v. 2, n. 21, 2022

Scientific Journal of Applied Social and Clinical Science

# ACADEMIC APPROACH ON SOLAR PHOTOVOLTAIC ENERGY IN BRAZIL

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**Abstract**: The objective of this study was to verify how photovoltaic solar energy in Brazil has been approached in the scientific literature. Therefore, searches were carried out in the ScienceDirect database, using the words "Brazilian and photovoltaic and energy" and limited by the type "review" and "research". A total of 160 articles were found, four were discarded, leaving 156 articles. Among the 156 articles, within the adopted classification, research was carried out on technologies and equipment; hybrid or complementary generation systems; power generation using buildings; laws, rules, regulations, tariffs; Marketplace; residential use of photovoltaic energy; comparison between energy sources; environmental impacts; education and training; and studies for a better location for the implementation of photovoltaic plants. What emerged from the research was the wide variety of topics, but especially the proposals for the use of photovoltaic solar energy sources, such as, for example, in hydroelectric power plant reservoirs and weirs; in the structure of commercial, residential, public buildings; on the roof of homes; hybrid systems associated with other sources, such as wind power; and in technology parks.
**Keywords**: Renewable energies, Photovoltaic solar energy, Energy sources, Energy generation, Environmental impacts.

## INTRODUCTION

The need for energy, at the moment, is great and is expected to grow in the future, and this increase in demand and how to meet it has become one of the great global challenges (DAVID et al., 2020). This has led to the search for zero-emission alternatives, that is, renewable energies to meet this energy demand. The increase in demand is not the only cause, the increase in fossil fuel prices and global warming are also among the main factors for such a search (ELAVARASAN et al., 2020).

In Brazil, the electricity matrix is strongly influenced by renewable sources, with hydroelectricity having the largest contribution (CARVALHO et al., 2020; MEDEIROS et al., 2021; SILVA et al., 2020). On the other hand, the world energy matrix is predominantly non-renewable, as it uses highly polluting resources, mainly due to greenhouse gas emissions (CARDOSO et al., 2021).

Despite all the advantages provided by the role of hydroelectric energy in the electrical matrix, it also leads to a great dependence on the rainfall regime and the flow of water in hydrographic basins (CAMPOS; NASCIMENTO; RÜTHER, 2020; NASCIMENTO; RÜTHER, 2020). The limited availability of water resources, increased demand for electricity and water and pressure on the environment, provoke efforts to diversify this matrix to include other renewable sources (MEDEIROS et al., 2021).

In recent years, photovoltaic solar energy has become the fastest growing form of renewable electricity generation in the world. Due to its vast tropical territorial area, Brazil is one of the countries with great potential for implementing this form of energy generation (CARSTENS; CUNHA, 2019; ROSA et al., 2020), as it has an average annual irradiation higher than most other countries. European countries, where photovoltaic technology is being widely explored and implemented (PEREIRA; JUCÁ; CARVALHO, 2019). The country also has great potential for a paradigm shift related to the growth of renewable sources in the grid alongside traditional sources (MARTELLI; CHIMENTI; NOGUEIRA, 2020).

Within this perspective, the objective of this study was to verify how photovoltaic solar energy in Brazil has been approached in the scientific literature.

## THEORETICAL FOUNDATION

The conventional energy system is facing problems of progressive depletion of fossil energy resources and low energy efficiency (CARDOSO et al., 2021) changing the concern of resource availability (i.e., oil, gas and coal reserves) to availability energy (wind and solar radiation) and the consequent change in the interests of stakeholders, such as policymakers, companies and the general public (KRAAN et al., 2019). Energy efficiency can be understood as the reduction of energy demand, that is, the cheapest and least consumed energy according to Freitas et al. (2020).

In recent years, the operational planning of electrical systems has undergone changes that have involved the incorporation of new technological, social and environmental characteristics. An important factor observed is the increasing use of different types of renewable energy sources. Among these sources, photovoltaic and wind systems have become more accessible (LEITE NETO; SAAVEDRA; OLIVEIRA, 2020).

Thus, photovoltaic energy has been identified as one of the main sources of energy in the transition from non-renewable to renewable sources (BRITO, SANTOS; SHIBAO, 2021; GARLET et al., 2019; RIGO et al., 2019), considered as a a source of clean energy generation (BELLIDO et al., 2020; DAVID et al., 2020; SANTOS; BRITO; SHIBAO, 2022) and will be able to meet the energy demand both in the urban environment and in projects in places of difficult access (ROSA et al., 2020).

The Brazilian electrical system is one of the largest integrated electrical energy networks in the world. It is a centralized system in which electricity is generated at different points in the territory and then distributed through an extended transmission system. External and internal circumstances brought changes in the composition of the electricity generation matrix over time, leading to a greater participation of fossil sources. On the other hand, renewable generation has become a relevant component, thanks to the decreasing costs of new technologies (MARTELLI; CHIMENTI; NOGUEIRA, 2020) and has the potential to play a transformative role in an energy transition (BELLIDO et al., 2020).

Although Brazil is particularly privileged due to its high levels of solar irradiance, due to the continental proportions and geographic location, its great potential for solar energy still has a discreet participation in the national electricity matrix (DEBASTIANI et al., 2020). According to the National Energy Balance (BEN, 2021) of the Energy Research Company (EPE), the share of solar energy in the domestic energy supply in 2020 was only 0.3%.

Among the largest energy consumers, buildings have historically been responsible for a large fraction of world consumption (GONZÁLEZ-MAHECHA et al., 2019; ZOMER et al., 2020), at approximately 40% (NEMATCHOUA; ASADI; REITER, 2020). and it is estimated that it will continue to increase in the coming decades (HARKOUSS; FARDOUN; BIWOLE, 2018).

In order to minimize this problem, the civil construction sector is looking for alternative sources of renewable energy, mainly from solar energy, to reach the level of zero energy consumption. Building Integrated Photovoltaics (BIPV), converts the external structures of buildings into local power plants (FREITAS et al., 2020), is a technology that can be widely integrated into the urban environment (DÁVI et al., 2016), because in addition to Being a pollution-free and renewable energy generation technology, photovoltaic modules can be integrated into the architecture (ZOMER et al., 2020).

In this conception, when design strategies are used to reduce energy consumption and on-site renewable energy generators provide all energy needs, the building is called a net zero energy (NZE) or zero energy building (ZEB), and it is a typical case of power generation using photovoltaic technology (ZOMER et al., 2020), that is, offering conditions of internal comfort, as well as meeting other functionality requirements with the lowest possible energy consumption (FREITAS et al, 2020). Net zero energy or also net zero energy buildings (NZEB) was introduced to limit energy consumption and pollution emissions in buildings (HARKOUSS; FARDOUN; BIWOLE, 2018).

Another way of generating photovoltaic energy is through the use of hydroelectric plant reservoirs, installing floating photovoltaic plants on the free surface of the water of these reservoirs. This photovoltaic generation model can be applied without restriction to micro and mini plants, as well as to small hydroelectric plants with lower investments. The Northeast region is the most promising area in Brazil due to the high solar irradiation and low latitudes (STIUBIENER et al., 2020).

Distributed photovoltaic generation, for example, is becoming increasingly competitive and has the potential to contribute to the reduction of emissions, in addition to generating economic benefits for consumers who use it (HEIDEIER et al., 2020). This fact was corroborated by Cardoso et al. (2021) who mentioned that there is evidence that this distributed generation contributes to making the energy matrix cleaner, has less impact on nature, reduces electrical energy losses, optimizes the distribution network and makes consumers aware of the more rational consumption of energy. energy.

Another generation model that has become attractive is distributed generation through small-scale systems in which the consumer has the possibility to generate part or all of the energy consumed. Although this generation model is attractive to many consumers, financial support systems are needed to make technology cheaper in the long term and attract these consumers (NASCIMENTO; RÜTHER, 2020; OLIVEIRA et al., 2020).

In recent years, there have been some initiatives aimed at creating and studying hybrid energy systems for centralized generation. Among renewable energy technologies, the combination of wind and solar photovoltaic energy, when there is complementarity, appears as a possibility for electricity production (SANTOS et al., 2020).

## METHODOLOGICAL PROCEDURES

This study is characterized as descriptive, with qualitative approaches, through content analysis (BARDIN, 2009). A literature review is an effective attribute of academic research. An effective review establishes a solid foundation for advancing knowledge. It facilitates the development of theory, consolidates areas where there is an abundance of research and discovers areas where research is essential (WEBSTER; WATSON, 2002).

Searches were carried out in the ScienceDirect database using the words "Brazilian and photovoltaic and energy" and limited by the type "review" and "research". This database was chosen because it has relevant journals, classified in the Qualis A1 extract (2013-2016) such as, for example, Energy and Buildings; Energy Policy; Journal of Cleaner Production; Renewable Energy; Renewable and Sustainable Energy Reviews; among others, high impact factor and also for ease of access. The survey was conducted between September 2020 and January 2021.

## RESULTS AND DISCUSSIONS

160 articles were found and the titles were read to verify if they fit the object of the study. If it was not possible to identify by title, the keywords and abstracts were read and, later, if necessary, the articles. After this verification, the articles that dealt with the topic were selected, leaving 156 articles.

### EVALUATED ARTICLES

The articles were classified into ten themes, as shown in Table 1, according to the objectives and themes of the articles.

| Nº | Subjects | Quantity |
|---|---|---|
| 1 | Technology and equipment | 49 |
| 2 | Hybrid and/or complementary generation systems | 26 |
| 3 | Buildings used in the production of photovoltaic solar energy: | 21 |
| 4 | Laws, rules, regulations, tariffs | 19 |
| 5 | Market | 11 |
| 6 | Residential use of photovoltaic energy | 11 |
| 7 | Comparison between energy sources | 7 |
| 8 | Environmental impacts | 6 |
| 9 | Education and Training | 3 |
| 10 | Studies for the best location for the implementation of photovoltaic plants | 3 |
| | Total | 156 |

Table 1 – Subjects of the evaluated articles.

Source: Research data.

The topic technology and equipment, with 49 articles, presented a series of researches, among which we can highlight: development and evaluation of technologies; floating photovoltaic systems; fault detection in photovoltaic plants; optimization of renewable energy sources; one- and two-axis solar tracking; inverter sizing; fault detection and diagnosis; modular Internet of Things (IoT) monitoring system; small-scale photovoltaic solar energy; reduced efficiency of solar cells; solar energy in the form of light; energy storage systems; cloud monitoring system; sprinkler system with water cooling on the photovoltaic modules; development of photovoltaic systems; comparison between static panel and single axis panel; real-time electricity generation; instrument for inverter testing; satellite-derived daily insolation values; cost reduction of solar cells and modules.

The topic hybrid or complementary generation systems, with 26 articles, revealed research in development, construction, complementarity, efficiency between wind and photovoltaic generation; financial risk in energy projects; hybrid photovoltaic storage system; customized hybrid system with organic photovoltaic cells; complementarity between solar, wind and tidal sources; solar photovoltaic-diesel hybrid generators; hybrid generation integrated to sugarcane mills; risk analysis in the generation of hydro, wind and solar energy; autonomous photovoltaic-wind hybrid energy system; hybrid system that combines photovoltaic modules and fuel digesters; photovoltaic cells and fuel cells for continuous energy supply; complementarity between hydroelectric and photovoltaic energy; photovoltaic systems with energy storage connected to diesel generators.

Solar energy generation using buildings, with 21 articles, exhibited research on the potential and performance of photovoltaic systems integrated in buildings; climate change affects Zero Energy Building (ZEB); influence of partial shading on the performance of BIPV systems; limitations and levels of solar radiation received by building surfaces; power generation from photovoltaic windows; solar yield potential for different surfaces; use of photovoltaic systems in airports; building photovoltaic power generation.

Laws, rules, regulations, tariffs, with 19 articles, presented research on economic, environmental, social, political impacts and investments in photovoltaic energy; expansion of the use of renewable energy sources; photovoltaic systems and energy storage systems; photovoltaic solar electricity in Brazil, challenges and opportunities; evolution of distributed photovoltaic solar generation; evolution of regulatory incentives for the use of photovoltaic solar energy; role of regulatory institutions in the possible lock-in to photovoltaics; price-based demand response and photovoltaic distributed generation; Chinese and Brazilian energy policies; Resolution RN482 / 2012 of the National Electric Energy Agency ANEEL; impacts of centralized solar energy generation auctions; situation and future perspectives of photovoltaic solar energy; photovoltaic equipment industry in Brazil.

The market theme, with eleven articles, presented research on connections between the main participants in the electricity market; panorama of distributed generation of photovoltaic energy; barriers and drivers for the introduction of photovoltaic solar technology; development of the Brazilian photovoltaic sector; potential of photovoltaic solar energy generation; energy scenarios for photovoltaic applications in Brazil; assessment of solar energy resources generated in the Solar and Wind Energy Resource Assessment project; different uses of renewable energies in Latin America.

Residential use of photovoltaic energy, with eleven articles, showed research on economic impact on residential tariffs in transition to distributed photovoltaic generation systems; cost-effectiveness of abatement opportunities to reduce CO2 emissions in the residential sector; scenarios of energy consumption, generation and ideal amount of photovoltaic panels; minimum monthly residential demand for consumers; projection of the diffusion of photovoltaic systems in residential consumers; distributed generation for consumer as microgenerator; photovoltaic solar panels as an alternative in the context of the Brazilian energy crisis; technical-economic potential for photovoltaic solar energy in the residential sector.

The theme comparison between energy sources, with seven articles, showed the comparison of the results of the contest for wind and photovoltaic energy; advantages and disadvantages of systems interconnection processes between Brazil and South American countries; offer of renewable technologies in Argentina, Brazil, Chile and Mexico; renewable energy can be maintained in the Brazilian system; economic viability of renewable energy technologies; time evolution of the energy balance of energy conversion technologies.

Environmental impacts, with six articles, presented the effect of energy mix in 150 countries on environmental impacts; carbon payback time from a photovoltaic plant; spectral impacts on the performance of new generation photovoltaic systems; life cycle of energy and greenhouse gas emissions; energy costs and CO2 emissions in the manufacture of photovoltaic modules; reduction of greenhouse gases in the life cycle of a photovoltaic energy system.

The education and training theme presented three studies on the experience of the Kalapalo ethnic group in the Aiha village (Xingu Indigenous Land), with photovoltaic energy in a school environment; application of learning as a way of including renewable energy subjects in the classroom; evaluation of the photovoltaic systems installation and maintenance course carried out by students at the Federal University of Pernambuco.

The studies for the best location for the implementation of photovoltaic plants showed in three articles the adequacy and positioning of areas for photovoltaic plants in the states of Minas Gerais and São Paulo; model to indicate the best location for the implementation of large-scale photovoltaic plants; mathematical modeling to measure the level of competitiveness of municipalities for the photovoltaic installation.

## DISCUSSIONS

The importance of including the effects of climate trends in the evaluation of future energy projects was emphasized by Medeiros et al. (2021) and can be directed towards the development of energy-related investment strategies. Some areas, such as semi-arid regions, are more vulnerable to climate change and not considering climate trends can compromise the viability of renewable energy systems and lead to economic and environmental losses.

Guarda et al. (2020) also warned about the impacts of climate change on the vulnerability of buildings with regard to configuring renewable energy systems to reach the net balance. In this regard, a major challenge and trend for sustainable buildings is to reduce electricity consumption and, at the same time, try to meet their own energy demand with self-generation (SORGATO; SCHNEIDER; RÜTHER, 2018). Zomer et al. (2020) suggested that photovoltaic modules can be used in architecture and/or architectural integration materials. Sorgato, Schneider and Rüther (2018) mentioned that it is possible to meet the annual net energy demand of a commercial building respecting some specific conditions in BIPV systems.

Debastiani et al. (2020) recalled that the use of small wind turbines associated in a hybrid way with photovoltaic panels is not of great interest when evaluated on a commercial scale, but it may seem an attractive alternative when installed in isolated areas. Corroborating with the authors, Figueiredo Neto and Rossi (2019) mentioned that photovoltaic systems are considered a good alternative for the supply of energy in rural areas with indigenous communities and, as a consequence, they have caused significant improvements in local teaching conditions and in the community in general.

Fossile et al. (2020) evaluated the use of photovoltaic energy in ports and concluded that photovoltaics is the most viable renewable energy source for Brazilian ports to invest in.

One of the options to increase the participation of photovoltaic energy in the Brazilian energy matrix, according to Rigo et al. (2019), is to invest in small-scale distributed generation. However, this generation represents less than 0.3% of the demand consumed in the country's captive market. Even if Brazilian consumers are interested in acquiring photovoltaic systems, selling the system is still a challenge for the sector, since the sales conversion rate represented only 6.88% in 2018.

According to Leite Neto, Saavedra and Oliveira (2020), the high variability of renewable energy sources is one of the main barriers to their efficient use and availability in isolated microgrids. Microgrids are small electrical distribution systems with a growing share of renewable sources. Bellido et al. (2020) cited that the increasing development of technologies can drive the faster expansion of the microgrid.

For the monitoring of photovoltaic plants Oliveira, Aghaei and Rüther (2020) suggested the aerial infrared thermography system (aIRT) which is a non-destructive, no downtime, fast and economical method to monitor large-scale photovoltaic plants and assist in the fault detection. Another form of monitoring was proposed by Pereira, Jucá and Carvalho (2019), a system using free software and hardware, through the internet of things (IoT) concept, with the objective of modularizing, reducing costs and making the system monitoring system is practical and fast in data processing.

Regarding generation through hybrid sources, according to Santos et al. (2020), there is great potential for the implementation of centralized wind-photovoltaic hybrid plants. They found that in the Brazilian semi-arid region there are highly favorable characteristics of high wind speeds and excellent conditions of solar irradiation. However, the possibility of generation from centralized wind-photovoltaic hybrid systems is a relatively recent issue and is not foreseen in the current national regulation.

Campos, Nascimento and Rüther (2020) proposed a combination of 40% wind and 60% solar generation, citing that it is the ideal portfolio mix to meet the load in the Northeast region of Brazil. This combination is the result of two particularities of the region: the increase in daytime demand, coinciding with photovoltaic solar generation, and the demand curve; and the predominance of wind generation at dusk and throughout the night.

As for solar energy for homes, González-Mahecha et al. (2019) mentioned that energy efficiency in the residential sector is a key measure to reduce CO2 emissions. There is a wide range of technological options that can save energy and, consequently, mitigate GHG emissions in Brazil. However, the implementation of such measures in the residential sector faces barriers that must be overcome to achieve this potential. These barriers can be related to the market, energy costs, financial, technological and cultural or information issues. The design of appropriate policies, programs and instruments can remove the barriers that prevail in the sector.

For the development of the sector, Carstens and Cunha (2019) mentioned that, for the growth of photovoltaic energy in the country, among the main issues is the need to establish specific policies for photovoltaic energy technologies, including clear long-term objectives, tax and financial incentives. The lack of development of new technologies, the low transfer of knowledge, the shortage of qualified professionals and the small internal market complete the main challenges for this growth.

In this sense, Martelli, Chimenti and Nogueira (2020) analyzed the most important and uncertain factors over a five-year horizon and concluded that they are development policies and electric energy policies. According to the authors, development policies can point towards an open world market or towards protectionism and electric energy policies could keep the traditional centralized market protected or create conditions for alternative business models.

Another aspect observed by Carstens and Cunha (2019) is the potential for generating solar energy, considering the vast territory and the high solar irradiance, Brazil has the potential to substantially increase energy generation from photovoltaic energy, capable of generating tens of thousands of GWh with this energy source alone.

Rosa et al. (2020) warned that identifying challenges and opportunities for photovoltaic growth positively impact the overall performance of solar power generation in Brazil. The incentive to install solar systems, through public policies based on subsidy actions, benefits society as a whole, through the impact on the percentage of renewable sources in the country's electrical matrix and consequent reduction of dependence on water sources, increase in the supply of jobs in cities, in the purchasing power of consumers, reduction in environmental pollution rates and the consequent advance of research in the area of solar energy.

In periods of drought or high demand, hydroelectric plants do not meet the demand and are dependent on thermoelectric plants powered by fossil fuels, therefore, a large-scale expansion of photovoltaics could reduce this need, as drought periods coincide with periods of better photovoltaic production. Energy from non-renewable sources could be gradually deactivated, and the Brazilian energy matrix will reach the highest level of use of renewable energy in the world (RIGO et al., 2019).

## CONCLUSION

The objective of this article was to verify how photovoltaic solar energy in Brazil has been approached in scientific articles. Among the 156 articles, within the adopted classification, research was carried out on technologies and equipment; hybrid or complementary generation systems; power generation using buildings; laws, rules, regulations, tariffs; Marketplace; residential use of photovoltaic energy; comparison between energy sources; environmental impacts; education and training; and studies for a better location for the implementation of photovoltaic plants. What was verified from the research was the wide variety of themes, highlighting proposals, such as the use of photovoltaic solar energy sources, in hydroelectric power plant reservoirs and weirs; in the structure of commercial, residential, public buildings; on the roof of homes; hybrid wind, photovoltaic, hydroelectric systems; using infrastructure of technology parks, among others.

The Brazilian photovoltaic energy compensation system can be profitable for consumers. The payback time was shorter in places with higher electricity rates. Economic scenarios vary by location and depend on the applicable electricity tariffs and discount rates (DÁVI et al., 2016).

The most important issues that must be addressed by the Brazilian government in relation to the diffusion of large amounts of energy efficiency measures are the collection of taxes and the increase in tariffs according to Heideier et al. (2020). The increase in tariffs can be mitigated if energy efficiency actions are implemented in grid locations with high marginal costs, or focused on specific actions in the peak load period to avoid using expensive electricity.

The current challenge for developing economies is to face the increase in consumption and reduce the impact of the use of non-renewable sources, stimulating the advancement of technologies that exploit renewable sources of energy, in order to address the political, economic and environmental factors involved in the electricity generation (GARLET et al., 2019).

What can be inferred is that the most researched topics, within the classification adopted here, technologies and equipment and hybrid or complementary generation systems, probably indicate the growth of the search for new generation alternatives within the field of photovoltaic solar energy, either through the development or equipment improvements or by hybrid forms of generation using renewable means of generation.

This study is limited by consulting only one database (ScienceDirect), which limits the conclusions expressed here, it is suggested to extend this research using other databases, such as Scopus and Web of Science, and compare with the results found here.

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