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SOLAR PHOTOVOLTAIC TECHNOLOGY IN BRAZIL

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Abstract:
In recent years, the use of solar systems has been increasing worldwide in an accelerated rate, with the perspective of staying among the main sources of renewable energy for the following decades, along with wind power. The photovoltaic energy in Brazil currently represents 4,5 GW (2,5% of the national electric matrix). Solar thermal energy is called when solar radiation is used to transfer energy to a medium, usually water or air. It is a renewable, sustainable and environmentally friendly source of energy. The number of solar thermal energy applications is very extensive when considering all temperature levels and energy demands. In this context, the present work shows the evolution of solar photovoltaic energy in Brazil, bringing a discussion regarding to solar power characteristics, working principles and different technologies of solar cells, as well as aspects of operation and maintenance of the photovoltaic panels. Investments in research for the development of new technologies and valuation of existing ones for solar energy should also be prioritized, as well as for better planning and sustainable use of photovoltaic energy, given the advantages for the economy, society and the environment provided by this renewable and clean source.

Keywords: Solar Plants, Renewable Energy, Solar Cells, Sustainability, Clean Energy

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INTRODUCTION

The production of energy through clean sources is currently focused of many discussions and studies, mainly due to the environmental damages caused by the burning of fossil fuels. It is well known that gradual increase of the average temperature of the Earth due to greenhouse gases might lead to climatic occurrences increasingly more extreme, with impacts to sustainable development of several countries (Wessier, 2007; Sovacool and Watts, 2009; Palmer, 2014; Wizelius, 2015; Rao et al., 2017; Cheng et al., 2019). At the 2015 Paris Agreement regarding climate changes, Brazil committed to reduce greenhouse gases emissions through an increase both in reforestation and in the participation of renewable sources in the country's electric matrix until 2030. In this sense, amongst the varieties of energy sources that meet these criteria, are solar, wind, biomass, tidal, geothermal, and hydro power. All these types of energies cause some sort of environmental impact, even if minimal; however, they do not interfere with pollution in a global scale. In the last years, solar power usage has been increasing significantly in Brazil and worldwide, being considered a good alternative for diversification the global energetic matrix and, consequently, the less dependence on fossil fuels to generate energy for electricity, heating, cooking, and transport.

The technology of photovoltaic power generation has been increasingly regarded in many countries as an alternative to reduce the environmental impacts associated with climate changes and dependence on fossil fuels (Ferreira et al., 2018). The sun is a light and heat source present all over the world (Parida et al., 2011). Brazil has locations with high insolation indexes, especially in the Northeast region of the country. The direct solar radiation in Brazil between the years of 1999 and 2018 was measured in 1095 to 2264 kWh/m². By comparison, in the years of 1994 to 2018, Germany had between 803 to 1168kWh/m² of direct solar radiation (Global Solar Atlas, 2019). The study of Choudhary and Srivastava (2019) greatly pointed out that solar photovoltaic technology has emerged with exceptionally high potential future energy contributor to a scale of multi-terawatt sustainability sector by mid-century 2050. However, apart from core technology improvements, the authors recommend for innovative policies adoption, substantial fall in energy cost, social acceptance, capacity building and collaborations for future energy establishment. China has become the world's largest clean energy country in terms of the total installation of wind and photovoltaic power and annual newly installed capacity. However, weather conditions render renewable energy unstable, thereby restricting its application to a power grid; reducing the randomness in wind or photovoltaic power is the major challenge of the utilization of solar and wind energy (Li et al., 2021). In this perspective, this work presents the development of solar photovoltaic energy in Brazil, as a source of clean and renewable technology to promote sustainable development in the country. Special emphasis is done for the characteristics of the different technologies of photovoltaic cells. Highlights for aspects of operation and maintenance of the panels are also undertaken.

Overview Of Solar Photovoltaic Energy In Brazil

Modernity's advances and mankind's growing dependence on technologies in constant evolution demand efficient and reliable energy sources. Since the days of the Industrial Revolution, this energy was mainly supplied through fossil fuels. However, their finite availability and the anticipated environmental damage resulting from fossil sources continued and unrestrained use have raised questions about alternative and sustainable sources of energy production (Seetharaman et al., 2019). Thus, the power provided by the sun, that will remain active for billions of years, has been explored and developed increasingly more due to its enormous potential for energy production. Clean energy refers to energy sources that do not release pollutants into the atmosphere and that only cause environmental impacts at the project installation site. Solar energy is defined as all energy sources that use solar radiation to generate heat or electricity. As a globally available resource, the development of solar energy is expected to have a significant impact on the energy consumption of human civilization, as it does not release by-products that result in environmental damage, and because it has a source that is essentially infinite in nature, even if its availability is considered circumstantial (Pipe, 2016; IRENA, 2019). Since the turn of the millennium, solar energy has undergone significant advances, with an increase of 395% in the contribution of global energy production to solar energy in a single decade. Countries like China, the United States and Germany are world leaders in the production and installation of photovoltaic panels.

The annual increases in global energy consumption, along with its environmental issues and concerns, are playing significant roles in the massive sustainable and renewable global transmission of energy. Solar energy systems have been grabbing most attention among all the other renewable energy systems throughout the last decade. However, even renewable energies can have some adverse environmental repercussions (Rabaia et al., 2021). Brazil is a privileged country with regard to photovoltaic energy, as it has a high rate of direct solar irradiation on its surface, especially in the Northeast region, which is the main requirement for the feasibility of this energy generation technology. Highlight for the São Francisco Valley, which has high numbers of global solar radiation, standing out among all geographic locations, with the highest annual average (Pereira et al., 2017). Annual average radiation in the country varies between 1200 and 2400 kWh/m²/year, while in Germany it is between 900 to 1250 kWh/m²/year (EPE, 2020). Furthermore, Brazil has one of the largest reserves of quality quartz and is the fourth largest supplier of metallurgical grade silicon (first stage in the production of solar grade silicon). The highest numbers of solar radiation can be observed in the central region of Bahia state (6.5 kWh/m²/day), also covering the northwest region of Minas Gerais state. The temperatures in Brazil correspond to a regime of low cloudiness and high incidence of radiation in semiarid regions throughout the year (Portal Solar, 2021). The average annual numbers of daily insolation in

Brazil are higher than the levels of solar incidence in countries that develop photovoltaic projects more frequently, such as Germany, France and Spain. In Brazil, despite the large existing solar potential, the encouragement to technology is still incipient (Ferreira et al., 2018).

Historically, Brazil stands out for having a high percentage of renewable sources in its electrical matrix when compared to the rest of the world (Martins et al., 2008; EPE, 2020; FGV, 2020). The Brazilian electricity matrix is diversified and, with the expansion of renewable energies, Brazil has been increasing its contribution to clean energy generation every year. As presented in Table 1, hydropower is still predominant in Brazil, and, though solar power has a contribution of only 2,5% (4,5 GW) in the national electric matrix, the number of photovoltaic systems installed in the country has been increasing considerably, mainly in the South and Southeast regions, primarily in households as an auxiliary measure to reduce electric bill prices, either through thermal energy (for heating up water) or through photovoltaic energy (for electricity generation). It is estimated that by 2024 Brazil will have around 887 thousand solar energy systems connected to the energy supply network (Portal Solar, 2021).

Table 1. Participation of solar photovoltaic energy in the Brazilian electric matrix.

Source	Installed Capacity (MW)	Installed Capacity (%)
Hydroelectric	103,0 GW	57,1%
Wind	20,1 GW	11,1%
Natural Gas	16,3 GW	9,0%
Biomass	15,5 GW	8,6%
Petroleum	9,0 GW	5,0%
SHP[a]/GHP[b]	6,4 GW	3,5%
Solar Photovoltaic	**4,5 GW**	**2,5%**
Coal	3,6 GW	2,0%
Nuclear	2,0 GW	1,1%
Other fossil	0,2 GW	0,1%
Total	*180,6 GW*	*100%*

[a] SHP: Small Hydropower Plants; [b] GHP: Gas Hydropower Plants (Source: the authors, based on data from Aneel (2021).

Among the largest solar plants in Brazil, the solar complex in the city of Pirapora, in Minas Gerais state, stands out as one of the largest in Latin America, with a generation capacity of up to 400 MW. Also, in the state of Minas Gerais, in the city of Janaúba, what will be the largest solar complex in all of Latin America is under construction, with 14 solar plants totaling up to 700 MW of energy capacity for the Brazilian electrical system, equivalent to demands of 933 thousand households. In the state of Pernambuco, in the Northeast region of the country, the construction of a solar complex was also started in the city of São José do Belmonte, which will have 7 solar plants with a total production capacity of 1,100 MW (FGV, 2020). These three projects were made by a Spanish energy group and are a reference in photovoltaic energy worldwide.

Centralized And Distributed Generation Of Solar Photovoltaic Energy In Brazil

In the main states producers of solar photovoltaic energy in Brazil, Minas Gerais leads the ranking, with 5,853.8 MW of potency installed for centralized generation, and 977.3 MW for distributed generation. Centralized generation corresponds to a photovoltaic plant (also known as a solar park or solar plant) which is a large-scale photovoltaic system designed for the generation and supply of photovoltaic energy to the electricity grid. They are composed of projects above 5 MW sold in two contract environments (free and regulated market). Distributed generation, on the other hand, refers to the production of energy located close to the consumer unit, regardless of the size or source of generation. In practice, it corresponds to small and medium-scale solar photovoltaic systems, with a capacity of up to 5 MW, installed in homes, farms, businesses and public buildings. Most centralized solar power plants are ground-mounted photovoltaic systems, but they can also be installed in lakes and dams, also called floating solar power plants. A distinct innovation that is being implemented in centralized generation is hybrid plants, which is when the solar photovoltaic plant is installed in parallel with or coupled to other plants, be they wind, hydro or even non-renewable sources such as thermoelectric.

Distributed generation can be off-grid or in-grid. Off-grid systems are isolated, autonomous solar power generation systems that use batteries connected to them that act as energy storage devices. This system consists of solar modules, cables and support structures (such as inverters and charge controllers - power generation blocks - and batteries). In this system, the charge controller prevents overcharging inside the batteries, the battery bank stores excess energy, and the inverter converts direct current (DC) into alternating current (AC). In the off-grid system, there is no connection with the supply network or energy cooperatives. Thus, during blackouts, the energy supply is made through reserves stored in the battery bank, which requires the proper metering of the storage unit to meet local demands. The system on the grid, however, is connected to the mains. In this system, the solar inverter not only converts direct current (DC) into alternating current (AC), but also synchronizes the system with the utility grid. In this case, whenever there is a surplus of energy produced by the on-grid system, it is injected into the conventional energy supply network. In this way, the energy meter oscillates in the opposite direction and the surplus is converted into credits for the consumer. In Brazil, the consumer saves on the electricity bill and pays only the amounts defined by the National Electric Energy Agency (ANEEL). In addition, if the energy produced is not enough to meet demands, the electricity grid supplies what is left to the consumer, who then pays the energy supplier. Thus, with the on-grid system the consumer can save more than 90% on electricity bill prices. Credits acquired in the generation of energy can be used by other consumer units, through a simple registration.

According to Luna et al. (2019), the current electric generation in Brazil to meet its demand is based on centralized electricity generation, however, a new decentralized model is emerging in light of the recent advance of distributed generation (DG), among them, solar photovoltaic DG. An analysis of the evolution of solar photovoltaic DG in Brazil, after the Normative Resolution (NR) No. 482/2012 of the National Electric Energy Agency (ANEEL) conducted by Luna et al. (2019) indicated a growth of solar photovoltaic DG in the country since 2012, with a significant increase in 2015. However, there is a need for further regulatory improvements to boost this market. In addition, the authors proposed that existing regulations could be improved in order to reduce or exempt taxes on equipment of solar photovoltaic DG, as well as provide government incentives, enable consumers to enjoy greater benefits by allowing the surplus energy to be sold to the distributor or the free market, exempt taxes for non-profit institutions, and include in housing programs and projects, the requirement of energy efficiency and solar photovoltaic DG. In this context, it is noted that the on-grid system is advantageous for consumers who are close to the electricity grid, as it does not require the use of batteries to regulate energy. On the other hand, the off-grid system is advantageous for consumers who live in remote locations, far from electricity supply networks.

With regard to the evolution of photovoltaic sources around the world, their growth is presented as an exponential curve from about 1992 onwards and continues until today. During this period, photovoltaic energy evolved from a niche market of small-scale applications to a conventional electrical source. After solar photovoltaic systems were recognized as a renewable energy source for large-scale applications, programs such as feed-in tariffs were implemented by several countries to provide economic incentives to investors. The main purpose of feed-in tariffs is to provide compensation based on the costs of producing renewable energy, providing safety margins and long-term contracts that help finance investments in renewable energy. This program is part of a policy mechanism designed to accelerate investments in alternative energy technologies, allowing for long-term contract offers to renewable energy producers based on the production costs of each technology. Since 2012, the mechanisms to encourage the insertion of photovoltaic solar energy in Brazil, as well as the adaptation of centralized and distributed systems to the national electricity matrix, began to be discussed in greater depth. Data from Brazilian

Association of Solar Energy (ABSOLAR, 2021) show that until 2012 there were only 7 solar plants in operation in Brazil. In 2016, this number jumped to 93 plants and, in 2017, to 1,159 plants (191 for distributed generation and 968 for centralized generation). In 2020, this amount totaled 7,470 solar photovoltaic plants (4,377 for distributed generation and 3,093 for centralized generation), an exponential growth of this renewable source. An important milestone for the increased use of solar energy systems was ANEEL Ordinance No. 482/2012, which established incentives. For example, energy compensation, with the creation of the producer-consumer figure, within the net metering system. The main characteristic of the net metering system is the possibility of injecting the excess energy produced by the photovoltaic panels into the electrical network, converting it into credits for subsequent compensation, when demand exceeds the production of the modules. Later, in 2015, the aforementioned ordinance was reissued by the federal government through ordinance No. 687/2015, expanding incentives for distributed generation of solar energy, increasing the limited installed power from 1 MW to 5 MW, extending the validity period of credits generated for up to 5 years, creation of shared generation modality and possibility of remote self-consumption, as well as simplification of the registration process of solar energy producers to local energy projects. It is also noteworthy that only as of 2014 solar photovoltaic energy became part of energy auctions held by the Federal Government. In addition, with the progressive reduction in costs, the increase in the efficiency of solar energy systems and the tariffs of energy supply companies, the parity between the final costs of the photovoltaic energy generated and the prices of energy supply companies is already a reality, which encourages self-production of energy.

METHODS

Characteristics Of Solar Photovoltaic Energy

The energy supplied by the Sun is not renewable. It is, however, an inexhaustible source when considering the time scale of life on planet Earth. Solar radiation on the surface presents spatial and temporal variability associated with the planet's movements, with well-defined daily and seasonal cycles. Solar radiation is also affected by atmospheric factors, such as pollutant emissions, cloudiness variability and aerosol concentration (Pereira et al., 2017). Solar thermal energy is called when solar radiation is used to transfer energy to a medium, usually water or air. It is a renewable, sustainable and environmentally friendly source of energy. The number of solar thermal energy applications is very extensive when considering all temperature levels and energy demands. Pipe (2016) and Pereira et al. (2017) explained that these applications range from agricultural processes, to food cooking and water desalination, a wide spectrum of industrial processes, and even refrigeration and air conditioning. The solar thermal effect generates the heat needed for heating and freezing water, as well as generating steam for industrial and domestic use. Thermal energy also can generate electricity through a process known as CSP (concentrated solar power). In this case, complex systems use mirrors that concentrate sunlight by radiating a large area to a single focal point, which transports the received heat to a steam turbine that generates electricity (Yousef et al., 2021).

RESULT AND DISCUSSION

The use of solar power for heating up water to temperatures below 100º C is, currently, the most spread-out application in Brazil, mainly in replacement to electric heating systems or gas heating systems. This is due to the fact that technology for conversion of solar power to thermal energy is simple in nature and widely available in Brazilian markets, with multiple suppliers and manufacturers, as well as the financial viability easily achieved in well done projects. Government incentives are instigators of the large-scale use of residential solar heating systems. Among them can be mentioned: Tax exemption, obligatory usage in certain situations, equipment offered free of charge through ANEEL's programs of energy efficiency or housing social programs. The use of solar energy to heat water at temperatures below 100º C is currently the most widespread application in Brazil, mainly as a replacement for electric or gas heating systems. This is due to the fact that the technology for converting solar energy into thermal is simple in nature and widely available in the Brazilian market, with multiple suppliers and manufacturers, in addition to the financial feasibility easily achieved in well-executed projects. Government incentives are the instigators of the large-scale use of residential solar heating systems. These include: tax exemption, mandatory use in certain situations, equipment offered free of charge through ANEEL's energy efficiency programs or social housing programs. When electricity generation occurs through the use of solar radiation as the primary source of energy, the so-called photovoltaic solar energy emerges. In this case, when light is captured by solar (or photovoltaic) modules, electricity is generated, to be used in homes, stores and industries.

Thus, solar heating, electricity generation and HVAC systems illustrate processes and technologies produced by scientific and technological developments. There has been significant development in recent decades, both in thermal use to meet the demands of residential or industrial processes, and for electricity generation (Ahmad and Zhang, 2020). The use of photovoltaic energy for electricity demands has also undergone intense development, which is currently resulting in a significant growth in the share of solar energy in the global energy matrix, as discussed earlier in this study. The generation of photovoltaic electricity has great potential in Brazil, as indicated in Figure 1. In the less sunny place in Brazil, it is possible to generate more solar energy than in the sunniest place in Germany, for example. The map shows the maximum annual energy efficiency (measured in kWh of electricity generated per year for each kWp of installed photovoltaic power) across the entire Brazilian territory, both for large-scale centralized terrestrial plants and for distributed roof-mount photovoltaic generation.

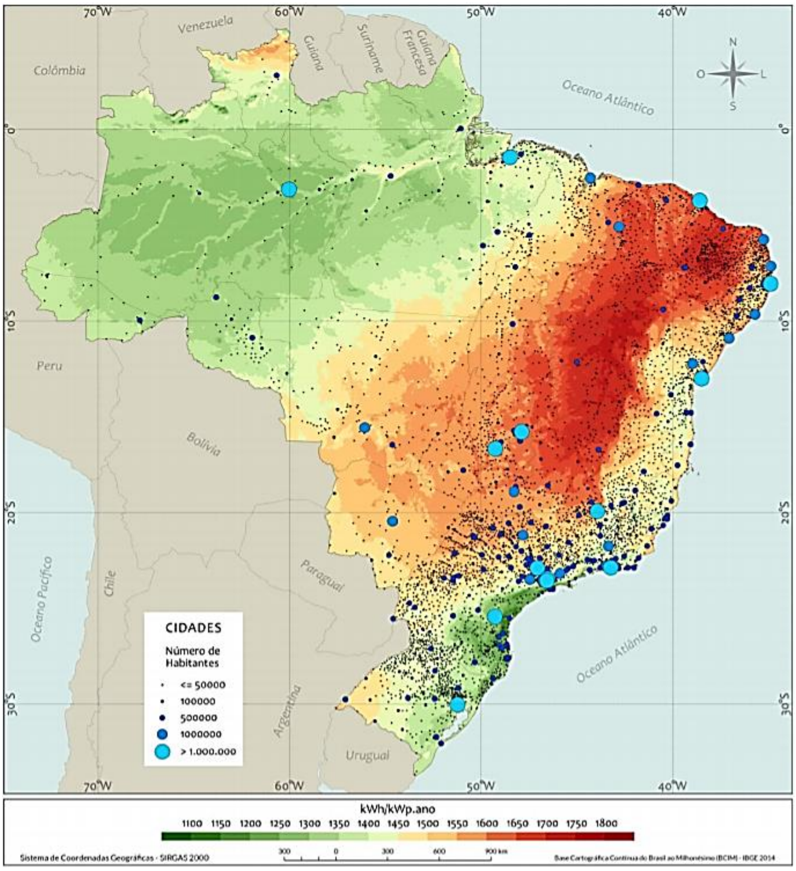

Figure 1. Map of the photovoltaic solar generation potential in terms of annual energy efficiency for the whole of Brazil (measured in kWh/kWp.Year, in the color profile), assuming a performance rate of 80% for fixed photovoltaic generators and distribution of the Brazilian population in cities. Source: Pereira et al. (2017).

As can be seen, the use of solar resources in Brazil presents itself as an excellent option to complement conventional and established energy sources, such as hydroelectric power. The use of solar resources favors the control of water in the reservoirs, especially in times of rainfall shortage, and allows for the optimization and planning of new investments in energy generation, transmission and distribution. Joint venture strategies between solar and hydroelectric energy allow forecasts of a possible increase in income for some of the poorest regions of the country, such as the Northeast region, with the promotion of a socially fair economy that is less vulnerable to climate change, thus reducing a secular regional asymmetry of social and economic inclusion (Pereira et al., 2017). Despite this, there are still many challenges to be overcome for solar energy in Brazil. It is estimated that, currently, the Brazilian market is 15 years behind in relation to other markets. Obstacles include difficulties in accessing credit for legal or non-legal entities, with credit lines that do not correspond to what is necessary for participation in photovoltaic solar energy generation projects. It is also important to note that solar grade crystalline silicon production costs are high, although current models are increasingly effective compared to 30 years ago. Silicon mining also results in various environmental impacts, such as water and soil pollution. It is also essential that adequate work environments are offered to workers, in order to avoid work accidents and the development of occupational diseases, since crystalline silicon is carcinogenic, capable of causing lung cancer if chronically inhaled.

Furthermore, the mass installation of photovoltaic units in solar power plants must take into account the possible environmental impacts that may occur. The landscape surrounding the plant will be altered and it is possible that the soil may be contaminated by residues resulting from the installation, due to the use of chemical products, in addition to the risk of damage to the local fauna and flora. There can also be social impacts, of a positive or negative nature. Either through the generation of jobs during the installation process of the photovoltaic units, or through the depletion of resources available to the local population with the destination of those that will be used in the installation of the solar plant. There is also concern about the final destination of thousands of solar units at the end of their useful life. Japan's Ministry of Environment estimates that by 2040, the country will produce around 800 million tons of solar waste. The International Renewable Energy Agency estimates that, by 2050, the number of solar units worldwide will be around 750 million, weighing around 250 thousand tons, which could result in a major solid waste problem (IRENA, 2019). For these reasons, the panels must be disposed of properly, as they have potential for toxicity, and recycling has not yet reached satisfactory levels to this day. Although they have valuable materials such as copper and silver, they are not worth as much as those recovered from cell phones and other devices. Therefore, the common destination for used solar panels is, for now, dumps. For more sustainable alternatives to the disposal of photovoltaic panels, IRENA (2019) highlights the approval of legislation in the state of Washington, United States, which requires manufacturers to prepare recycling plans for their products. And in Europe, in 2016, the first solar panel recycling plant in the world was inaugurated.

Therefore, despite being renewable and free from polluting gas emissions, photovoltaic solar energy has characteristics that must be taken into account. Although promising, it will only solidify as an economically viable source through cooperation between the public and private sectors and investments in research aimed at improving technologies that cover the entire production process, from the purification of silicon to the disposal of photovoltaic cells. Of the advantages of photovoltaic solar energy, its longevity can be mentioned in practical terms, due to its essentially infinite source: sunlight. It does not create noise or air pollution, and there is no wear and tear on the solar panels resulting from energy production. It's also incredibly versatile, requiring no more than a flat surface to set up the solar plant. On the other hand, the installation of solar units requires large spaces, therefore, it is important that an analysis is made for the most suitable location for installation, as there will be suppression of the local flora. Another issue to be considered concerns the availability of solar radiation, which is not present at night, and it is necessary to consider the use of batteries and alternative energy sources in the planning stages.

Working Principle Of A Photovoltaic Solar Panel

As the world looks for low-carbon sources of energy, solar power stands out as the single most abundant energy resource on Earth. According to Sengupta et al. (2021), photovoltaics, solar heating and cooling, and concentrating solar power (CSP) are primary forms of energy applications using sunlight. These solar energy systems use different technologies, collect different fractions of the solar resource, and have different siting requirements and production capabilities. Reliable information about the solar resource is required for every solar energy application. This holds true for small installations on a rooftop as well as for large solar power plants; however, solar resource information is of particular interest for large installations because they require substantial investment, sometimes exceeding 1 billion dollars in construction costs. Before such a project is undertaken, the best possible information about the quality and reliability of the fuel source must be made available. That is, project developers need reliable data about the solar resource available at specific locations, including historic trends with seasonal, daily, hourly, and (preferably) sub hourly variability to predict the daily and annual performance of a proposed power plant. Without these data, an accurate financial analysis is not possible. Additionally, with the deployment of large amounts of distributed photovoltaics, there is an urgent need to integrate this source of generation to ensure the reliability and stability of the grid.

As discussed above, the use of solar energy resources consists of converting the energy emitted by the sun in the form of light into thermal energy, or directly into electrical energy, in which case it is called a photovoltaic process. The use of solar energy conversion technologies has been increasing worldwide at high rates for both thermal and photovoltaic applications. Generally, solar panels are made up of several silicon-based cells that, when radiated by beams of sunlight, generate electricity. A solar panel is composed of solar cells, which are made of previously purified and doped semiconductor materials, such as silicon, a material of crucial importance to the industry for several reasons, such as its high abundance in the earth's crust, from 14 to 16% efficient in converting sunlight into electricity. The semiconductor material is the main component of traditional solar cells, which, when put together, form the core of the solar panel. It is worth remembering that Brazil is one of the largest suppliers of metallic silicon in the world, with China leading the ranking. The fundamental principle by which a photovoltaic unit operates is the so-called photovoltaic effect, a phenomenon presented by certain materials that generate electrical currents when exposed to radiation (Fahrenbruch and Bube, 1983). The photovoltaic effect can be described as the appearance of a potential difference (voltage) between two layers of a semiconductor in which the conductivities are opposite, or between a semiconductor and a metal, under the effect of a light beam. Thus, the photovoltaic effect is a process by which an electrical voltage or current is generated in a photovoltaic cell when it is exposed to sunlight.

The photovoltaic effect was first observed in 1839 by Edmond Becquerel. When conducting experiments involving cells moistened with silver compounds, he observed that the cells generated voltage when the silver panels were exposed to sunlight. Using solar cells, the photovoltaic effect occurs when short wavelengths of sunlight excite electrons in the material. The electromagnetic radiation emitted by the solar panel is collected by another material. This ejection of electrons results in an increase in voltage, generating energy that can be stored in a battery cell for later use. Two electrodes are used to collect electrical voltage, which can then be transferred to the power grid. This generation of electricity is possible because, when exposed to solar radiation, the electrons in the photovoltaic cell material acquire a higher level of energy and are free to move through the material, which generates electrical current. However, it is still necessary to provide the means to allow this freedom of movement. Therefore, a layer of impurities is added to dope the semiconductor material of the photovoltaic panel (Gatti et al., 2021). Through doping, the separation of positive and negative charges between the layers of semiconductor material and the added impurities occurs, resulting in a potential difference in the photovoltaic cell, which establishes an electrical current that can then be captured by metallic terminals at the ends of the photovoltaic panel, resulting in the generation of electricity (Gatti et al., 2021).

In this way, photovoltaic modules capture sunlight and convert it into direct current. The current passes through an inverter, where it is transformed into alternating current. The excess energy can then be injected into the energy network and, thus, the consuming units receive credits towards the electricity bill. Thus, photovoltaic solar cells are manufactured in different shapes and sizes. Sometimes a single cell is needed to power a single device, but more often than not multiple cells are connected together to create solar panels or modules. These modules can be connected to create photovoltaic arrays that can be used to power small buildings or large complexes. The resulting load of photovoltaic energy depends on the size of the array. This size can vary depending on the amount of sunlight available and the amount of energy required. Although the energy output of a photovoltaic system depends on the total amount of exposure to sunlight, it can still generate energy on cloudy days. In order to store energy for subsequent transmission, a variety of storage systems are available to consumers. The most reliable storage systems use a combination of rechargeable batteries and energy storage capacitors, some of which can be designed for AC or DC. The amount of energy available on cloudy days and at night for a PV power system depends on the power output of the PV modules and the layout of the batteries. Adding extra modules or batteries will increase the available produced power, but it will also increase the cost of the system. For best results, a total cost vs. need analysis should be done to design a system that balances costs and needs with convenience of use. The conventional types of photovoltaic cells currently available are crystalline cells and thin-film cells. Within the scope of these two technologies, there are multiple variations of projects, production processes and semiconductors that are used to reduce costs and increase the efficiency of both cells and panels. Currently, mono and polycrystalline silicon cells are the ones that have the greatest presence in the market. In contrast, many other types of crystalline cells and thin-film cells emerge as technological bets, for example, organic and multijunctional solar cells, among many others, as presented below.

Operational And Technical Aspects Of Photovoltaic Cells

Ground-mounted solar plants can have either a fixed angle or an adjustable angle, which, despite having better performance, also increases installation and maintenance costs. Solar power plant designs often use fixed angle solar module structures designed to provide maximum energy production. The photovoltaic modules are generally oriented towards the equator tilted at an angle slightly below the local latitude. In some cases, depending on local topography, climate or electrical assessment, different slope angles can be used, or arrays can also be designed to compensate through the regular east-west axis, allowing for morning and afternoon production.

The lifetime of a solar panel is approximately 25 years and its size and weight can vary considerably. They are very practical as they do not require heavy maintenance (remembering that the other components of the system can have a longer or shorter life in comparison). For a residential project, the payback period for the investment in a photovoltaic system is variable and depends on the amount of energy demanded. Despite this, the main advantage of the home system is the economy: once this payback period is reached, the electricity bills will no longer have to be paid. The size and weight of solar panels are extremely variable. Although there are many types and variations, an average panel is approximately $1m^2$ wide and weighs just over 10kg. A panel of these proportions is composed of about 36 photovoltaic cells, capable of producing around 17V and having a power of up to 140W. Current models can generally range between 5 and up to 300W of maximum power, depending on the intended use and the technology on which it was based. In addition, different combinations of photovoltaic panels can be used, which can be arranged in different ways, allowing processes that operate in multiple forms of solar energy systems.

During the life of the photovoltaic cells, periodic inspections are necessary to check for dust, debris or accumulation of other interfering agents (such as bird waste). Cleaning should be done with a damp cloth and neutral soap, always wearing rubber gloves and checking exposed or oxidized wires (which happens mainly in regions of high humidity or salty air) to avoid accidents.

Mainly, there are three basic types of photovoltaic solar panels: monocrystalline panels, polycrystalline panels and thin film panels. Monocrystalline solar panels have high efficiency and are composed of monocrystalline silicon cells, that is, each cell is composed of a single crystal of this element. The production process for this type of panels is complex, as it is based on the production of a single crystal of high purity silicon for each photovoltaic cell.

Polycrystalline solar panels, on the other hand, are less efficient than monocrystalline panels and the cells themselves are made up of multiple crystals rather than a single one. The end result is a photovoltaic panel with a shattered glass appearance. Finally, there are thin-film panels, in which the photovoltaic material is deposited directly onto a surface (it can be metal or glass) to form the panel. Although cheaper, the electrical efficiency is considerably lower, which requires a much larger area to compensate. This is true for thin films of amorphous silicon or even microcrystalline silicon, which require the production of two or more junctions (with a more expensive manufacturing process) to obtain cells that can compete with crystalline silicon in terms of efficiency. Thin-film photovoltaic devices have a very small share of the energy production market, but the benefits and possibilities surrounding this technology stimulate great efforts in research and production of thin-film photovoltaic cells and modules. Several research centers and manufacturers around the world have been looking for new materials for thin film production with a good cost-benefit analysis. Among them are cadmium tellurite (Cd-Te) and the copper-indium-gallium-selenide alloy (CIGS), which allow the fabrication of cells and modules whose efficiency can reach (and sometimes surpass) the numbers of crystalline silicon.

Although crystalline silicon photovoltaic cells are currently the market standard, CIGS cells can commercially compete with crystalline silicon cells. According to Polman et al. (2016), among their advantages, is the low energy production costs, compared to crystalline silicon, and the use for the production of thin-film panels, which, unlike crystalline panels, are made of flexible and thin materials, as CIGS cells strongly absorb sunlight, which saves on material costs and extends their reach for multiple different applications, such as windows and polymers. The thin film deposition process can be done through several methods, one of the most commonly used being physical vapor deposition (PVD). Despite this, CIGS cells have limitations, as the indium element becomes scarce in production and in high demand by other industries. Hydrogen selenide, used in the CIGS cell production process, is classified as highly toxic. Crystalline silicon is generally more efficient than thin-film CIGS cell panels (Polman et al., 2016).

The choice of the type and quantity of panels to be installed depends on multiple aspects, such as: energy demand, purpose of the energy used, location of the system installation and available area. To meet the demand for hot water in a house with three to four residents, for example, 4m² of solar panels are needed. Residential solar panels are generally installed on roofs, although the recommendations must be observed. The solar panel's power generation can be hampered by strong winds, shadows and reflective surfaces, which interfere and decrease efficiency. It is also important to have good airflow to prevent overheating. The roof must also support the weight of the installed units. In Brazil, it is recommended that all components are certified by the National Institute of Metrology, Quality and Technology in Brazil (INMETRO), which implemented, in 2014, Decree No. 357, with the objective of regulating photovoltaic energy generating units.

CONCLUSION

This work aimed to present the current scenario and characteristics of photovoltaic solar energy in Brazil, showing its growing use for energy production in the country, bringing multiple regional and national benefits by contributing to the sustainable development of remote and agricultural places, where most solar power plants are concentrated. The overall numbers shown in this study correlate with Brazil's great potential for the production of photovoltaic solar energy.

Through new market possibilities, the implementation of large solar parks plays a fundamental role in the diversification of the Brazilian electricity matrix, aiming to reduce dependence on hydroelectric sources and, more importantly, on fossil fuels. It was discussed that, as solar technologies evolve, the deployment of photovoltaic solar energy in Brazil becomes increasingly accessible. Despite the advances made by solar energy in the country, there is still room for a wider use of solar panels. Stimuli and incentives are needed for the use of solar energy to gain more and more prominence, such as the reduction of tariffs and taxes related to the production and distribution of solar energy, social programs for the installation of photovoltaic panels in rural areas isolated from the grid electrical system, and financing of projects that aim to promote the replacement of fossil fuels by clean energy. Investments in research for the development of new technologies and valuation of existing ones for solar energy should also be prioritized, as well as for better planning and sustainable use of photovoltaic energy, given the advantages for the economy, society and the environment provided by this renewable and clean source. Therefore, the strategic role that solar photovoltaic energy plays in Brazil is increasingly visible and stimulating, as demonstrated by its strong growth in recent years. Recently, the technology has established itself as one of the most competitive clean energy sources in the country, with its affordable prices confirmed in recent auctions promoted by the Federal Government. In addition to meeting the electrical energy demands of industries, companies and homes, the electrical energy generated by the photovoltaic effect can also be used in the production of hydrogen and synthetic carbohydrates, through electrolysis, in hybrid plants, a reality that is increasingly present in the world in recent years.

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