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Development of a technical and economic feasibility study for the deployment of photovoltaic solar energy on the IFPB campus in Catolé do Rocha - Brazil

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ABSTRACT: *In view of the great growth of studies in the area of energy efficiency and energy quality, the work in question aims to analyze the feasibility of developing a photovoltaic system project integrated to the Catolé do Rocha campus of the Institute Federal of Paraíba (IFPB). The development of this work is based on the dimensioning of the photovoltaic system, evaluating some parameters, among them: positioning, number of modules, degree of irradiation, type of inverter, generator and support structure.*

KEYWORDS: *Energy efficiency, Photovoltaic System, IFPB, Catolé do Rocha.*

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I. INTRODUCTION

The awareness of man in the face of environmental problems has promoted the search for new forms of cleaner and renewable energy that cause the least possible impact on the environment and promote sustainable development.

A point well highlighted by Knirsch (2012) refers to the relentless pursuit of development and economic growth that unquestionably leads to unlimited and uninterrupted demand for electricity. Still, according to the aforementioned author, the current global energy scenario shows indications of depletion of natural resources aimed at energy generation. The growing use of various equipment that requires electricity has two effects: the increase in electricity consumption and the increase in the industrial production process. This development cycle, consequently, increases the emission of polluting gases that trigger the so-called greenhouse effect.

The current context has led nations to seek new forms of energy generation that cause less damage to the environment and are also more economically viable.

This energy renewal has been accompanied by the growth of photovoltaic solar energy, a well-developed source for the production of electrical energy. In the national field of Brazil, the challenges regarding photovoltaic solar energy have been slowly overcome, showing an evolution in the sector in recent years. There are still several challenges for this renewable energy source to be implemented with lesser obstacles and, therefore, it is important to provide an overview of this type of generation in the country.

Due to this great advance in the applicability of the production of electric energy through solar rays, the federal government started to invest in this technology, with an approximate resource of 60 million for the next years, destined to the federal institutions of technological education (Portal MEC 2020).

For the Institute Federal of Paraíba (IFPB), the Ministry of Education and Culture (MEC) intends to release approximately 1 million reais (Jornal da Paraíba, 2019) for the implantation of solar power plants. Imagining that these resources may be close to being released, the IFPB campuses need to study the best feasibility and economic techniques for the perfect installation.

In addition, bearing in mind that technical schools play a very important role in the training of young people, it is evident that contact with sustainable technologies favors the construction of a collective conscience, and of adults more engaged in the conservation of the environment.

Thus, this study refers to the implementation, in the consumer unit of the campus of Catolé do Rocha, of the technology of electric power generation through the use of sunlight. The interest in this topic came about in view of the need to evaluate opportunities for cost reduction, through the implementation of other alternative renewable sources of electricity generation.

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II. THEORETICAL ANALYSIS

The advancement of the photovoltaic system in the construction market is indisputable, however, to reach the current level, several studies were made, especially in relation to the materials used, the technologies, the technical feasibility and the operation. Thus, as well as a successive advance in the progress of solar energy, this research will fit into this successive model of stages, in which the theoretical foundation is very important for the understanding of the problem to be studied and faced.

Thus, this item will present the main topics related to studies of photovoltaic solar energy that encompasses, in particular, production, technical feasibility for design and operation, as well as recent research in this medium.

II.1 Photovoltaic Solar Energy

The main source of energy on our planet is the light energy from the sun. The Earth's surface receives an amount of solar energy in the form of sufficient light and heat annually to supply the world's energy needs thousands of times during the same period, only part of that energy is used, almost all the energy used by man on the planet has origin in the sun. When it passes through the atmosphere, a large part of the solar energy takes place in the form of light, in infrared and ultraviolet rays, capturing this light, it is possible to transform it into forms of energy such as electrical energy, which are determined exactly by the type of energy. equipment used for this transformation, so if we use a dark-colored surface, we are obtaining heat, and if we use photovoltaic panels, electricity results. This process occurs in photovoltaic cells, which can be built by different technologies, such as crystalline silicon and thin-film cells (GAZOLI, 2012).

According to Severino and Oliveira (2010), the photovoltaic effect is generated through the absorption of sunlight, which causes a potential difference in the structure of the semiconductor material. Complementing this information, Nascimento (2014, p.14) states that “A photovoltaic cell does not store electrical energy. It only maintains a flow of electrons in an electrical circuit as long as there is light on it. This phenomenon is called the Photovoltaic Effect”.

II.2 Technical feasibility analysis

A photovoltaic generation system, regardless of power, requires several technical conditions for success. The type and position of the installation, the preconditions of the site, the solar resource, the selection of components, and several other factors will influence the final performance of the installation. Even if a location has several positive factors such as an adequate resource, good positioning, and quality components, just one limiting factor is enough for the system to become unviable.

Thus, the design of a photovoltaic system involves module orientation, area availability, aesthetics, availability of the solar resource, demand to be met, and several other factors. The project aims to adapt the photovoltaic generator to the needs defined by demand. The dimensioning of a photovoltaic system (SFV) is the adjustment between the radiant energy received by the sun by the photovoltaic modules and the need to supply the demand for electricity.

According to Galdino and Pinho (2014) that a photovoltaic project is successful, it is necessary to reconcile many variables, and, possibly, the best cost/benefit ratio will not be linked only to one of these pillars: technical, regulatory, and commercial. Technical and commercial criteria must be observed by designers, integrators, or project owners, as these are mostly subjective so that the interpretation of the real impact they can cause on a photovoltaic system must be studied on a case-by-case basis.

II.3 Operation of Solar Energy

Solar energy works as follows: solar panels capture sunlight and generate energy that is “transported” to the solar inverter, responsible for converting the generated electrical energy to the characteristics of the electrical network. The generation of energy occurs through the photovoltaic effect.

During the day, solar panels (called photovoltaic modules) capture sunlight and generate energy. The direct incidence of solar radiation is very important for photovoltaic cells to have the best efficiency in converting solar radiation into electrical energy, because the more direct light the solar panel receives, the more electrical energy will be generated.

This is because the functioning of the photovoltaic cells that make up the modules is extremely dependent on the entry of light particles (the photons) inside. The big secret is the positioning of the solar plates so that they receive a greater direct solar radiation, without the interference of shadows. The result of this is the release of continuous electric current, captured by the conducting filaments of the photovoltaic module. This current is then sent to the interactive inverter, a device that transforms this energy from direct current to alternating current, which is the type used in our homes or businesses.

This energy passes through a device called a solar inverter, responsible for converting this energy to the characteristics of the local electrical network. In other words, the energy generated by the solar panel is in direct current (DC), which is all types of current that, when traversed in a circuit, do not change its direction of circulation. After the conversion process, the inverter delivers alternating current (AC) electric energy for consumption, which has this nomenclature, because as the name says, because it changes its direction of circulation within the circuit, periodically.

After passing through the inverter, solar energy can be used to power any appliance in the house, such as refrigerators, lamps, and air conditioning, for example, generating savings in the electricity bill.

Eberhardt (2005) states that some factors, such as the definition of standard conditions, measurement of the current-voltage curve, light source, area measurement, and reference sensor, influence the determination of efficiency.

III. DESCRIPTION OF THE STUDY AREA

The Federal Institute of Paraíba (IFPB), is located in the city of Catolé do Rocha (Figure 1), a city in the interior of the state of Paraíba, Brazil, its geographical coordinates are: -6.340745 S /-37.755456 W with an altitude of 307 meters. It has an average annual temperature of 27.6 ºC and an average annual relative humidity of 73%. The Consumer Unit is 5 / 1914788-3 and its UTM coordinates, in spindle 24 are X: 637656.16763307 and Y: 9298960.9536832. The generator was dimensioned based on the annual consumption of the property, reaching the conclusion that the amount generated of approximately 14,059 kWh / month meets the financial needs of the project. Such dimensioning uses the Cresesb portal as a data source to obtain information about the ideal radiation and inclination of the modules, information necessary for us to be able to calculate and dimension correctly. In this project, losses due to transformation, transmission, temperature, dust and depreciation were considered, the total efficiency value of the project found is 85%, with daily irradiation being the highest annual average in the 5 ° N inclined plane.

Figure 1 Location of the Federal Institute of Paraíba (IFPB), in the municipality of Catolé do Rocha **-** PB, Brazil.

IV. RESULTS

In the analysis of the results, the dimensioning for the generator and the power required for the campus were evaluated. The generator was dimensioned based on the annual consumption of the property, reaching the conclusion that the amount generated of approximately 14,059 kWh / month meets the financial needs of the project. Such dimensioning uses the Cresesb portal as a data source to obtain information about the ideal

radiation and inclination of the modules, information necessary for us to be able to calculate and dimension correctly.
In this project, losses due to transformation, transmission, temperature, dust and depreciation were considered, the total efficiency value of the project found is 85%.
The daily irradiation has the highest annual average in the inclined plane of 5 ° N, and the monthly irradiation data are described in table 1.

Jan	Fev	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
5,86	5,98	6,06	5,85	5,50	5,16	5,53	6,20	6,59	6,51	6,39	5,98

Table 1. Monthly irradiation data for the city of Catolé do Rocha.

There were 228 photovoltaic modules with a power of 410 Wp each, oriented to the north and divided into twelve arrays connected in series within each array. The three inverters with an individual rated power of 25000 W will be responsible for converting the DC energy generated by the modules and synchronizing with the Energisa network, complying with the minimum and maximum limits imposed by internal standards.
Figure 2 presents detailed data on efficiency, average consumption, irradiation and monthly savings.

NETWORK CONNECTED PHOTOVOLTAIC SYSTEM (NCPS)											
Efficiency (TD - %)	Plaque Power Ph. (Wp)	Inclination(°N)	Value kWh (R$)	Quantity. Plaq. REC.	Quantity. Plaq. (Npv)	Á Mín. PV (m²)	Power. Generator (kWh/year)	Irradiation (kWh/m².day)	Daily consumption (kWh/day)	Daily generation (kWh/day)	
85	330	21	0,65	8,03	6	15,58	1,98 kWp	5,15	0,99	0,72	
Month	Daily consumption (kWh)	Irradiation (kWh/m².day)	Gerneration PV (kWh)	(%)	Consumption billable (kWh/month)	Consumed on the network (kWh/month)	Cumulative credit (kWh)	Invoice without GD (R$)	Invoice with GD (R$)	Economy (month/R$)	
January	500	5,22	263,56	52,71%	100	-236,44	-236,44	R$ 325,00	R$ 153,69	R$ 171,31	
February	600	5,61	283,25	47,21%	100	-316,75	-316,75	R$ 390,00	R$ 205,89	R$ 184,11	
March	300	5,28	266,59	88,86%	100	-33,41	-33,41	R$ 195,00	R$ 65,00	R$ 130,00	
April	150	5,24	264,57	176,38%	100	114,57	114,57	R$ 97,50	R$ 65,00	R$ 32,50	
May	300	4,63	233,77	77,92%	100	-66,23	48,34	R$ 195,00	R$ 65,00	R$ 130,00	
June	460	4,5	227,21	49,39%	100	-232,80	-184,46	R$ 299,00	R$ 151,32	R$ 147,68	
July	256	4,58	231,24	90,33%	100	-24,76	-24,76	R$ 166,40	R$ 65,00	R$ 101,40	
August	136	5,45	275,17	202,33%	100	139,17	139,17	R$ 88,40	R$ 65,00	R$ 23,40	
September	236	5,09	256,99	108,90%	100	20,99	160,16	R$ 153,40	R$ 65,00	R$ 88,40	
October	465	5,33	269,11	57,87%	100	-195,89	-35,72	R$ 302,25	R$ 65,00	R$ 237,25	
November	632	5,3	267,60	42,34%	100	-364,40	-364,40	R$ 410,80	R$ 236,86	R$ 173,94	
December	236	5,55	280,22	118,74%	100	44,22	44,22	R$ 153,40	R$ 65,00	R$ 88,40	
Total	**356**	**5,15**	**259,94**	**73,03%**	**100**	**-1151,73**	**44,22**	**R$ 2.776,15**	**R$ 1.267,75**	**R$ 1.508,40**	

Figure 2 Monthly data on efficiency, inclination, generation, consumption and savings of the photovoltaic system

The photovoltaic generator has the ability to transform the energy from the sun into electricity, such generation occurs cleanly and this is one of the several benefits of this solution, which has been gaining more followers every day. The generator works independently without any specific training for the customer, the equipment itself disconnects from the network in the event of system failures.

The composition of the generator works from modules that generate energy in direct current (DC), the inverter that converts DC energy into alternating current (AC) and synchronizes with the company's network, also has the structure that supports and fixes the modules; cabling with specific cables for external use, having several protections; connectors to ensure efficiency and long system life; AC circuit breakers that allow the disconnection of the energy that goes to the network, enabling the equipment for maintenance; DPS AC that protects the inverter against possible surges that can spread through the company's network; DC disconnect switch that disconnects between the module arrangement and the inverter; CC DPS that protects against the surge in the CC part of the system.

Another point assessed corresponds to gas emissions since the growing volume of greenhouse gas emissions is a matter of debate and concern in Brazil and in the world, which is increasing every day. Photovoltaic energy is one of the ways to stop this evolution. It is estimated that for each kWh generated there is a reduction of 0.57 CO_2, therefore, we can make the following comparison:

Reduction in monthly emissions: **14.059*0,57 = 8.013 Kg**
Reduction in Annual Emissions: **(14.059*12)*0,57 = 96.163 Kg**
Reduction in 25 years: **(14.059*12)*25)*0,57 = 2.404.089 kg**

The estimated CO2 reduction in 25 years would be equivalent to 21.174 trees planted or about 5.141.668 km driven by car. Such initiatives can in the long term represent a significant improvement in the quality of life on the planet.

After dimensioning, the installation location of the photovoltaic modules on the campus was determined, for which care was taken with the incidence of possible shadows on the panels, both near and distant shadows, since the effect of the shadows must be carefully evaluated, as the shadows on the panels produce a significant reduction in production, especially if they occur in the central hours of the day. Figure 3 shows the location of the installation point for the photovoltaic modules on the campus.

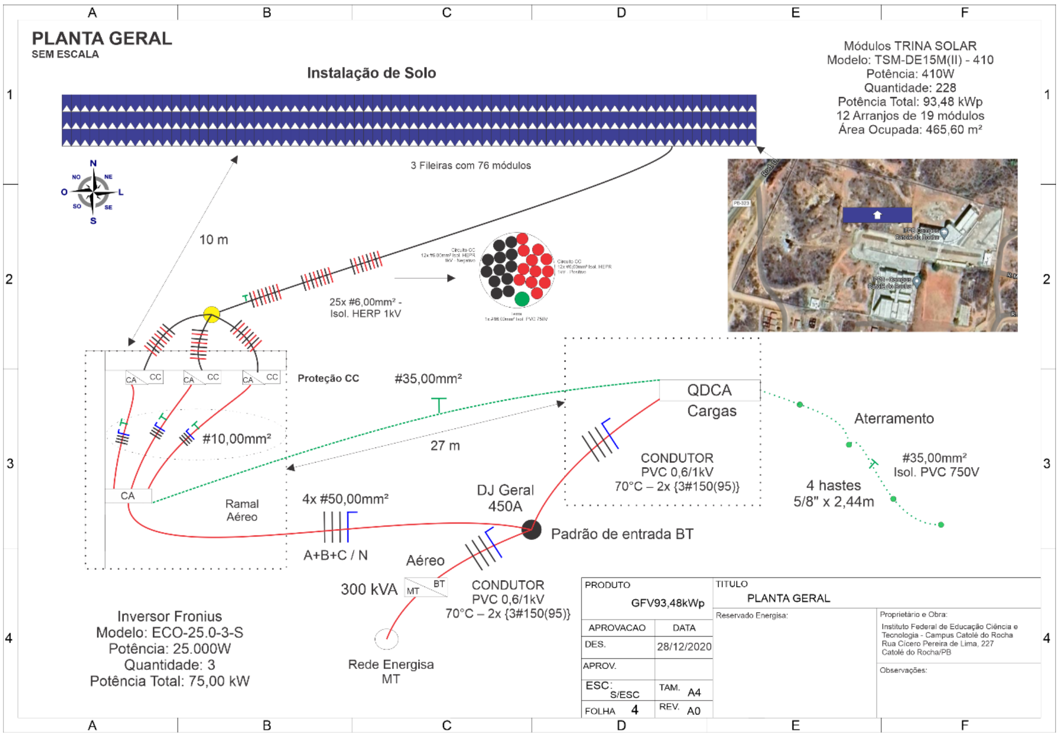

Figure 3. Location of photovoltaic modules in campus

Figure 4 shows, in addition to the positioning of the modules, the inverter house, the 300 kVA transformer and the transformation cabin.

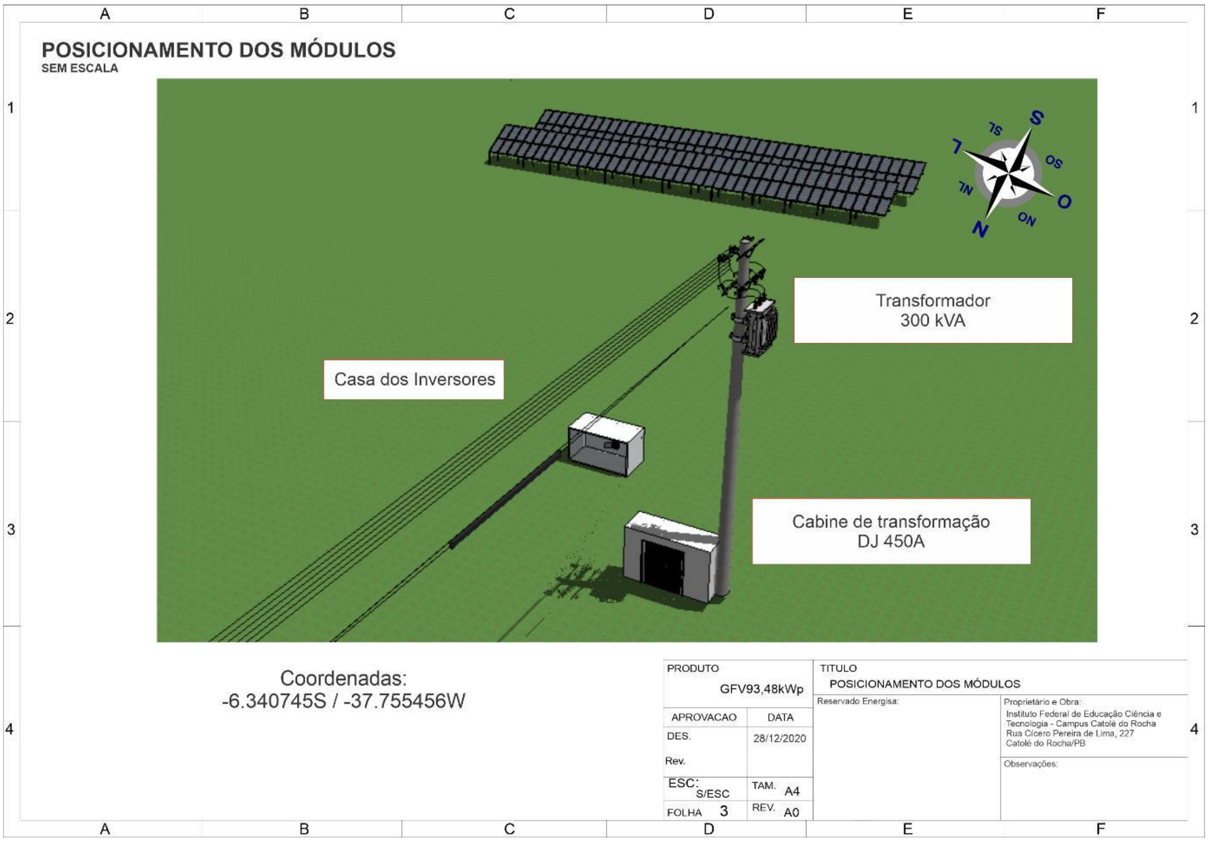

Figure 4. Positioning of modules

The modules will be fixed using metallic structures of anodized aluminum of high resistance and supports of galvanized steel with stainless steel screws. They will be mounted directly on the ground with their own structure for fixing photovoltaic panels, below is some information provided by the manufacturer:

- Dimensioning according to NBR 6123 wind loads
- Galvanized steel according to NBR 6323 standard
- Structural design according to NBR 8800
- Easy installation
- High strength 6063-T6 aluminum beams and clamps
- Stainless steel clamp screws

Figure 5 shows the layout of the support structure for installing the modules.

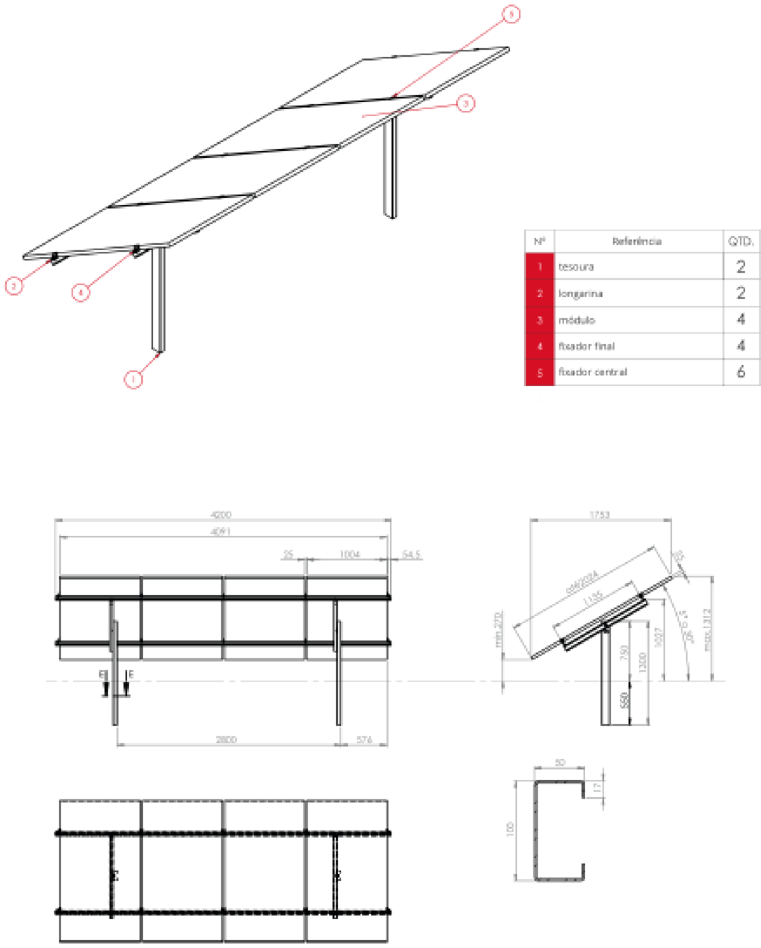

Figure 5. Support structure

The modules must be connected in series and connected to the inverter. It is important to emphasize the need to measure the modules before connecting to the inverters, the measurement presented must follow the data presented in Table 2.

Disposition	Voltage Vcc	Current Icc
01	773,30 V	10,07 A
02	773,30 V	10,07 A
03	773,30 V	10,07 A
04	773,30 V	10,07 A
05	773,30 V	10,07 A
06	773,30 V	10,07 A
07	773,30 V	10,07 A
08	773,30 V	10,07 A
09	773,30 V	10,07 A
10	773,30 V	10,07 A
11	773,30 V	10,07 A
12	773,30 V	10,07 A
Inverter input 01	773,30 V	40,28 A
Inverter input 01	773,30 V	40,28 A
Inverter input 01	773,30 V	40,28 A

Table 2. Arrangement of the rows of modules and their respective voltages and current

Some characteristics of the modules can be verified through table 3.

Discription	TSM-DE15M (II)-410
MANUFACTURER	TRINA SOLAR
NOMINAL MAX POWER (Pmax)	410 w
OPERATING VOLTAGE (Vmp)	40,70 Vcc
OPEN CIRCUIT VOLTAGE (Voc)	49,40 Vcc
CIRCUIT CURRENT (Imp)	10,07 A
OPEN CIRCUIT CURRENT (Isc)	10,59 A
EFFICIENCY	20,40 %
INMETRO REGISTRATION	001160/2020

Table 3. Description of modules

V. CONCLUSION

The work, presented here, designed a photovoltaic energy system for the IFPB Catolé do Rocha campus. The theoretical basis that supported the study and the results for the dimensioning of the system components were presented, requiring 228 photovoltaic modules with a power of 410 Wp. Currently, consumers of solar energy take into account the environmental aspects that prove that this type of energy is green, some of these aspects have been shown, such as the non-emission of CO_2. In addition, the project was economically validated, bringing a surplus of R$ 1600,00 a year, that is, in addition to the system making all the energy payments, there is still that amount left over.

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