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MONTE CARLO ECONOMIC AND FINANCIAL FEASIBILITY ANALYSIS OF A PHOTOVOLTAIC SYSTEM FOR DISTRIBUTED GENERATION

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ABSTRACT

Although technological development promotes greater energy efficiency of equipment and devices, the demand for energy increases with population growth and the search for more comfort and well-being. Sustainable growth comes from low-cost renewable energy sources. The geographical position of Brazil shows a high potential for photovoltaic solar energy favoring distributed generation; however, the initial investments are considered limiting for greater participation in the Brazilian electricity matrix. The aim of this paper is to analyze the economic and financial viability of a photovoltaic system for distributed generation. The scientific methodology for this study considered a real scenario, applying investment analysis and Monte Carlo simulation techniques, using probabilistic distributions for the main input parameters involved in the analysis. The result for the adopted case presented slight project viability, being characterized as the main scientific contribution of the work. Better results will be obtained as the costs of photovoltaic systems become more attractive through economies of scale, technological development and more incentive regulations.

Keywords: Monte Carlo; Decision Making; Distributed Generation; Photovoltaic.

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1. INTRODUCTION

Humanity evolves with technological development and the use of material resources to ensure basic needs, as well as increase people's comfort and well-being, and in most cases this evolution promotes increased energy consumption.

The world population will grow from 7.6 to 8.6 billion people by 2030; In Brazil, the population will increase by 16 million people, reaching 225 million inhabitants (United Nations, 2017). This growth will imply greater demand for food, clean water and, consequently, more energy.

Since the last century, fossil fuels have been the main energy source on the planet; however, in recent decades, scientific research has reported on its damage to the environment, among which stand out those resulting from global warming with all the consequences for the future (Facci et al., 2018) and the related damage to people's health.

Brazil's geographical position shows a high potential for photovoltaic solar energy, favoring distributed generation; however, the installed capacity has low representation in Brazil's energy matrix despite the significant annual growth of 54% (2016/2015).

The share of renewable sources in the Brazilian energy matrix is far above the world average (EPE, 2017). Within this matrix, electricity accounted for 579 TWh, corresponding to 17.5% of the total. In the Brazilian generation of electricity, 81.7% of renewable sources were used, and for generation there was a net importation of electricity of 40.8 TWh for service.

Electricity generation in Brazil is predominantly centralized and, although largely interconnected, it has high transmission costs due to the continental dimensions of our country. A disadvantage of the large participation of hydroelectric dams is the vulnerability to climate issues (lack of rainfall) that influence reservoir levels. This is because below a minimum threshold there is a demand for greater use of thermal power plants (Dranka; Ferreira, 2018), which in most cases are non-renewable and more expensive sources and therefore impact on consumers' energy bills and the environment.

In Brazil, Distributed Generation (DG) still has a low installed capacity: in 2016 it was 72.5 MW, which represented 0.05% of the installed capacity for electric power generation which was 150,410 MW. The regulatory evolution, mainly from Normative Resolution 482/2012, has been favoring the expansion of DG's capacity in Brazil.

The National Electric Energy Agency (ANEEL – *Agência Nacional de Energia Elétrica*, 2017) announced on October 19, 2017 that photovoltaic technology covers 99% of consumer units with DG in the country: of the 16,109 units, 15,970 are solar plants, 53 are wind farms, 66 are thermoelectric, and 20 are hydroelectric generating plants (CGH – *Centrais Geradoras Hidrelétricas*).

Brazilian civil construction highlights the trend towards sustainable construction and eco-efficiency (Marchi et al., 2018). The adoption of photovoltaic (PV) systems will contribute to minimize the use of non-renewable resources.

When a PV system is considered to have a life cycle of up to thirty years, the economic and financial viability for distributed generation is demonstrated (Lammoglia; Brandalise, 2018). The problem is the economic and financial viability with return on investment in a few years (Solano; Brito, 2018). Regulation, mainly through normative resolutions 482/2012 and 687/2015, has contributed to encourage the adoption of PV (Gomes *et al.*, 2018); however, the initial investments are considered limiting for greater participation in the Brazilian electricity matrix.

Technological development in photovoltaic panels and other system components has resulted in better throughput rates. This development coupled with the economy of scale has contributed to reducing the initial investments for systems deployment (Zeb *et al.*, 2018).

The general objective of this work is to analyze the economic and financial viability, by the Monte Carlo method, of a photovoltaic system for distributed generation.

This work is justified by the fact that PV to DG solar energy contributes to minimize energy costs to consumers in a sustainable way. Although the initial investment is considered high in relation to the return time, this investment has low representativeness in the total cost of the work and is partially or totally added to the value of the property. Additionally, the system minimizes possibilities for additional energy bills during periods of low reservoir water levels.

2. LITERATURE REVIEW

Photovoltaic solar energy

A photovoltaic system directly converts sunlight into electricity; therefore, photovoltaic generation capacity depends on the direct incidence of sunlight. The basic device of this system is the photovoltaic cell. Cells can be grouped to form panels or arrays. A panel is formed by a set of connected cells to obtain large output voltages and/or currents. A photovoltaic array can be a panel or array of panels connected in series or parallel to form large photovoltaic systems. The

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voltage and current available at the terminals of a photovoltaic device can directly feed small loads such as lighting systems and direct current motors. More sophisticated applications require electronic converters to process electricity from the photovoltaic device. These converters can be used to regulate voltage and current in the charge, control the flow of power in grid-connected systems, and especially track the maximum power point of the device (Villalva et al., 2009).

Figure 1 illustrates the physical structure of a photovoltaic cell, which is basically a semiconductor diode, whose p - n junction is exposed to light.

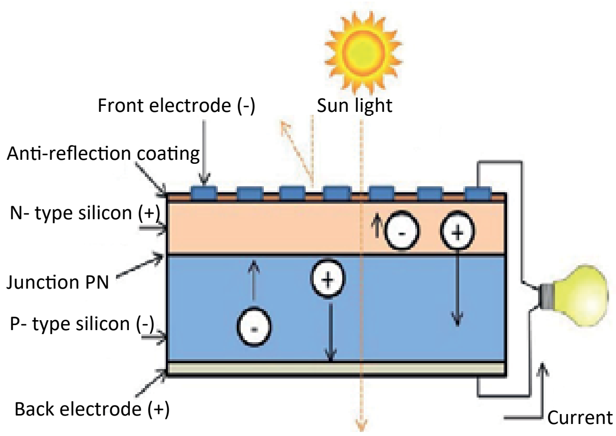

Figure 1. Physical structure of a photovoltaic cell
Source: Sampaio; González (2017)

Photovoltaic cells are made of various types of semiconductors using different manufacturing processes. Monocrystalline and polycrystalline silicon cells are the only cells found on a commercial scale today. Silicon cells are composed of a thin layer of silicon connected to the electrical terminals. One side of the layer is doped to form the p - n junction. A thin metal grid is placed on the semiconductor surface facing the sun. The photovoltaic phenomenon can be described as the absorption of solar radiation, the generation and transport of free transporters at the p - n junction and the collection of these electrical charges at the device terminals (Villalva *et al.*, 2009).

Distributed generation

ANEEL is responsible for regulating the generation, transmission, distribution, and sale of electricity.

Before the privatization of the electricity distribution sector, which took place at the beginning of this century, companies were verticalized and there was no separation of business from the chain (generation, transmission and distribution). With the liberalization of the market, the Electricity Distribution companies (DEE – *Distribuidoras de Energia Elétrica*) now have Distribution Procedures (Prodist – *Procedimentos de Distribuição*) that have disciplines, conditions, responsibilities and penalties related to the connection, expansion planning, operation and measurement of electricity. DG has been consolidating itself in the last decades and the pertinent regulations have facilitated the insertion of sustainable energies in the main countries of the world (Andrade; Silveira, 2018).

In Brazil, according to Normative Resolution 687/2015 that revised Resolution 482/2012, the production of electricity from small plants that use renewable sources connected to the distribution network by consumer units is considered mini or distributed micro-generation. Microgeneration has installed capacity lower than or equal to 75 kilowatts (kW), while distributed mini-generation has installed power greater than 75 kW and lower than or equal to three megawatts (MW) for hydro and five MW for other sources. (ANEEL, 2016).

ANEEL Normative Resolution No. 482/2012 is the main document regulating the operation of grid-connected PV systems in Brazil. The resolution defined the main rules for the operation of the so-called distributed micro and mini generation, a model in which small users can produce their own electricity in an integrated way to the utility distribution network.

The resolution defined the main rules for the operation of the so-called distributed micro and mini generation, a model in which small users can produce their own electricity in an integrated way to the utility distribution network. Each unit of energy produced by the system translates into savings of the same amount that the utility would charge to deliver to the consumer, in kWh.

When the consumer produces more than he consumes for a month, the utilities will provide their credit, in kWh, which is valid for 60 months for use when consumption is greater than power generation, as in times of lower irradiation. If the consumer is interested in producing all the energy he consumes, he will pay in the monthly bill only the other expenses, almost all fixed, such as the “availability cost”, known as the “minimum fee”, eventual tariff flags and the contribution for public lighting.

DG, through small generators close to consumption and within the scope of the respective DEE, has some potential advantages: postponement of investments in generation, transmission and distribution of electricity; low environmental impact; improvement of the voltage level of the network in the peak period; and diversification of the energy matrix. However, it has some disadvantages resulting from the growth of small uncoordinated distributed generator

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installations, such as: greater operational complexity of the network; differentiation in the billing system and loss of billing by DEE.

Among the main sources of economically viable sustainable energies, photovoltaic solar energy has great potential in Brazil given the high rates of solar irradiation. Figure 2 presents a map of solar irradiation in the world, in kWh/m².

PV generation is not yet representative and is not highlighted in the relevant statistics, as can be seen in Figure 3, which shows that, despite a 44.7% growth in 2016 over 2015, it does not appear in the volume variation (EPE, 2017). Therefore, there is a great potential for growth in view of regulatory progress, even though funding constraints and the costs of DG deployment are significant.

Monte Carlo Simulation

The construction of the first atomic bomb gave rise to the Monte Carlo simulation method, which took place during World War II during research at the Los Alamos laboratory. It was proposed by Von Neumann and Ulam to solve mathematical problems that were not viable through analytical treatment.

Initially it was intended for the evaluation of multiple integrals for the study of neutron diffusion. It was later found that it could be applied to other more complex mathematical problems of a deterministic nature. The name Monte Carlo was adopted because the presence of randomness resembles gambling alluding to the famous casino of Monaco founded in 1862, and for reasons of secrecy (Brandalise; Cardoso, 2010).

Monte Carlo simulation is a probabilistic approach that allows uncertainty to be considered when calculating the expected value, i.e. assessing what might happen and how it is likely to occur. Using probabilistic distributions for the main input parameters involved in the analysis, it is possible to retrieve the resulting value as a probability distribution from which uncertainty information can be derived using common statistical methods. Each Monte Carlo iteration consists of sampling random values from the given input distributions and computing the corresponding result (Pillot et al., 2018).

Investment Analysis Techniques

Deciding on an investment requires knowledge and use of appropriate techniques so that the analysis results contribute to the best decision. In the case of this study, the techniques chosen were Net Present Value (NPV) and Internal Rate of Return (IRR). NPV and IRR are commonly used to evaluate the return on an investment by calculating the difference between discounted cash flow values over the life of

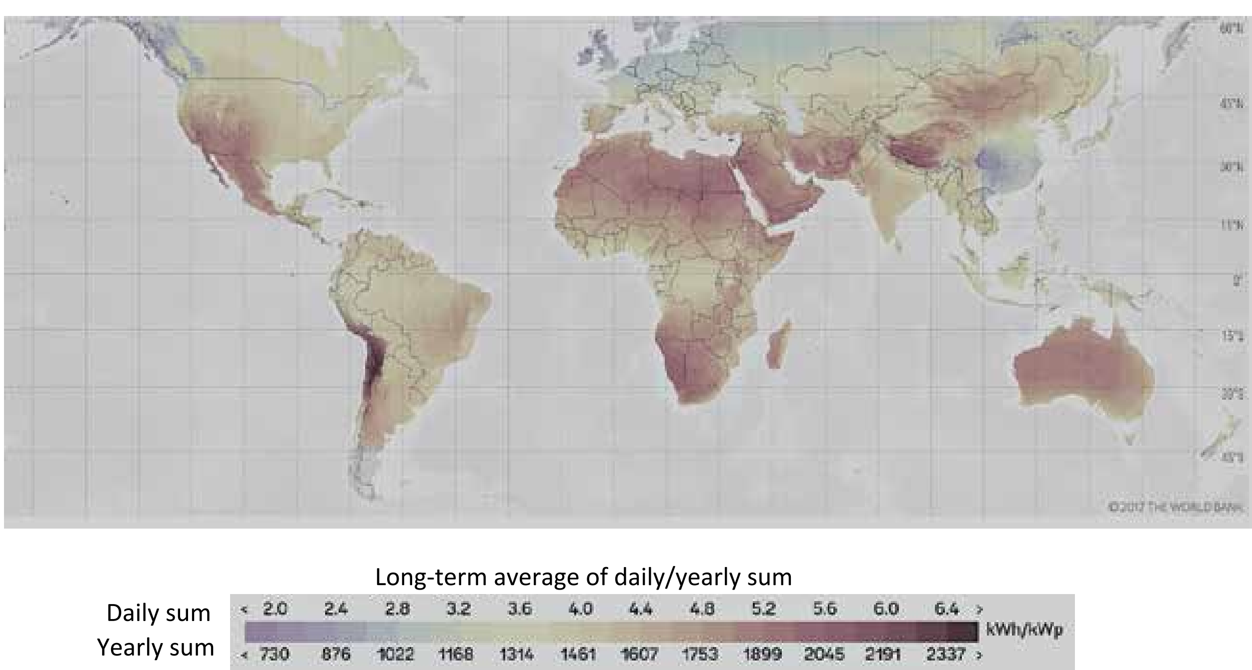

Figure 2. World map of solar irradiation in kWh/m²
Source: Adapted from Solargis, 2018

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Energy source (Mtoe)	2015	2016	Δ 16/15
Renewable	123,7	125,4	1,4%
Hydraulic energy *	33,9	36,3	7,1%
Sugarcane Biomass	50,6	50,3	-0,6%
Firewood and Charcoal	24,9	23,1	-7,2%
Wind power	1,9	2,9	52,6%
Solar	0,005	0,007	40,0%
Bleach and other renewables	12,4	12,8	3,2%
Non-renewable	175,9	163,0	-7,3%
Oil and derivatives	111,6	105,4	-5,6%
Natural gas	41,0	35,6	-13,2%
Mineral coal	17,6	15,9	-9,7%
Uranium (U3O8)	3,9	4,2	7,7%
Other non-renewable	1,8	1,9	5,6%
* Includes importation of electricity from water source			

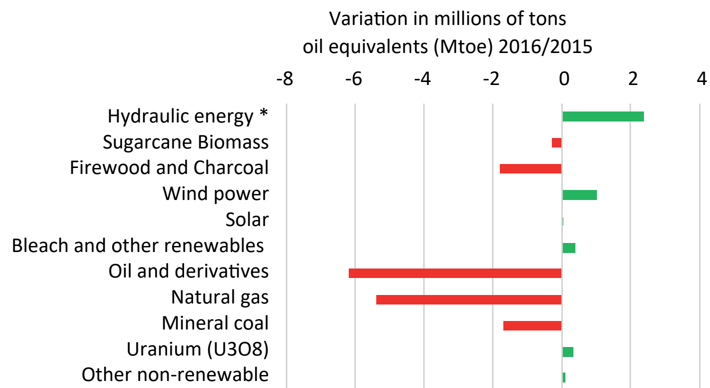

Figure 3. Internal energy supply in Brazil 2016/2015
Source: EPE, 2017

projects. Both allow for intuitive performance comparison across regions and technologies for different projects.

$$VPL = \left[\sum_{t=1}^{n} \frac{FC_t}{(1+K)^t}\right] - \left[I_0 + \sum_{t=1}^{n} \frac{I_t}{(1+K)^t}\right] \quad (1)$$

According to Samanez (2010), the NPV method aims to calculate, in terms of present value, the impact of future events associated with an investment alternative, i.e. it measures the present value of cash flows generated by the project over its useful life. NPV takes into account the present value of money. It is the most accepted standard method used in financial evaluations for long term projects. If there is no capital restriction, it is argued that this criterion leads to the optimal choice as it maximizes the value of the company. NPV is expressed as equation 1:

Where:

FCt = cash flow (benefit) of each period;

K = project discount rate, represented by the minimum return required;

I0 = investment processed at time zero;

It = estimated investment value in each subsequent period;

Σ = sum, indicates that the sum of date 1 to date n should be performed;

Decision Criteria: If NPV> 0, the project is economically viable.

The IRR, on the other hand, aims to find an intrinsic rate of return and not the assessment of absolute profitability at a given cost of capital, such as NPV (Samanez, 2010).

The size of the IRR correlates directly with the attractiveness of the investment as a percentage, i.e. a high IRR indicates that the investment opportunity is favorable.

$$I_0 + \sum_{t=1}^{n} \frac{I_t}{(1+K)^t} = \sum_{t=1}^{n} \frac{FC_t}{(1+K)^t} \quad (2)$$

IRR can be represented by equation 2 (Medina et al., 2015), and is usually presented in percentage values:

Where:

I0 = amount of investment at time zero (project start);

It = expected amounts of investment at each subsequent time;

K = periodic equivalent rate of return (IRR);

FC = expected cash inflows in each project life period (cash benefits).

Decision making criteria

Decision making should consider the main factors that influence the PV system. Table 1 shows the factors that influence the system throughput rate and consequently the economic performance. Knowledge of these decision factors is necessary for the proper sizing of the system. Geography is the first decision factor as it considers the level of solar radiation from the site where the project will be installed. The Sergio de S. Brito Reference Center for Solar and Wind Energy (CRESESB), with the objective of providing a tool to support PV systems sizing, provides the SunData v 3.0 pro-

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gram for the calculation of average daily solar irradiation on a monthly basis in any part of the national territory, according to their latitude and longitude.

Chart 1. Factors for Decision Making

Factor	Effect on Economic Performance	
Geographic location	+	The higher the level of irradiation the better; shadows impair
External Temperature	-	Above 25º the performance begins to reduce
PV System Performance Rate	+	More effective panels have a strong influence, micro inverters as well
Building Types	-	Orientation and Slanting Restrictions of Existing Roofs
Residential Demand	+	High consumption equipment (e.g. pool heaters)
Energy Prices	+	The high cost of energy favors in Brazil
Regulation	+	Net metering system
Maintenance	-	Despite the low maintenance cost, it has some influence
Capital Cost	-	Strong influence of initial investment

Source: Adapted from Lang et al., 2015

3. SCIENTIFIC METHODOLOGY

To analyze the feasibility of implementing the system, a real scenario was adopted by applying investment analysis techniques and Monte Carlo simulation. Thus, it was considered as a reference a residence in a neighborhood in the city of Guaratinguetá, in the interior of the state of São Paulo, whose Latitude 22.816389 South and Longitude 45.1925 West indicate a total annual irradiation of 1,726.25 kWh/m², according to the SunData v 3.0 program, with a monthly average consumption of 584.1 kWh reported in the energy bill of September 2018, covering the previous twelve months, served by the distributor *Energias de Portugal* (EDP).

The analyzes and calculations were performed using Microsoft Office Excel software, as its use facilitates the calculations and is guaranteed to the numbers randomness, independence, evenly distributed value, and non-repetition of sequences.

For calculations of sizing and value to be invested, the information on connection type, minimum consumption rate, public lighting rate, monthly household consumption, available roof area, total annual irradiation, module efficiency, system performance rate, in addition to the following parameters selected for Monte Carlo simulation: service life, attractiveness rate, installed Wp price, wasted power, charged rates, and maintenance costs.

Market research was conducted to verify the prices of equipment, accessories and labor that make up the price of the installed Wp and the respective total amount to be invested.

For Monte Carlo simulation, 5,000 iterations are considered. Each NPV value was calculated and then counted to retrieve the corresponding output probability distribution.

4. RESULTS ANALYSIS

For decision making, the main factors that influence the PV system were considered, especially regarding the yield rate. NPV was a suitable investment analysis technique for this study and the use of the Monte Carlo probabilistic approach allowed the uncertainty to be considered in the expected value calculation.

After 5,000 iterations, the viability of NPV was found to be greater than zero.

The initial information for the project was obtained from the September 2018 monthly energy bill of a consumer from the city of Guaratinguetá in the state of São Paulo. This account shows the consumption history of the last 12 months, the type of connection (single-phase, two-phase or three-phase) that defines the minimum consumption tariff, the detailing of the unit energy costs by consumption range with the respective taxes, as well as additional costs for different tariff flags and any fixed street lighting costs, for example.

Solar irradiation levels are the basis for sizing any PV installation project. From the latitude and longitude information of the site where the system installation is projected, it was obtained, through the solar potential program SunData v 3.0, the average monthly values of irradiation, as described in Table 1, and the average daily value for the year was 4.74 kWh/m^2.

Table 1. Solar irradiation: daily and monthly average

Month	days/month	kWh/m²/day	kWh/m²/month
jan	31	5,56	172,36
feb	28	5,79	162,12
mar	31	4,91	152,21
Apr	30	4,48	134,40
May	31	3,68	114,08
Jun	30	3,41	102,30
Jul	31	3,55	110,05
Aug	31	4,51	139,81
Sep	30	4,67	140,10
Oct	31	5,15	159,65
Nov	30	5,24	157,20
Dez	31	5,87	181,97

Source: Prepared from the SunData Program v 3.0, CRESESB

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After the system sizing calculations, market research, whose lowest prices are described in Table 2, were performed.

The parameters selected for Monte Carlo simulation with their minimum, most likely and maximum values are presented in Table 3.

Using the parameters in Table 3, the NPV was calculated and from 5,000 iterations, the average was R$ 518.14, the median R$ 365.90, and the standard deviation of R$ 6,442.33, distributed as displayed in Figure 4, showing the cumulative distribution of the random results generated.

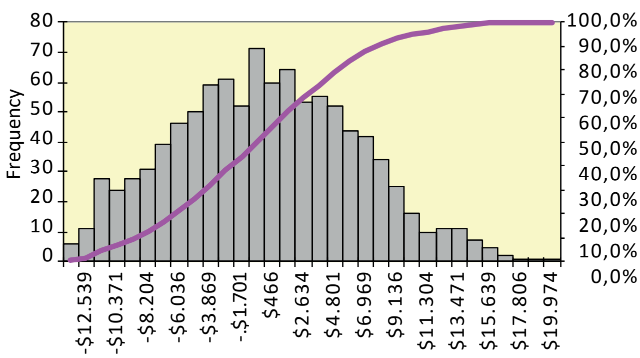

Figure 4. Distribution of NPVs
Source: The authors (2018).

After the five thousand iterations, the presented probability of NPV being greater than zero is 53.2%.

5. CONCLUSION

The Monte Carlo investment analysis and simulation techniques, using probabilistic distributions for the main input parameters involved in the analysis, applied in a real case, proved to be effective in the economic and financial viability analysis of a photovoltaic system for distributed generation, reaching the purpose of this work.

This study showed that the scaled photovoltaic system has a 53.2% probability of returning with a NPV above zero and therefore a slight economic viability.

As recommendations for future work, it is suggested the application of risk calculation to the relevant study, as well as aggregate other decision-making methods and broaden the relative parameters in this area of study that is impacted by technological and regulatory developments, and make comparisons with other technologies.

REFERENCES

Andrade, H. M.; Silveira, D. M. C. (2018), "Inserção das energias sustentáveis na perspectiva regulatória para a geração distribuída no Brasil," XXV SIMPEP - Simposio de Engenharia de Produção, Bauru, SP, 07-09 de Novembro de 2018.

Agência Nacional de Energia Elétrica - ANEEL (2017), Regulação do Setor Elétrico - ANEEL. Available at: http://www.aneel.gov.br/regulacao-do-setor-eletrico (Accessed: July 4, 2018).

Table 2. Price detailing

Product	Amount	Unit Value (R$)	Total value (R$)	Participation in Total Cost (%)
Painel Solar 330 Wp	22	680,00	14.960,00	47%
Inversor Grid-Tie	1	4.149,00	4.149,00	13%
Module Support	22	250,00	5.500,00	17%
String Box	1	752,00	752,00	2%
Several	1	1.000,00	1.000,00	3%
Installation (Manpower)	1	5.272,20	5.272,20	17%
Total			31.633,20	100%

Source: The authors (2018)

Table 3. Parameters for Simulation

Parameters	Minimum	More probable	Maximum
Lifetime (years)	20	22	25
Attractiveness Rate	6,50%	10,00%	12,00%
Price (R$/Wp)	6,00		9,00
Energy not wasted (kWh/year)	6.409,20	6.409,20	6.409,20
Fare with charges (R$/kWh)	0,77	-	0,85
Maintenance (OPEX) - % do CAPEX	0,00500	0,00550	0,00600

Source: The authors (2018)

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DOI: 10.20985/1980-5160.2019.v14n4.1489

Agência Nacional de Energia Elétrica - ANEEL (2016), Micro e Minigeração Distribuída; Sistema de Compensação de Energia Elétrica, 2ª ed., ANEEL, Brasília.

Brandalise, N.; Cardoso, R. (2010), "Análise de risco em estudo de viabilidade econômico- o comércio de água mineral", XXX Encontro Nacional de Engenharia de Produção, São Carlos, SP, 12-15 out. 2010.

Dranka, G. G.; Ferreira, P. (2018), "Planning for a renewable future in the Brazilian power system", Energy, Vol. 164, pp. 496–511.

Empresa de Pesquisa Energética – EPE (2017), Balanço Energético Nacional 2017, EPE, Brasília.

Facci, A. L.; Krastev, V.; Falcucci, G. et al. (2018) "Smart integration of photovoltaic production, heat pump and thermal energy storage in residential applications", Solar Energy, Vol. 192, pp. 131-143.

Lammoglia, J. A. M.; Brandalise, N. (2018), "Analysis of economic and financial viability with the use of Monte Carlo Simulation for microgeneration," XXV SIMPEP - Simposio de Enegenharia de Produção, Bauru, SP, 07-09 nov 2018.

Lang, T.; Gloerfeld, E.; Girod, B. (2015), "Don't just follow the sun - A global assessment of economic performance for residential building photovoltaics," Renewable and Sustainable Energy Reviews, pp. 932–951. DOI: 10.1016/j.rser.2014.10.077.

Marchi, C.; Bohana, M.; Fernandez, J. (2018), "Environmental management in solid waste: sustainable construction and eco-efficiency," Sistemas & Gestão, Vol. 13, No. 1, pp. 118–129. DOI: 10.20985/1980-5160.2018.v13n1.1319.

Medina, D. S.; Santana, F. S.; Oliveira, R. S. V. et al. (2015), "Utilização das técnicas tir e vpl como análise de investimento: um estudo de caso numa empresa do ramo de autopeças" III Congresso de Administração do Sul de Mato Grosso – CONASUM, Rondonópolis, MT, 8-10 de Dezembro, 2015. pp. 1–20.

Pillot, B.; Siqueira, S.; Dias, J. B. (2018), "Grid parity analysis of distributed PV generation using Monte Carlo approach: The Brazilian case" Renewable Energy, Vol. 127, pp. 974–988. DOI: 10.1016/j.renene.2018.05.032.

Samanez, C. P. (2010), Matemática Financeira, 5ª ed., Pearson, São Paulo.

Sampaio, P.; González, M. (2017), "Photovoltaic solar energy : Conceptual framework", Vol. 74(March), pp. 590–601.

Solano, J. C; Brito, M. C. (2018), "Impact of fixed charges on the viability of self-consumption photovoltaics", Energy policy, Vol. 122, pp. 322–331.

Solargis (2018), "Potencial de Energia Fotovoltaica", Available at: https://solargis.com/es/maps-and-gis-data/download/world.

United Nations (2017), World Population Prospects: The 2017 Revision, United Nations.

Gomes, P. V.; Knak Neto, N. Carvalho, L. et al. (2018) "Technical-economic analysis for the integration of PV systems in Brazil considering policy and regulatory issues," Energy Policy, 115, pp. 199–206. DOI: 10.1016/j.enpol.2018.01.014.

Villalva, M. G.; Gazoli, J. R.; Ruppert Filho, E. (2009), "Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays", IEEE Transactions on Power Electronics, Vol. 24, No. 5, pp. 1198–1208.

Zeb, K.; Uddin, W.; Khan, M. H. et al. (2018), "A comprehensive review on inverter topologies and control strategies for grid connected photovoltaic system", Renewable and Sustainable Energy Reviews, Vol. 94, pp. 1120–1141. DOI: 10.1016/j.rser.2018.06.053.

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