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TECHNO-ECONOMIC ASSESSMENT OF A GRID-CONNECTED PHOTOVOLTAIC SYSTEM INSTALLED AT UNIOESTE (WESTERN PARANÁ STATE UNIVERSITY), CASCAVEL - PR CAMPUS

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ABSTRACT

This article aimed to carry out the techno-economic assessment of a grid-connected photovoltaic system at Western Paraná State University - UNIOESTE, Cascavel - PR campus. The system was built in order to meet the electricity demand of the Alternative Energy Systems Analysis Centre (CASA Project) and consists of ten photovoltaic modules with 330 Wp each (two strings with five modules in series), and a 4 kWp voltage inverter. For the technical assessment of the system, energy data collections were carried out in four different ways: the first one using the data that is provided by the bidirectional meter installed in the system; the second one through electricity bills provided by the local electric utility (COPEL); the third one through the Solar Man website, where the data provided by the inverter is stored; and the fourth one using data recorded by the EMBRASUL RE7000 electrical quantities analyser. As for the economic evaluation, a system feasibility analysis was performed, using the Net Present Value (NPV), the Internal Rate of Return (IRR) and the Discounted Payback (DP) as decision criteria. The results obtained in the study show that the values of electricity generation collected by the website and by the RE7000 are close, however, the values of the website are slightly higher. The total efficiency of the system was 13.32%. The return on investment occurs in 12 years, the IRR is 14.1% and the NPV is R$25,564.07, values that make the investment viable, but very close to the minimum acceptable limits.

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INTRODUCTION

In recent decades, the global electricity industry has faced major changes. On the supply side, although fossil fuels are still the most relevant sources, the transition to renewable energies has increasingly drawn the attention of researchers, politicians, companies, and the general public. (CORIA; PENIZZOTTO; PRINGLES, 2019; COPIELLO; GRILLENZONI, 2017). The concern with the environment and sustainability, combined with new technologies, changes in habits and techniques that would allow a more efficient use of energy are current needs. The best use of energy, as well as alternatives that reduce its consumption, become particularly important. In this context and combined with the new distributed renewable energy conversion systems, free access to power grids and the local use of renewable energies to supply consumers are increasingly encouraged. (SOUSA; FERNANDES; MARTINS, 2018). Photovoltaic panels and concentrated solar thermal energy are the most well-established technologies used to convert solar energy into electricity. The use of photovoltaic cells (PV) to convert light into electricity is a clean and sustainable way of producing energy. Today, the dominant solar technology uses crystalline silicon (polycrystalline and monocrystalline) as a semiconductor material. However, solar technology using advanced materials such as amorphous silicon, copper indium gallium selenide or cadmium telluride are increasingly attractive due to greater efficiency in different climatic conditions and lower production costs (MUSSARD; AMARAM, 2018). In this context, it can be said that photovoltaic solar energy is one of the most prominent forms of renewable energy for the coming years, justifying the need to seek as much information about it. This article presents a study on a photovoltaic solar system installed at the Western Paraná State University, Cascavel - PR campus, in order to quantify the energies (generated by the system, injected into the grid and consumed by the building), determine the energy efficiency of generation, and verify the economic feasibility of implementing the system.

LITERATURE REVIEW

In recent decades, with the process of restructuring the energy system, centralised energy sources are used with decentralised ones.

This phenomenon resulted in a new concept in electric power systems, particularly in distribution systems, known as Distributed Generation (DG). On the one hand, the use of GD is important for safe generation and reduction of energy losses. On the other hand, the widespread use of these technologies introduces new challenges for power systems, as their ideal location, protection devices, voltage setting and problems with power quality (RAZAVI et al, 2019). In 2018, after a growth encouraged by regulatory actions, micro and mini distributed generation reached 828 GWh with a 670 MW installed capacity, with emphasis on the photovoltaic solar source, with 526 GWh and 562 MW generation and installed capacity respectively (BEN, 2019). ANEEL's (Brazilian National Agency of Electrical Energy) Normative Resolution (REN) 482/2012 published on 17th April 2012 was an important milestone in Brazilian legislation, where it has been establishing the general conditions for the access of micro and mini-generation distributed to electrical energy distribution systems, through the electrical power compensation model, also called net metering, allowing electricity consumers to generate part or all of the energy that they consume using renewable energy sources (TIEPOLO, 2015). Among renewable energy sources, photovoltaic solar energy appears as a promising alternative, as it does not emit polluting gases in the generation process and because it is practically inexhaustible and accessible in all parts of the world. In addition, the production chain of photovoltaic modules also has a low environmental impact, as the chemical effects resulting from its production are correctly discarded, the negative effects are next to nil. As for the manufacturing process for photovoltaic generators, the resulting greenhouse gas emissions are very low and the energy used in their production is compensated in a few years of operation (MOCELIN, 2014).

Solar radiation entering the Earth's atmosphere consists of two components: direct radiation, which derives directly from the direction of the sun and reaches the surface without undergoing deviation in its path, producing sharp shadows and diffuse radiation, which comes from all directions and reaches the surface after being scattered by Earth's atmosphere. On completely cloudy days, 100% of the radiation that reaches the surface is diffuse, while on clear cloudless days, the diffuse radiation is around 20%, the other 80% is direct radiation. However, if the analysed surface is inclined in relation to the horizontal, there will be a third component reflected by the environment (medications, soil, vegetation, etc.), where the reflection coefficient of these surfaces is called albedo. (CEPEL – CRESESB, 2014; TIEPOLO et al, 2017). The conversion of solar radiation into electricity occurs due to the photovoltaic effect, which was first observed by Becquerel in 1839. This effect occurs in materials known as semiconductors, which have two bands of energy, in one of them the presence of electrons is allowed and in the other, there is no presence of them, that is, the band is completely "empty" (conduction band). The most used semiconductor material is silicon, the second most abundant element on Earth. Its atoms are characterised by having four electrons that connect to their neighbours, creating a crystalline network (SAMPAIO & GONZÁLEZ, 2017). The production of electric energy by photovoltaic systems can be obtained in two main ways, according to NBR (Brazilian Standard) 11704:2008 Photovoltaic Systems - Classification: photovoltaic system connected to the electric power grid (SFVCR) or on grid system, and photovoltaic system isolated from the electrical grid (SFVI) or off grid system (ABNT, 2008). Photovoltaic systems connected to the grid (SFVCR) are characterised by being integrated into the public electrical grid, the systems connected to the grid do not have elements to store the electrical energy, since during the moments when there is no generation of electrical energy coming from the panels, the system uses the utility's network as a source of energy (TONIN, 2017). The SFVCR consists of photovoltaic panels, inverter, which provides alternating current electricity for installation and also injects the surplus energy generated into the grid and bidirectional meter, which measures the energy injected into the utility's grid and the energy consumed by the establishment (URBANETZ JUNIOR, 2010).

The SFVCR is regulated by the Brazilian National Agency of Electrical Energy - ANEEL, as well as the taxes involved and how the energy compensation system works. In this way, the compensation system converts the surplus energy produced by the photovoltaic system into credits (kilowatt-hour, kWh) that will be deducted from the total consumption in the electricity bill. For this, a bidirectional meter is used, which is responsible for recording the amount of energy generated / injected into the grid, in kWh, and the energy consumed by the utility, in kWh. And with that, the surplus energy production becomes credits for later use by the customer (TONIN, 2017). On the other hand, off grid photovoltaic systems (SFVI) have no connection to the public electricity grid, so they are usually installed in places where the transmission network is inaccessible or deficient, or even for reasons of technical and/or financial feasibility. Therefore, an energy storage element is needed to ensure system autonomy. (TONIN, 2017; PAZUCH, 2017). SFVI are basically composed of four pieces of equipment, the photovoltaic panel that transforms solar radiation into direct current, the charge controller, electronic equipment used to control and monitor the charge and / or discharge of the battery bank, avoiding overloads and deep discharges, thus increasing the useful life of the battery bank, the inverter that converts the direct current from the panel or the battery bank into alternating current, and the battery that is responsible for storing electrical energy to be used in times when there is no sun and no other source of energy (TONIN, 2017; URBANETZ JUNIOR, 2010).

MATERIAL AND METHODS

Site Characterisations: The study was carried out at the Western Paraná State University, Cascavel - PR campus, with geographic location defined by the coordinates: latitude 24° 59' south, longitude 58°23' west, and average altitude of 785 meters. The photovoltaic system deployed at the site was sized to meet the demand of the Alternative Energy Systems Analysis Centre - CASA Project. There is a laboratory and two residences on site, one with construction aspects considered innovative, with respect to the rational use of electricity, and the other with conventional construction aspects. The photovoltaic system has a total power of 3.3 kWp and consists of ten polycrystalline photovoltaic modules facing true north direction, with a tilt angle of 21°. The system is also composed of a 4 kWp inverter, connected to two strings of photovoltaic modules - with five modules each - allowing a separate evaluation of the energy generated in each string. Figure 1 shows the installed system.

Figure 1. Photovoltaic system installed at Unioeste

Equipment Used for Measurement: For the present study, solar radiation data on photovoltaic modules were required. These data were obtained through a pyranometer installed horizontally in relation to the photovoltaic panels, this pyranometer is connected to a datalogger, thus enabling data collection.

Figure 2 shows the multi-wire diagram of the photovoltaic system.

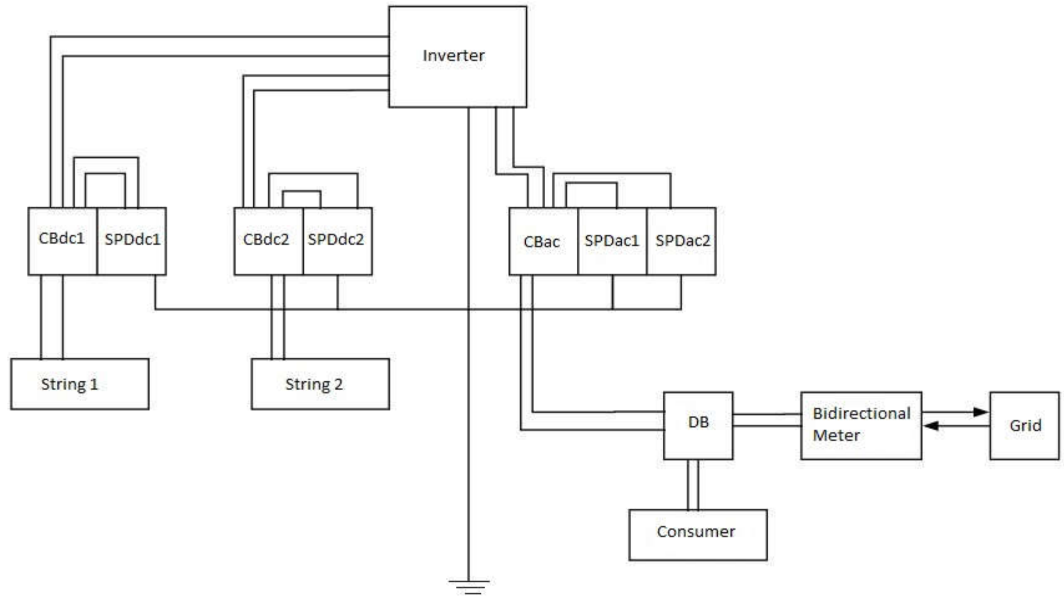

Figure 2. Multi-wire diagram of the system

Table 1. Equations to correct solar radiation

Equation	Comments
$\boldsymbol{\delta = 23,45\, sen\left(360\frac{284+n}{365}\right)}$ (1)	δ = Solar declination (degrees); n = Days of the year.
$\boldsymbol{\omega'_s = min\begin{bmatrix} cos^{-1}\ (-tan\,\phi \tan\delta) \\ cos^{-1}(-\tan\phi + \beta)\tan\delta \end{bmatrix}}$ (2)	ω'_s = Sunset Hour Angle for a given surface slope. ϕ = Local latitude (-24.9555^0 southern hemisphere);
$\boldsymbol{\cos\ \omega_s = -\frac{sen\,\phi\, sen\,\delta}{\cos\phi\cos\delta} = -\tan\phi\tan\delta}$ (3)	ω_s = Sunset Hour Angle (degrees);
$\boldsymbol{\bar{R}_b = \frac{\cos(\phi+\beta)\cos\delta\, sen\,\omega'_s + \left(\frac{\pi}{180}\right)\omega'_s\, sen\,(\phi+\beta)\, sen\,\delta}{\cos\phi\cos\delta\, sen\ \omega_s + \left(\frac{\pi}{180}\right)\omega_s\, sen\,\phi\, sen\,\delta}}$ (4)	$\bar{R}_b$ = Ratio between extraterrestrial radiation on the inclined and horizontal plane; β = Surface Slope (21^0 degrees).
$\boldsymbol{H_0 = \frac{24\times3600 G_{SC}}{\pi}\left(1 + 0,033\, cos\,\frac{360n}{365}\right)\times\left(\cos\phi\cos\delta\, sen\ \omega_s + \frac{\pi\,\omega_s}{180}\ sen\,\phi\, sen\,\delta\right)}$ (5)	H_0 = Daily extraterrestrial radiation integrated into a horizontal surface; G_{SC} = Solar constant (1367 W/m^2).
$\boldsymbol{\bar{K}_T = \frac{\bar{H}}{\bar{H}_0}}$ (6)	$\bar{K}_T$ = Monthly average clearness index; $\bar{H}$ = Global solar radiation on the horizontal plane, on a monthly average; $\overline{H_0}$ = Daily extraterrestrial radiation, monthly average.
$\boldsymbol{\frac{\bar{H}_d}{\bar{H}} = 1,391 - 3,560\bar{K}_T + 4,189\bar{K}_T^2 - 2,137\bar{K}_T^3}$ (7)	$\bar{H}_d$ = Diffuse sky radiation on the inclined plane, on a monthly daily average; $\bar{H}$ = Global solar radiation on the horizontal plane, on a monthly average;
$\boldsymbol{\frac{\bar{H}_d}{\bar{H}} = 1,311 - 3,022\bar{K}_T + 3,427\bar{K}_T^2 - 1,821\bar{K}_T^3}$ (8)	
$\boldsymbol{\bar{R} = \frac{\bar{H}_T}{\bar{H}} = \left(1 - \frac{\bar{H}_d}{\bar{H}}\right)\bar{R}_b + \frac{\bar{H}_d}{\bar{H}}\left(\frac{1+\cos\beta}{2}\right) + \rho_g\left(\frac{1-\cos\beta}{2}\right)}$ (9)	$\bar{R}$ = Monthly average solar radiation on a tilted surface; $\overline{H_T}$ = Global solar radiation on the inclined plane, on a monthly average; ρ_g = Reflectance of the neighbourhood in the vicinity of the solar collector (for grass, ρ_g =0,2).

Source: (DUFFIE, J.; BECKMAN, W., 2013).

As the pyranometer is installed horizontally, that is, it is collecting global solar radiation data at 0□ angle, it is necessary to correct this angle to 21□, the slope value of the photovoltaic modules in the city of Cascavel - PR, at noon, with isotropic sky, in the middle of the month and with modules directed exactly to the true north. For this, a series of equations obtained through Duffie and Beckman and presented in table 1 were used. Using this series of equations, it was possible to obtain table 2, which represents the recommended average values of solar declination for days of the year in the middle of the month. The datalogger used to read and record solar radiation data was the Campbell Scientific CR 1000 model, which has eight analog inputs, storing the data obtained by the pyranometer every 10 seconds, averaging the values collected every minute, and then every hour of the day.

The pyranometer is manufactured by Kipp & Zonen, model CMP3, with a sensitivity of 15.30 microvolts/watt.m^2. An EMBRASUL electrical quantities analyser, model RE7000, was used to obtain the electric energy data produced by the photovoltaic system. This equipment was installed at the inverter output, and stores data on voltage, current, active, and reactive energy, power factor and any electrical disturbances that may occur on the grid.

METHODOLOGY

Energy Data Assessment: Energy data generated, consumed, and injected into the grid by the system were obtained in four ways:

Table 2. Recommended average values for solar declination

		For mid-month		
Month	Day per month	Date	N	δ
January	I	17	17	-20.9
February	31 + i	16	47	-13
March	59 + i	16	75	-2.4
April	90 + i	15	105	9.4
May	120 + i	15	135	18.8
June	151 + i	11	162	23.1
July	181 + i	17	198	21.2
August	212 + i	16	228	13.5
September	243 + i	15	258	2.2
October	273 + i	15	288	-9.6
November	304 + i	14	318	-18.9
December	334 + i	10	344	-23

Source: (DUFFIE, J.; BECKMAN, W., 2013).

a) Using the data provided by the bidirectional meter, where the values referring to the energy consumed in the residence and the energy injected into the utility's grid are quantified.
b) Using the data presented in electricity bills provided by COPEL.
c) Using the Solar Man site data, where the active and reactive energy values are stored, current and voltage supplied by the inverter of the photovoltaic system.
d) Using data from the Solar Man website, where the values of active and reactive energy, current and electrical voltage provided by the inverter of the photovoltaic system are stored.

Energy Efficiency of Photovoltaic System: The total efficiency of the photovoltaic system was calculated from the ratio between the apparent power generated by the photovoltaic system (kVAh day^{-1}), and the daily solar radiation on the panels (kWh day^{-1}), as shown in equation 10.

$$E_f = \frac{S_{ca}}{E_{rad}} \times 100\% \quad (10)$$

Whereby:

E_f = Efficiency of photovoltaic system, %;
S_{ca} = Apparent daily power generated by the photovoltaic system, kVAh dia^{-1};
E_{rad} = Daily solar radiation on panels, kWh dia^{-1}.

Economic Assessment: The economic assessment was carried out based on the photovoltaic system acquisition and maintenance costs - considering the useful life of each equipment - and the avoided costs of the energy consumed by the utility, obtained from electricity bills. For this work, a useful life of 10 years was considered for the inverter, circuit breaker and DPS, and 25 years for the photovoltaic panels and other electrical components of the installation. It was also considered a Minimum Acceptable Rate of Return (MARR) of 6% p.a. (value considered appropriate to assess power generation systems). To quantify the economic viability of the system, the Net Present Value (NPV), Internal Rate of Return (IRR) and Discounted Payback Period (DPP) indexes were used.

RESULTS AND DISCUSSION

The data regarding solar radiation (obtained through a pyranometer connected to the datalogger), and regarding the electrical quantities of voltage, current and power (obtained through the RE7000), were collected for September, October, and November 2019. The other data related to the generation, injection and consumption of electricity were obtained from COPEL's electricity bills, the bidirectional meter and the Solar Man website, for every month of the year 2019. Figure 3 shows the frequency values for the occurrence of solar radiation for the months studied. The most frequent values of solar radiation occur between 0 and 99 W/m^2, and between 200 and 299 W/m^2, while the lowest incidences are between 1100 and 1200 W/m^2.

Energy Data Assessment: Observing the electricity bills provided by the utility (COPEL), it was possible to represent the amount of energy consumed and injected into the grid by the photovoltaic system in 2019. Figure 4 shows these values.

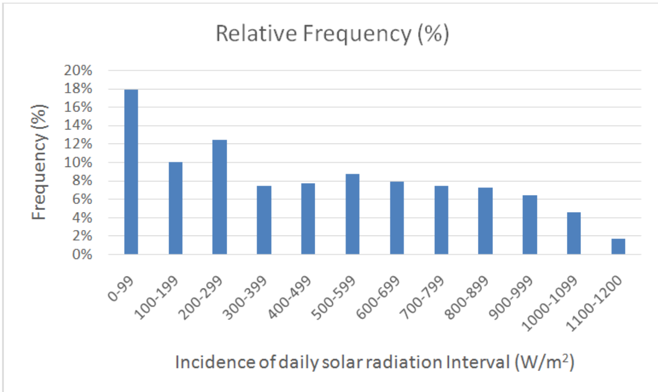

Figure 3. Frequency of radiation occurrence (%) x Incidence of daily solar radiation (W/m2)

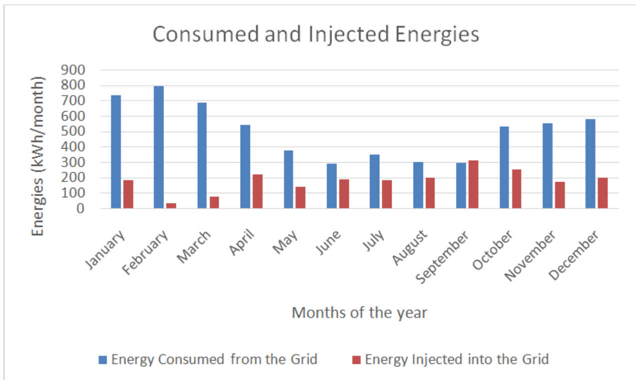

Figure 4. Energy consumed (kWh / month) and injected energy (kWh / month) x months of the year

It can be seen that, in most months, the energy consumed from the grid was higher than the injected energy, except for the month of September, where generation slightly higher than consumption occurred. Using the energy data generated by the photovoltaic system, injected and consumed by the grid, obtained from COPEL's electricity bill, the bidirectional meter and the Solar Man website, a summary table of the photovoltaic system was elaborated (Table 3):

Whereby:

A) Total energy generated by the photovoltaic system (kWh);
These data were obtained using the Solar Man website, considering the energy that was generated during the days that comprised the bill. E.g.: The November 2019 invoice comprises the days 15-Oct-2019 to 13-Nov-2019.
B) Total energy consumed in residences (kWh);

It was obtained through equation 11:

$$E_{con\ res} = E_{tot\ FV} - E_{inj\ rede} + E_{tot\ con\ rede} \quad (11)$$

Where:
$E_{con\ res}$ = Total energy consumed in residences (kWh);
$E_{tot\ FV}$ = Total energy generated by the photovoltaic system (kWh);
$E_{inj\ rede}$ = Total energy injected into the grid (kWh);
$E_{tot\ con\ rede}$ = Total energy consumed from the grid (kWh).

C) Total energy consumed from the grid (kWh);
Obtained directly from the electricity bill.

D) Total energy injected into the grid (kWh);
Obtained directly from the electricity bill.

E) Balance of energy stored in previous months (kWh);
It was obtained through equation 12:

$$Saldo_{armaz} = E_{inj\ rede} - (E_{tot\ con\ rede} - Saldo_{armaz\ mês\ anterior} - E_{faturada}) \quad (12)$$

Where:

$Saldo_{armaz}$ = Balance of stored energy (kWh);
$Saldo_{armaz\ mês\ anterior}$ = Balance of energy stored in the previous month (kWh);

$E_{faturada}$ = Billed energy (kWh).

H) Total invoice WITHOUT the photovoltaic system (R$);
It was obtained through equation 15:

$$Fatura_{SEM\ FV} = (E_{con\ res} \times Tarifa_{com\ imp.}) + Ilum. Pública \quad (15)$$

Where:

$Fatura_{SEM\ FV}$= Total invoice WITHOUT the photovoltaic system (R$);

I) Total saved (R$).

Difference between the values of invoices WITHOUT and WITH the photovoltaic system, according to equation 16:

$$Total_{Econ} = Fatura_{SEM\ FV} - Fatura_{COM\ FV} \quad (16)$$

Where:

$Total_{Econ}$ = Total saved (R$);

As seen in Table 2, most months had a generation of energy below consumption. The only month in which the energy generated exceeded consumption was in September with 115 kWh, energy that was used later in October. It was also possible to verify that the energy billed in 2019 was 3,853 kWh, which represented a cost of R$2,647.70 with the photovoltaic system. If the photovoltaic system was not available, this invoiced energy would represent a cost of R$4,879.85, which reflects savings of R$2,232.14 over the year.

Table 3. Summary of the Photovoltaic System

Month	A	B	C	D	E	F	G	H	I
January	354.9	898.9	733.0	189.0	0.0	544.0	347.24	544.44	197.20
February	128.3	885.3	796.0	39.0	0.0	757.0	460.52	530.95	70.43
March	189.0	793.0	686.0	82.0	0.0	604.0	406.54	509.41	102.87
April	343.0	661.0	542.0	224.0	0.0	318.0	211.94	398.11	186.17
May	322.1	560.1	380.0	142.0	0.0	238.0	183.24	359.58	176.34
June	277.3	378.3	295.0	194.0	0.0	101.0	83.47	235.49	152.02
July	286.7	454.7	352.0	184.0	0.0	168.0	126.81	285.69	158.88
August	378.2	478.2	301.0	201.0	0.0	100.0	88.62	306.92	218.30
September	408.4	393.4	300.0	315.0	0.0	100.0	87.32	261.07	173.75
October	454.4	730.4	530.0	254.0	115.0	161.0	132.75	463.10	330.35
November	378.0	758.0	556.0	176.0	0.0	380.0	258.74	476.98	218.25
December	427.6	809.6	583.0	201.0	0.0	382.0	260.52	508.11	247.59
TOTAL	3,947.9	7,800.9	6,054.0	2,201.0	115.0	3,853.0	2,647.70	4,879.85	2,232.14

F) Billed energy (kWh).

It was obtained through equation 13:

$$E_{faturada} = E_{tot\ con\ rede} - E_{inj\ rede} - Saldo_{armaz} \quad (13)$$

Note: If the billed energy is less than or equal to 100 kWh / month, the minimum value of 100 kWh / month is considered (availability fee charged by the utility, for three-phase input patterns).

G) Total invoice WITH the photovoltaic system (R$);

It was obtained through equation 14:

$$Fatura_{COM\ FV} = (E_{faturada} \times Tarifa_{com\ imp.}) + Ilum. Pública \quad (14)$$

Where:

$Fatura_{COM\ FV}$ = Total invoice WITH the photovoltaic system (R$);
$Tarifa_{com\ imp.}$ = Electricity tariff with taxes (R$ / kWh);
$Ilum. Pública$ = Street Lighting plus other additional fees charged eventually.

In Figure 5, the effective energy generated values were compared with the total consumption values of the CASA project. As can be seen in figure 5, in almost every month of the year the energy generated by the system fell short of the energy consumed by the CASA project residences, with the exception of September, where generation was higher than consumption, generating a surplus that was used the following month. Throughout the year, actual generation totalled 3,947.9 kWh, while the energy consumed totalled 7,800.9 kWh, the first being 49.4% less than the second.

Energy Efficiency of Photovoltaic System: The energy efficiency of the system was determined from the solar radiation and energy generated data obtained for September, October, and November 2019, according to equation 10 (Figure 6). The total average daily efficiency of the photovoltaic system for September was 14.04%, in October, 12.9% and in November, 13.02%. Resulting in an overall system efficiency of 13.32%.

Economic Assessment: To quantify the economic viability of the system, the Net Present Value (NPV), Internal Rate of Return (IRR) and Discounted Payback Period (DPP) indexes were used.

Some assumptions were adopted to enable the purposes of the calculation:

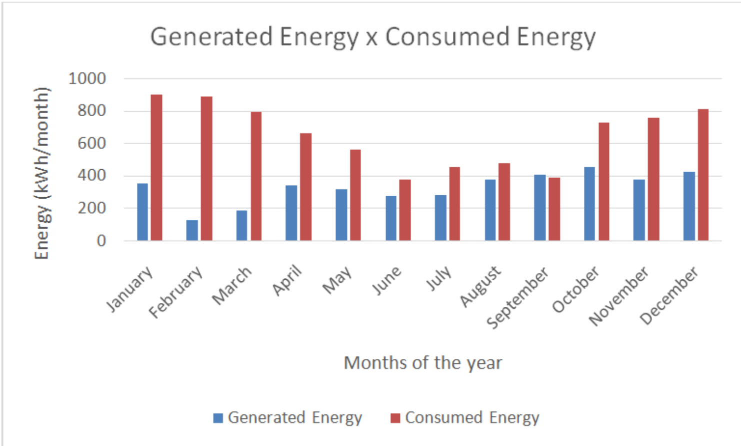

Figure 5. Effective energy generated by the system (kWh) and total energy consumption of the CASA project (kWh) x months of the year

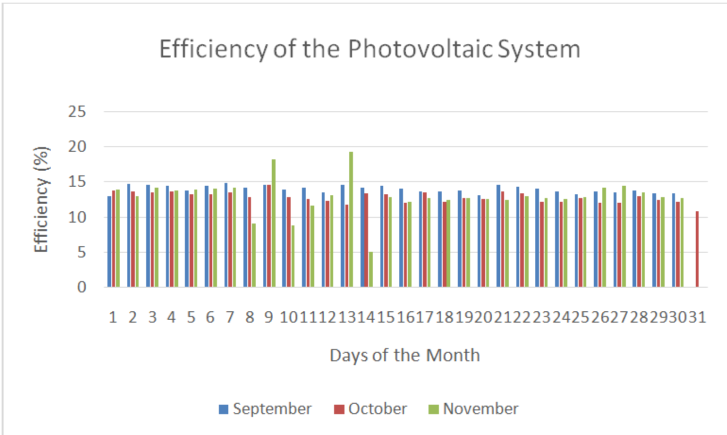

Figure 6. Total average daily efficiencies of the photovoltaic system x days of the month

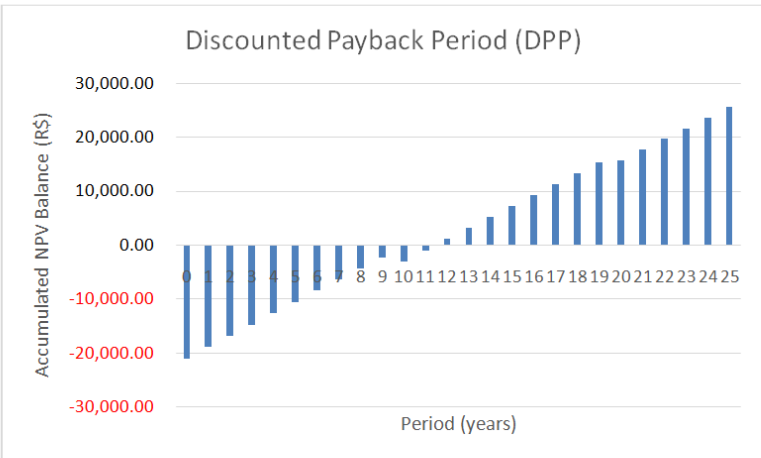

Figure 7. Result of the project economic assessment

- Inverter, circuit breaker and DPS service life: 10 years.
- Service life of photovoltaic modules and other electrical devices: 25 years.
- Minimum Acceptable Rate of Return (MARR): 6% p.a.
- Energy tariff above-inflation rise: 0.7% p.a.
- Energy depreciation of the photovoltaic system: 0.8% p.a.
- Total cost of the photovoltaic system installation: R$20,980.00;
- Inverter cost: R$ 5,000.00

Figure 7 shows the values for the economic assessment carried out for the photovoltaic system.

From the economic evaluation carried out, it was found that it takes 12 years for the investment to pay off (discounted payback), the IRR is 14.1% per annum, and the NPV is R$25,564.07. All indexes indicate that the investment is economically viable (payback less than the total useful life of the system, IRR greater than the adopted MARR, and positive NPV). Nevertheless, the proximity of the indexes found to the limit values indicate that such viability is not significant, and that any political and economic instability in the country, over the years, could change this positive projection.

CONCLUSIONS

In 2019, the cost of electricity after the installation of the photovoltaic system was R$2,647.70. If the photovoltaic system were not installed, this cost would be R$4,879.85, reflecting savings of R$2,232.14 over the year. The energy actually generated by the system fell short of the energy consumed by the CASA project residences, in almost every month of the year, except in September, where there was a surplus of 115 kWh. The average efficiency value of the photovoltaic system for the three months of study was 13.32%. For the economic evaluation, the discounted payback was 12 years, the IRR was 14.1% p.a., and the NPV was R$25,564.07, results that confirm the economic viability of the system, but with a very limited safety margin.

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