatility of the Chinese panels of 19.23% per year.

Therefore, the factors will be obtained as follows:

$$u_2 = e^{\sigma\sqrt{\Delta t}} = e^{0.1923\sqrt{1}} = 1.2120$$

$$d_2 = \frac{1}{u} = \frac{1}{1.2120} = 0.8251$$

To calculate the up and down factors of the energy tariff, the volatility found was 11.76% per year.

Therefore, the factors will be obtained as follows:

$$u_1 = e^{\sigma\sqrt{\Delta t}} = e^{0.1176\sqrt{1}} = 1.12479$$

$$d_1 = \frac{1}{u} = \frac{1}{1.12479} = 0.88905$$

To build the tree, it is necessary to calculate the risk dimensioning, represented by what is called by some authors synthetic probabilities to calculate the Net Present Value—*NPV*, with the options of investing, not investing or waiting. In the case of the model developed, four possible states will be considered, as explained above. Therefore, the values of φ_a, φ_b, φ_c and φ_d will be obtained.

$$\begin{bmatrix} 1.265162 & 1.265162 & 1 & 1 \\ 1.469027 & 1 & 1.469027 & 1 \\ 1.265162 & 1.858556 & 1 & 1.469027 \\ 1 & 1 & 1 & 1 \end{bmatrix} \times \begin{Vmatrix} \phi_a \\ \phi_b \\ \phi_c \\ \phi_d \end{Vmatrix} = \begin{bmatrix} 1.124794 \\ 1.212034 \\ 1.363289 \\ 0.961538 \end{bmatrix}$$

Calculating the inverse of the matrix U to find φ:

$$\phi_{4\times1} = U_{4\times4}^{-1} c_{4\times1}$$

$$\begin{bmatrix} 11.81194 & -8.04066 & -8.04066 & 8.040658 \\ -8.04066 & 8.04066 & 8.04066 & -11.81194 \\ -11.81194 & 10.17273 & 8.04066 & -10.17273 \\ 8.04066 & -10.17273 & -8.04066 & 14.94402 \end{bmatrix}^{-1} \times \begin{bmatrix} 1.124794 \\ 1.212034 \\ 1.363289 \\ 0.961538 \end{bmatrix} = \begin{bmatrix} 0.310113 \\ 0.305571 \\ 0.223963 \\ 0.121892 \end{bmatrix}$$

Therefore, p_a, p_b, p_c and p_d will be respectively:

$$p_a = \phi_a (1 + rf) = 32.25\%$$

$$p_b = \phi_b (1 + rf) = 31.78\%$$

$$p_c = \phi_c (1 + rf) = 23.29\%$$

$$p_d = \phi_d (1 + rf) = 12.68\%$$

The diagram shown in Figure 5 below makes this representation.

In the present time the manager has two possible decisions: not to invest or to wait to invest next year. The diagram shows the present value of the option to wait to invest next year of R$ 3,406,189.15. When choosing to postpone the investment, the decision trigger, represented by V_1, will occur in front of the four branches and the investment will only become interesting if the energy tariff rises and the price of solar panels decreases V_1 (P_u, I_d).

5.3. Analysis of Investment Possibility within Two Years

A second simulation considers the realization of investment in each time of up to two years, as shown in Figure 6. The factor V_2 will represent the trigger of the decision which will be the maximum value of the option.

The results found and presented in the following diagram show that, in the first period, if the energy tariff falls and the price of solar panels rises, the investment will not be interesting, and the recommended decision is not to make the investment.

In all other combinations, the highest value option is to wait to make the investment in the last period. In the second year the investment option will be advisable in case of one or two consecutive rises in the energy tariff and one or two falls in the price of solar panels, $P_{uu}I_{ud}$ - $P_{uu}I_{du}$ - $P_{uu}I_{dd}$ - $P_{ud}I_{dd}$ - $P_{du}I_{dd}$, the state that will provide the highest return is the one resulting from two rises in the energy tariff and two falls in the prices of the panels. The investment recommendation will also be made in the case of two consecutive falls in the energy tariff and two falls in the price of energy boards, $P_{dd}I_{dd}$. The states mentioned above are represented in the diagram (Figure 7) below.

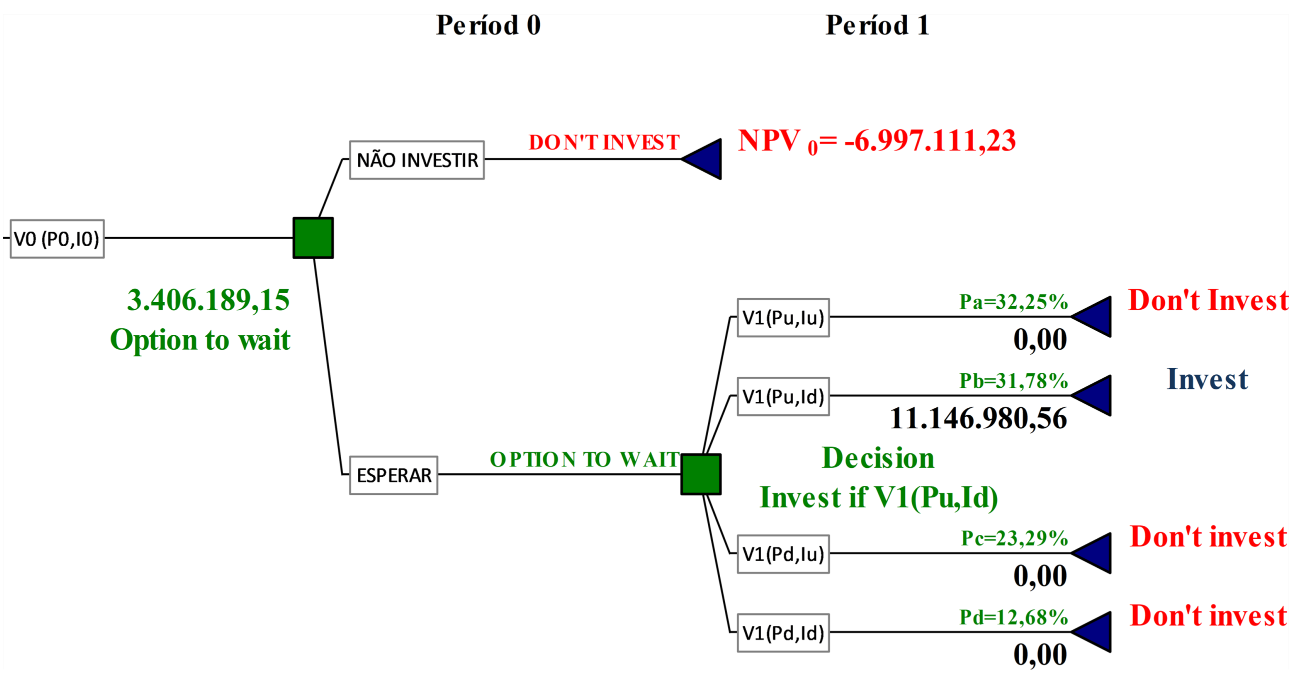

Figure 5. Decision tree of one period.

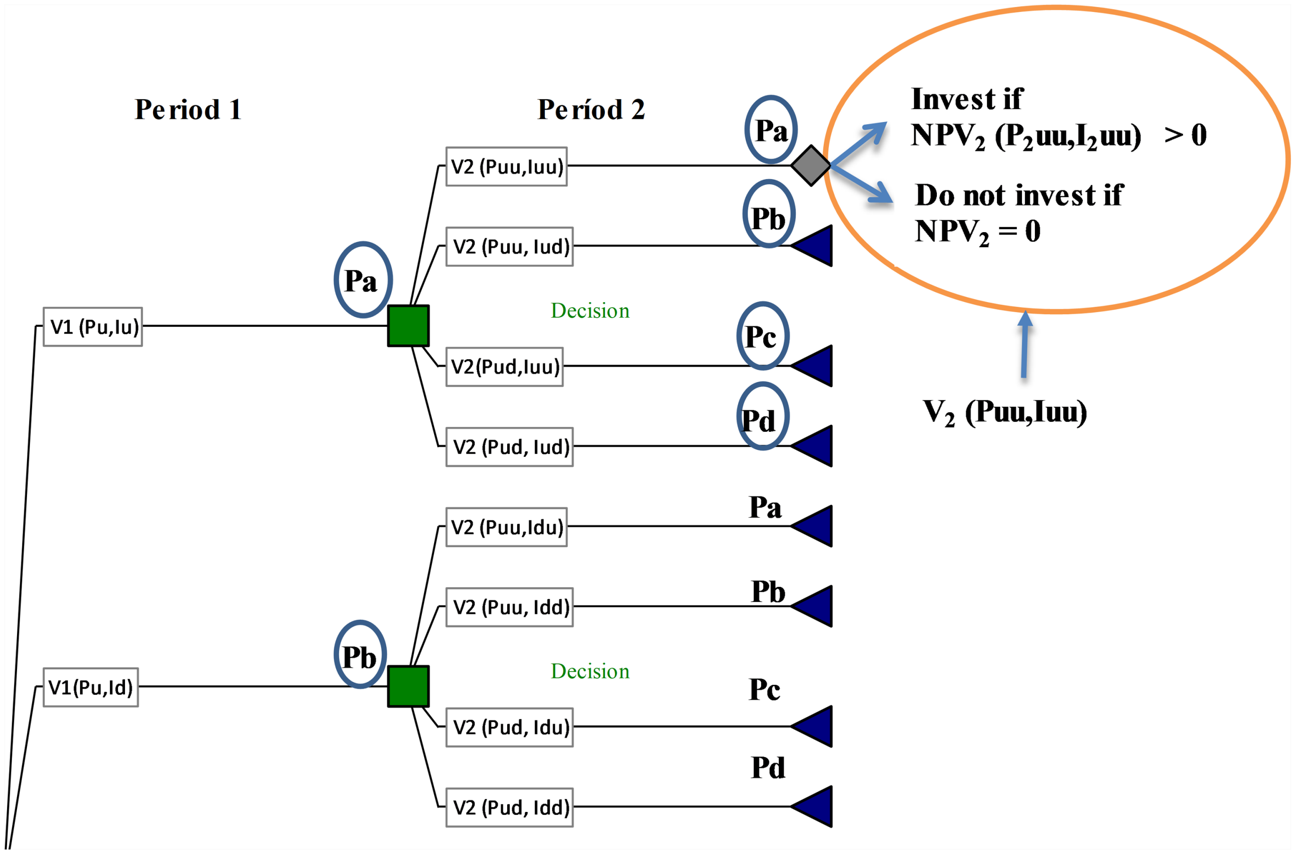

Figure 6. Decision recommended last term.

5.4. Option Value with Matlab Software (Shopping)

Up to three periods it was possible to build the quadrinomial tree in Excel. After that, it became very difficult. For this reason, the use of MATLAB software was necessary.

Table 6 below shows the evolution of the number of branches in the last period and the total number of branches per case from 0 to 15 periods for decision making:

Up to three periods it was possible to search for the solution through Excel, as previously mentioned, after the third period, the number of branches increased. If the manager takes 15 years to decide to invest in own energy generation, the number of branches in the last period will be 1,073,741,824.

According to the results obtained, even if the manager takes longer to make the decision, the option of waiting will prevail in the first period.

The greater the number of periods, the more complex dynamic programming becomes, making a normal computer present result up to twelve periods only, and estimation with more periods is not possible.

The results obtained are described in Table 7 below.

As observed in Table 7 the more time passes, the higher the option value, until the variation starts to decrease and the option value also. The initial variation started with 51.36%, increasing the number of periods the variation ended with 5.16%.

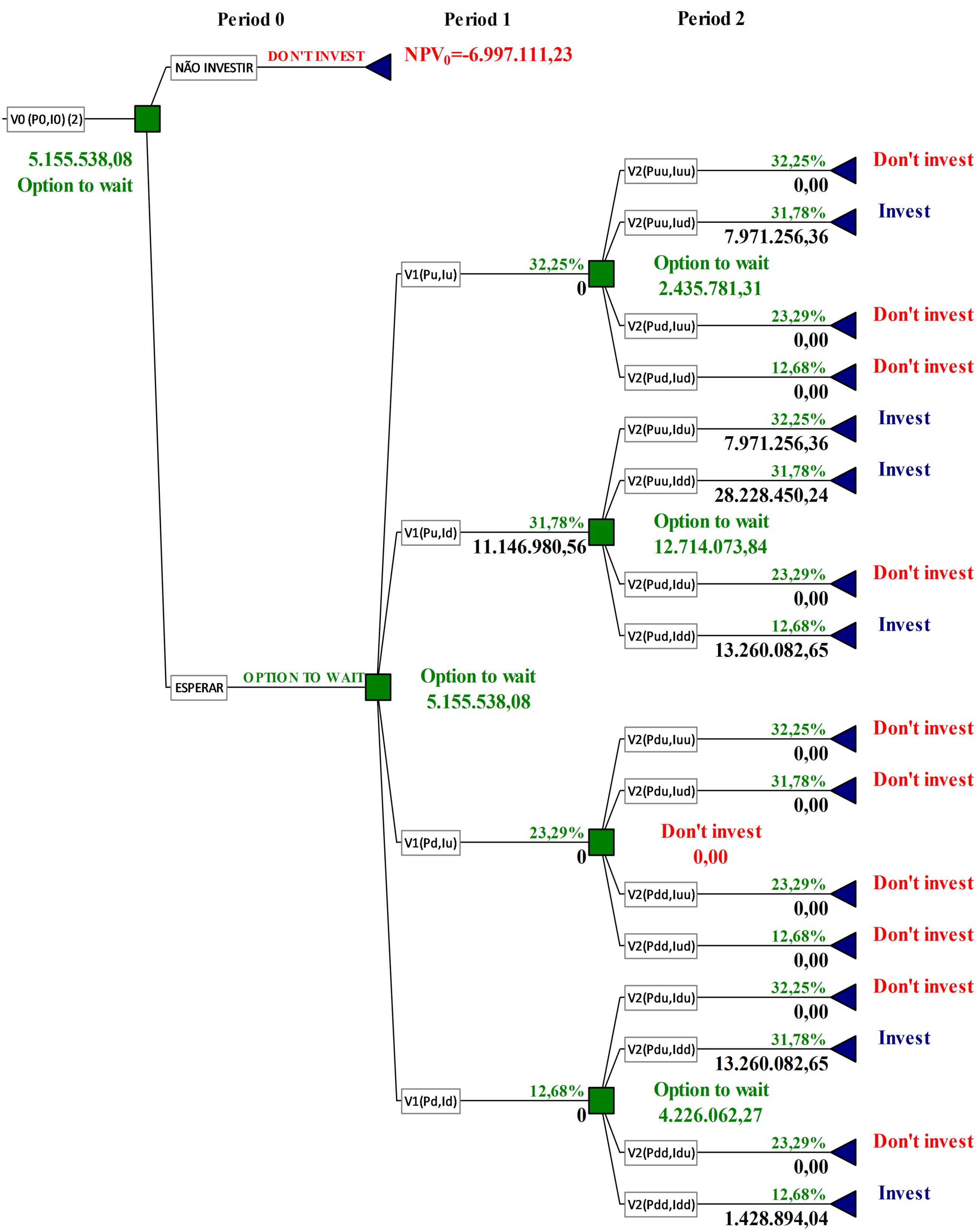

Figure 7. Decision tree with two periods.

Table 6. Number of branches.

No. of Periods	Number of branches in the last period	Total number of branches
0	1	1
1	4	5,00
2	16	21,00
3	64	85,00
4	256	341,00
5	1.024	1.365,00
6	4.096	5.461,00
7	16.384	21.845,00
8	65.536	87.381,00
9	262.144	349.525,00
10	1.048.576	1.398.101,00
11	4.194.304	5.592.405,00
12	16.777.216	22.369.621,00
13	67.108.864	89.478.485,00
14	268.435.456	357.913.941,00
15	1.073.741.824	1.431.655.765,00

Source: developed by the authors.

Table 7. Value of the Investment Option considering more periods: Shopping Mall.

No. of Periods	Value with options (R$)	Variation (%)
1	3.406.189,15	
2	5.155.538,08	51.36%
3	6.224.000,00	20.72%
4	7.607.400,00	22.23%
5	8.765.400,00	15.22%
6	9.895.400,00	12.89%
7	10.867.000,00	9.82%
8	11.818.000,00	8.75%
9	12.675.000,00	7.25%
10	13.501.000,00	6.52%
11	14.272.000,00	5.71%
12	15.009.000,00	5.16%

Source: developed by the authors.

The decision maker can wait up to twelve years to decide to invest, the estimated value of the option will be R$ 15,009,000.00. However, it should be noted that the static NPV is negative and that the option to wait, at first, is the most valuable.

The model developed provides the decision maker of the shopping mall to analyze each period and thus identify the existing options, choosing the most valuable, making it possible to trace the best path for the realization or not of its investment. It is observed that, following the rules of optimal decision, the inverse relationship between the variables, being positive for energy tariff and negative for the price of energy plates provides the options of greater value, because it means that the exchange of energy obtained from LIGHT for own generation of energy with photovoltaic solar source is more viable for the investor as long as the decision maker observes the behavior of the variables over time and follows the rules of optimal decision.

By taking too long to make the decision, the solution becomes more complex, requiring the help of software, as seen above.

The developed model of real options, considering two variables of uncertainties, provided the definition of the best way to go as the uncertainty was being resolved over time, making the manager identify the most valuable decision at each period.

6. Conclusions

For the calculation of the feasibility of investment in a solar photovoltaic project in a medium voltage business, the orthodox theory does not satisfy, since the absence of the consideration of flexibility would cause the manager not to invest in the project, when verifying that the Net Present Value found was negative, totaling -R$ 6,997,111.22. By extending the orthodox theory of investment analysis, with the Real Options Theory, it was possible to capture the uncertainties, using recursive dynamic programming and calculating the risk sizing factors for four possible states, these states were the result of the combination of two variables of uncertainties: the energy tariff and the price of the photovoltaic solar energy generation plates. The uncertainty impacted the Net Present Value by 148.72%, if the manager analyzes the possibility of investment in up to one year, for the investment in up to two years, the uncertainty impacted the Net Present Value by 173.74%, performing the simulation in up to twelve periods the impact of uncertainty reaches 314.69%. Strategic opportunities were identified, and cost and revenue estimates were created for each path. Then, the strategies along the different paths were valued with the recursive process. In the comparison between the Net Present Value and the value of the option, the recommendations of "invest", "do not invest" or "wait" to realize the investment in one, two or three periods were assigned. The simulation was carried out considering the limit of twelve periods with the MATLAB software. Given the initial objective proposed, the optimal conditions and timing for the realization of each recommendation were determined, considering the uncertainties, and consequently contributing to the help and improvement of the manager's decision on making investments in photovoltaic solar energy.

Considering the optimal sizing of uncertainty, the recommendation for investment in the solar power generation system within one year was to wait and only invest in case of an increase in the energy tariff and a drop in the price of solar panels.

If the manager decides to take another period to make the decision, the recommendation not to make the investment in the previous period (first period) will only be made in case of a drop in the energy tariff and an increase in the price of the boards. If the manager waits to make the decision in the last period (second period), the option to invest will only be recommended if the energy tariff has risen once or twice in the two years and the price of solar panels has fallen once or twice. The state that will provide the highest return for the manager will be the one in which there are two increases in the energy tariff and two decreases in the price of solar panels. Otherwise, if the energy tariff falls and the price of solar panels rises, the decision not to invest will be the most recommended option.

It is concluded that, in the case analyzed, the Real Options Theory applied was able to capture the uncertainty and help the manager in improving his decision to invest in photovoltaic solar energy generation projects.

For the expansion and continuity of this study, it is recommended to apply the methodology developed in other businesses; it is also suggested to expand the methodology by inserting other stochastic variables in the calculations, another study that could be developed is the adaptation of the methodology using a longer historical series to test other stochastic processes such as the mean reversion process with spikes.

Acknowledgements

I thank FAPERJ—Carlos Chagas Filho Foundation for Research Support of the State of Rio de Janeiro for funding the research.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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