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Analysis of Payback Time in Photovoltaic Systems: Case Study with Two Projects

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Abstract

Nowadays, the increasing of implematation distribuited generation around the word has stimulared the development of several research taking into account the impact of this gerneration, However, in most cases such research is related to the electrical problems that the distribution grids will face with the insertion of this new source and few articles aim to study the economic impact to the user if they choose a products of dubious quality. Therefore, this article was developed with the motivation of the growth of this type of generation in the Brazilian territory, much justified by some aspect like: the high energy tariff, the incentives that some users receive with the installation of this equipment and the decrease of the installation cost of such system. Thus, the article aims to conduct an economic feasibility study, focusing mainly on payback time, for two types of photovoltaic systems differentiated only by the certification of the Brazilian quality control organizations. Two scenarios will be analyzed, the first one supposes that the both system will operate with the loss reported by the manufacturers and the second one will assume a larger drop in the loss that was reported by the manufacturer for the uncertified product, and the impact of this will be analysi in the payback time. So, this work will use grid systems to survey the economic study and will be presented in a basic way, such as energy compensation policy, the criteria to be considered during the design of the system, and the criteria to be performed for the study of payback.

Keywords

Solar System, Economic Analysis, Payback Time

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1. Introduction

Nowadays, the high cost of electricity, the increased concern about global environmental problems, and the decrease in the initial investment of a photovoltaic system are reasons that influence and encourage the use of photovoltaic energy around the world.

In Brazil, with the rise in implementation of solar energy at the Brazilian renewable energy matrix, the national agency of electrical energy (ANEEL), through the normative resolution n° 482, on April 17, 2018, established the rules of connection of micro (up to 1MW) and mini (up to 100kW) generation in the distribution system [1]. Furthermore, this resolution also provided information about net metering. However, should be emphasized that this resolution shows only the minimum criteria of connection in the distribution system, so this enables a free standard for connection, according to each utility company.

Therefore, with the diffusion of this technology, it became more important to develop studies and technical opinions about how this equipment would be marketed. In Brazil, there is a Brazilian program of electrical energy conservation

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(PROCEL); this federal program was created on December 30, 1985. The goal of this program is to promote the efficient use of electrical energy and avoid losses. PROCEL operates in different areas; for instance, one area pertains to equipment, whereby it identifies through the PROCEL seal the most efficient equipment present in the Brazilian market [2], so this labelling guarantee a technological improvement. Working together with PROCEL is the INMETRO (Nacional Institute of Metrology, Quality, and Technology). Linked to the Ministry of Development, there are many goals in this institute, one of which involves executing the national of metrology and quality policies [3], thus ensuring that there are products certified according to the Brazilian metrology standard.

Besides this technical development about the products available for purchase, it`s also worthwhile to develop studies that seek to inform about economic viability during the installation of these systems. In the literature, many methods seek to inform the trader of this viability. The main methods are:

a. NPV (Net Present Value) - Performs a study through all of the cash flows, displaced to the present moment, thus indicating to the investor if the business is profitable or not The NPV is defined as the difference between the present value of net cash inflows associated with the project and the initial investment required [4].
b. Payback Period (PBP) - Shows the investor the minimum time needed to pay the initial investment.
c. IRR (Internal rate of return) - Shows the investor the minimum interest that would zero the NPV, so this rate aims to assess which applications are most advantageous. The IRR is defined as the required rate that, when used, results in an NPV equal to zero [5].

In the literature, there are many research developments about economic analysis and photovoltaic systems. Some research focus in economic parameters as NPV, PBP, Energy Payback Time and other indicators [6]. Others research focus only in economic viability of the project [7][8][9] or risk analysis during the implementation of the photovoltaic system [10]. It's important to jut that exist a lot of project that the photovoltaic energy can be study, so in the literature there are many papers where the objective are equals but their implementations are totally different only because their project [11-14].

Although there are many articles about development in this subject in the literature, few of those take into account the efficiency and certifications of the panels chosen for their studies. With this, research that consider these things became extremely important, especially to those countries that are inserting the photovoltaic generation into the planning of renewable energy expansion of their energy matrix.

Therefore, this article aims to carry out an economic feasibility study based on the use of two types of technologies available in the Brazilian market; these photovoltaic technologies are differentiated by the certification of PROCEL and INMETRO.

2. Method

This section presents a theoretical conception about the assumptions considered during the development of this paper, informing concepts that involve from the types of photovoltaic systems currently present to systems of energy compensation, basic system design, and economic analysis.

2.1. Description of the Photovoltaic System

There are two types of photovoltaic systems: on grid and off grid. For the analysis carried out, the on-grid system was considered for case generation. In the case of on-grid configuration, there is a system connected to the electric grid where its generated energy is quickly drained. In general, this type of system has a lower loss and, consequently, higher performance when compared to the off-grid system, since it does not have any energy storage equipment. Another factor directly impacted by the nonexistence of storage systems is cost, since such storage systems become costly.

It is important to point out that the on-grid system is extremely dependent on regulation, since this topology are connected to the electric grid. Due this condition, it is need connection policies as well as compensation policies regarding the generated energy [15]. One cannot fail to observe the existing regulations regarding protection systems for different islanding situations [16-17].

The most commonly used equipment for on-grid systems includes.

a. Photovoltaic panel - Equipment responsible for the conversion of solar energy into electricity. Most of these elements have a 25-year guarantee against loss of performance of more than 20% (depreciation of 0.8% per annum, average value found in the datasheet) and 10 years against manufacturing defects [18]. The equipment is tested at 25 ° C and presents a loss of yield according to the elevation of temperature. In the literature, there are ideal temperature coefficients for such equipment, ranging from -0.35%/°C to -0.47%/°C [18].
b. Inverters - Equipment responsible for integrating the solar panels into the power grid. Its main function is to convert the direct current generated by the panels to an alternating current. However, such equipment still has other functions,

such as energy protection and the generation of data on the photovoltaic system. Its lifespan varies from 5 to 10 years, according to the environmental conditions that such equipment is exposed to.

2.2. Power Compensation System

Due to the enormous influence of energy compensation policy on economic feasibility studies, it is a brief theoretical review on the subject.

A global perspective on these policies is of the work presented in Table 1 [19-20].

Table 1. Types of compensation policies.

Countries	Rate type
Brazil	Net metering
Denmark	Net metering
France	Feed-in
Germany	Feed-in
Switzerland	Feed-in
Portugal	Feed-in

The compensation policy used in Brazil is net metering, whereby the energy is "transferred" to the concessionaire through loans and is later compensated in the consumption of energy. It is important to point out that there is a resolution n° 482 (modified by the ANEEL resolution n° 687), which informs criteria regarding how such compensation is made [21].

Another important factor in this compensation policy is that, in Brazilian territory, the energy injected into the electricity grid may suffer some types of taxation and there is tax authorities to deal with these issues

2.3. Design of the Photovoltaic System

In general, the consideration of several factors, such as overall system power, panel voltage level, inverter input voltage level, peak solar panel power, and maximum inverter power, is key for system design.

Consider the design of a photovoltaic system for the service of a residence with a monthly energy consumption of "X" kWh/month. By also considering the system availability rate in "y" kWh/month, the photovoltaic system can be sized using Equation (1):

$$Emês = X - y \left[\frac{kWh}{month}\right] \quad (1)$$

Where: Emês represents the energy required to be produced in a month.

Because there is a system availability rate, the power account will not be reset. Therefore, to avoid oversizing the system, it is essential to consider this rate. After this consideration, it is necessary to find the daily energy produced by the panel. For this, it is necessary to consider that the load requires constant energy over 30 days, which can be calculated as Equation (2):

$$Edia = \frac{Emês}{30} \left[\frac{kWh}{day}\right] \quad (2)$$

Where: Edia represents the daily energy required to be produced.

Since there are losses associated with the inverter, the efficiency of the inverter (ηinv) should be considered during the calculations, so the energy needed to be produced by the panel will be that obtained by Equation (3):

$$Epainel = \frac{Edia}{\eta inv} \quad (3)$$

Where: Epainel refers to the energy produced by the solar panel and ηinv represents the efficiency of the inverter.

The peak power of the system will be found by considering the irradiance index of the locality. In Brazil, there are several well-established and reliable solarimetric databases, such as the Brazilian Solar Energy Atlas and the SunData Program [22]. In this work, the SunData Program, developed by Cresesb, will be used as a way of considering local irradiation, since the program can reliably report the irradiation index anywhere in the Brazilian territory.

Therefore, the peak power is calculated according to Equation (4):

$$P_{pico} = \frac{Epainel}{HSP} \quad (4)$$

Where: Ppico is the peak power of the photovoltaic system and HSP is the number of hours of full sun during the day, this being the average index of irradiation in a certain locality.

After discovering the peak power of the system, it is indispensable to know the number of panels needed to meet such peak demand. As the peak power value of each panel is reported in its datasheet, with a simply use this value along the peak power of the system is possible to find the number of modules required as showed in Equation (5).

$$N_{modules} = \frac{P_{pico}}{P_{mod}} \quad (5)$$

Where: Pmod represents the power of the photovoltaic panel.

After the dimensioning of the solar panels, an inverter must be found that meets the specifications of the system. For the choice of the inverter, it is necessary to consider the open circuit voltage level of the system, the system operating voltage level, and the peak power of the system.

The peak power of the system is already known through in (4), so the inverter must meet the following specification (Equation (6)):

$$0.8 < Pinv < 1.25\, Ppico \quad (6)$$

Where: Pinv refers to the power of the inverter.

As mentioned, another factor to be taken into consideration during the sizing of the inverter is the voltage level. For this, it is essential to know the number of modules connected in series and parallel; in the literature, there are several methods for choosing these values. If the number of modules in series knows, we have the voltage values, following Equations (7) and (8):

$$Voc_{(system)} = N_s . Voc_{(panel)} \quad (7)$$

$$Vf_{(system)} = N_s . Vfl_{(panel)} \quad (8)$$

Where: Voc is the open circuit voltage, NS is the number of panels in series connection and Vfl is the voltage at full load.

It is essential to emphasize that, in addition to the dimensioning of the equipment presented, it is also necessary to dimension the cables, fixing structures, and protection system (circuit breakers, breakers, fuses, among others); however, in this work, we will not be considering the sizing of such items.

2.4. Energy Generated and Energy Account Calculation

In order to have a feasibility study of the implementation of a photovoltaic system, it is essential to know the amount of energy generated in a given period by the photovoltaic system implemented. Therefore, Equations (9) to (11) estimate the energy generated:

$$E_G^{day} = HPS . Pmod . N_{modules} \quad (9)$$

$$E_G^{month} = E_G^{day} . 30 \quad (10)$$

$$E_G^{year} = \sum_{i=1}^{12} E_G^{month}(i) \quad (11)$$

Where E_G^{day} represents the daily energy produced, E_G^{month} is the monthly energy produced, and E_G^{year} refers to the annual energy produced.

After knowing the estimated energy produced annually, it becomes necessary to know the amount of energy paid, or in this case, what will be the energy difference payed. For this, it is necessary to know the availability rate of the use of the distribution network; in Brazil, the resolution of ANEEL n ° 414, on November 9, 2010 [21], informs about this tariff. For consumers in group B, which is the simulated case, the cost of availability varies according to the customers' connection type. In this article, the consumer connection will be considered a three-phase installation that has a minimum tariff of 100kWh/month.

Therefore, to estimate the amount of energy paid per year, basically, two cases were considered. In the first case, the consumer is generating more than consuming, that is, the consumer has a positive energy credit and will pay only the cost of availability from the Web. The second case, when the consumer produces less than the own consume, will soon not have energy credits; thus, paying the difference between consumption and production.

a. Case 1 $[E_G^{year} > 12.(X - 100)]$

$$Value\ paid = 100. Energy\ Tariff \quad (12)$$

b. Case 2 $[E_G^{year} < 12.(X - 100)]$

$$Value\ paid = [(12.X) - E_G^{year}]. Energy\ Tariff \quad (13)$$

In this case, the consumer will pay the difference between the energy generated by the panel and the energy consumed by the consumer. In this article, the option of the consumer to have energy credits will not be considered.

2.5. Payback Calculation

As demonstrated, the payback will inform the investor on how long will get the return the initial investment. There are several formulas for the calculation of payback presented in the literature. This work will use the simple Payback for case analysis.

This choice was considered feasible due to the lack of knowledge of the TMA (Minimum Rate of Attractiveness), which is generally used to calculate the discounted Payback. The value of TMA will not be calculated in the present work; due to the simplifications used, the value of TMA calculated would not impact.

Payback was calculated and indicate in Equation (14) as follows [23].

$$Payback = \frac{Initial\ Investment}{FCM} \quad (14)$$

Where: FCM refers to the average cash flow.

2.6. Scenarios Analysis

Due to the lack of reliability of products without the certification of the competent organizations, it is essential to generate at least two cases for the analysis of payback time. This generation of scenarios becomes important, as noncertified products can show a change in performance over those reported in the equipment datasheet. Therefore, two cases were generated for analysis:

Scenario 1

In the scenario 1, all of the equipment is responding according to its datasheet. In this case, only the linear yield drops of 0.8% per year, which is the value reported in the panel datasheet, were considered.

It is worth mentioning that, due to inverter changeover every 5 years, the drop in efficiency of this equipment was not considered at the time of calculation.

Scenario 2

In this case, the equipment that is not certified shows a drop in yield more than that reported in the datasheet. In this research is considered a drop in yield of the linear system of 2.4% per year.

It is important to note that this drop in efficiency includes the loss of efficiency of the panel together with the decrease in the efficiency of the inverter, thus representing a drop in efficiency 3 times higher than that reported in the datasheet.

3. Results

This section presents the results obtained at the end of the study. The type of system (certificated or not certified) will present the results. In addition, it is important to emphasize that there will be two scenarios analyzed above, and in the second scenario, only the system without certification will present changes.

In this study, the names of the chosen equipment will not be presented; only the basic information about such equipment will be presented in Tables 2, 3, 4, and 5. All the monetary values are represented by Reais (R$).

Table 2. Certified Panel data.

Certified Dashboard Data	
Pmax (W)	335
Voc (V)	45.8
Vpc (V)	37.4
Max current (A)	8.96
Efficiency	17.23
Price	R$ 700.00

Table 3. Certified Inverter data.

Certified Inverter Data	
Pmax (W)	5400
Voc (V)	580
Vpc (V)	125~550
Efficiency	0.978
Price	R$ 8,500.00

Table 4. Non-Certified Panel data.

Non-Certified Dashboard Data	
Pmax (W)	150
Voc (V)	23.6
Vpc (V)	18.5
Max current (A)	-
Efficiency	27.8
Price	R$ 400.00

Table 5. Non-Certified Inverter data.

Non-Certified Inverter Data	
Pmax (W)	5200
Voc (V)	500
Vpc (V)	100~490
Efficiency	0.975
Price	R$ 4,600.00

3.1. Design System

For the system design, the irradiation index obtained by the SunData program was considered [22]. This program provides the irradiance index for latitude and longitude reported at four different angles. Table 6 shows the results obtained in the software.

Table 6. Irradiation Index.

Irradiation Index (kWh/m^2)				
Month	**Horizontal Plan**	**Angle (latitude)**	**Highest annual Average**	**Highest Monthly Minimum**
	0° N	**23° N**	**20° N**	**32° N**
Jan	6.04	5.45	5.56	5.06
Feb	6.22	5.93	6	5.63
Mar	5.06	5.21	5.22	5.1
Apr	4.36	4.93	4.89	5
May	3.59	4.42	4.34	4.6
Jun	3.35	4.34	4.24	4.58
Jul	3.34	4.21	4.12	4.41
Aug	4.20	4.95	4.89	5.08
Sep	4.43	4.71	4.71	4.67
Oct	5.11	4.98	5.03	4.79
Nov	5.14	4.73	4.81	4.44
Dec	5.93	5.27	5.39	4.88

For the design of the photovoltaic system, the irradiation index was considered in the horizontal plane, with a mean irradiance of 4.73 kWh/m².day. In addition, the consumption of the residence in question was 700kWh/month. It is important to emphasize that the possibility of increasing the residence load throughout the useful life of the system was not considered. Which does not have availability of installation of new equipment and if it were necessary to change some equipment, the new equipment would have a better efficiency.

The peak power of the photovoltaic system chosen was 5.1 kW, thus requiring about 16 panels of the certificate and 35 panels of the non-certificated. This difference in panel number occurs because the maximum power of the uncertified panel is lower.

With the number of panels chosen, one can verify how much energy is expected to be generated annually. The results will be presented for each case previously described.

3.2. Scenarios for Payback Time Study

Scenario 1

This part of the article will present the results obtained for the best system. The total investment of the system in first year was R$ 19,700.00 for the certified system and R$ 18,600.00 for the non-certified system. The prices are close, even with the uncertified system presenting more than twice the number of plates. This is due to the low price of the non-certificated system when compared to the certified system. This difference is shown in Tables 2 and 4. The energy generated by each type of system will be presented in Table 7. It is valid that a linear yield decreases of 0.8% per year was adopted. The Table 8 shows a comparison with different systems options considering the cost of the energy that will be consumed by electric grid.

Considering the consumption of the residence in question together with the availability rate. It can be inferred how much energy will be paid with the application of each system. The price of the energy tariff was considered to be equal to R$ 0.78 in Year 1; this tariff was stipulated considering the tariff of a concessionaire operating in Brazil. It is important to emphasize that the value of this tariff will change according to each locality from the country. In addition, this rate is corrected with the inflationary target present in the country. It currently revolves around 4.5% per year.

Taking all these costs and gains into account. One can build up the system's expected cash flow. Table 9 will present the annualized values.

Table 7. Generation data.

Energy Generated (kWh/year)		
Year	**Non-certified system**	**Certified system**
1	8824.37	8902.10
2	8753.77	8830.88
3	8683.18	8759.67
4	8612.58	8688.45
5	8541.99	8617.23
6	8471.39	8546.01
7	8400.80	8474.80
8	8330.20	8403.58
9	8259.61	8332.36
10	8189.01	8261.15
11	8118.42	8189.93
12	8047.82	8118.71
13	7977.23	8047.50
14	7906.63	7976.28
15	7836.04	7905.06
16	7765.44	7833.85
17	7694.85	7762.63
18	7624.25	7691.41
19	7553.66	7620.20
20	7483.06	7548.98
21	7412.47	7477.76
22	7341.87	7406.55
23	7271.28	7335.33
24	7200.68	7264.11
25	7130.09	7192.90

With the knowledge of the cash flow over the period, one can calculate the Payback time for each system. The Payback time found for the uncertified system was 2.8 years. Whereas for the certified system it was 3.1 years. This higher payback time for the certified system was expected, since due to its guarantee of service information contained in its datasheet. The components present in that system present higher prices than the non-certified products.

Scenario 2

At that time, the result will be presented considering that the uncertified system will show a yield drop of more than 0.8% per year. The yield drop chosen was 2.4% per year; this value is only 3 times higher than the norm allowed value.

The tables of energy generated over the useful life (Table 10), the energy bill value (Table 11) and, the cash flow over the useful life (Table 12) will be presented again.

Table 8. Energy Payment.

Energy Price (R$)			
Year	**Non-certified system**	**Certified system**	**Without System**
1	732.00	732.00	5124.00
2	764.94	764.94	5354.58
3	799.36	799.36	5595.54
4	835.33	835.33	5847.34
5	872.92	872.92	6110.47
6	912.21	912.21	6385.44
7	953.25	953.25	6672.78
8	996.15	996.15	6973.06
9	1040.98	1040.98	7286.84
10	1087.82	1087.82	7614.75
11	1136.77	1136.77	7957.42
12	1187.93	1187.93	8315.50
13	1241.39	1241.39	8689.70
14	1297.25	1297.25	9080.73
15	1355.62	1355.62	9489.37
16	1416.63	1416.63	9916.39
17	1480.37	1480.37	10362.62
18	1546.99	1546.99	10828.94
19	1616.61	1616.61	11316.25
20	1689.35	1689.35	11825.48
21	1765.37	1765.37	12357.62
22	1844.82	1844.82	12913.72
23	1927.83	1927.83	13494.83
24	2014.59	2014.59	14102.10
25	2227.89	2117.71	14736.69

Table 9. Cash Flow.

Cash Flow (R$)		
Year	**Non-Certified System**	**Certified System**
1	2160.00	2050.00
2	4217.64	4217.64
3	4424.17	4424.17
4	4640.00	4640.00
5	4865.54	4865.54
6	41.23	-4248.77
7	5347.53	5347.53
8	5604.91	5604.91
9	5873.87	5873.87
10	6154.93	6154.93
11	1388.64	-2901.36
12	6755.57	6755.57
13	7076.31	7076.31
14	7411.49	7411.49
15	7761.74	7761.74
16	3067.76	-1222.24
17	8510.25	8510.25
18	8909.95	8909.95
19	9327.64	9327.64
20	9764.12	9764.12
21	5160.25	870.25
22	10696.90	10696.90
23	11195.00	11195.00
24	11715.51	11715.51
25	12136.80	12246.99

Tables 10, 11 and 12 present the results found when considering a yield decrease of 2.4% for the non-certified system. It can be verified that the values found already diverge from the presented values of the certified system. In this scenario, the payback time for the uncertified system was 3.8 years higher than the non-certificated system, which is 3.2 years.

Table 10. Generation data.

Energy Generated (kWh/year)		
Year	**Non-certified system**	**Certified system**
1	8824.37	8902.10
2	8612.58	8830.88
3	8400.80	8759.67
4	8189.01	8688.45
5	7977.23	8617.23
6	7765.44	8546.01
7	7553.66	8474.80
8	7341.87	8403.58
9	7130.09	8332.36
10	6918.30	8261.15
11	6706.52	8189.93
12	6494.73	8118.71
13	6282.95	8047.50
14	6071.16	7976.28
15	5859.38	7905.06
16	5647.59	7833.85
17	5435.81	7762.63
18	5224.03	7691.41
19	5012.24	7620.20
20	4800.46	7548.98
21	4588.67	7477.76
22	4376.89	7406.55
23	4165.10	7335.33
24	3953.32	7264.11
25	3741.53	7192.90

Table 11. Energy Payment.

Energy Price (R$)			
Year	**Non-certified system**	**Certified system**	**Without System**
1	732.00	732.00	5124.00
2	764.94	764.94	5354.58
3	799.36	799.36	5595.54
4	835.33	835.33	5847.34
5	872.92	872.92	6110.47
6	912.21	912.21	6385.44
7	953.25	953.25	6672.78
8	996.15	996.15	6973.06
9	1101.62	1040.98	7286.84
10	1343.18	1087.82	7614.75
11	1604.25	1136.77	7957.42
12	1886.10	1187.93	8315.50
13	2190.06	1241.39	8689.70
14	2517.56	1297.25	9080.73
15	2870.10	1355.62	9489.37
16	3249.28	1416.63	9916.39
17	3656.76	1480.37	10362.62
18	4094.34	1546.99	10828.94
19	4563.90	1616.61	11316.25
20	5067.42	1689.35	11825.48
21	5607.02	1765.37	12357.62
22	6184.92	1844.82	12913.72
23	6803.48	1927.83	13494.83
24	7465.19	2014.59	14102.10
25	8172.67	2117.71	14736.69

Table 12. Cash Flow.

Cash Flow (R$)		
Year	**Non-Certified System**	**Certified System**
1	2160.00	2050.00
2	4217.64	4217.64
3	4424.17	4424.17
4	4640.00	4640.00
5	4865.54	4865.54
6	41.23	-4248.77
7	5347.53	5347.53
8	5604.91	5604.91
9	5813.22	5873.87
10	5899.57	6154.93
11	921.16	-2901.36
12	6057.40	6755.57
13	6127.63	7076.31
14	6191.17	7411.49
15	6247.26	7761.74
16	1235.11	-1222.24
17	6333.86	8510.25
18	6362.60	8909.95
19	6380.35	9327.64
20	6386.06	9764.12
21	1318.60	870.25
22	6356.79	10696.90
23	6319.35	11195.00
24	6264.91	11715.51
25	6192.02	12246.99

4. Conclusions

The purpose of this article is to highlight the importance of the use of certified equipment using Payback time as a comparison method. It can be concluded that investing in an uncertified system is not advisable, since such products do not have any of their yield or efficiency throughout their useful life. With a larger system in mind, this difference in Payback time when the system no longer has its nominal yield can represent a high loss to the investor.

Besides the factors already presented, it is important to emphasize that the system without certification does not have guarantees against other criteria such as the sinking of voltage and time of protection action.

Therefore, it is vital that there be an awareness on the part of the investors so that products that do not have certifications are not acquired. Furthermore, it is of extreme importance that the existence of rules, standards and enforcement more active so that the commercialization of products not certified be prohibited.

In addition to what has been described, it is necessary that there be more regulations on the quality of energy delivered by such equipment since there are currently no standards to be followed regarding the quality of energy delivered.

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