# Solar Energy: The study of electricity through the photovoltaic systems ON-Grid and OFF-Grid in Brazil

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**BSc Environmental Enginnering**

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## SOLAR ENERGY: THE STUDY OF ELECTRICITY THROUGH THE PHOTOVOLTAIC SYSTEMS ON-GRID AND OFF-GRID IN BRAZIL


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## TABLE OF CONTENTS

**TABLE OF FIGURES**

**TABLE OF TABLES**

1 ABSTRACT

Solar energy corresponds to energy from the light and heat emitted by the Sun. This source of energy can be used in a photovoltaic or thermal way, generating electrical and thermal energy, respectively. As it is considered a clean energy source, solar energy is one of the most promising alternative sources for obtaining energy.

Nowadays, it is the second largest source of energy in Brazil. With 23.9 gigawatts (GW) in operation, it is second only to water sources and surpassed wind sources, according to a survey by the Brazilian Association of Photovoltaic Solar Energy (Absolar). The result was obtained through the sum of power plants and own energy generation systems, such as domestic use, for example. As a result, in 2022 solar energy grew by 64% compared to 2021.

The purpose of this thesis is to create an analysis about the generation of energy through sources presented in the solar energy, calling them ON-Grid and OFF-Grid photovoltaic systems, and the impacts (socio, technical and economical) that are generated when they start to be used, having at the end the incentives presented in Brazil regarding this evaluation.

Advantages and disadvantages of both systems are being discussed, which make a conclusion offering great alternatives to reduce impacts and showing diversity when it comes to sustainability, in order to improve the quality of life of our generation and future ones as well.

Keywords: Solar energy, solar systems, environment, engineering, sustainability.

# 2 INTRODUCTION AND OBJECTIVES

In the year 1950, the world population was estimated at around 2.6 billion people, whereas in the year 1987 the population reached 5 billion. In 1999, the number of inhabitants was 6 billion and, after ten years, the 7 billion mark was reached. In 2017, it was estimated that there were around 7.6 billion inhabitants in the world. (UN BRAZIL, 2019)

The rapid expansion of the number of inhabitants on planet Earth has important implications in many sectors of life. Some of these implications can be cited, such as: health and aging, urbanization, demand for housing, inadequate food supply, access to potable water and energy.

Among the aforementioned issues, energy is highlighted in this work because it is necessary for human life, such as: turning on the light, as well as preparing meals. This energy is provided through a set of sources available to meet the energy demand - energy matrix. However, the electrical matrix - a set of sources available for the generation of electricity in the world - is part of the energy matrix, which is composed of non-renewable and renewable sources.

Non-renewable energy sources use limited natural reserves, with slow formation processes and short existence compared to the rapid consumption by humans. Such sources use natural resources, which will be depleted in a short period of time or even in the long term. On the other hand, renewable energy sources are inexhaustible, due to constant renewal when used within a significant time interval. Also, they are considered clean because they emit less greenhouse gases - henceforth GHG - compared to fossil sources.

The present work aims, therefore, to study renewable energy as a way of generating electricity in a sustainable way, that is, without polluting or harming the ecosystem. Given this, the growing search for technologies and sources that contribute positively to the environment becomes an efficient measure as a way to reduce socio-environmental impacts and pollution in the world.

To this end, it is worth emphasizing that it is necessary to develop policies, government programs, economic and social studies, so that there is a greater conscious use of renewable sources. In addition, according to INPE (2017), it is of paramount importance to innovate and develop technologies, so that the available natural energy resources are used and converted, so that there is development and, consequently, a reduction in socio-environmental impacts.

Thus, the important regulatory framework for the development of renewable sources in Brazil began with Normative Resolution 482/2012. As of December 2012, generation systems that use renewable sources, such as solar, wind, water and biomass, have been able to inject energy in parallel with the electrical grid of the country's electrical distribution concessionaires.

In high-income countries, the initial purpose of photovoltaic systems was to provide electrical energy in isolation from the utility grid. Subsequently, and gradually, these systems were also interconnected to the network electric.

Photovoltaic systems are classified according to the methodology used to produce electricity using solar energy. Such systems have become important because of the way in which they contribute to a more sustainable society through abundantly renewable energy. However, solar photovoltaic renewable source is considered intermittent source of energy. This term is due to the high temporal variations associated with the meteorological conditions present at the location of the plant.

In these contexts, the chosen theme will be developed based on photovoltaic systems, which can be installed autonomously (OFF-Grid) or connected to the conventional distribution grid (ON-Grid). The evolution of these types of systems becomes one of the factors that justify the need to carry out more comprehensive research that is related to the process of generating energy through a clean and renewable sour

Therefore, studies related to the benefits, or not, generated by the application of the two photovoltaic systems, which use the direct conversion of solar energy into electrical energy, are necessary. Such conversion is the result of radiation effects on some semiconductor materials, in which the photovoltaic effect stands out.

In addition, photovoltaic systems represent an efficient way, both for the consumer to use them connected to the electricity distribution network (ON-Grid), and also as a solution to meet small energy demands, in places of difficult access (OFF-Grid).

✓ **Main goal**

The main focus of this work is the comparative study of photovoltaic systems, which use the direct conversion of solar energy into electrical energy. Thus, this study aims to present and compare the generation of electricity through two main types of photovoltaic systems, which will be addressed in this work: the ON-Grid system and OFF-Grid system.

It should also be noted that the theoretical approach given to the study is aimed at three parameters: technical, social and environmental.

✓ **Specific objectives**

*The specific objectives of this work are:*

- develop analyzes on the ON-Grid photovoltaic system and on the OFF-Grid system
- OFF-Grid and ON-GRID pv, both from a technical point of view and from a socio-environmental point of view, with the purpose of sustainability;
- compare the two photovoltaic systems, in order to present where they are most used

of;

- make future readers of this work aware of the importance of using alternative sources of renewable energy (in this case, solar energy), in order to avoid greater pollution of waste and/or polluting gases that generate the greenhouse effect and global warming.

# 3 LITERATURE REVIEW

Currently, society uses electricity intensively, especially in more developed countries. This is due to the advancement of technologies, as well as population and industrial growth, as well as society's consumption patterns.

Consequently, there is an increase in polluting agents in the environment that cause various effects, such as: deforestation and desertification, soil, air and groundwater pollution, global warming, greenhouse effect and acid rain, as well as depletion of non- renewable natural resources.

There is, then, the need to preserve the environment in a way that is allied to human development. Thus, through sustainable development it is possible to improve the quality of life of human beings on Earth and respect the production capacity of ecosystems. It is worth highlighting the great importance of sustainable development - with regard to the preservation of the environment - and the importance of the union of countries, with the purpose of reducing the emission of pollutants in the environment, in order to alleviate the problems caused in the environment.

In this context, it is understood that the importance of mitigating the amount of pollutants in the environment is due to the fact that one of the main environmental risks faced up to the present day is the greenhouse effect, which is associated with increased energy consumption, that is, when using sources that emit polluting gases into the atmosphere. Therefore, the fundamental relevance of studying photovoltaic systems stems from the concern with the present use of energy sources, as well as with future generations.

Another major concern is the shortage of oil, given that the reserve of fossil fuels is running out. The energy that drives economic activity is provided by the burning of fossil fuels, which produces carbon dioxide (PIVA, 2010).

In this way, due to the scarcity of non-renewable natural resources, the search for renewable and clean energy sources is growing.

Renewable energy is considered an inexhaustible supply source in the long term and the elements used as raw material can be recomposed in nature.

On the other hand, it is considered as a source of non-renewable energy the use, through the system, of resources that will be depleted in nature (CEMIG, 2012).

In Brazil, for example, the main source of energy generation comes from hydroelectric plants, since the country has excellent water availability. The Brazilian electricity matrix is predominantly renewable (EPE, 2018a).

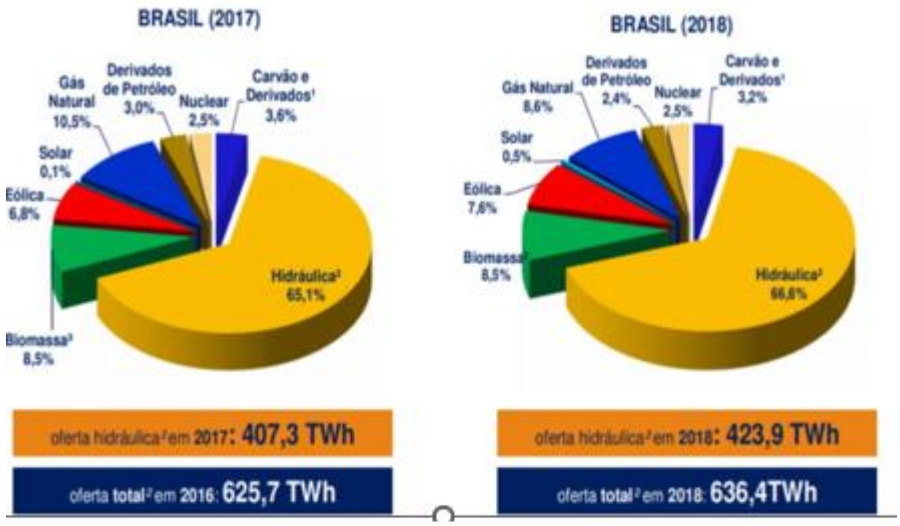
The electrical matrix in Brazil is presented in figure 1 through graphs that show the supply of energy from the different sources used in Brazil. The total energy offers in 2018 was 636.4 TWh, in which 66.6% of this total energy supply refers to hydraulics, which represents 423.9 TWh.

In Figure 1, it is possible to see that the country's main source is hydroelectric plants.

The graphs also show the energy supply in the years 2017 and 2018, respectively. It can be seen, therefore, that the hydraulic supply had an increase of 1.5%. The supply of natural gas, on the other hand, had a decrease of 1.9%; the supply of biomass and nuclear remained the same as in 2017; the offer of wind energy gained an increase of 0.8%; the supply of petroleum derivatives and coal decreased by 0.6% and 0.4%, respectively.

Finally, the supply of solar energy, the source studied in this work, had an increase of 0.4% between one year and other.

Figure 1 – Brazilian Electric Matrix.




Source: BEN, 2019.

However, this source of renewable energy, which comes from hydroelectric plants, has been affected due to the large increase in electricity consumption and the effects caused by human activity on the environment. In addition, the impacts associated with climate change and flooding in areas where hydroelectric plants are installed cause the loss of local biodiversity and often cause the displacement of populations.

### 3.1 Solar Energy

"Primary sources of energy are those available as they are found in nature and which have not yet undergone any conversion" (CEMIG, 2012). In addition to this statement, it is emphasized that for the production of useful energy, eight important primary sources are used, namely:

1. Fossil fuels
2. Solar radiation
3. Winds
4. Water resources
5. Biomass
6. Radioactive elements
7. Geothermal
8. Oceans

With this, it appears that there are many primary sources of energy available. However, it is worth emphasizing that, in this work, solar energy will be addressed, due to the fact that the sun is the largest primary source of renewable energy on the planet, in addition to being responsible for development and life on earth, due to the large amount of heat and light that are provided by it.

According to INPE (2017), solar energy is an inexhaustible source, since the time scale of life on planet Earth must be considered. The sun is an average star that radiates energy due to the nuclear fusion reactions of hydrogen atoms to form helium and, for this reason, the sun is one of the most advantageous energy possibilities for humanity.

IBGE (2019a) assures that the Sun is the largest body in the solar system, with a mass of 1.989x1030 kg, which represents 99.8% of the total mass of the solar system (composed of the Sun and all celestial bodies that orbit around it). from him). The Sun has a radius of about 695 km and is approximately 150 million km from Earth. In addition,

it is mainly composed of hydrogen (91%) and helium (8.9%). The temperature at the Sun's core is approximately 15,000,000 °C and at the surface it reaches 5,500 °C.

The origin of the majority of existing energy sources comes from this star (the Sun) to Earth, and we can mention hydroelectric generation, which takes place through evaporation, responsible for the water cycle and thus enabling the damming of rivers for the subsequent generation. Wind energy, on the other hand, comes from the winds, through solar radiation that induces large-scale atmospheric circulation. Likewise, the energy of biomass (firewood, charcoal, alcohol, etc.) depends on solar radiation for the process of photosynthesis, in which it is directly absorbed and stored in the chemical bonds of organic molecules and which serves to sustain the entire chain feed the planet.

Throughout the year, Brazil has great potential for harnessing solar energy and in places further away from urban centers, this energy can be used for the development of the region.

The Earth's atmosphere annually receives 1.5x1018 kWh of energy from the Sun. This indicates that solar radiation, in addition to being responsible for maintaining life on Earth, is also an inexhaustible source of energy, which has enormous potential for use through systems for capturing and converting it into another form of energy, the example of thermal and electrical, among others (CRESESB-CEPEL, 2008).

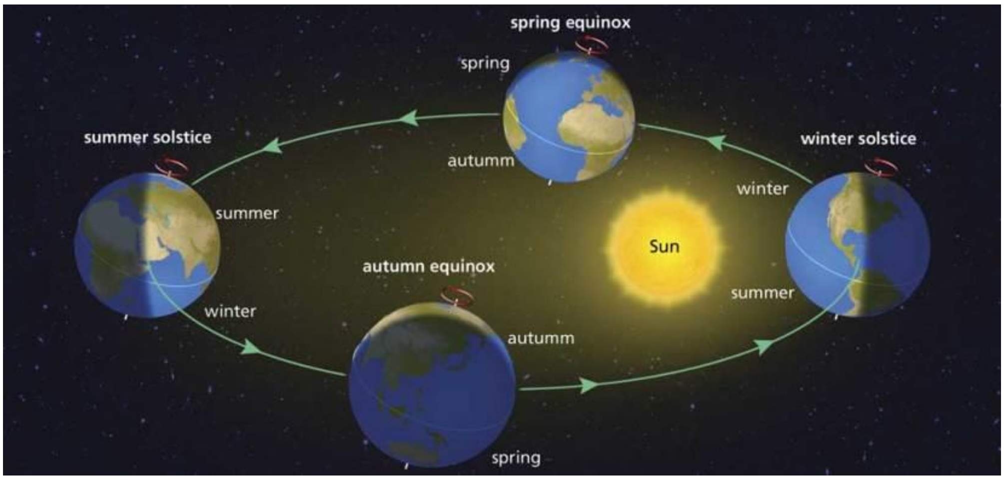
The sun's energy radiates on Earth enough to meet ten thousand times the consumption world's annual energy source and produces around 1,700 kWh of electricity per year for each square meter of area. The availability of solar radiation, on the other hand, depends on the latitude of the region, since the movement of the Earth around the Sun is described by an inclined plane of 23.5o in relation to the plane of the Equator (EPE, 2006-2007).

There is radiation in all regions of the spectrum. However, human eyes are sensitive to less than an eighth of this radiation, about 400 to 750 THz (400 to 750 nm) - the visible region, which is narrow. However, the Sun has 45% of all energy. Known as the solar constant, the power density of solar radiation has a value of approximately 1360 Wm2.

Such density indicates the number of Watts per square meter (energy flow) and varies according to the distance between the Earth and the Sun (ROSA, 2015).

It is worth noting that figure 2, below, shows the rotation and translation movement that the Earth makes around the Sun and the representation of the seasons, in which the first rotation movement refers to the movement that the Earth performs around its own imaginary axis and takes approximately 24 hours to complete (this period is called a day). During this time interval one part of the planet is illuminated while another is dark, which causes day and night. The second movement of translation refers to the movement that the Earth performs around the Sun and lasts approximately 365 days (this period is called a year).

Figure 2 – Earth’s rotation and translation movements.




Source: GIS Crack, 2020.

## 3.2 Photovoltaic Systems

According to Fadigas (2012), one of the pioneers in research on the photovoltaic effect was the French physicist Alexandre Edmond Becquerel, who discovered, in 1839, that solar energy can be transformed into electrical energy. The experiments were carried out by him using electrodes exposed to light and immersed in an electrolyte. In this way, Becquerel understood the photovoltaic effect. Later, Adams and Day observed the same effect in solid selenium, in the year 1877.

In 1883, the photovoltaic cell was produced with selenium, however, this cell had a conversion efficiency of only 1%. In order for the photovoltaic effect to become more understood, a more in-depth study regarding the solid-state junction was necessary, through the physicists Lange, Grondahl and Schottky. In the year 1941, Ohl obtained the first photocell made of monocrystalline silicon. In 1949, Billing and Plessnar performed measurements related to the efficiency of crystalline silicon cells. At this time, Shockley divulges the theory of the PN junction. All this boost to photovoltaic generation was only possible from the explanation about the photoelectric effect given by Albert Einstein.

According to Matos (2006), the first photovoltaic cell made of mono-crystalline silicon was developed in 1954 with an efficiency of 6%. The researchers: chemist Calvin Fuller, physicist Gerald L. Pearson and engineer Daryl Chapin created this technology in the United States and carried out the first practical application of solar cells with this type of material. In 1959, a new method of growing silicon crystals was developed, through experiments with solar cells made of polycrystalline silicon, which would culminate in lower costs related to the production of cells.

Photovoltaic cells were initially used between the 1960s and 1970s in satellites. This impulse came about through the space race between the USA (United States of America) and the USSR (Union of Soviet Socialist Republics). Currently, countries that dominate space technology continue to use photovoltaic energy as a source of energy supply.

To this day, research is carried out on the manufacture of photovoltaic cells, with the aim of ensuring greater efficiency, without harming the environment.

With this new technology, one can understand the importance of the sun as a form of heat, light, life, energy and also electricity.

Energy comes from an abundant source (the Sun), in addition to being considered inexhaustible on our planet. This source of light and life produces renewable, clean and silent energy. And it is worth saying that the Sun is full of atoms that transform mass into energy.

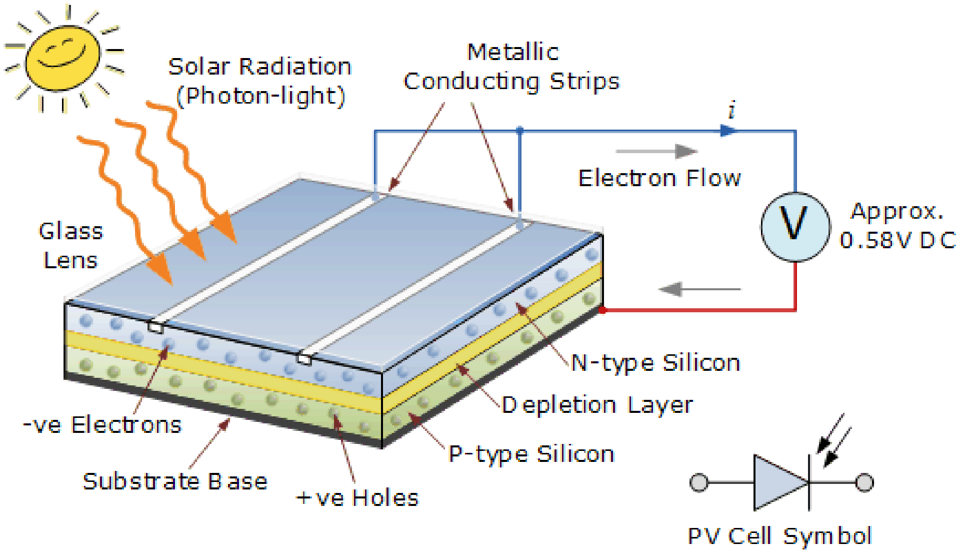
The Sun transforms 657 million tons of hydrogen into 653 million tons of helium and the other 4 million tons are transformed into energy and discharged into space in the form of solar radiation. However, the electromagnetic energy that the Earth receives is only two billionths. One of the most used methods of harnessing sunlight is photovoltaic.

In order to generate electricity, this process takes place from the direct conversion of sunlight into electricity, through the photovoltaic effect. This type of conversion occurs in devices known as photovoltaic cells, which are optoelectronic components that directly convert solar radiation into electricity. In addition, semiconductor materials, such as silicon, are fundamental in the construction of these cells.

The photovoltaic effect is produced by this incidence which, in addition to circulating an electric current in the material, creates electrical energy. Through the photovoltaic effect there is the development of the potential difference between the two electrodes, due to the transfer of electrons generated between the different bands of the material (CEMIG, 2012, p. 16).

Figure 3 shows how energy is obtained through the direct conversion of light into electricity through the photovoltaic effect.

Figure 3 – Composition of a photovoltaic cell.




Source: Alternative Energy Tutorials, 2021.

The way in which the semiconductor is transformed into a photovoltaic cell is through steps such as purification and doping, so that the latter consists of adding some chemical elements, such as boron and phosphorus, with the purpose of altering the electrical properties. In this way, two layers in the cell are created: p-type layer (excess positive charges) and n-type layer (excess negative charges), relative to pure silicon.

Thus, in order to produce electrical energy, the incidence of sunlight is necessary in the modules that are composed of photovoltaic cells. This direct conversion of rays solar cells into electrical energy comes from these cells, which are composed of semiconductor elements, in which silicon is generally used. This sunlight acts as a stream of particles (photons). When the NP junction is illuminated, the phenomenon of absorption of photons by electrons (photoelectric effect) occurs and, thus, some pass from the valence band to the conduction band.

In this way, the electrons that reach the conduction band wander through the semiconductor until they are pulled by the electric field that exists in the junction region. Through an external bond, the electrons are taken out of the cell to be used. Each electron that leaves the cell is replaced by one that returns from the charge. Thus, this energy is converted into electrical energy through photovoltaic panels and electrical radiation concentrators.

# 4 MATERIAL AND METHODS

The methodological procedure used to collect information about the topic in question is characterized as bibliographical research. This attribution will take place through the use of publications carried out by agents in the energy and solar energy sectors, as well as analyzes carried out based on documents, academic articles, as well as research related to Brazilian legislation.

To this end, the present study was prepared from a review of the scientific literature related to photovoltaic systems, in which it aims to analyze the two types of photovoltaic systems ON-Grid and OFF-Grid and, in a complementary way, to compare technically these two systems. The technical comparison will be made through the study related to the equipment belonging to the photovoltaic systems.

In this context, the methodological criteria for developing the critical analysis, relating linked to photovoltaic systems, are organized in the form of a flowchart, which basically combines the technique and the socio-environmental analysis, like presented below. This method makes possible to understand, in a theoretical and intuitive way, each stage of the development of this work.

The work presents two analyses, namely:

- **Technical analysis:** describes the ON-Grid and OFF-Grid photovoltaic systems, based on the technologies used, as well as the importance of each one for the different situations in which the systems are used. In addition, it presents the main advantages of photovoltaic systems, as well as an example of a financial simulation for each of these systems. This simulation was carried out by a company in the solar energy sector.
- **Socio-environmental analysis:** describes market demand, the Brazilian potential for photovoltaic solar energy generation, socio-environmental impacts, sustainability, as well as the main incentives for photovoltaic systems in Brazil.

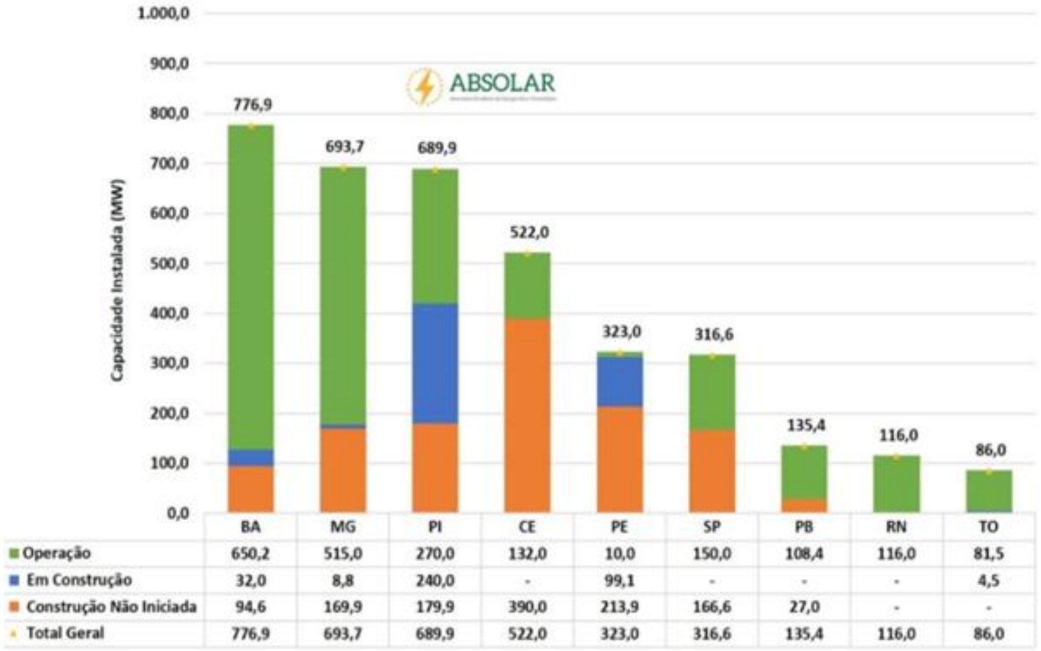
## 5 RESULTS AND DISCUSSION

### 5.1 Technical analysis

According to INPE (2017), large power plants are installed on the ground on inclined and fixed metal structures or with following the apparent trajectory of the sun on an axis. They are being leased mainly in the Northeast, Midwest and Southeast regions of Brazil. Other regions will become competitive, as areas and energy transmission systems become saturated or even require greater investments to accommodate growing installed capacities, as well as the South and Southeast regions, since they have shorter distances. of the great centers; there is a large concentration of load from the National Interconnected System (SIN); new transmission lines are not necessary, since there is a greater availability of grid connection. In this way, centralized photovoltaic generation will be able to spread throughout the country.

Figure 4 below shows the nine states in the Northeast, Southeast and North regions of Brazil, with solar photovoltaic plants in operation, construction and, also, construction not yet started, according to the installed capacity in each state. Thus, the states of Bahia, Minas Gerais and Piauí stand out in terms of higher values of installed capacity, with 776.9 MW, 693.7 MW and 689.9 MW, respectively.

Figure 4 – Installed power (MW) and status of centralized photovoltaic solar generation by state.




| | BA | MG | PI | CE | PE | SP | PB | RN | TO |
|---|---|---|---|---|---|---|---|---|---|
| Operação | 650,2 | 515,0 | 270,0 | 132,0 | 10,0 | 150,0 | 108,4 | 116,0 | 81,5 |
| Em Construção | 32,0 | 8,8 | 240,0 | - | 99,1 | - | - | - | 4,5 |
| Construção Não Iniciada | 94,6 | 169,9 | 179,9 | 390,0 | 213,9 | 166,6 | 27,0 | - | - |
| Total Geral | 776,9 | 693,7 | 689,9 | 522,0 | 323,0 | 316,6 | 135,4 | 116,0 | 86,0 |

Source: CCEE/ABSOLAR, 2019.

Centralized solar photovoltaic generation, consisting of large- scale power plant projects, as well as many other applications of solar photovoltaic technology in Brazil, has increasingly consolidated itself as a renewable source of electricity generation with high added value to Brazilian society. This system is and should continue to be one of the main pillars for the growth of this source in the country, with the participation of the sector in electric energy auctions organized by the federal government, through which the 2,000 MW that are in operation in Brazil.

Distributed generation is considered to be the generation of electricity in the consumer establishment itself or close to the place of consumption. In this way, distributed generation is understood as the power plant that connects directly to the energy distribution network, in which the consumer can inject power into the network (when not using it) or, then, receive power from the network when there is a need to consume more electricity.

In addition to the great importance of converting solar energy (a resource of great abundance) into electricity, it should be noted that distributed generation uses renewable sources and is located close to the center of electricity consumption. Due to the fact that photovoltaic solar energy has great potential in Brazil, distributed generation will be studied, as well as the main rules that govern it.

With the entry into force of ANEEL Normative Resolution 482/2012, consumers can generate their own electricity from renewable sources and can even supply the surplus to the local distribution network.

Solar energy makes up approximately 84% of the available capacity in the year 2018, which corresponds to 562.3 MW, as can be seen in table 1:

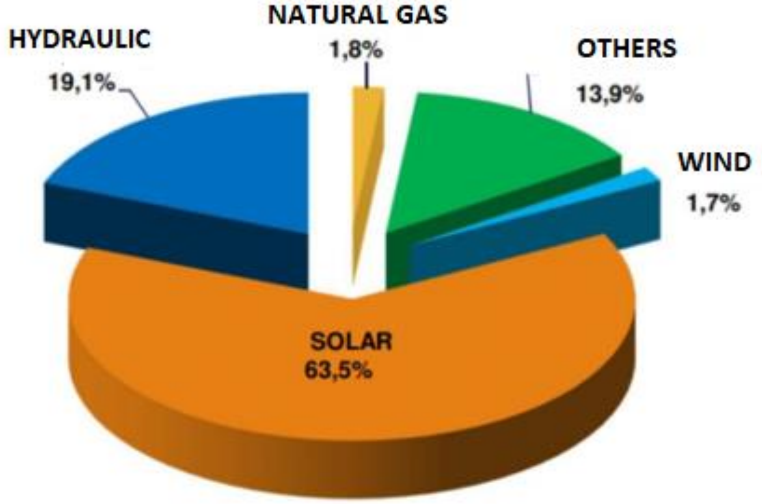
Table 1 – Installed capacity - Distributed Generation (MW).

| Source | 2017 | 2018 |
|---|---|---|
| **Hydraulic** | 37,3 | 58,9 |
| **Thermal** | 24 | 38,1 |
| **Wind** | 10,3 | 10,3 |
| **Solar** | 174,5 | 562,3 |
| **Capacity** | 246,1 | 669,6 |

Source: EPE, 2019.

It can be seen in figure 6, just below, that the solar source had a greater participation in distributed generation, with 63.5% of the total. Then, hydraulic energy represents the second position with 19.1% in 2018. The participation of the energy sources represented in the graph corresponds to a total of 828 GWh, which is equivalent to a 131% increase, if compared to the year 2017.

Figure 5 - Participation of each source in Distributed Generation in 2018.




Source: EPE, 2019.

Distributed generation has the following predominant benefits: encouraging the use of renewable energy on a small scale, reducing losses and investments in the electrical energy network, in addition to increasing energy security through the use of different generation sources.

According to ANEEL (2018), incentives for distributed generation are justified by the potential benefits that this modality can provide to the electrical system. Among them is the postponement of investments in the expansion of the transmission and distribution systems, the low environmental impact, the reduction in network loading, the minimization of losses and the diversification of the energy matrix.

In this sense, there are two types of operations described in this work: the systems ON-Grid and OFF-Grid, which will be explained in detail below.

## 5.2 ON-Grid System

ON-Grid systems, also known as systems connected to the electrical grid, have an exponential growth in the photovoltaic market in developed countries.

They are, therefore, considered a complementary source to the electrical system and used in places already served by electricity. This photovoltaic solar energy system uses sunlight to generate electricity. The utility grid works like a battery that receives all surplus energy generated by the system.

This type of system uses distributed generation and can be classified according to the generated power. In a microgeneration photovoltaic system, generally, the consumer unit - where the distributed microgeneration or mini-generation is installed - is in homes or on lots close to the place where the energy generated by this type of system is consumed. The types of consumer units that use a mini-generation photovoltaic system are mostly commercial buildings.

Developed countries show greater growth in photovoltaic systems connected to the electricity grid and there is great potential for such systems to be applied in sunny urban areas around the world, since, if there is a peak demand during the day, these systems can contribute for the maximum capacity of a network. Furthermore, when the demand for electricity is greater in the summer and - if compared to the winter period - the possibility of the load coinciding with the availability of solar resources increases.

Developed countries have most of the photovoltaic market growth with ON-Grid installations and, it should be noted, that there is immense potential for these systems to be applied in sunny areas around the world. The wide availability of solar energy in Brazil makes the country stand out. Thus, if there is a peak demand during the day, photovoltaic systems can contribute to the maximum capacity of a network, such as commercial areas with high air conditioning loads during the day.

Thus, if the peak load values in summer and winter are confronted, it can be seen that the greater the demand in summer, the greater the possibility that the load coincides with the availability of solar energy; typical behavior of most Brazilian capitals.

Consumption data for urban areas in Brazil show a difference between regions where commercial buildings dominate and residential regions, so that the first has demand peaks during the day, while the second has peak demand values at dusk (INPE, 2017).

This type of system works through the photovoltaic panel, henceforth PV, which has the function of generating electrical energy in direct current (DC), converting it into alternating current (AC) and injecting it into the electrical power grid. The interface between the panel and the electrical network takes place through the frequency inverter.

Thus, PV modules are mounted directly in residential buildings or commercial areas, in parking garages or even in free areas and facades. An important component of the ON-Grid photovoltaic system is the photovoltaic generator, which is composed of modules that produce electricity in direct current and which is subsequently converted into alternating current. These modules are composed of photovoltaic cells made of semiconductor materials connected in series (to increase the voltage) and in parallel (to increase the system current). After this conversion, the energy coming from the sun can be used at the place of consumption or it can even be transferred to the electrical grid.

The assembly and installation structure are based on the assembly of metallic structures to support photovoltaic modules on the roof, which are manufactured in aluminum and steel and, therefore, are resistant to environmental storms, in addition to having an innovative design, simplifying the installation of the solar panel.

The inverter is a device responsible for changing the energy that comes from the photovoltaic generator to be used in the electrical grid. Such equipment converts the DC, generated by photovoltaic modules, into AC. Thus, electricity is in the same standard used by various electrical equipment. As the inverter allows the energy generated by the solar panel to be connected to the grid, then the generated voltage must have the same amplitude, frequency and phase as the grid.

Figure 7 shows the ON-Grid system, which basically uses several photovoltaic panels connected to the inverter and, subsequently, to the electricity grid. This system does not store energy. Therefore, the generated energy that is not used by the consumer/generator is delivered directly to the electrical grid.

Figure 6 – System connected to the network.


Source: Portal Solar Brasil, 2018.

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1. PHOTOVOLTAIC PANEL

The photovoltaic solar panel converts solar radiation into electrical energy, in direct current. Each panel is composed of photovoltaic cells. The arrangement of several photovoltaic panels can compose public lighting, in addition to residential, commercial, industrial roofs and facades, among other consumer units.

2. INVERTER

The photovoltaic inverter transforms energy from DC to AC, as most electronic devices use AC, so that this energy can be used in residential or even commercial consumer units. This equipment is capable of making the voltage and frequency compatible with the utility grid, to which the system is interconnected.

According to INMETRO (2011), inverters to be applied in photovoltaic systems must have a pure sinusoidal waveform; efficiency greater than 85% in the range between 50% and 100% of the rated power and total harmonic distortion (DHT) less than 5%, at any operating power.

The inverters must also have the other characteristics (CRESESB-CEPEL, 2014):

- high reliability and low maintenance;
- operation over a wide input voltage range;
- good output voltage regulation;
- low emission of electromagnetic interference and audible noise;

- tolerance to starting surges of the loads to be supplied;
- security for people and facilities;
- IP protection degree suited to the type of installation;
- Factory warranty of at least two years.

3. DISTRIBUTION TABLE

The electrical energy produced by the photovoltaic cells in the panels and subsequently transformed by the inverter is conducted to the local distribution board - where the system is being implemented - so that, in this way, the energy is distributed to be used.

4. ELECTRICAL APPLIANCES

The energy produced by the ON-Grid system reaches the electrical and electronic devices connected to the socket and, automatically, these devices will use photovoltaic energy for their own operation.

5. BIDIRECTIONAL ENERGY METER

The bidirectional meter has the function of monitoring the energy consumed from the network, as well as the energy injected into the network. Therefore, if the system produces less electricity than is consumed at the moment, the public network automatically supplies the necessary energy so that the consumer does not run out of energy. Conversely and in a complementary manner, the system, by producing more

energy than is needed at the time, causes this excess energy to be injected into the utility's electric

And therefore, in this case, the bidirectional meter will account for this energy and the consumer/generator will have a positive balance on the monthly energy bill. This balance will be automatically deducted when the customer needs to use grid power again. Therefore, the bidirectional energy meter registers the consumed and surplus energy generated for compensation of credits at the end of the month. In this way, the consumer can make the switch to the electricity grid and reduce the electricity bill, as the excess energy generated and not consumed is injected into the grid, generating credits and savings at the end of the month.

In addition to the aforementioned components, the system integration components (Balance of System - BOS) are also used, which are composed of photovoltaic module attachment structures and electrical protection components.

Figure 8 shows the cash value of this system in that company, which is equivalent to R$ 10,366.00 (~ 2000 EUR), a monthly savings for consumers of this consumer unit of R$ 225.58 (~ 226 EUR) and the payback is in three years.

And, it can be comprehended, that the photovoltaic solar system for the referred UC produces an estimated monthly energy of 232 kWh of generation. Such energy is generated through five photovoltaic modules - which, by the way, have a useful life of 25 to 30 years and peak power of 1,825 kWp.

Figure 7 – ON-Grid System.


Source: Blue Sol, 2019.

## 5.3 OFF-Grid System

OFF-Grid systems are known as isolated systems or also known as considered as systems not connected to the electrical grid. These systems work autonomous, that is, they do not work in parallel with the conventional electrical network. According to Decree (2010):

- isolated systems: these are public electric power distribution service systems that, in their normal configuration, are not electrically connected to the National Interconnected System - SIN, for technical or economic reasons;
- remote regions: small groups of consumers located in an isolated system, far from municipal headquarters and characterized by the absence of economies of scale or density.

Currently, more than 800 million people in the world do not use electricity. These numbers show the importance and need for the entire world population to have access to an adequate quality of life. In view of this, the decentralization of energy distribution and the use of renewable energy sources are ways to minimize or even extinguish this sad situation.

The inhabitants furthest away from the main sources of generation realize how difficult it is to have electricity. The main reason for this difficulty is related to the high costs of distribution and transmission, as well as the low demand in these locations compared to large consumption centers, since an extensive high voltage transmission network is required to serve these consumers.

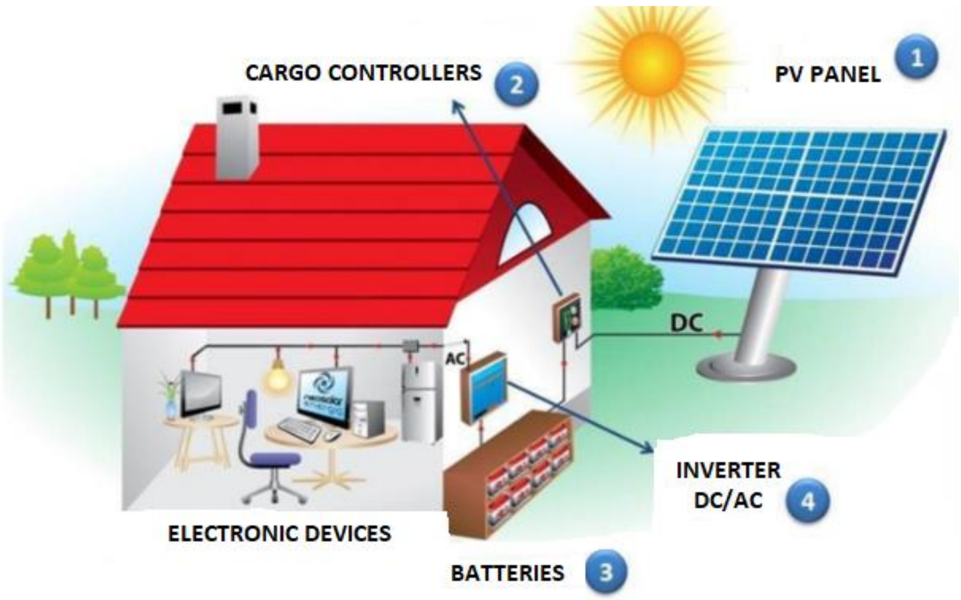
And, therefore, it becomes unviable for energy concessionaires for economic and technical reasons.

Therefore, OFF-Grid systems can be used in remote regions, lacking an electrical distribution network or that have a precarious supply of electrical energy. As an example of the application of these systems, there are rural areas, farms, farms, parking lots and beaches.

In these contexts, OFF-Grid systems are disconnected or isolated systems. Therefore, they do not depend on the utility grid to generate electricity during periods such as the night, when the systems do not produce energy. For this, they have an energy storage system, through the use of batteries.

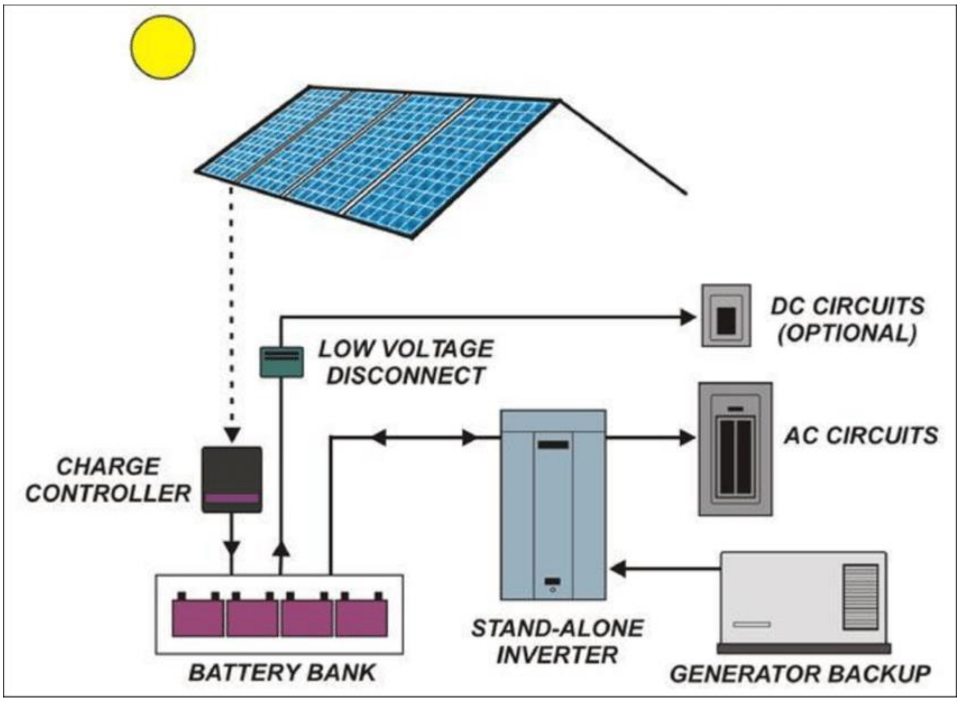
Figures 10 and 11 below represent an OFF-Grid system model and its diagram depending on the load used, respectively.

Figure 8 – OFF-Grid system process in a house.




Source: FPME, 2019.

Figure 9 – Diagram of photovoltaic systems according to the load used.




Source: ResearchGate, 2018.

In figure 10, one can see the use of four pieces of equipment to compose the OFF-Grid photovoltaic system. Here it follows:

1. PHOTOVOLTAIC PANEL

As in ON-Grid systems.

2. CARGO CONTROLLERS

Controllers protect the battery or battery bank from overcharging or deep discharging. The charge controller is used in small systems, where the appliances used are low voltage and direct current (DC). In isolated systems, these charge controllers must not fail as there may be irreversible data. In addition, they must be designed according to the characteristics of different battery types. When the battery reaches full charge, the controllers must disconnect the photovoltaic generator and stop the power supply if the battery state of charge reaches a minimum safe level. Thus, there is an increase in the useful life of the batteries. The adjustment of the parameters, as well as the choice of the control method, must be suitable for the different types of batteries.

3. BATTERIES

In isolated systems, there is the use of some form of energy storage, which can be done by means of batteries, so that the consumer can use electrical appliances or, even, in the form of gravitational energy, when pumping water to tanks in supply systems. Some isolated systems do not need storage, which is the case with irrigation, where all pumped water is directly consumed or stored in reservoirs.

Currently, there are several types of batteries on the market, however, for economic reasons, lead-acid batteries are still the most used for photovoltaic purposes, although other types present greater efficiency and useful life, such as Nickel-Cadmium, Lithium Ion, etc.

4. INVERTER

As in ON-Grid systems. To power AC equipment, an inverter is required.

This device generally incorporates a maximum power point tracker, necessary for optimizing the final power produced. This system is used when you want more comfort when using conventional appliances. Isolated systems, as the name suggests, are not connected to the conventional distribution grid. These systems can handle DC loads without storage, DC loads with storage, AC loads without storage, and AC loads with storage.

Figure 11 shows DC-type and AC-type loads connected to the isolated photovoltaic system.

- ***DC charge without storage:*** for systems with DC load without storage, electrical energy is used at the time of generation by equipment operating in direct current. An example of this use is a water pumping system with motorized pumps of direct current.

- ***DC charge with storage:*** this is the case in which you want to use electrical equipment, in direct current, regardless of whether or not there is simultaneous photovoltaic generation. For this to be possible, electrical energy must be stored in batteries; a device is also used to control the charging and discharging of the battery. Such equipment is called a charge controller, whose main function is to prevent damage to the battery by overcharging or deep discharge.

- ***AC load without storage:*** for AC loads without storage, the working principle is similar for DC loads. However, the difference is that the load is powered by AC power, therefore, an inverter must be used between the photovoltaic generator and the load. An example of this use is when you want to use pumps with conventional motors in photovoltaic systems.

- ***AC charge with storage:*** to power AC equipment, an inverter is required.

This device has the function of transforming direct current into alternating current, transforming voltage, for example, 12 V into direct current, to 127 V in alternating current.

As in the ON-Grid systems, data from a financial simulation will also be presented using the calculation base stipulated by the Blue Sol company. This research aimed to analyze the return time on investment in solar energy of a consumer unit, which stops buying electricity from the concessionaire, in order to become independent of the electricity distributor to generate its own energy.

This CU is made up of four electricity consumers, with an average monthly consumption of R$ 250.00 (~ 46 EUR), when it was still connected to the energy concessionaire's network.

It can be seen, through figure 12, that the cash value of this system in that company is R$ 12,501.25 (~ 2300 EUR). The monthly savings for consumers of this consumer unit is R$ 137.74 (~ 26 EUR) and the payback is in six years. In this case, the photovoltaic solar system consists of five photovoltaic modules, with a peak power of 1,825 kWp and an estimated monthly energy production of 232 kWh, as shown in figure 13.

Figure 10 – OFF-Grid system.


Source: Blue Sol, 2019.

## 5.4 ON-Grid System x OFF-Grid System

PV (photovoltaic) systems can contribute to the maximum capacity of a grid when peak demand occurs during the daytime. Most Brazilian capitals has this behavior and, the greater the demand in the summer, compared to the winter period, the greater the possibility that the load coincides with the availability of the solar resource.

Some important contributions of photovoltaic generation, in the case of distributed generation, are:

- easy installation, since a short time is required for the execution of the projects;
- reduction in the demand for electricity transmission over long distances, since there is proximity to load centers;
- reduction of electrical losses, negative socio-environmental impacts and minimization of costs.

PV systems are composed of equipment that transform the sun's energy into electrical energy, through solar panels composed of photovoltaic cells. The two categories of photovoltaic systems, ON-Grid and OFF-Grid, have a basic configuration composed of modules, a power control unit, in addition to having or not storage unit.

ON-Grid photovoltaic systems are systems connected to the electrical distribution network that, in addition to supplying their own demand, are also capable of supplying the electrical network with energy, which can be used by any consumer of the network. Therefore, they are also defined as energy sharing systems.

Connected systems have a great advantage over isolated systems, as they do not use batteries and charge controllers, which makes them around 30% more efficient, as well as ensuring that all energy is used, locally or elsewhere. from the Web. ON-Grid systems can be used both to supply a property or simply to produce and inject energy into the electrical grid, as well as a hydroelectric or thermal plant. Therefore, when the owner of the system produces more energy than it consumes, the energy produced will cause the photovoltaic system to inject energy into the electrical grid.

When producing less than it consumes, the power grid will inject electricity into the place of consumption where the system was installed. The bidirectional meter will account for the flow of energy in both directions of power flow.

From the point of view of the components, a photovoltaic system connected to the grid is basically composed of solar panels and inverters. The inverters, in addition to transforming direct current into alternating current, synchronize the system with the public grid.

Some of the advantages of grid-connected systems are described below:

- energy is produced close to the load, resulting in lower losses in distribution and transmission networks;
- the space where electricity is produced is already integrated into the building;
- electricity consumption, mainly in commercial buildings, is higher when it occurs at times of higher energy production by photovoltaic modules;

- consumers who increase the building load and already have the system installed need extra space to expand the system in the building; Therefore, the ON-Grid system has modularity, in addition to reducing dependence on electricity from the utility.
- the cladding and roofing materials of the building can be replaced by installing the ON-Grid system. In addition, this system has been highlighted in architectural projects and civil construction, as the project can receive environmental certification, through environmental sustainability criteria, such as lower consumption of electricity.

The biggest advantage of distributed generation of energy for the consumer is the savings in the energy bill when installing a micro or mini generator. Savings can be up to 95% on the energy bill, due to the fact that the consumer has to pay an availability fee to the energy concessionaire, as he is connected to the network and this needs maintenance. In addition, the photovoltaic system can supply up to 100% of the energy consumption of the place where the system is inserted (home, company, etc.). Therefore, the consumer who generates his own energy becomes energetically independent and free of high tariffs from energy distributors and continuous inflation (INPE, 2006).

OFF-Grid systems, on the other hand, serve a specific and local purpose, unlike ON-Grid systems. The main purpose of isolated systems is to serve locations in remote areas. Therefore, the supply of energy through the conventional electrical network becomes unfeasible, due to access difficulties and the high costs of building substations and long transmission and distribution circuits, to meet a small punctual demand or a few consumer units.

Some advantages of isolated photovoltaic systems are presented below:

- increase in the rate of self-consumption;
- resilience to power grid fluctuations;
- autonomy when faced with an interruption in the electricity supply.

The use of photovoltaic systems in isolated communities is a good alternative from an economic, social and environmental point of view, bearing in mind that, generally, these communities are made up of low-income or low-education residents, who do not always have access to information and basic sanitation services and others that increase and the vulnerability of this population.

In this sense, the installation of small photovoltaic solar energy systems greatly changes the lives of these communities and people in a positive way. As an example, there are small and medium-sized systems for pumping clean water, refrigerating food and medicine (vaccines), lighting, communication, among other applications. Simple and relatively low-cost systems that are capable of saving lives, modifying the way of living and bringing information, inclusion and improving the quality of life of isolated communities, which will be able to receive information and development, through an internet signal, TV and telephony, in addition to electricity.

Thus, it is necessary to use viable energy alternatives for the consumer, energy concessionaires and the environment. Therefore, one of the most suitable systems to take advantage of this energy is photovoltaic, since it allows the distributed generation of electricity in small and medium scale plants - homes or businesses.

Therefore, when comparing the financial simulations, referring to the two types of photovoltaic systems addressed in this work, carried out through the company Blue Sol, it can be concluded that for an average monthly consumption of R$ 250.00 (~ 46 EUR) a monthly energy production would be necessary estimated at 232 kWh, through five photovoltaic modules, with the peak power of the system equivalent to R$ 1,825 kWp.

However, it can be seen that the ON-Grid photovoltaic system has a lower financial cost compared to the OFF-Grid photovoltaic system, considering that isolated systems use a charge controller and batteries as equipment for control and storage of energy and, therefore, there was an increase in the value of these systems.

In this way, electricity from ON-Grid and OFF-Grid photovoltaic systems is of paramount importance for consumers who are concerned with the development of a more sustainable world. Therefore, the type of photovoltaic system must be chosen according to the consumer's needs.

## 5.5 Socio-environmental analysis

### 5.5.1 Market demand

Droughts that cause energy crises in the Brazilian electricity sector are recurrent. However, the main source of energy in the country comes from hydroelectric plants. Thus, due to the fact that this renewable source of energy is subject to climatic factors, such as periods of drought or lower incidence of rain, the water levels in the reservoirs can reach critical values and cause energy insecurity. Thus, the supply of energy decreases and, consequently, energy prices increase in the country, due to the conditions of generation.

In this sense, the hydrological risk and the price of energy are directly related with the calculation for activating the tariff flags, in which part of the amounts paid by consumers, through the energy bill, are passed on to compensate for the extra costs of energy production in periods of drought. Therefore, the diversification of the energy matrix in the country becomes essential to meet the present and future demand for electricity, in addition to reducing the high tariff adjustments.

It should be noted that the development and relationships of the human species took place through the use of energy. Initially, humanity, due to its needs, made use of simpler forms of energy found in nature, such as the driving force of winds, rivers, the use of firewood, etc. If, on the one hand, the great abundance of fossil energies in nature and their initially reduced price allowed man a developmental leap never seen before, on the other hand, the growing demand for these forms of energy also caused the price to rise in an overwhelming and reserves were running out, due to the needs of industrialized countries to consume energy on a large scale.

The energy crises in the world were mainly due to the demographic growth of the world population, as well as the current pace of material progress.

It should be noted, however, that excessive energy consumption can only be maintained as long as supply is able to meet demand.

Table 2 presents the proportion of the population with access to electricity in Brazil in households, since 2011 and this access presents important critical issues in all areas of sustainable development, involving a wide range of social and economic impacts, including the facilitating the development of home-based income-generating activities and easing the burden of household chores.

The calculation formula used by IBGE to find the proportion of the population with access to electricity, in percentage, is:

***[(population that has access to electricity) / (total population)] x 100***

Table 2 – Proportion of population with access to electricity (%).

| Brazil and the Regions | Year | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
| Brazil | 99,3 | 99,5 | 99,6 | 99,7 | 99,7 | 99 | 99 | 99 |
| North | ... | ... | ... | ... | ... | 98 | 98 | 98 |
| Northeast | ... | ... | ... | ... | ... | 98 | 99 | 99 |
| Southeast | ... | ... | ... | ... | ... | 99 | 100 | 99 |
| South | ... | ... | ... | ... | ... | 99 | 100 | 99 |
| Midwest | ... | ... | ... | ... | ... | 99 | 99 | 99 |

Source: IBGE, 2019.

According to BRASIL (2018), the Brazilian population in 2018 was estimated at approx. 208 million inhabitants.

Therefore, according to the table, in 2018, Brazil had 1% of the population without access to electricity, around 2 million inhabitants, which indicates that many Brazilians still do not have an adequate quality of life.

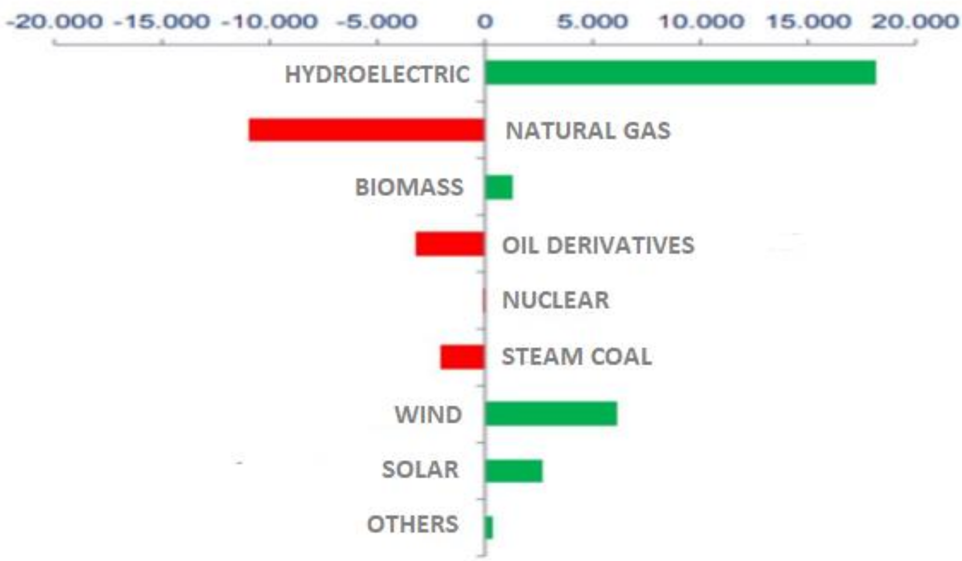
Table 3 and figure 14 show how the electricity generation, through the solar source photovoltaic, stood out in 2018 compared to 2017.

Table 3 – Electric Generation (GWh).

| Source | 2017 | 2018 | △ 18/17 |
|---|---|---|---|
| Hydroelectric | 370.906 | 388.971 | 4,90% |
| Natural Gas | 65.593 | 54.622 | -16,70% |
| Biomass | 51.023 | 52.267 | 2,40% |
| Oil Derivatives | 12.458 | 9.293 | -25,40% |
| Nuclear | 15.739 | 15.674 | -0,40% |
| Steam Coal | 16.257 | 14.204 | -12,60% |
| Wind | 42.373 | 48.475 | 14,40% |
| Solar | 832 | 3.461 | 316.1% |
| Others | 14.146 | 14.429 | 2,00% |

Source: BEN, 2019.

Figure 11 – Electric Generation (GWh).




Source: BEN, 2019.

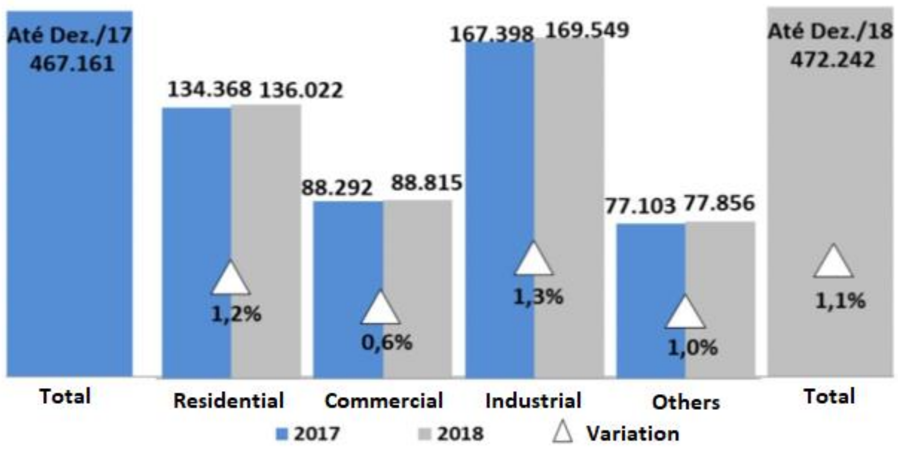
The significant increase in photovoltaic solar generation, shown in the figures, was approximately 316%. This result reveals that Brazil is increasingly interested in diversifying its energy matrix and reducing greenhouse gas emissions in order to preserve the environment. It mainly shows that photovoltaic energy is gaining an important place in the country's energy sector. And, the total electricity generation in 2018 was 601,396 GWh, representing an increase of 2% when compared to with the year 2017.

According to figures 3 and 14, 2018 saw a sharp decline in the supply of oil derivatives, a decline in hydraulic generation and a consequent increase in thermal electricity generation, as well as small increases for energy-intensive products and energy consumption. electric. For the full year of 2018, total supply grew by 2%. The share of renewable sources should continue to increase. Wind had a 14.4% increase in electricity generation. Solar energy is in a process of strong increase in the energy supply matrix with 316.1%.

It can be seen that, in general, the demand for electricity has increased over the years, mainly through renewable energy sources.

Figure 15 represents the electricity market between 2017 and 2018. The electricity market is shown in the graph, which includes residential, commercial, industrial and other consumption. It is possible to verify that, in 2017, the electricity market had a total of 467,161 GWh, while in 2018 there was an increase of 1.1%, equivalent to 472,242 GWh. It is also noticeable that all classes: residential, industrial, commercial and others showed an increase of 1.2%, 0.6%, 1.3% and 1.0%, respectively, compared to 2017.

Figure 12 – Electricity market in 12 months – GWh.




Source: EPE - Monthly Review of the Electric Energy Market, 2019.

Still, according to figure 5, the consumption of industrial electricity, between one year and another, was 1.3% higher. Then, the residential class had an increase of 1.2%, reaching a value of 136,022 GWh.

In January 2019, the National Electrical System Operator (ONS) recorded four consecutive records of demand for electricity in the country. Prior to these records, in 2014, the maximum demand reached 85,708 MW. Already in the last record of 2019, the load reached 90,525 MW. These high demand values are due to the high temperatures registered in the country. Thus, with the intense heat in the country, there is an increase in the use of showers and air conditioners. However, due to the low level of the hydroelectric reservoirs and the increase in electricity consumption, the system operated with restrictions, due to the unavailability of some plants.

As a result, the complexity of operating the electrical system increases, which now depends on a greater number of thermoelectric plants in operation and on large amounts of energy being transferred from one region of the country to another, over long distances, due to the low Reservoir levels that remain lower than expected. Thus, if there is a drop in one line, it is difficult to replace it with another one that is already being fully used. Therefore, the Brazilian energy system is more vulnerable to faults and blackouts, in addition to becoming more complex.

In this sense, Brazilians are increasingly looking for information on alternative energies, since electricity consumption is increasing in Brazil. Therefore, a solution to such problems lies in the diversification of the Brazilian energy matrix. The use of photovoltaic systems is recommended, mainly because they use the solar renewable source and also because they produce a lot of energy at times of high solar incidence, times like those with the highest records of maximum demand.

According to ANEEL (2019a) and according to data updated at the time of the survey, through 87,306 Photovoltaic Generating Centers (UFV), 109,088 Consumer Units (UCs) with distributed generation received credits. The total installed power is 925,355.28 kW.

A number of 12,402 plants, in the remote self-consumption mode, led to 44,018 UCs receiving credits, a total of 240,985.22 kW of installed power.

In the shared generation modality, a number of 284 plants resulted in 1,215 UCs receiving credits, a total of 24,627.71 kW of installed power.

In the generation modality in the UC itself, a number of 74,905 plants made 74,905 UCs receive credits, a total of 801,764.04 kW of power installed.

And finally, in the multiple UC modality, a number of 730 plants led to 201 UCs receiving credits, a total of 628.17 kW of installed power (ANEEL, 2019b).

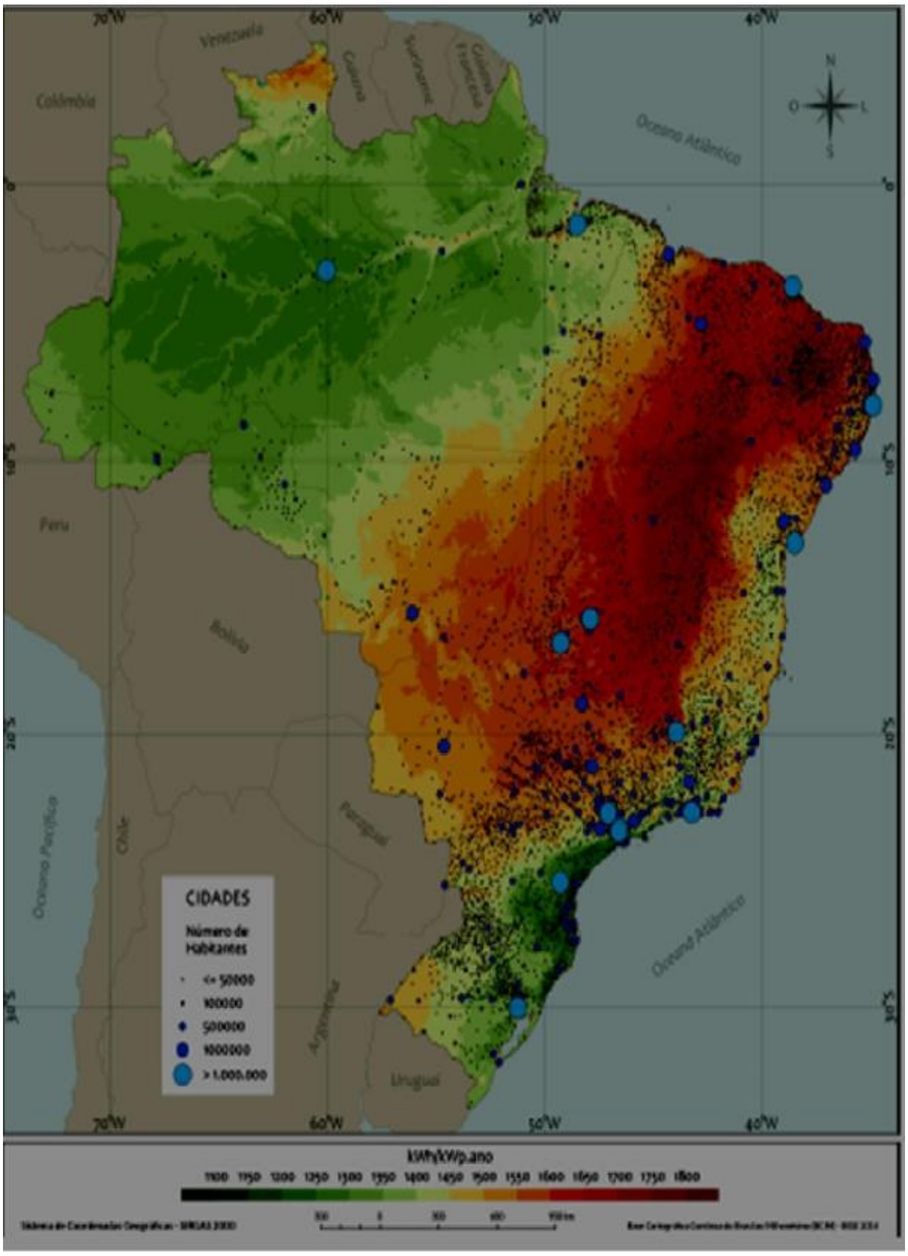
### 5.5.2 Brazilian potential for photovoltaic solar energy generation

According to INPE (2017), Brazil has great potential with regard to photovoltaic generation of electricity, as shown on the map in Figure 16. For example, in the least sunny place in Brazil, it is possible to generate more electricity solar than in the sunniest place in Germany.

The map displays the maximum annual energy yield (measured in kWh of electricity generated per year, for each kWp of photovoltaic power installed throughout Brazil), referring to large-scale centralized and ground-installed plants and distributed photovoltaic generation integrated into roofs and coverings of buildings.

An average annual performance rate of 80% was adopted, which represents the performance of a photovoltaic generator well designed and installed with good quality equipment and labeled by INMETRO. The Brazilian population concentration is also shown through the blue circles scattered throughout the national territory, as will be seen below:

Figure 13 – Map of photovoltaic solar generation potential, in terms of annual energy yield for all of Brazil (measured in kWh/kWp.year in the color profile), assuming a performance rate of 80% for fixed photovoltaic generators and distribution of Brazilian population in cities.




Source: Brasil Mapa, 2019.

According to CRESESB-CEPEL (2008), the desert regions are the ones most provided with solar radiation, such as the Arabian desert, in Sudan, and the Mojave Desert, California, United States. Brazil can be compared with such regions due to the fact that the values of daily solar radiation, monthly averages, maximums, minimums and annual values are close to each other. In table 6, the areas located in Northeast Brazil compare with the best regions in the world, with regard to daily, monthly and annual solar radiation values.

Table 4 – Regions compared in radiation level.

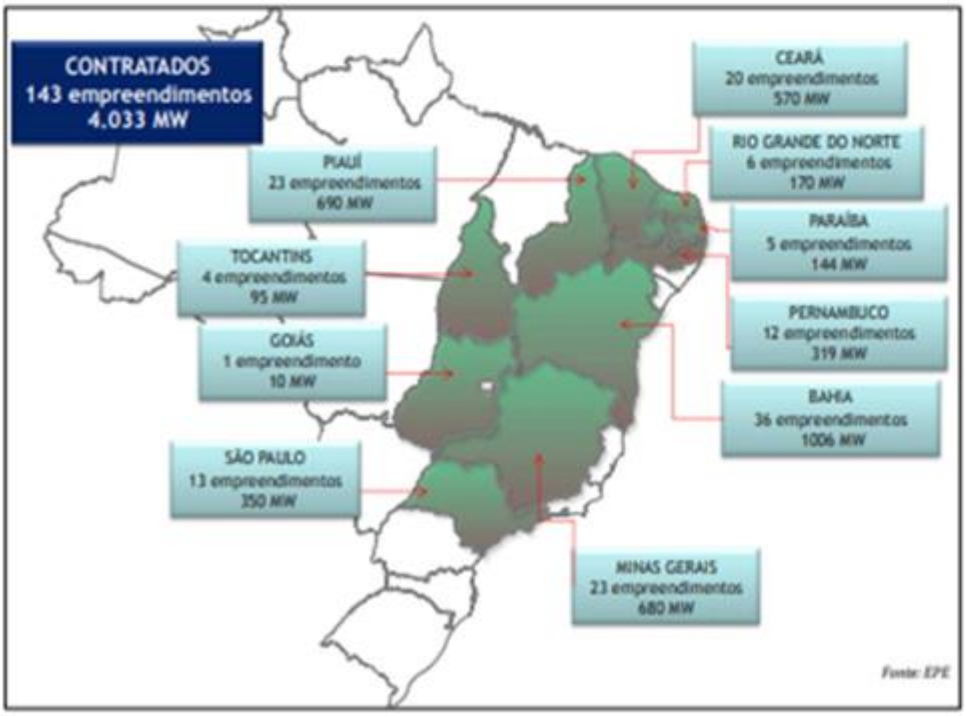
| (Locality) | Latitude | $H_{t(mínimo)}$ (MJ/m²) | $H_{t(máximo)}$ (MJ/m²) | $H_{t(anual)}$ (MJ/m²) | $H_{t,máx}/H_{t,mín}$ |
|---|---|---|---|---|---|
| *Dongola-Sudão* | 19°10' | 19,1(Dez) | 27,7(Mai) | 23,8 | 1,4 |
| *Dagget - USA* | 34°52' | 7,8(Dez) | 31,3(Jun) | 20,9 | 4,0 |
| *Belém-PA-Brasil* | 1°27' | 14,2(Fev) | 19,9(Ago) | 17,5 | 1,4 |
| *Floriano -PI-Brasil* | 6°46' | 17,0(Fev) | 22,5(Set) | 19,7 | 1,3 |
| *Petrolina-PE-Brasil* | 9°23' | 16,2(Jun) | 22,7(Out) | 19,7 | 1,4 |
| *B. J. da Lapa -BA-* | 13°15' | 15,9(Jun) | 21,1(Out) | 19,7 | 1,3 |
| *Cuiabá-MT-Brasil* | 15°33' | 14,7(Jun) | 20,2(Out) | 18,0 | 1,4 |
| *B. Horizonte-MG-Brasil* | 19°56' | 13,8(Jun) | 18,6(Out) | 16,4 | 1,3 |
| *Curitiba-PR-Brasil* | 25°26' | 9,7(Jun) | 19,4(Jan) | 14,2 | 2,0 |
| *P. Alegre-RS-Brasil* | 30°1' | 8,3(Jun) | 22,1(Dez) | 15,0 | 2,7 |

Source: CRESESB – CEPEL, 2019.

In order to meet market growth in the regulated environment and increase the share of renewable sources in the Brazilian energy matrix, many projects are contracted through energy auctions, in which contracts began in the energy and reserve auctions in 2014 Figure 17 shows that, until 2018, 143 projects were contracted and the installed capacity of this set of plants is 4,033 MW, located mainly in the Northeast and Southeast regions of Brazil.

According to estimates, on average, the Northeast represents 75% of the total registered power plants, where Bahia has the largest number of registered projects (EPE, 2018c).

Figure 14 – Location of PV solar projects contracted in energy auctions.




Source: EPE - Ten-Year Energy Expansion Plan 2027, 2018.

By 2030, the ProGD program could move more than 100 billion in investments, in which 2.7 million UCs will be able to generate their own energy, whether in homes, businesses, industries, as well as in the agricultural sector. The result could be: 23,500 MW (48 TWh produced) of clean and renewable energy, equivalent to half the generation of the Itaipu hydroelectric plant. With this, Brazil can prevent the emission of 29 million tons of CO2 into the atmosphere.

According to ANEEL, by 2024, approximately one million two hundred thousand solar energy generators will be installed in homes and businesses in Brazil. This number represents 15% of the Brazilian energy matrix. In addition, by the year 2030, the photovoltaic energy market should move around R$ 100 billion.

Brazil often has a photovoltaic solar energy potential higher than the country's total electricity consumption. This potential can be compared with the Itaipu hydroelectric power plant, which contributes about 25% of the electricity consumed in the country. As an example, by covering the entire flooded part of Itaipu (an artificial lake measuring 1350 km2 located on the Brazil-Paraguay border) with photovoltaic solar module it would be possible to generate twice the energy generated by Itaipu, which is equivalent to 50% of the electricity consumed in Brazil.

Therefore, the energy potential available in a country is related to economic growth and, consequently, to the development of a society. In this way, the energy matrix must be diversified with renewable natural resources, since in a country where there is a predominance of one source, it is possible that there is greater dependence on this source. For this reason, it is necessary to expand the offer of renewable energies.

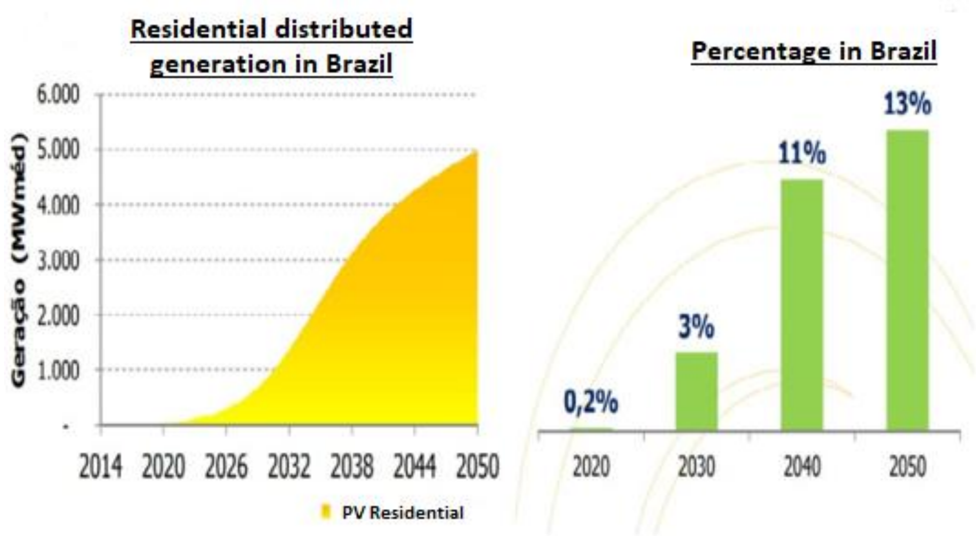
According to the 2018 Ibope Intelligence survey, 89% of Brazilians want to generate renewable energy at home and, according to the 2016 DataFolha survey, 79% of Brazilians want to install photovoltaic solar energy at home, if financing is available. For this, companies must adapt to the new reality and expectations of the consumer.

It is worth mentioning that in Australia and the United States there are more than 2 million distributed solar photovoltaic generation systems with consumers. In Australia, one in five households generates clean, renewable and cheap electricity on their own roof, through the sun, thus making further progress in the democratization of distributed photovoltaic solar generation.

In Brazil, according to EPE (2014), by 2050, more than 33 GWp should be installed in the residential sector, about 13% of the sector's load. There are around 15 million households or 18% of the total potential, as shown in figure 18.

Table 7 shows an estimate of investments in the electricity sector in period 2018-2027. The supply of electricity through centralized generation will have an investment of 226 billion reais, while distributed generation will have 60 billion reais invested in transmission. However, the biggest investment will still be in oil and natural gas, with an investment value of 1,382 billion reais (Brazilian currency).

Figure 15 – Distributed photovoltaic generation.




Source: EPE - PNE 2050, 2019.

Table 5 – Summary of investment estimates.

| | R$ bilhões Período 2018-2027 | % |
|---|---|---|
| Oferta de Energia Elétrica | 393 | 21,7% |
| Geração Centralizada (1) | 226 | 12,4% |
| Geração Distribuída (Micro e Minigeração) | 60 | 3,3% |
| Transmissão (2) | 108 | 5,9% |
| Petróleo e Gás Natural **(Oil and Natural Gas)** | 1.382 | 76,1% |
| Exploração e Produção de Petróleo e Gás Natural | 1.340 | 73,8% |
| Oferta de Derivados de Petróleo | 34 | 1,8% |
| Oferta de Gás Natural | 8 | 0,4% |
| Oferta de Biocombustíveis Líquidos **(Liquid Biofuels)** | 41 | 2,3% |
| Etanol – Usinas de produção | 34 | 1,9% |
| Etanol – Infraestrutura dutoviária e portuária | 4 | 0,2% |
| Biodiesel – Usinas de produção | 3 | 0,2% |
| TOTAL | 1.816 | 100% |

Source: EPE, 2018.

### 5.5.3 Socio-environmental impact

Currently, many changes in the environment are experienced by human beings, such as natural variations such as earthquakes, floods, hurricanes and fires.

These changes, also caused by human action, are related to the misuse of natural resources, especially energy resources, which are more evident in industrialized countries, as well as population growth.

The oil crises are examples of how important it is to diversify the energy matrix. In the 1970s, the growing consumption of oil and its derivatives in a large part of the world meant that countries that purchase and depend on this energy, coming mainly from Arab countries, had to buy oil at a 400% higher price. As a result of this crisis, countries dependent on this source began to change their energy policies, so that crises like this one would not occur again.

According to the report released by the United Nations Environment Program (UNEP), global carbon dioxide (CO2) emissions increased again in 2017 after a three-year hiatus, highlighting the imperative of countries to comply with the historic Agreement of Paris to keep global warming below 2oC above pre-industrial levels.

CO2 gas that traps heat in the atmosphere is largely responsible for rising global temperatures. In 2016, the energy sector was responsible for the emission of 423.5 million tons of carbon dioxide equivalent (CO2e), which corresponded to 19% of the total annual emissions in Brazil. The Industrial Processes and Use of Products sector was responsible for 4% of Brazilian emissions, which is equivalent to 95.6 million tons of CO2e.

Currently, carrying out energy planning is concerned with the environment, as well as with minimizing socio-environmental impacts. Due to the large share of renewable sources in the energy matrix, GHG emissions per unit of energy consumed in Brazil are small compared to other countries. However, the country still has a long way to go to reach socioeconomic standards comparable to those of developed countries.

For this reason, per capita energy consumption is expected to increase considerably by 2030 and a trend towards a reduction in emissions from the energy

sector is not expected. The sector's emissions will increase, even with the wide participation of sour renewable.

Brazil stands out for having, currently, an energy matrix with a large share of renewable sources, a reality seen in few countries in the world. This means that greenhouse gas emissions per unit of energy consumed in Brazil are small compared to other countries.

According to the EPE (2006-2007), by 2030, 2.7 million consumer units will be able to generate their own energy, which could result in 23,500 MW (48 TWh produced) of clean and renewable energy, which represents half of the generation of the Itaipu hydroelectric plant.

In this way, Brazil can prevent 29 million tons of $CO_2$ from being emitted into the atmosphere. Therefore, it is understood that more polluting sources, such as fossil fuel thermal, will no longer be used.

The socio-environmental impacts related to the production of electric energy are being discussed worldwide. This is due to the fact that large concentrations of GHG have a negative impact on the lives of living beings (GOLDEMBERG; LUCON, 2011).

According to the EPE technical note (2017a) on the socio-environmental analysis of energy sources of the Energy Planning and Development (PDE) 2026, the use of photovoltaic solar energy does not cause harm to the environment, since there is no emission of $NO_x$ pollutants, $SO_2$, CO, as well as greenhouse gases ($CO_2$, $CH_4$, $N_2O$ and others).

Still, according to the aforementioned technical note, in the manufacturing process of photovoltaic systems, job creation has a positive impact on the population. Conversely, there are negative impacts, such as those associated with the transformation industry and mineral extraction, which can be intensified with the growth in demand for manufacturing photovoltaic cells.

However, some impacts of photovoltaic generation - related to land use and occupation - are associated with the construction of plants, earth movement, as well as the implementation of access roads. In addition, it should be noted that there may be some interference with the fauna and flora, if the plants require significant vegetation suppression, as well as generate negative impacts on the landscape. Another important aspect is the installation location of the plants, since the excess of dust and wind will require a differentiated cleaning of the panels, through the adoption of new technologies and processes or greater water consumption.

With the progress of industrialization over the years, in an increasingly intense way, technology is updated and contributes, due to unbridled consumerism, to the generation of more waste in the environment. It is worth noting, therefore, about the disposal of solar panels, in view of the environmental impact that the components of such panels can cause. The electricity generation system using photovoltaic panels is a worldwide growth trend. In this sense, the release of waste into the environment will gradually increase, which will probably lead to a serious environmental problem.

The rapid growth of photovoltaic systems raises concerns regarding the impact that these systems may have on the environment. One of these impacts is related to the life cycle of a photovoltaic system caused during and after the useful life of the product, which involves the amount of energy demanded by the product and the amount of material, in addition to the amount of pollutants and waste emitted during use, as well as after the validity of these systems - usually around 25 years. Therefore, the importance of studying the socio-environmental impacts related to the future disposal of these photovoltaic materials in the environment.

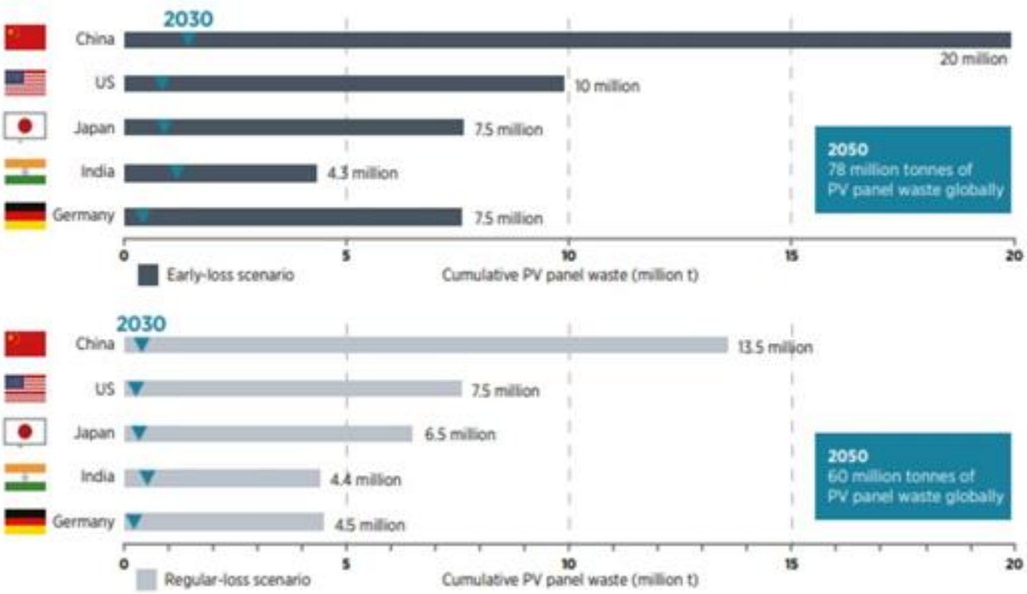
Brouwer et. al. state that solar energy presents the opportunity to generate clean electricity, which can lead to a sustainable lifestyle. However, established manufacturing processes in the electronics industry are creating alarming amounts of hazardous waste at the end of their products' lifecycles.

From the point of view of the production of photovoltaic cells, it should be stated that the use of different gases and chemicals is necessary for their production. Currently, cell production control is high and these are produced in a controlled environment and all waste is treated. Thus, in current times, the environmental impact of cells is very low.

However, according to IRENA (2016), in the regular loss scenario, the waste of photovoltaic panels corresponds to 43,500 tons at the end of 2016 with a projected increase to 1.7 million tons in 2030. A drastic increase expected by 2050 from, approximately 60 million tons, as shown in figure 19.

The anticipated loss scenario projection, however, estimates higher total photovoltaic waste flows with 250,000 tons by the end of 2016. This estimate would increase to 8 million tons in 2030 and 78 million tons in 2050. This is because the anticipated loss scenario assumes a higher percentage of failures in the PV array compared to the regular loss scenario.

Figure 16 – Estimated cumulative end-of-life photovoltaic panel waste volumes by top five countries in 2050, by anticipated loss scenario and regular loss scenario.



Source: IRENA, 2016.

Still, according to IRENA (2016), on the increase in waste volume in 2030-2050: the worldwide increase in PV deployment and the average life and failure rates for panels, waste volumes will certainly increase more quickly until 2030.

Considering that in 2030 the top three photovoltaic panel manufacturers should include China, Germany and Japan. For then, China is still predicted to have accumulated the largest amount of waste (13.5-20 million tons).

However, Germany is overtaken by the US (7.5-10 million tonnes), Japan is next (6.5-7.5 million tonnes) and India follows (4.4-7.5 million tonnes ).

Regular loss and early loss waste estimates by top five countries in 2030 and 2050.

Responsibility for end-of-life waste management with downstream activities (waste generation, collection, transport, treatment and disposal) are typically covered by the three main stakeholders presented below:

- **society:** end-of-life management of these PV system components must be carried out by society in conjunction with government organizations in order to control the management of operations, financed by taxes. This could generate revenue for municipalities and eliminate the fixed costs of building new infrastructure, providing benefits of economies of scale. Drawbacks can include lack of competition and slower cost optimization.
- **consumers:** consumers who produce their own electricity using panels and waste are responsible for end-of-life management of these components, including proper treatment and disposal of panels. The consumer may try to minimize costs, which can have a negative effect on the development of good waste collection and treatment. This approach currently remains the dominant framework in most countries for end-to-end PV array management.
- **producers:** end-of-life management is based on extended producer responsibility. This holds producers physically and financially accountable for the impact of their products on the environment until end of life and provides incentives to develop products with lower environmental impacts. This principle can also be used to create funds to finance proper collection, treatment and recycling and disposal systems.

Therefore, safe disposal of solar panels suggests dismantling solar panels in a way that no harmful material is released into the environment.

So, in terms of a solution, it should be noted that companies must undertake to dispose of such waste in a relevant manner, bearing in mind that the equipment is harmful to the environment, hence the importance of recycling these materials.

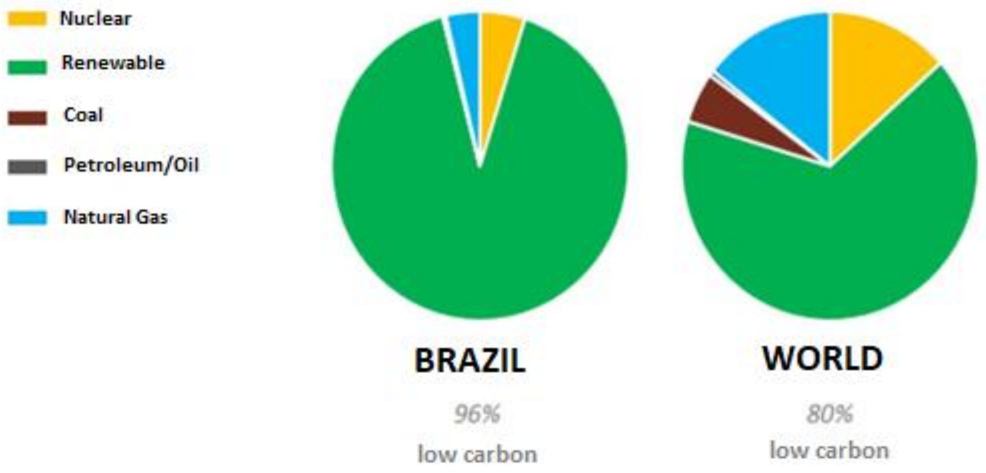
In order to reduce pollution, it is therefore necessary to diversify the energy matrix, through research or investments in technologies that use renewable natural resources, as well as environmental studies carried out in the project's environmental licensing phase. To this end, it is of fundamental importance to value the low impacts - low GHG emissions - caused by the system photovoltaic.

In addition, the generation of clean and renewable solar energy is important for the country to achieve the goals assumed at COP21. In the agreement signed at the end of 2015, the country committed to expanding the domestic use of energy generated by renewable sources, in addition to hydropower, to at least 23% of the electricity matrix by the year 2030.

According to figure 20, low-carbon energies - renewable and nuclear - will increase their share in the Brazilian electricity generation matrix by the year 2040.

Brazil will have 96% of low-carbon energy, since the largest area shown in the graph is renewable energy. In contrast, the world will have 80% low-carbon energy.

Figure 17 – Electricity Generation Matrix 2040 (Projection).




Source: EPE, 2019.

However, nature, the source of primary resources of the energy system, if exploited, causes socio-environmental impacts that, in order to be mitigated, sustainable practices in the energy sector are necessary, since climate change characterizes threats to humanity and the planet. Thus, it is important for all countries to participate with the aim of increasingly reducing global greenhouse gas emissions.

Some of the benefits of photovoltaic solar energy for Brazil are:

- generation of clean, renewable and sustainable energy;
- contribution to the country's emission reduction targets;
- the non-emission of gases, liquids or solids during operation;
- no noise generation.

Therefore, electrical energy from solar sources is not only clean and renewable, but also more competitive, expanding the diversification of the Brazilian electrical supply, since the country is very dependent on hydroelectric and fossil thermoelectric plants.

Therefore, photovoltaic systems are a relief for water reservoirs, in addition to reducing the pressure for other strategic uses, such as human supply, agriculture, irrigation and industrial processes. Complementarily, it reduces the activation of fossil thermoelectric plants, which are more expensive and polluting, in addition to helping to reduce the high costs of electricity for consumers and collaborating in mitigating the impacts of climate change.

### 5.5.4 Sustainability

The process in which the relationship between society and the environment is evaluated and re-evaluated, or even development that meets the needs of the present without compromising the needs of future generations, are concepts related to sustainable development. In 1987, the term sustainable development appeared in the report of the World Commission on Environment and Development – Report Brundtland.

In 1992, the term was exposed at the II Conference of the United Nations on the environment and human development - RIO 92 - and, later, the term was disseminated with the purpose of regulating sustainable development and inserting the concept globally. In addition to the aforementioned initiatives, the Kyoto Protocol, created in 1997, derived from the United Nations Framework Convention on Climate Change - Conference of the Parties III. The Kyoto Protocol is understood as an international treaty, which aims to stabilize greenhouse gas emissions in the atmosphere.

The energy source that comes from the sun complements other renewable energy sources and brings environmental benefits, such as: less pollution, contribution to reducing emissions, economic benefits (investments, sectoral diversification, strong impact on industry, commerce and services), in addition to of social benefits (generation of high-skill jobs and income). It is a technologically advanced industry with a close relationship with other segments (electronics, chemicals, glass, etc.).

According to the Brazilian Association of Photovoltaic Solar Energy (ABSOLAR), based on international data, photovoltaic solar energy is the largest generator of renewable jobs in the world: from 25 to 30 direct jobs for each MW installed per year, in the areas of installation, manufacturing, sales and distribution, project development and others (ABSOLAR, 2017).

The use of natural resources is essential for growth and also for the progress of a country. Thus, this development is linked to innovation and technologies for conversion and use of natural energy resources. In this sense, sustainable development is fully associated with the energy sector, since energy is essential for socioeconomic and environmental development.

In view of this, the insertion of renewable energy sources has become a sustainable means of reducing impacts on the environment. However, according to SACHS, I. (1986), economic growth, as well as the rhythm of production and insertion of raw materials, responsible for environmental imbalances, must be well distributed so that sustainable development is progressive. In this context, Sachs defines the main aspects to guide development, namely:

- satisfaction of basic needs;
- thinking and solidarity with future generations;
- participation of the population involved;
- preservation of natural resources and the environment in general;
- development of guaranteed employment, social security and cultural respect;
- education programs.

Therefore, measures to combat rapid climate change are essential to satisfy basic needs. These changes are linked to development, considering that every human being depends on natural resources to exist.

So, the concern with the quality of life becomes so important nowadays, since there is still a high consumption of energy and finite natural resources and, to take advantage of them, it is necessary to eradicate extreme poverty and improve the quality of life. people's health and well-being, through more efficient actions that make people's lives easier, always respecting the environment.

For this, it is necessary to have thoughts and, therefore, solidarity actions with future generations, in addition to recognizing that climate change is a common concern of humanity, that is, there must be, above all, harmony between nature and human beings. It is extremely important to use renewable sources as a way to guarantee the survival of future generations, in order not to jeopardize the health of the Earth.

From this perspective, it is understood that the citizen who consumes products and services, in a conscious and sustainable way, contributes to the environment without harming the current and future generations (CEMIG, 2012). The participation of the population, including civil society, the private sector, financial institutions, cities and other subnational authorities, local communities and indigenous peoples, is of great relevance, in order to defend themselves and promote sustainable development, and the reduction of GHG in the environment.

And, it is worth mentioning that, for the preservation of natural resources and the environment, in general, development models are necessary, so that the lifestyles of rich nations are restructured, as well as the world economy. Furthermore, government support for sustainable development actions is crucial.

Sustainable development provides job creation, social security and cultural respect, since there is the promotion of economic growth. In this context, distributed generation uses alternative and clean energy sources; as a result, the energy matrix becomes more diversified, which generates jobs for the development of a new market and industrial production chains to meet the demand for equipment, such as installation and maintenance of solar generators.

According to the Brazilian Association of Photovoltaic Solar Energy (ABSOLAR), for every 1 MW of photovoltaic solar energy installed, whether centralized or distributed, 25 to 30 direct jobs are provided, and the expansion of Distributed Generation could contribute to boosting and heating up the economies of municipalities, states and the Union.

According to a survey by ABSOLAR, based on official data, there are currently more than 2,000 MW in centralized solar photovoltaic generation plants in operation in Brazil. The number represents more than R$ 10 billion in private investments attracted to Brazil since 2014, which enabled the generation of more than 50 thousand new local jobs qualified by the sector in the regions where the projects were implemented.

In these contexts, educational programs are important for the development of sustainable development, since the participation of the population for this development to be achieved is a direct and functional way, so that it is possible to preserve the natural resources.

Currently, the source has one of the most competitive prices for the generation of clean and renewable energy in the Brazilian electricity market and, in addition, promotes financial relief for families and increased competitiveness of the productive sector in the country. From this perspective, the production of renewable energy has the following purposes: sustainability, job and income generation in communities, energy security, in addition to greater control over the energy input (quality, quantity at the right time and known price). In addition, the production of renewable energy aims to have a competitive advantage, promote energy inclusion and democratization.

### 5.5.5 Main incentives in Brazil

Brazil is a country rich in renewable sources. However, for the country to develop, with regard to the increased use of these sources, regulatory incentives are needed as a way to encourage the use of clean sources, such as government programs, technical standards, as well as financial and/or incentives, or tax. These incentives provide the country with cheaper alternative sources of clean energy, such as photovoltaic energy that uses solar resources.

According to ANEEL (2015a), in the current market there are still not many stimuli for direct competition between companies. For this to happen, innovation and efficiency in regulated sectors must be promoted through the development of strategic partnerships.

It is also stated that an important tool in the formulation of public policies is the convergence of interests and strategies regarding products and solutions that meet the specific interests of the energy sector, without disregarding the demands and needs of consumers and society.

In this sense, it is understandable that ANEEL has signed cooperation agreements or even used a similar or equivalent instrument with various government agencies and national institutions, through strategic partnerships. And, therefore, it is believed that the joint effort between electric power companies, industry and academia are important tools for development.

In this context, the technical cooperation agreement between ANEEL and MMA, represented by the Secretariat for Climate Change and Environmental Quality (SMCQ/ MMA), aims to reduce greenhouse gas emissions by promoting energy efficiency and renewable energies.

The main theme foreseen in the agreement is the energy efficiency project at ANEEL headquarters. One of the projects covers lighting and air conditioning systems and a photovoltaic solar energy generation plant. Thus, this project can be used as a reference for public and private institutions, as good practices to combat energy waste, and also serve as an example of the implementation of a photovoltaic solar energy generating center.

The innovative energy joint action plan aims to coordinate development actions in innovation and improve the integration of the support instruments made available by BNDES, ANEEL and also by FINEP, with the purpose of promoting the following:

- support for the development and expansion of electronic devices, microelectronics cos, systems, integrated solutions and standards for the implementation of smart grids in Brazil;
- support to Brazilian companies, referring to the development and technological mastery of alternative renewable energy production chains, namely: solar photovoltaic and wind power, for electric power generation;

- support for initiatives to promote the development of integrators and thickening of the chain of components in the production of electric and ethanol hybrid vehicles, as well as improving the energy efficiency of motor vehicles in the country;
- increased coordination of promotion actions and improved integration of available financial support instruments.

Several incentive programs for the acquisition of technology are promoted nowadays and, with that, several facilitated conditions are offered for industries and individuals, who have the purpose of acquiring solar energy capture systems.

In this sense, the ECO Award, one of the most important in the country in the area of business sustainability, promoted by the American Chamber of Commerce for Brazil (AMCHAM), awarded in two categories: 'Sustainability in Processes' and 'Sustainability in Products or Services'. CELESC won in the Products - Large Companies category with the Bonus Photovoltaic Project, which is part of the CELESC Energy Efficiency Program and was operated by ENGIE, Geração de Energia Fotovoltaica (name of the Brazilian company).

The objective of this project was to encourage the residential generation of solar energy, through the installation of complete photovoltaic solar energy production systems in up to one thousand homes. Participants benefited from a 60% bonus on the acquisition of a photovoltaic system and five LED lamps.

In 2015, the MME launched the Program for the Development of Distributed Electricity Generation (ProGD), in order to encourage consumers to generate energy through renewable sources (especially solar photovoltaics), in addition to reducing expenses with electricity.

Another important incentive in Brazil is through renewable energy auctions, whose purpose is to enable the regulation of the renewable energy market to insert renewable energy sources in the country's electricity market. Private companies participate in the auctions, with the aim of getting bids to sell projects that allow the use of natural resources in energy systems.

According to EPE, holding auctions to expand the supply of electricity was a mechanism introduced in the reform of the electricity sector and consolidated with the effective participation of several institutions of the Brazilian Electricity Sector. These auctions were introduced in 2004 and aim to increase competitiveness among entrepreneurs, in addition to minimizing the costs of the electrical system.

In 2014 and 2015, reserve energy auctions (LER) provided more than 3 GW auctioned/contracted. With that, an initial demand was created for the establishment and development of a productive chain of the sector in Brazil. In 2017, a new energy auction (LEN) was held, which contracted over 574 MW in photovoltaic energy. In Auction A-4, seventeen distributors contracted 298.7 average MW, which corresponds to an installed capacity of 1,024.5 MW. These contracts come from four hydroelectric projects (19.7 average MW), two thermoelectric projects powered by sugarcane biomass (17.1 average MW), four wind projects (33.4 average MW) and 29 photovoltaic projects (228, 5 average MW / 1,032.5.

Solar energy projects demand a high initial capital. To facilitate the realization of photovoltaic systems, Brazil has the BNDES, an important financing company. Finame (financing of machinery and equipment) is carried out by the BNDES and aims to finance the acquisition and sale of solar and wind energy generation systems and solar heaters. In addition, it includes the installation service and associated working capital.

Below is who can finance:

- companies headquartered in the country;
- public administration;
- individual entrepreneurs and micro-entrepreneurs;
- farmers;
- autonomous cargo transporters;
- foundations, associations and cooperatives based in the country;
- natural persons resident and domiciled in the country.

The following items are financeable, according to BNDES (2018):

- photovoltaic generator systems of up to 375 kW - solar energy generation;
- wind turbines of up to 100 kW - wind power generation;
- solar heaters/collectors - water heating;
- installation services for the above items;
- working capital associated with the items above, only for micro, small and medium companies - limited to 30% of the amount financed.

In addition to financing, the country has some tax incentives that facilitate investment in plants. Some of these incentives are:

- Exemption from the Goods Circulation Tax (ICMS) for operations with equipment and components for harnessing solar and wind energy - CONFAZ Agreement 101/97);
- Concession by States of ICMS incentives for micro and mini-generation – for residential, commercial and industrial users - CONFAZ Agreement 16/2015.

The Support Program for the Technological Development of the Semiconductor Industry

(PADIS) was created in 2007 and is a set of federal tax incentives, established with the objective of contributing to the attraction of investments in the areas of semiconductors and displays, being These are used as inputs for electronic products.

The country has Law 13,169 /2015, which provides exemption from PIS/COFINS for micro and mini-generation - intended for residential, commercial and industrial consumers who produce their own energy, in accordance with the terms of resolutions 482/2012 and 687 /2015 from ANEEL.

The Brazilian Photovoltaic Labeling Program (PBE)/INMETRO provides quality, safety and energy efficiency, both for domestic and imported products.

# 6 CONCLUSIONS AND SUGGESTIONS

In view of all the content exposed throughout the text, it is noticeable that the production of electricity by converting solar radiation is a promising, clean and renewable technology to produce electricity. Brazil offers exemplary conditions for the generation of solar energy, since the country has excellent potential for solar energy.

As a consequence of the use of this energy, the present work presented the photovoltaic systems, which generate electricity in a sustainable way. In addition, it showed the differences between systems connected and isolated from the electrical network and pointed out the characteristics and purposes of each.

Therefore, the use of ON-Grid systems is more recommended in urban areas, due to the fact that they are connected to the electricity utility grid.

On the other hand, OFF-Grid systems are not connected to the electrical grid and are more used in remote regions, far from large urban centers, since they do not depend on the electricity from the energy distributor to function.

The purpose of using these types of systems is to reduce or eliminate the monthly energy bill, as well as to reduce greenhouse gas emissions in the environment, in addition to contributing to diversify the Brazilian electrical matrix through renewable energies.

Photovoltaic solar generation has several economic, social and environmental benefits.

Among which, the main ones are: greater freedom of choice for consumers, who start to generate and better control their own expenses with electricity; the generation of many local and quality jobs; low environmental impact and contribution to the sustainable development.

However, the growing increase in the manufacture of components used in systems photovoltaics generates greater concern regarding the correct disposal of these components. In this sense, products with lower environmental impacts must be developed. Furthermore, it is necessary to use adequate collection, treatment and recycling, so that harmful materials are not released into the environment. It is good to see how Brazil has dealing with those systems as well compare in further studies the way it is done here in Hungary, and make comparisons and set parallels between these two countries.

It is well known that Hungary has a good development when it comes to this field. In the university we can see great examples of Solar Energy along the campus, creating an environment that put students, professors and researchers at the “starting point”, being able to spread the world to the community and from there having a better outcome for this initiative.

This work had, therefore, as purpose, the study of photovoltaic systems ON-Grid and OFF-Grid. However, it was not part of the research scope to address hybrid systems. These systems are those that, disconnected from the conventional grid, have several sources of energy generation, resulting from the combination of two or more of the following primary energy sources: solar, wind, biomass, water and/or diesel. Such questions may, therefore, be deepened in further studies, in order to make electrical energy consumers aware of the different ways of using energy renewable.

# 7 SUMMARY

Solar radiation for harnessing solar energy in the world has high values, especially in the Asian and African continents, reaching up to 1424 and 2003 kWh/kWp of specific potential, respectively, according to the Global Solar Atlas. The distribution of solar energy systems in the world has grown exponentially in recent years. According to the IEA (International Energy Agency), the use of solar energy could reach 30% in 2022 in countries with greater installed generation capacity, such as China, Germany, Japan and the USA.

Solar energy is being used in Brazil mostly in homes, as an aid in reducing the electricity bill, either through thermal energy, heating water, or with the use of photovoltaic energy, generating electricity. Brazil entered, according to Canal Rural, for the first time on the list of the ten countries with the highest accumulated installed power from photovoltaic solar source. The country ended 2022 with 24 gigawatts (GW) of solar operating power, being the 8th country with the highest generation of solar energy in 2022.

The current work places the use of solar energy for the production of electricity in its proper context and includes research on photovoltaic systems that are ON-Grid and OFF-Grid, or connected to and unconnected from the electrical grid, respectively. As a result, this work gives two analyses of solar systems that are ON-Grid and OFF-Grid. It should be mentioned that the studies were conducted from the technical and socio-environmental viewpoints. As a result, the first analysis evaluates the ON-Grid and OFF-Grid photovoltaic systems directly. On the second it is the examination of the market demand, the potential for photovoltaic solar energy generation in Brazil, the socio-environmental impact, sustainability, and the primary photovoltaic system incentives in Brazil. The work's applicability is a result of the fluctuating cost of electricity tariffs and high carbon dioxide emissions, which have an impact on the climate and ecosystems of the earth, and showing the importance of learning and developing new technologies.

In conclusion, the study emphasizes the significance of mindful and sustainable consumption in order to improve the standard of living for both the present and future generations.

Keywords: Solar Energy, On-Grid, Off-Grid, Brazil, Environmental Analysis.

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# 9 APPENDIX

## 9.1 APPENDIX I – STUDENT AND SUPERVISOR'S DECLARATION

**STUDENT DECLARATION**

Signed below, Luiz Felipe Scarpi Lopes, student of the Szent István Campus of the Hungarian University of Agriculture and Life Science, at the BSc Course of Environmental Engineering declare that the present Thesis is my own work and I have used the cited and quoted literature in accordance with the relevant legal and ethical rules. I understand that the one-page-summary of my thesis will be uploaded on the website of the Campus/Institute/Course and my Thesis will be available at the Host Department/Institute and in the repository of the University in accordance with the relevant legal and ethical rules.
Confidential data are presented in the thesis: yes **no***

Date: 2023 May 9th

Student

**SUPERVISOR'S DECLARATION**

As primary supervisor of the author of this thesis, I hereby declare that review of the thesis was done thoroughly; student was informed and guided on the method of citing literature sources in the dissertation, attention was drawn on the importance of using literature data in accordance with the relevant legal and ethical rules.
Confidential data are presented in the thesis: yes **no** *

Approval of thesis for oral defense on Final Examination: **approved** / not approved *

Date: 2023 May 9th

Dr. Csegődi Tibor László, tanársegéd

Signature

## 9.2 APPENDIX II – STATEMENT ON CONSULTATION PRACTICES

**STATEMENT ON CONSULTATION PRACTICES**

As a supervisor of Luiz Felipe Scarpi Lopes RZYA3G, I here declare that the final essay/thesis/master's thesis has been reviewed by me, the student was informed about the requirements of literary sources management and its legal and ethical rules.

I **recommend/**don't recommend the final essay/thesis/master's thesis/portfolio to be defended in a final exam.

The document contains state secrets or professional secrets: yes / **no***

Place and date: 2023 year May month 9th day

Dr. Csegődi Tibor László, tanársegéd

Internal supervisor