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Article

Systematic Review of Global Goals for the Development of Photovoltaic Power Plants: Focus on Environmental Consequences and Generation Performance

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ABSTRACT

The ideal proposal for the implementation of a photovoltaic plant must be carefully planned, considering various technical, economic, environmental, and social factors. This study presents a systematic and scientometric review of the global purposes for the implementation of photovoltaic plants, focusing on environmental consequences and generation performance. A total of 3,960 scientific articles from the Scopus platform were analyzed, of which 31 were selected based on strict inclusion criteria. The analysis revealed that most studies (77.4%) focus on generation performance, while only 19.4% focus on environmental consequences. We discuss the importance of balancing operational efficiency with environmental considerations to ensure sustainable progress in photovoltaic energy. We also note a predominance of publications from the United States, Switzerland, and the United Kingdom, highlighting the economic and scientific relevance of these nations. The study concludes that, despite the focus on performance optimization, there is a critical need for greater attention to environmental impacts to promote a sustainable energy future. Although the environmental issues of plant implementation are not addressed with evidence, once implemented, these indicators are indirectly achieved.

Keywords: UF; sustainability assessment; energy efficiency; environmental benefits and impacts.

RESUMO

O presente estudo buscou avaliar variáveis de crescimento e o desenvolvimento fenológico de plantas de *Palicourea rigida* Kunth em população natural, e determinar seu potencial ornamental. Foram estudadas dez plantas, que tiveram suas localizações registradas por meio de GPS, avaliadas mensalmente (dezembro de 2013 a dezembro de 2014). O crescimento da planta foi avaliado através de características como: altura da planta; altura da primeira bifurcação; número de ramificações na primeira bifurcação; diâmetro do caule a 20 cm do solo e diâmetros da copa nos sentidos Norte-Sul e Leste-Oeste. O acompanhamento fenológico foi realizado de forma qualitativa (observando-se mensalmente a presença e ausência das fenofases folhação, floração e frutificação) e quantitativa (por meio de uma escala de notas de um a dez). Mensalmente, determinou-se ainda, a parte da planta de maior valor ornamental no momento da avaliação, considerando-se o caule, a folhagem, as flores ou os frutos. A espécie *Palicourea rigida* apresentou crescimento

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lento, sendo uma planta de pequeno porte, copa baixa, pequena e arredondada, pouco ramificada, com folhagem perene e inflorescências com flores de coloração quente, amarelo-alaranjada. A espécie apresenta floração durante nove meses, e frutificação por oito meses. *P. rígida* possui características que indicam alto potencial ornamental para uso inclusive em projetos paisagísticos.
Palavras-chave: Cerrado; planta nativa; douradão; crescimento; ornamentação.

Introduction

The search for alternative forms of energy in Brazil is associated with a wide range of historical varieties in which the pursuit of development favored models based on engineering structures and the construction of hydroelectric dams (Silva 2018). Even though they appear to be ecologically sustainable models, especially as an alternative to fossil fuels, hydroelectric plants also bring heavy socio-environmental liabilities (Johnson 2021).

The adoption of photovoltaic power plants reflects a significant change in the way societies generate and consume energy. This transition seeks economical and viable energy solutions for large corporations and individual consumers. However, the main function of these facilities, the generation of clean and sustainable energy, often takes a back seat. Photovoltaic solar energy, which converts sunlight into electricity, stands out as an attractive option, especially where traditional energy costs are rising (Arimoto 2011; De Luna Pamanes et al. 2020; Meho 2020) .

Companies and institutions are more inclined to install large-scale photovoltaic plants, such as solar complexes or parks, while residential rooftops are used for small-scale installations. This movement is evidenced by the rapid expansion in the number of photovoltaic installations, seen as an investment in sustainability and economy. The reduction in installation and maintenance costs, combined with the increased efficiency of photovoltaic technologies, has motivated various sectors to adopt this energy source.

Although the environmental advantages of photovoltaic plants—renewable energy generation without direct greenhouse gas emissions—are recognized, they often take a back seat to other motivations for adopting this technology. For many investors and consumers, environmental benefits are seen as an added bonus to the immediate economic benefits. This phenomenon is particularly noticeable in regions where environmental policies and incentives for renewable energy are less robust, leading to financial considerations predominating in the adoption of solar energy.

University governance is fundamental to the sustainability of higher education institutions, influenced by rankings that highlight scientific output and sustainability in addition to financial governance. Global institutions adjust their policies to meet international criteria for excellence, focusing on performance targets based on scientific productivity and social responsibility (Dutra e Silva et al. 2021) .

However, this economic orientation does not diminish the strategic importance of photovoltaic plants in the global energy matrix. As more entities recognize solar energy as an economical solution, there is an increase in investments in production capacity and technological innovation, benefiting the environment by reducing dependence on fossil fuels. This evolution is aligned with a vision of sustainable development, where economic and environmental goals begin to converge, even if initially motivated by economic reasons (Energy Research Company – EPE 2023; Ministry of Mines and Energy – MME 2023).

Therefore, the expansion of photovoltaic plants represents a growing global trend, where economic imperatives pave the way for a broader energy revolution, supporting long-term sustainability goals. As technology evolves and costs decrease, the environmental benefits of photovoltaic plants are expected to gain prominence, promoting a cleaner and more sustainable energy future (Barbosa Filho et al. 2015; ECOM 2020) .

Thus, this article aims to conduct a systematic review of global purposes for the implementation of photovoltaic plants, focusing on scientific articles and other research studies that investigated the environmental benefits and/or impacts of these implementations, as well as the quality of the energy generated by these plants.

Theoretical Framework

Systematic review is a research method that identifies, evaluates, and synthesizes evidence related to a specific research question. It involves a structured approach to gathering, analyzing, and interpreting the literature on a topic. At the same time, scientometrics quantifies scientific and technological activities and focuses on aspects such as the number of citations, countries of origin, author affiliations, and publication journals (Galvão and Ricarte 2019; Kugley et al. 2017; Macias-Chapula 1998; UNESP 2012).

Energy Concepts

To align the content of this scientific paper with the principle of energy conservation, known as the First Law of Thermodynamics, which states that energy cannot be created or destroyed, only transformed, the terms "production" and "generation" of electrical energy will be used (Moran et al. 2018).

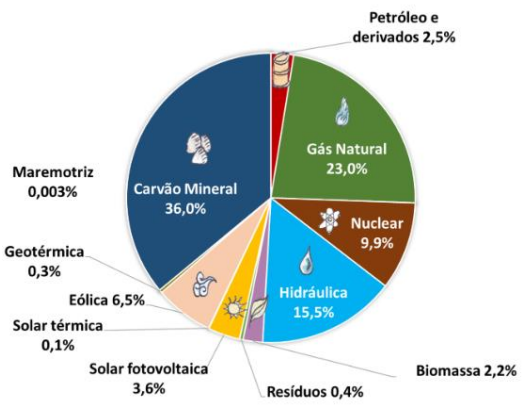
Based on information from EPE (2023), there is some confusion regarding the concepts of energy matrix and electrical matrix. The energy matrix includes sources for vehicles, stoves, and electricity, while the electrical matrix is restricted to electricity generation, being part of the energy matrix. The energy matrix encompasses renewable and non-renewable sources. Renewable energy, according to Bozio (2018), is energy obtained from natural sources that are practically inexhaustible and capable of regenerating over time. Unlike fossil fuels, whose reserves are limited and non-renewable, renewable energy sources are sustainable in the long term.

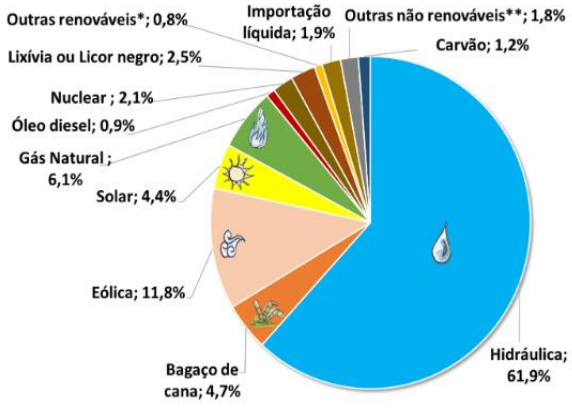
Electricity is of fundamental importance for the development of today's societies, as it can generate light, heat, sound, and mechanical power. Widely used, it is mainly generated in hydroelectric plants, harnessing the potential of water, but also in wind, thermoelectric, solar, and nuclear plants (EPE 2023; MME 2022, 2023).

Composition of the global and Brazilian electricity matrices

Based on indicators provided by the MME (2022, 2023) and EPE (2023, 2024), the global electricity matrix is predominantly sustained by non-renewable sources, especially through the use of fossil fuels, such as coal and natural gas, in thermoelectric plants, as illustrated in Figure 1a. However, this research also reveals that the updated survey of the composition of the Brazilian electricity matrix is mostly composed of renewable sources, thus diverging from the global electricity matrix. These composition indicators are presented in Figure 1b.

When analyzing the indicators, it can be seen that renewable sources, such as solar and wind, account for only 10.1% of the global electricity matrix. Incorporating the contribution of hydroelectric power, the total share of renewable sources reaches 25.6%. The composition of the Brazilian electricity matrix differs significantly from the global average, revealing a more significant use of renewable hydro sources. The combination of solar, wind, and hydro sources reaches a remarkable 78.1%, representing more than half of the national electricity matrix. Notably, 61.9% of this total comes from hydroelectric generation.





World Electricity Matrix 2021 (first graph). Brazilian Electricity Matrix 2022 (second graph)

Figure 1: Composition of the global and Brazilian electricity matrices. Source: (EPE 2022 and 2023)

Importance and impacts of hydroelectric and wind power plants

Bermann (2012) conceptualizes that hydroelectric plants exploit the potential energy of moving water, using dams to create reservoirs and establish height differences. The water released from this height is directed to turbines, driving electric generators and converting kinetic energy into electricity. This is considered a clean and renewable method of generation, as it does not involve the burning of fossil fuels.

However, according to researchers Albuquerque Filho et al. (2010) and Molle et al. (2012), and Pereira et al. (2023), hydroelectric plants, despite their importance in the global and Brazilian electricity matrix, can have environmental impacts, such as changes in the hydrological regime, displacement of communities, and problems in reservoirs, such as sedimentation and impacts on fauna and flora. Organic decomposition in reservoirs can also release greenhouse gases. Furthermore, according to Zhouri and Oliveira (2007), the socioeconomic impacts, in addition to the initial displacement, include changes in livelihoods and local cultural practices.

On the other hand, wind power generation presents itself as a promising alternative in the search for clean and renewable sources. In this method, the kinetic energy of the wind is converted into electricity by wind turbines. When the wind hits the blades, it transfers its kinetic energy to a generator, producing electricity. Wind farms optimize production efficiency. In addition to diversifying the energy matrix, wind power generation reduces greenhouse gas emissions, promoting a sustainable system (Freitas 2023; Kohler et al. 2021; Martins et al. 2008).

Although wind power is a clean and renewable source, it is not without environmental impacts, such as the risk of collisions for birds and bats, occupation of agricultural areas, concerns about noise, and altered landscapes. The production and disposal of turbines are challenges, and *offshore* turbines impact marine ecosystems. Many impacts can be mitigated with appropriate practices and innovations in the wind industry. The search for sustainable solutions is crucial (Carvalho et al. 2023; Mahela et al. 2020; Vital et al. 2023).

Reexamining the Brazilian electricity matrix (Figure 1b), the predominance of hydroelectric power stands out, representing 61.9% of the total available. Despite its importance, environmental impacts and complex construction pose challenges, leading to high tariffs, especially in dry periods. Wind power generation requires high investments, and environmental impacts, such as on wildlife and land use, are also significant. In reassessing these indicators, we reinforce the focus on sustainable energy generation via photovoltaics, an alternative for the global energy solution, taking advantage of Brazil's high solar radiation, especially in residential systems (Bühler et al. 2015; EPE 2023; Güntzel 2018; MME 2023; Molle et.al 2012).

Solar energy generation – photovoltaic

According to the National Institute for Space Research (INPE 2019), Brazil does not yet have the highest radiation rates in the world; however, as a tropical country, it retains an average potential of 2000 kWh/m²/year, which is already sufficient for good use of this energy matrix. According to studies conducted in the second edition of INPE's Brazilian Solar Energy Atlas, even in the southern region, which has the lowest solar radiation levels, there is a certain advantage to using photovoltaic systems (Barbosa Filho et al. 2015; ECOM 2020).

Photovoltaic solar energy is generated by systems that convert sunlight directly into electricity. Photovoltaic cells, usually composed of silicon, absorb sunlight and transform it into electrical current. Grouped into modules or solar panels, they form the basis of solar systems. The direct current (DC) generated is converted

into alternating current (AC) by an inverter. The electricity can be used locally, integrated into the power grid, or stored in batteries. This type of electricity generation is considered clean and renewable, contributing to sustainability and reducing greenhouse gas emissions (Alves 2019; Kuramoto and Appoloni 2002; Soares 2018; Zhouri and Oliveira 2007).

Brazil's solar potential, combined with the risk of electricity shortages due to hydroelectric and thermoelectric plants, is driving the search for renewable alternatives. Photovoltaic generation stands out by exploiting a renewable source with less environmental impact than conventional forms. It is important to recognize and mitigate the environmental impacts of solar power plants, as photovoltaic systems, whether centralized or decentralized, are growing globally, driven by demand and resource constraints, aggravated by environmental degradation (ANEEL 2022; Barbosa Filho et al. 2015; Lima et al. 2022).

Photovoltaic plants can be implemented in two systems, both using solar panels: *On-grid*, connected to the distribution network (centralized generation), and *Off-grid*, not connected to the network (decentralized generation). Both contribute to the transition to cleaner energy sources, reducing gas emissions and dependence on fossil fuels. The benefits include a reduced carbon footprint, resource conservation, and climate impact mitigation. However, the implementation of photovoltaic plants presents challenges, such as resource consumption in the production of panels, the need for effective waste management, and, in some cases, changes in land use. It is essential to address these aspects to ensure a sustainable transition (Oliveira 2023; Boggian 2023; Soares 2018).

In *off-grid* systems, surplus production is stored in batteries, which play a crucial role in remote locations. However, to ensure effectiveness and reliability, challenges such as sizing, efficient storage management (batteries), and maintenance are essential. The initial cost can be high, and battery production and disposal can have significant environmental impacts, highlighting the need for sustainable approaches. Storage capacity directly influences the autonomy of the system (Subramaniam et al. 2020; Narasimhulu et al. 2023).

On-grid photovoltaic systems integrate with the conventional electricity grid, allowing direct injection of the electricity generated. This integration supplies local consumption and returns surpluses, generating credits. However, there are challenges and environmental impacts, especially in the quality of the injected energy. Variations in solar generation due to weather conditions can cause voltage and frequency instabilities, affecting the electricity supply and potentially damaging sensitive equipment (Benavente et al. 2018; Dantas and Pompermayer 2018; Freitas 2023; Mahela et al. 2020; Narasimhulu et al. 2023; Urbanetz junior 2010).

Returning to the analysis of Figures 1a and 1b, we note that the global electricity matrix, which is mostly non-renewable, contrasts with the Brazilian reality, which stands out for its successful transition to cleaner and more sustainable sources, with an emphasis on hydroelectric power. The rise of photovoltaic generation, taking advantage of the vast national solar potential, appears promising. However, environmental, technological, and regulatory challenges require a careful approach for an efficient and balanced transition. Innovative solutions, investment in cutting-edge research, development, and international cooperation are crucial (EPE 2023, 2024, 2022; MME 2023, 2022; PEB 2024; IMF 2024).

Materials and methods

This study was conducted using the advanced resources of the computer labs at the Evangelical University of Goiás, specifically using Elsevier's Scopus platform. This platform was chosen due to its recognized excellence in providing access to a wide range of scientific articles and academic reviews, which was essential for the depth of analysis required in this study.

Article Selection

We began the systematic review focused on the global purposes for the implementation of photovoltaic plants and their environmental and performance implications. The search was conducted on Scopus, using a combination of key terms such as *"solar energy," "photovoltaic," "performance," "power quality,"* and "*environmental impact."* We limited our search to articles published in the last five years, selecting those with a significant number of citations to ensure the relevance and timeliness of the data analyzed.

Inclusion and Exclusion Criteria

The inclusion criteria were strategically defined to select studies that specifically addressed the purposes of photovoltaic plants, as well as the associated environmental benefits and impacts.

The following were excluded:

- Articles published between 2018 and 2022 with fewer than 50 citations. However, for articles published in 2023, the citation count criterion was not applied.
- Publications without open access.
- Review articles and scientific articles published in languages other than Portuguese, English, Chinese, and German.
- Articles not published in the fields of engineering, energy, materials science, and environmental science.

Screening and Selection Process

The screening and selection process began with a rigorous analysis of titles, keywords, and abstracts. This was followed by a detailed review of the full texts to ensure compliance with the inclusion criteria. Two independent reviewers performed the final selection, resolving disagreements through consensus to ensure objectivity and accuracy in the selection of articles.

Data Analysis

We adopted a qualitative approach to data analysis, systematizing information related to the purposes, benefits, and impacts of photovoltaic plants. This analysis involved a careful synthesis of the results, allowing the identification of patterns and emerging trends in recent literature.

Study Quality Assessment

To ensure a thorough evaluation of the quality of scientific articles, a relevance matrix based on the citations attributed to each work was employed. In this sense, both the impact factor and the number of citations for each selected article were considered.

Tools and Software

We used Mendeley bibliographic reference management *software* to organize and manage the references collected, while data analysis was facilitated by the use of spreadsheets, allowing for efficient organization and detailed analysis of the data collected.

Results and Discussions

In this section, we present the results and discussion of this systematic review and scientometrics study on the global purposes for the implementation of photovoltaic plants, with an emphasis on environmental impacts and generation performance.

Selection of studies

Initially, 3,960 scientific articles were preselected. After applying filters on the Scopus platform, only 31 articles were selected. We excluded publications between 2018 and 2022 with fewer than 50 citations; for 2023, we included studies without this criterion to capture recent research. We also excluded publications without open access, review articles, and those written in languages other than English, Portuguese, Chinese, or German. We restricted the selection to articles in the fields of engineering, energy, materials science, and environmental science to ensure homogeneity. This rigorous selection resulted in only 31 articles, representing less than 1% of the initial total, highlighting the robustness of the selection process and the exclusion of unrelated research, ensuring consistency and relevance.

To understand the purposes of Photovoltaic Plants (UF), we present Table 1 with detailed indicators. The indicators were categorized into Environmental Consequences (impacts and benefits) and Generation Performance (governance, productivity, use of algorithms, and operational optimization).

Table 1 - Stratification of the selection of scientific studies related to the implementation of Photovoltaic Plants

Indicators analyzed	Total	Percentage	Subdivision of indicators	Periods studied				
				2023	2022	2021	2020	2019
Environmental Consequences	6	19.4	Environmental impacts	4				
			Environmental benefits	1		1		
Generation performance	24	77.4	Governance	2				
			Productivity	6			1	1
			Use of algorithms	4				1
			Operational optimization	4		1	1	2
Not directly correlated	1	3.2	***				2	
Total	31			21	0	2	4	4

Source: Prepared by the authors (2024)

Environmental consequences and benefits for the development of FUs

The analysis of the indicators shows that only 6 articles focused on environmental consequences, representing 19.4% of the total. Of the 6 studies, 5 were published in 2023, with 4 related to environmental impacts and 1 to environmental benefits. In 2021, only one study was published, which evaluated the environmental benefits of the construction and implementation of photovoltaic plants.

Among the studies evaluated, the work by Razmjoo et al. (2021) published in *Renewable Energy* (UK) stands out. This study addresses sustainable hybrid systems, including photovoltaic solar energy, for clean and sustainable electricity generation in Iran, with an emphasis on reducing CO2 emissions. The study emphasizes the importance of policies and investments in renewable technologies to boost sustainable energy. In examining indicators related to environmental impacts, we highlight the research by Abid et al. (2023) published by the *Ecological Engineering and Environmental Technology* Journal (Poland). In this work, the researchers point out that the implementation of UF plants brings several benefits, however, they critically highlight the environmental impacts, emphasizing not only the high cost of installation, but also the low operating efficiency of UF plants. Although recent, the publication has already been cited five times, indicating the relevance and impact of the study on the scientific community (Rabaia et al. 2021).

Continuing the analysis of Table 1, it is essential to highlight that generation performance has been the main focus of researchers in UF implementations. In this context, governance, productivity, algorithm use, and operational optimization indicators stand out as essential elements for ensuring the efficiency of photovoltaic electricity generation and/or conversion systems. Together, these indicators account for 74.2% of researchers' interests.

Generation Performance of FUs

Reinforcing the predominant focus on generation performance efficiency, significant studies such as those by Benavente et al. (2018) and Subramaniam et al. (2020) published in Energy Magazine (United Kingdom and Switzerland), with 55 and 50 citations, respectively, are noteworthy. These studies addressed battery testing aimed at improving service life and increasing charge availability to boost productivity, including system operating modes.

As for the most relevant scientific contributions related to the productivity indicator, we highlight Talapur et al. (2018) and Dehghani Tafti et al. (2019). Talapur et al. (2018), with 127 citations, proposed modified control techniques to compensate for reactive power demands, harmonic currents, and load imbalances, ensuring improved operation. Dehghani Tafti et al. (2019), with 75 citations, tested a Flexible Power Point Tracking (FPPT) algorithm model, presenting a rapid response to environmental changes and low power oscillations, contributing to improving the performance of UF plants.

Regarding the use of algorithms and computer simulations, when analyzing the selected articles, we noticed considerable use of these tools. This approach was widely adopted by researchers, seeking to improve both the performance of the plants and achieve more effective results in terms of environmental benefits and reduction of the impacts caused by UF facilities.

Lack of correction with the studies

Of the 31 articles analyzed, we identified that one of them did not have a direct correlation with the theme of this systematic and scientometric analysis. The research by Mahela et al. (2020) addresses technical issues related to the injection of surplus electricity from wind power sources. Although it touches on the topic of energy generation, we chose to exclude this specific study from our more in-depth analysis, since its approach focuses on a different source than that analyzed in the other articles, which are predominantly dedicated to photovoltaic solar energy.

Main keywords

According to studies by Galvão and Ricarte (2019) and Kugley et al. (2017), keywords are essential in scientific communication, functioning as entries for the identification, access, and understanding of works. Accurate selection facilitates efficient information retrieval, increasing the visibility of works. Relevant keywords contribute to consistent indexing, simplifying the categorization of knowledge. Therefore, investing in the appropriate choice of these words is essential to maximize the impact of researchers' contributions. Thus, we exported the keywords used in the selected articles and used a tool to create a word cloud to identify which words were most frequently used. This set of words is shown in Figure 2.

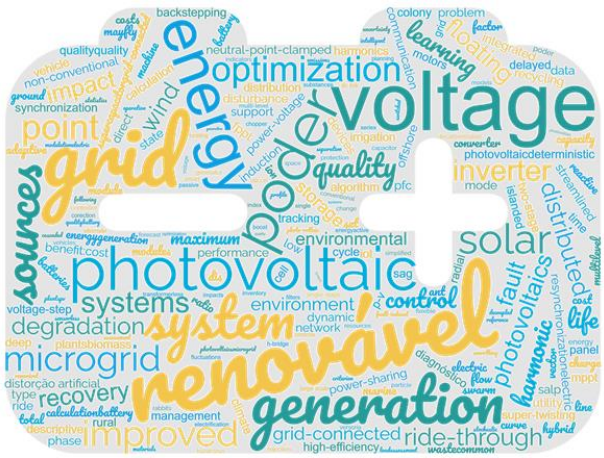


Figure 2 – Stratification of the keywords most used by authors in the selected articles. Source: Prepared by the authors (2024)

When analyzing Figure 2 and the report from *the WordClouds* – Tag Cloud (2024) technological tool, we identified that the most prominent words are related to the performance of UFs, highlighting the use of terms such as - power (20), - *energy* (15), - *photovoltaic* (13). Regarding environmental issues, words such as *renewable* (8), *environment/environmental* (3), and *impact* (2) stand out. Therefore, the preferences of researchers are once again evident and align with the results presented in Figures 1a and 1b – studies on the generation performance of UFs.

Number of publications per country

In order to deepen our understanding of the countries that have stood out in research on the purposes for the development of Photovoltaic Plants (UFs), we performed a stratification and present the results in Figure 3. In this graphic representation, we highlight the number of publications by country of origin, accompanied by the respective percentage in relation to the total of 31 publications.

In analyzing this survey, we highlight that the United States of America (USA) leads with 9 publications, followed by Switzerland with 8 and the United Kingdom with 4, collectively representing 67.7% of the total studies. Furthermore, according to the International Monetary Fund Report (2024), these countries occupy prominent positions among the world's largest economies, ranking 1st, 20th, and 6th, respectively. This correlation highlights the relevance of these nations in research on the subject in question, reinforcing the influence of these countries both in terms of scientific production and economic power in the UF scenario.

We also identified that the predominant language in the originals is English, with the United Kingdom (189), Germany (137), and the United States (127) standing out in terms of the number of relevant publications by citation count. In addition, we found diverse participation by researchers from various nations in this context. This multilateral approach contributes significantly to the scope and representativeness of the research, enriching the discussion on the purposes for the development of UF. The diversity of countries of origin of the researchers offers a global and enriching perspective for understanding these purposes, promoting a more inclusive and open dialogue in the scientific field.

The classification of the three main scientific journals was carried out with the aim of highlighting the influence and relative relevance of these publications. We considered both the impact factor, which represents the number of citations received by published articles, and the citation index, known as *CiteScore*, which represents the annual average number of citations of the publication. The three journals, along with their respective impact factor and citation index values, are: *Renewable Energy* (USA) with an impact factor of 16.1 and *CiteScore* of 8.7, *Environmental Chemistry Letters* with an impact factor of 15.7 and *CiteScore* of 14.04, and

Applied Energy with an impact factor of 11.2 and *CiteScore* of 21.1. This approach aims to provide a clear view of the importance of these journals in the scientific landscape.

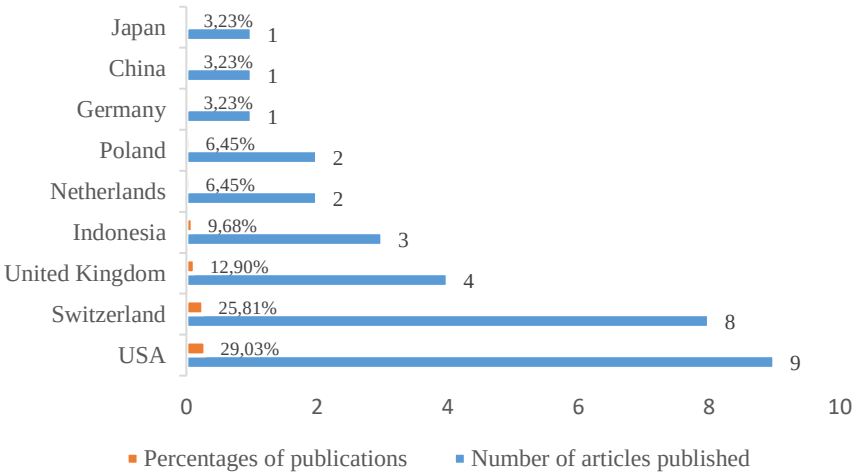


Figure 3 – Survey and stratification of publications by country of origin of scientific journals. Source: Prepared by the authors (2024).

Publication gap in 2022

In the 2022 academic publication indicator, we note the absence of specific works on the global purposes for the development of photovoltaic plants, focusing on environmental consequences and generation performance. Although we cannot say with certainty the reasons for this gap, it is plausible to consider that several factors, including the global situation due to the Covid-19 pandemic, may have influenced the production and dissemination of scientific research during this period. We highlight that many of the articles analyzed, although accepted by journals in 2022, were only effectively published in 2023.

Conclusion

Based on the studies in this systematic and scientometric review of photovoltaic plants, in the introductory approach, we highlight the relevance of the Brazilian electricity matrix in the transition to cleaner sources, with an emphasis on hydroelectric power. Contrary to the global electricity matrix, which is predominantly non-renewable, a successful transition is evident in Brazil. The rise of photovoltaic generation, taking advantage of solar potential, presents a promising outlook. However, environmental, technological, and regulatory challenges require attention to ensure efficiency. The study highlights the importance of innovative solutions and international cooperation for a sustainable future in electricity generation.

In the Results and Discussions section, we observe a predominant emphasis on research focused on performance optimization at the expense of environmental benefits, highlighting the need for greater attention to this crucial dimension, given the scarcity of specific studies on environmental impacts. We present our conclusions on this statement:

- Governance indicators, productivity, use of algorithms, and operational optimization accounted for 74.2% of the publications analyzed.
- The studies focused on improvements in service life and operational efficiency, highlighting a significant focus on generation efficiency.

- The keywords highlighted an emphasis on plant *performance*, indicating a prioritization of this aspect in the studies.
- Geographic representation highlighted the United States, Switzerland, and the United Kingdom as leaders in research on the development of photovoltaic plants.
- The journals highlighted works with high impact factors and citation numbers in environmental issues, such as *Renewable Energy* (United Kingdom) and *Environmental Chemistry Letters* (Germany), as well as in generation performance.

This review therefore offers valuable insights for researchers, professionals, and policymakers, providing an in-depth view of current approaches to research on photovoltaic power plants. Despite the focus on performance optimization, the importance of balancing operational efficiency with environmental considerations for the sustainable advancement of photovoltaic energy is highlighted.

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