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ECONOMIC EVALUATION OF PHOTOVOLTAIC SYSTEMS IN THE NATIONAL ENERGY CONTEXT

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Abstract: *Solar energy has great potential to contribute to many of the social and worldwide aspects. The efficiency and performance of photovoltaic systems and consequently their economic viability is directly related to the effects of temperature and solar irradiation. The main objective of this article is to demonstrate the effects that temperature and solar irradiation cause on the efficiency and performance of PV systems, as well as to perform an economic feasibility analysis and a sensitivity analysis for the acquisition of photovoltaic systems in five climatic regions of Brazil. For the purposes of analysis and projection of investment return (IR), it was considered an average annual energy consumption, proposed by the Energy Research Company, mainly covering families of Brazilian middle class, being this the greatest potential of acquisition of photovoltaic systems discussed in this article.*

Keywords: *solar energy, photovoltaic, irradiation, temperature.*

1. INTRODUCTION

Solar energy has great potential to contribute to many social and environmental aspects around the world (Schaefer et. al., 2012; Ordenes et. al., 2007; Rütther et. al., 2008). Photovoltaic (PV) solar generation has shown considerable cost reduction, through the years, mainly due to the increase in production as a result of incentive programs promoted by several developed countries (Razykov et. al., 2011). It is expected that, in developing countries, the electricity generated by photovoltaic systems will be cost competitive with other traditional sources of energy generation (Aman et. al., 2015; Pao and Tsai, 2011; Delucchi and Jacobson, 2011; Jacobson and Delucchi, 2011).

Owing to the expressive amount of energy generation by hydraulic source, Brazil has an energy matrix considered clean and renewable and a low consumption of electricity when compared to developed countries (Rütther et. al., 2011; Amaro et. al., 2018). The energy generated by hydroelectric plants currently corresponds to 60.9 % of the national generation and 14.83 % are produced by fossil fuels. Furthermore, the ongoing generation capacity by other alternative sources corresponds to approximately 18 %, where only 1.205 % of this capacity is produced by (PV) (Aneel, 2019).

Not until 2012, the National Electric Energy Agency (ANEEL) regulates the use of the solar source and establishes the rules for distributed Micro and Minigeration. Through Normative Resolution RN 482/2012, Brazil has adopted the energy compensation mechanism, in which a solar roof can be connected in the public electricity grid through the Consumer Unit (CU) and inject the surplus in the energy distribution network, accumulating credits to be offset in kWh. The power limit contemplated by RN 482/2012 was 1000 kWp in 2012 and in 2015; RN 687/2015 extended this limit to up to 5000 kWp per UC. The energy credits injected into the grid are valid for 60 months to be compensated, and a bi-directional electricity meter, as in other compensation systems, must be installed (Aneel, 2012; Aneel, 2015).

Therefore, the main objective of this article is to present a study on the return on investment (RI) of PV systems in different regions of Brazil and to verify the effects that RN 482/2012 and RN 687/2015 of ANEEL may have on the development of photovoltaic residential electricity generation in the country.

2. DEVELOPED METHODOLOGY

Brazil is a country of continental dimensions situated between latitudes 5° N and 34° S and longitudes 74° W and 34° W. The average annual irradiation varies between the maximum of 6.7 kWh/m² day and the minimum of 4.2 kWh/m² day in regions of lower irradiance (Pereira et. al., 2017). The localities considered in this study are: Belo Horizonte, São Paulo, Brasília, Fortaleza and Manaus. The six localities were chosen by the criteria of location, climate, political importance and solar irradiation.

In order to properly size each (PV) system in each representative city, it was considered the solarimetric index of Reference Center for Solar and Wind Energy Sergio Brito (Cresesb/Cepel, 2014), represented by the magnitude kWh/m² day, this result represents a solarimetric index annual estimate average for each region. Knowing the different levels of solar irradiation throughout the year, it was decided to use a medium (annual) irradiation range in the inclined plane for the design of the photovoltaic systems. For the collection of each average irradiation, the following procedure was used: with the assistance of Google Maps, each representative city was searched for its exact location (Table 1) and later the irradiation of each locality was sought.

Table 1 - Average radiation in inclined plane. Source: (Cresesb/Cepel, 2014)

City Name	Latitude	Longitude	Average Temperature [°C]	Tilted Radiation [kWh/m ² .day]	Climate Zone
Belo Horizonte	-19.93°	43.93°	28.5	5.36	Tropical Center
São Paulo	-25.63°	46.65°	27.6	4.45	Tropical Center
Brasília	-15.87°	47.93°	28.0	5.15	Tropical Center
Fortaleza	-3.77°	38.60°	29.9	5.58	Tropical Northwest
Manaus	-3.18°	59.95°	33.8	4.42	Equatorial
Porto Alegre	-30.02°	51.22°	32.5	4.64	Temperate

In order to carry out the sizing, a study was made available by the (MME, 2014; 2015) where it is defined that the average monthly consumption for a conventional Brazilian residence is estimated at approximately 167 kWh/month. Thus, this mean value of consumption was adopted as the standard for the six regions. The main daily consumption loads, powered by (PV) systems are represented in Table 2, and were determined respecting the defined consumption limit.

Table 2 - Monthly average Consumption. Source: (MME, 2014; 2015)

Equipaments	Quantity	Power (W)	Hours of use per day	Consumption (kWh/monthly)
Fluorescent Lamp	5	25	4	15.00
Televisor	1	40	12	14.40
Refrigerator (360 l)	1	134	8	32.16
Personal Computer	1	200	12	72.00
Others Equipaments	1	1115	1	33.45
Monthly total consumption in (kWh)	-	-	-	167.0

The calculation of the power of the system depends on a series of variables, which include: daily demand of electrical energy of the residence 167 kWh/month (Table 1), system efficiency that defines the capacity of the modules to generate energy in relation to the climatic conditions and the technological characteristics of the photovoltaic modules.

The power calculation is also affected by the legislation represented by ANEEL's regulatory resolutions, RN 687/2015 and by the legislation that establishes the collection of a minimum energy value for each residence by means of minimum energy availability (TUSD), so that the distributor company reimburses for the connection to the electricity grid. This minimum energy value is 30 kWh monthly if the connection is single-phase, 50 kWh monthly if it is biphasic and 100 kWh monthly in the case of three-phase (Aneel, 2012). Therefore, in this article, only de single-phase connection will be evaluated, since it is the most used in conventional residences. To initiate the design of the Photovoltaic System, it is necessary to determine the daily energy generated by the system, according to Eq. (1).

$$EG = \frac{\frac{(\text{Energy demand} - \text{MEA})}{(30 \text{ days})}}{(HSP) \times \eta_{total}} \quad (1)$$

Where:

EG – Energy generated (kW);

Energy Demand – Monthly energy demand, referring to the consumption of 167 kWh (MME, 2014; 2015);

MEA– Minimum energy availability for single phase, two phase and three phase systems, corresponding to 30 kWh;
HSP – Hours of Full Sun (h);
 η_{total} – Regarding the efficiency of the photovoltaic system.

The HSP or Hours of Full Sun determines the number of hours in which the Irradiance solar I_r [kWh/m²] should be constant and equal to 1 kW/m² of the photovoltaic modules, as shown in Eq. (2).

$$HSP = \frac{I_r [KWh/m^2]}{1 [KWh/m^2]} \quad (2)$$

Total loss of efficiency (η_{total}) of the system presented in Eq. (1) will be obtained according to Eq. (3) below.

$$\eta_{total} = \eta(T) \times \eta(S) \times \eta(M) \times \eta(C) \times \eta(E) \quad (3)$$

Where:

- $\eta(T)$ – Loss of efficiency associated with ambient (T) temperature (Will be calculated);
- $\eta(S)$ – Loss of efficiency associated with accumulation of dirt on the module = 2.5 %;
- $\eta(M)$ – Loss of efficiency associated with electrical incompatibility (Mismatch) = 2 %;
- $\eta(C)$ – Loss of efficiency associated with the electrical connections of the system = 0.5 %;
- $\eta(E)$ – Loss of efficiency associated with system electrical wiring = 2.5 %.

The incident solar irradiance and ambient temperature variations affect the operating temperature of the photovoltaic cells that make up the photovoltaic modules. Figure 1 and 2 shows how incident solar irradiance affects the output I-V (current and voltage) curve of a silicon photovoltaic cell maintained at a temperature of 25 °C (Wu et. al, 2017; Mehmood et. al., 2017; Coskun et. al., 2017). The electric current generated by a photovoltaic cell increases linearly with the increase of incident solar irradiance, while the open-circuit voltage (V_{oc}) increases logarithmically if the same temperature is maintained (Cresesb/Cepel, 2019). The variations of the incident irradiance and ambient temperature affect the operating temperature of the photovoltaic cells that make up the photovoltaic modules. The increase in incident irradiance and/or ambient temperature produces an increase in the temperature of the cell and, consequently, tends to reduce its efficiency. This is due to the fact that the cell voltage decreases significantly with increasing temperature, while its current undergoes a very small, almost negligible elevation (Siecker et. al., 2017; Barth at. al., 2016). Figure 2 illustrates the effect of temperature variation.

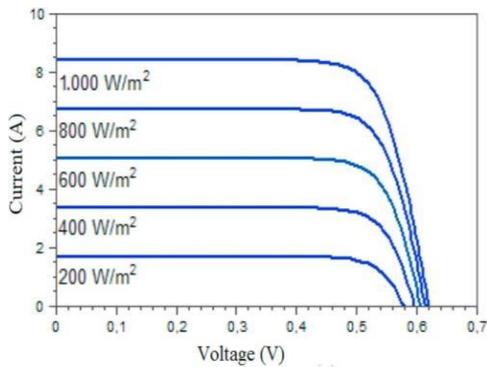


Figure 1 - Influence of the solar irradiance variation on the I-V characteristic curve of crystalline silicon photovoltaic cell at 25 °C. Source: (Pinho and Galdino, 2014).

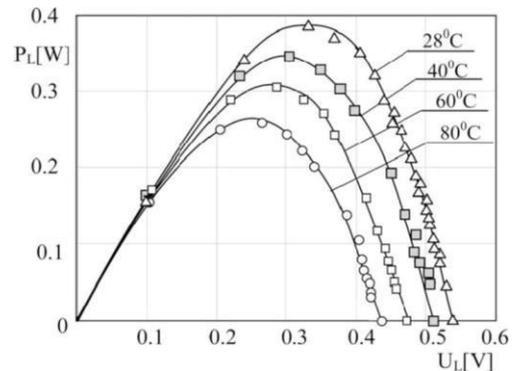


Figure 2 - Output power versus voltage of a crystalline silicon cell at various temperatures: 20 °C, 40 °C, 60 °C, 80 °C. Source: (Pinho and Galdino, 2014).

A crystalline silicon cell has a reduction in efficiency of 0.5 ± 0.05 % for each increase of 1 °C in temperature (Chandraekar et. al., 2015; Siecker et. al., 2017; Chandel and Agarwall, 2017). This is due to the decrease in the open circuit voltage of approximately 80 ± 10 mV/°C. Therefore, the loss of efficiency associated with ambient temperature $\eta(T)$ of a photovoltaic panel can be calculated according to Eqs. (4) and (5) (Pinho and Galdino, 2014).

$$\eta(T) = \left[1 + \frac{d\eta}{dT} \times (T - T') \right] \quad (4)$$

$$\eta(T) = [1 - 0.005 \times (T - T')] \quad (5)$$

Where $\eta(T)$ refers to the efficiency loss of the photovoltaic plate tested, (T) refers to the temperature of the photovoltaic plate (°C). The crystalline silicon modules have a lower influence on the peak temperature, although they also suffer a reduction in their performance. In addition, crystalline silicon modules from different manufacturers show significant differences in their temperature coefficients. For the simplified calculation of a photovoltaic module operating temperature under certain environmental conditions, use Eq. (6) below (Pinho and Galdino, 2014).

$$T_{mod} = T_{amb} + (K_t \times G) \quad (6)$$

Where:

T_{mod} – Module temperature (°C);

T_{amb} – Ambient temperature (°C);

G – Global irradiance incident on the module = 1000 (W/m²);

K_t – Thermal coefficient for the module (°C/W. m⁻²).

Whereas the standard test conditions do not represent in most cases actual operating conditions, the standards define a nominal temperature for the operation of the cells in the modules, in which the electrical characteristics may be closer to the actual field characteristics. Each module has a nominal temperature for its cells, which is obtained when the module is exposed in an open circuit at an irradiance of 800 W/m² in an environment with air temperature of 20 °C and suffering wind action with a speed of 1 m/s. This temperature is often found in the technical data sheets of the modules, usually identified by the NOCT (Nominal Operating Cell Temperature) and is usually between 40 and 50 °C (Pinho and Galdino, 2014). The NOCT is linked to the thermal and optical properties in the materials used in the construction of the module (Pinho and Galdino, 2014). From the NOCT informed by the manufacturer, the coefficient K_t of the module used in Eq. (6) can be calculated with the help of Eq. (7).

$$K_t = \frac{NOCT-20}{800} \quad (7)$$

Where:

K_t – Thermal coefficient for the module (°C/W. m⁻²);

NOCT– Nominal Operating Cell Temperature = 45 °C (°C);

20– Ambient temperature set for NOCT measurement (°C).

Equations (6) and (7) will calculate the efficiency loss due to the effects of temperature $\eta(T)$, available in Eq. (5). The number of panels (NP) employed is determined by dividing the value found in Eq.(1) by the power of a photovoltaic panel (PPP). The panel power chosen was (250 W). Thus, the amount of panels was determined by Eq. (8).

$$NP = \frac{EG(KW)}{\text{Power of the photovoltaic panel}} \quad (8)$$

The Peak power is found by multiplying the number of panels by the power of a panel, as described in Eq. (9).

$$\text{Peak power} = NP \times PP \quad (9)$$

Where:

NP – Number of panels;

PP – Power of a photovoltaic panel = 250 W.

The Frequency Inverter sizing is performed by multiplying the number of panels by the power of the module, according to Eq. (10).

$$\text{Inverter power} = NP \times \text{Power panel} \quad (10)$$

The electricity tariff is the most important variable when it comes to analyzing the return on investment in photovoltaic solar energy. On the value of tax-free tariffs (Residential B1), homologated by ANEEL, excise the state ICMS and federal taxes, PIS and COFINS. After inclusion of these taxes is that you have the final tariff of electric energy charged to the residential consumer that falls in the class B1. The ANEEL approved tariffs for residential consumers B1 for each electric energy distributor were available by ANEEL (Aneel, 2018). The rates available are expressed in unit R\$/kWh. The Brazilian Association of Electric Energy Distributors (ABRADEE, 2018) informed the

rates of ICMS that vary in each state and the federal contribution taxes PIS and COFINS are fixed values throughout the country. The total electricity tariffs with taxes were calculated according to Eq. (11).

$$Utility\ Bills = \frac{Taxes_{ANEEL}}{[1-(ICMS+PIS+COFINS)]} \quad (11)$$

The rates of PIS and COFINS may vary throughout the year, but the impact of such variations is negligible compared to the total amount of taxes paid. It was then decided to consider constant the rates of PIS and COFINS over the 20 years of investment analysis. The same procedure was applied in relation to ICMS rates.

For the definition and estimation of the necessary investments, the international prices of the equipment (modules and inverters) were taken as basis. Therefore, for the determination of the price of Watt-peak of photovoltaic systems a market research was carried out for the years 2016, 2017 and 2018. The price of (Wp) considers the values necessary for the final investment of the system, including the photovoltaic panels, the frequency inverter and the costs associated with electrical elements necessary to complete the system installation. Thus, when computing the peak power of the system, it will be multiplied by the value of (Wp). For the annual maintenance costs of the system, the value of 2 % of the final value of the project was considered. As the power of the analyzed PVsyst is low, the price of the (Wp) used was of (R\$7,04) (Greener, 2018) characterized by systems of up to 2 kWp. The photovoltaic modules considered for the projects are of crystalline Silicon, being this technology the most used in Brazil (Pinho and Galdino, 2014).

The indicators used to evaluate the economic viability of the projects were chosen based on the most common project management practices and their representative applicability to the variables involved, being: Net Present Value (NPV), Internal Rate of Return (IRR), and Cash Flow (Rocha, 2009). The financial returns, or installments, are represented by the energy savings that consumer / producer starts to have when installing the photovoltaic system in their home. In a simple way, this portion would be the amount that the consumer / producer fails to pay monthly to the energy distributor. The economics plots should always be those that are already discounted the rate of availability for the systems: single-phase, two-phase or three-phase. The net present value is determined for the photovoltaic system considering the interest rate or minimum attractiveness rate (TMA), the SELIC rate (Special Settlement and Custody System) with a value of 6.5 % (Selic, 2019). With the use of SELIC as the TMA of the project, it is admitted that there is no additional risk related to the project, since SELIC is the basic interest rate of Brazilian economy and is derived from all other existing interest rates.

3. RESULTS AND DISCUSSIONS

In order to remain equivalent to the electric charge conditions, households have the same consumption pattern as determined in Chapter 2. The monthly electricity consumption values of (167 kWh/month) are used as input values for the modeling of photovoltaic systems (PVsyst). The only difference between the selected locations and the financial analysis is represented by the climatic variation during the year, which is related to the latitude, longitude and the climatic regimes specific to each locality, as described in Chapter 2. The following are the results of the PVsyst system design for each representative region. The PVsyst modeling results are listed in (Table 4). The peak power of each (PV) system was determined according to Eq. (9). The number of plates (NP) was obtained according to Eq. (8) and the power of the frequency inverter was calculated according to Eq. (10), in order that the power of the system is within the voltage limits of the inverter. The efficiency of the PVsyst was calculated according to Eqs. (3), (4), (5), (6) and (7).

Table 3 - Manophasic System.

Location	System Peak Power Calculated (kWp)	Modules quantity	Potência de Pico Corrigida (kWp)	Inverter Power (kW)	Efficiency (η_{total})
Belo Horizonte	0.992	4	1.000	1.200	0.859
São Paulo	1.196	5	1.250	1.500	0.858
Brasília	0.978	4	1.000	1.200	0.857
Fortaleza	0.945	4	1.000	1.200	0.848
Manaus	1.114	5	1.250	1.500	0.830
Porto Alegre	1.172	5	1.250	1.500	0.840

The initial capital was determined from the values of (Wp), available in Table 3. The value of the (Wp) used for the initial investment in the PVsyst is a general price value that covers the whole of Brazil, since the research performed includes the average price of (Wp) in all Brazilian capitals. After 2012, with the regulation of distributed generation systems, the opening of several solar energy companies expand all over the country, where the largest number of PVsyst technology distribution and installation companies are located in the southeast and south of the country. The

final value of the projects differ from city to city based on the PVsyst peak power values. The energy tariff figures, calculated based on Eq. (10), are available in (Table 5).

Table 4 - Electricity tariff per each location, in (R\$).

City names	Utility	Taxes ANEEL (R\$)	ICMS (%)	PIS/COFINS (%)	Utility Bills (R\$)
Belo Horizonte	CEMIG – D	R\$ 0,59	25.0	9.25	R\$ 0.97
São Paulo	CPFL	R\$ 0,64	30.0	9.25	R\$ 0.81
Brasília	CEB – DIS	R\$ 0,53	25.0	9.25	R\$ 0.67
Fortaleza	COELCE	R\$ 0,49	25.0	9.25	R\$ 0.77
Manaus	AME	R\$ 0,60	29.0	9.25	R\$ 0.92
Porto Alegre	CEEE – D	R\$ 0,60	25.0	9.25	R\$ 0.91

The initial investment generates financial returns, diluted over the useful life of the photovoltaic systems, as a result of the production of electricity and the offsetting of invoices, which are no longer paid due to the energy self-production (Table 6).

Table 5 - Investment PVsyst in (R\$).

Type of connection	Belo Horizonte	São Paulo	Brasília	Fortaleza	Manaus	Porto Alegre
Manophasic System	R\$ 7,040.00	R\$ 8,800.00	R\$ 7,040.00	R\$ 7,040.00	R\$ 8,800.00	R\$ 8,800.00

The project cash flow is initially negative, owing to the initial capital expenditure; however has a positive evolution, generally increasing until the useful life of the photovoltaic system. The cash flow was calculated by discounting over 20 years of electricity bills offset values, considering the following components: Local energy tariff provided in Table 5, the cost of the PV system, Table 3, of the SELIC interest rate of 6.5 % and analysis time of 20 years as a conservative measure. Based on these results, it was possible to find the financial indicators NPV, IRR and Payback, presented in Tables 7, 8 and 9, respectively.

Table 6 - Net present value (NPV)

Type of connection	Belo Horizonte	São Paulo	Brasília	Fortaleza	Manaus	Porto Alegre
Manophasic System	R\$ 8,369.04	R\$ 3,675.46	R\$ 3,273.01	R\$ 5,060.74	R\$ 5,542.19	R\$ 6,604.28

Table 7 - Internal rate of return (IRR)

Type of connection	Belo Horizonte	São Paulo	Brasília	Fortaleza	Manaus	Porto Alegre
Manophasic System	20.03 %	11.67 %	12.22 %	15.05 %	14.07 %	15.40 %

Table 8 - Payback in (years)

Type of connection	Belo Horizonte	São Paulo	Brasília	Fortaleza	Manaus	Porto Alegre
Manophasic System	6.03	10.35	10.87	8.26	8.89	9.01

All the analyzed locations have positive values of (NPV), (IRR) and Payback of less than 20 years, demonstrating economic viability in all projects. Figure 3 shows a comparison between local mean temperature, solar irradiance and calculated peak power. It is observed that the higher the solar irradiance, the lower the peak power for the system. It is also observed the influence of the temperature as a function of the calculated peak power, since at each increased degree; there is a 0.5 % loss of efficiency of the photovoltaic plate.

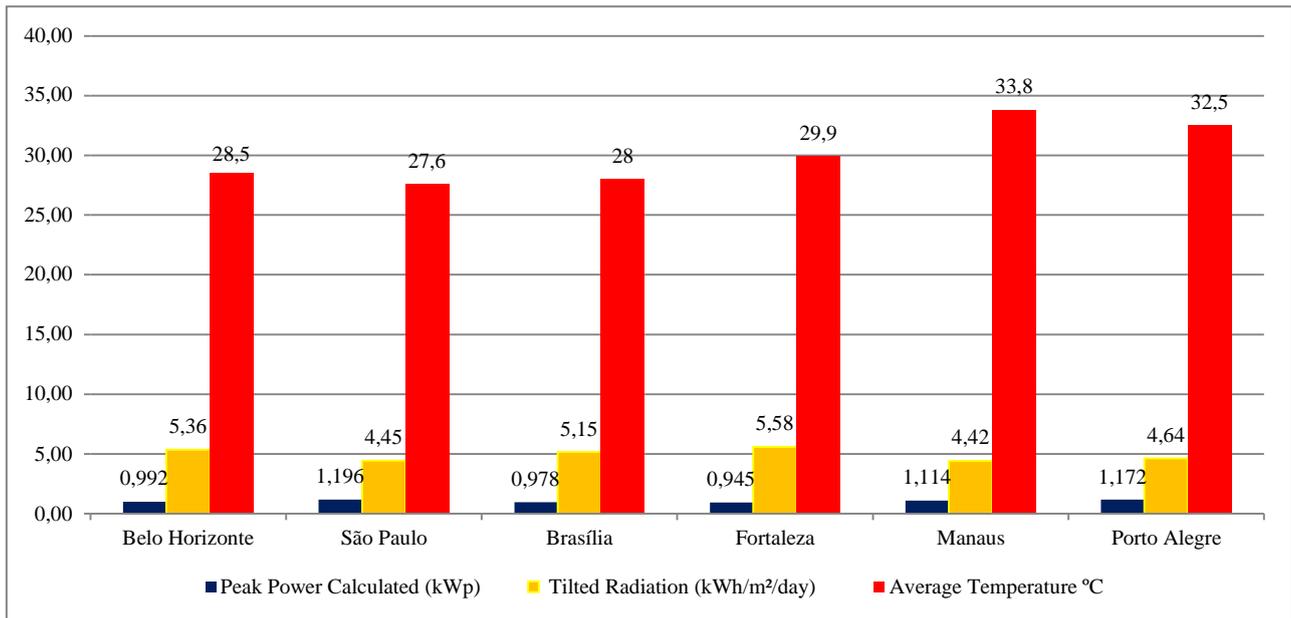


Figure 3 - Comparison between solar irradiation, Temperature and Peak Power.

The higher the solar irradiance, the lower the necessary financial investment. Taking Fortaleza as an example, with the highest solar irradiance in the analyzed regions and, consequently, require the lowest investment. In addition to solar irradiation, another factor that directly impacts the economic viability of PVsyst is the Electric Energy Tariff (TEE), available in (Table 9). The higher the (TEE), the faster the return on investment, since the price that would be paid with the use of conventional electricity is saved with the acquisition of PV technology. Belo Horizonte, has the highest electricity tariffs in the country (R\$0,97) and consequently presents the best results of the financial return indicators. In comparison with São Paulo, for example, which, in addition to presenting one of the lowest incidence of solar irradiation, presents the lowest (TEE) of all the analyzed locations, resulting in a lower financial attractiveness.

The degree of confidence in the feasibility indicators and the methods presented depends directly on the greater or less precision of the involved data analysis. Estimates of the data involved in the present are more reliable than those corresponding to the data in the future over the project. Therefore, it is evident that full precision cannot be guaranteed in all involved data analyzes, especially those affecting the future. It is also clear that the fees involved in feasibility studies (interest and increased costs and revenues) may be affected by factors other than engineering, where it is important to expect that the values or indicators that will be accountable for the feasibility of the project will be subject to a margin of error for more or less.

In the sensitivity analysis, optimistic and pessimistic estimates were built about a group of variables that have an impact on the return on investment. As described in Chapter 2, a variation of $\pm 60\%$ in energy consumption was used, only for single-phase systems, since it is the type of connection most used in Brazil and it has great insertion potential. The initial consumption was 167 kWh/month, the price of (Wp) of (R\$7,04), the Electric Energy Tariff (TEE) corresponding to each region and the (TMA) of the project of 6.5%. Sensitivity analysis was performed for Belo Horizonte, for being the locality that obtained the best result.

Figure 4 shows the variables that most impact the return on investment in Photovoltaic Systems. At the zero point are the values of (NPV). From this point on, the (NPV) variations occur due to the influence of the variables, it can be seen that the higher the energy consumption, the higher the NPV, since the monthly energy savings are higher, resulting in a higher (NPV) and a lower Payback. The higher the electric energy tariff (TEE) price, the higher is also the (NPV) because the consumer fails to pay for the conventional energy available from the concessionaires and to reduce the portion that would be paid in the project investment.



Figure 4 - Sensitivity analysis to evaluate the behavior of the Net Present Value for Belo Horizonte, in (R\$).

On the other hand, the lower the price of (Wp), the higher the (NPV) because the initial investment is lower; the same behavior is found when the interest rate (SELIC) is analyzed throughout the variation. The lower the interest rate, the higher the (NPV). Therefore, the greater the slope of the line, the greater the influence of the variable in the (NPV), where it is observed that the energy consumption is the variable that most influences the return of investment in photovoltaic systems, because it has the highest slope. Belo Horizonte, confirming the previous results presented one of the best results for the sensitivity analysis, being the capital that allows the greater variation between the variables. For this location, electricity consumption can be up to approximately 40 % lower than 167 kWh/month, which will still be positive (NPV), however, as the behavior of the graph is linear if the energy consumption increases by up to higher than 60 %, (NPV) also increases significantly, with values higher than (R\$ 20.000,00).

Minas Gerais has the highest installed power, probably because it is the state that has one of the largest (TEE) in Brazil, followed by Rio Grande do Sul (88,096 kWp). Although São Paulo has presented the less expressive results, as commented previously, it is the richest state and is the state that more consume electric energy in Brazil, justifying to be the third Brazilian locality that has one of the largest powers in installed photovoltaic solar energy (65,887 kWp), as shown in Figure 5.

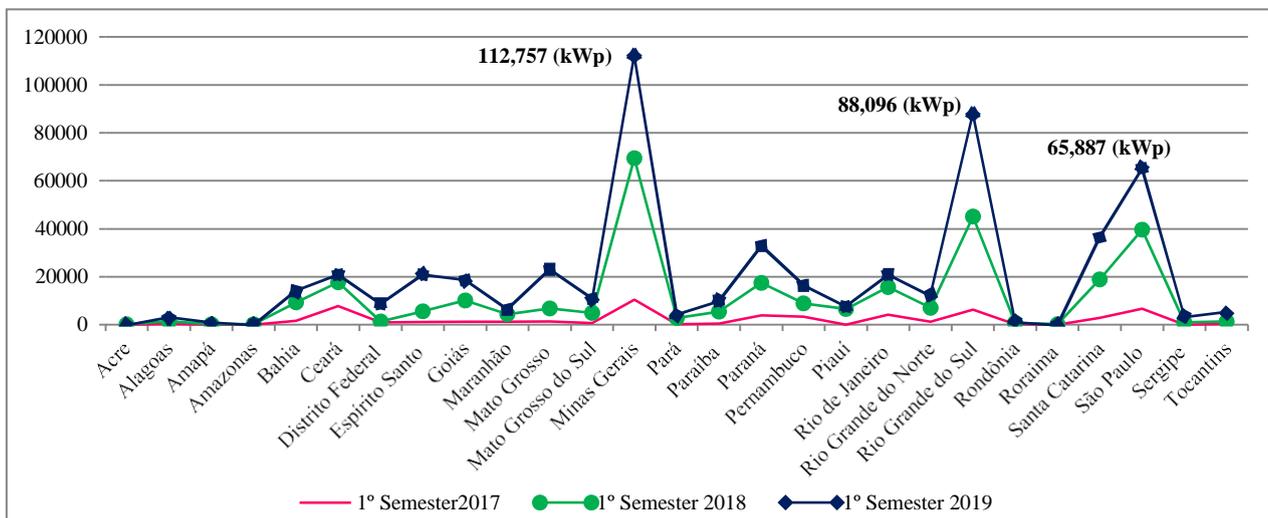


Figure 5 - Evolution of Installed Power in Brazil, in (kWp). Source: Adapted from (Greener, 2017, 2018, 2019)

4 CONCLUSIONS AND RECOMMENDATIONS

As a consequence of the water crisis that affected Brazil in 2011, mainly in the northeastern region of the country, the federal government in the year 2013 determined that there would be a 20 % reduction in the price of electricity tariffs throughout the country. This government initiative has increased the energy consumption of the Brazilian population. However, the volume of water in the reservoirs has drop dramatically, requiring in the use of fossil sources

for energy generation, which have the highest generation price (R\$/kWh) than generation by hydraulic source. This series of events caused a reverse effect, generating a billionaire deficit for electric power concessionaires leading to a significant growth in energy tariffs in just one year after the determination of the fall. The budget debt will be returned to the consumer, and should be paid until the year 2022.

Given the presented context, and with the creation of regulations RN 482/2012 and RN 687/2015 of Aneel, there was a significant increase in the number of installation of Photovoltaic Systems in Brazil, mainly owing to the installation of a photovoltaic system in a residence or company becomes an insurance against energy inflation. This is because, once the consumer generates his own energy, regardless the percentage of increase that the tariff has practically nothing changes in the portion of the energy bill paid, if the monthly expenses do not exceed the energy generated.

All the analyzed present results that could stimulate the federal government to reconsider how to manage and stimulate changes in the country's energy matrix. This analysis derives from the fact that, in all the studied localities, (a) the TIRs are higher than the inflation rate projected by the Brazilian economy (SELIC), (b) the NPVs are positive and exceed the negative cash flows, (c) the return time, is shorter than the life of the equipment. These factors can be improved with government conduct aiming the initial investment reduction, which still one of the biggest barriers for the residential investor. One governmental action that might reduce this barrier is the reduction of import taxes for imported goods and / or encourage the establishment of local suppliers/producers of technological items.

In order to promote the reduction of the initial investment, some financial incentives should be available, at least during the maturation period, to allow a national production free of import taxes and the training of qualified personnel for both the design and the installation of Photovoltaic Systems. What could also be discussed by the government is the capital loan at attractive interest rates by BNDES, for example, and other Brazilian banks. The sensitivity analysis presented demonstrated the importance of the reduction of the Interest Rate and the price of (Wp) for the attractiveness of Photovoltaic Systems. An interesting factor to be discussed is the monthly consumption of electric energy, which, as presented in the sensitivity analysis, for all localities, the higher the consumption, the higher the (NPV). Another important point that could be adopted by Brazilian government is the availability of photovoltaic solar energy financing in housing projects of a social character, such as the popular housing program "Minha Casa Minha Vida" where photovoltaic technology could be included in the residential project and compose financing with facilitated credit. All these government actions besides generating a greater number of jobs would also stimulate the reduction of the costs of the components necessary for the acquisition of Photovoltaic Systems, and the diversification of the national energy matrix.

Sensitivity analysis enables the evaluation of which parameters are most sensitive to the economic viability of Photovoltaic Systems. The charts provide the maximum and minimum variations that variables involved in a photovoltaic project can have for economic viability to occur. The most sensitive variable for all localities is the monthly consumption of electricity (kWh / month). Some regions admit a greater variation of the variables involved in the projects, as is the case of Belo Horizonte, which may have a reduction in the monthly consumption of electric energy up to 40 % (NPV). Sensitivity analysis allows a better understanding of the work since it can include all the social classes found in Brazil, making evident the variables that most economically impact the acquisition of Photovoltaic Systems. Thus, the main conclusion that can be drawn is that the implementation of public policies that stimulate the use of renewable energy sources such as solar photovoltaic, extremely important for (a) diversification of the energy matrix, (b) reduction (c) energy security, (d) job creation, (e) more competitive prices, (f) stimulation of national and international trade, (g) development of research.

The implementation of RN 482/2012 and RN 687/2015, coupled with the energy inflation found in Brazil in recent years, has stimulated distributed generation trade in Brazil. However, other government actions could be carried out, especially in relation to the price of photovoltaic technology, which today is practically all imported from other countries. Thus, there could be a greater financial and fiscal stimulus for the development of Brazilian companies that produce photovoltaic technology, since the country has one of the largest reserves of silicon in the world.

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6. RESPONSIBILITY

The authors are the only responsible for the printed material included in this paper.