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Research Article

Implications Of Photovoltaics And The Use Of Algorithms For Economic Development

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ABSTRACT

INTRODUCTION: Photovoltaic energy is a renewable, clean, and safe energy source obtained from sunlight. The challenges facing governments are challenging and require significant efforts to promote it as a solution to the global climate crisis and to help reduce environmental pollution. Emerging countries have seen the need to establish policies promoting photovoltaic energy supported with cutting-edge technologies and algorithms to achieve economic development. OBJECTIVES: Este trabajo tuvo por objetivos analizar las implicaciones de la energía fotovoltaica y el uso de algoritmos para el desarrollo económico. METHODS: The study used the bibliometric method of articles from 2013-2023. The information was obtained from the Scopus database. The analysis was done with the VOSviewer program, which allowed the creation of author maps through co-citation and keyword maps through co-occurrence.
RESULTS: The total number of articles found in the study period was 135. The results of the analysis of the co-occurrence of keywords by the author revealed the formation of two clusters. The first cluster identified with red color is related to photovoltaic efficiency, whereas the second cluster is related to sustainable development. For 2023, the research interest has turned to studies on the use of Machine Learning. CONCLUSION: The search terms used showed that globalization and the development of algorithms have posed new challenges for countries to adopt new technologies to achieve economic development. As the years have passed, scientific production has increased, as evidenced by the notorious increase of articles in 2021, 2022, and 2023. A line of research has been generated on machine learning, which requires multidisciplinary studies that enable the generation of knowledge on this subject applied to photovoltaic energy and economic development.

Keywords: Renewable energies, Artificial Intelligence, Sustainable development, 2030 Agenda, Machine Learning, Bibliometric analysis.

1. Introduction

Photovoltaic Energy (PE) is a clean and safe renewable energy source from sunlight (Buitrago-Rodríguez (2023); González-Vallejo (2023)) The challenges governments face are challenging and require significant efforts to promote them as a solution to the global climate crisis and to help reduce environmental pollution (Quiroz-Leal & Eslava-Zapata (2023); Andrade-Girón et al., (2023)). Emerging countries have seen the need to establish policies that promote PE, supported by cutting-edge technologies and algorithms, to achieve Economic Development (ED) (Fernández-Delgado et al. (2022); Tápanes-Suárez et al. (2023)).
Globally, the use of photovoltaic energy has been on the rise, given the concern for generating renewable energies to comply with the 2030 Agenda (Borges-de-Souza et al. (2023); Palomino-Quispe et al., (2023)).

Currently, the problem of climate change requires governmental measures that favor environmental protection and the generation of clean energy to the detriment of the use of fossil fuels (Eslava-Zapata et al. (2023); Cisnero-Piñeiro et al. (2022)). However, emerging countries are still far from meeting the objectives of the 2030 Agenda since they are not making the necessary investments as other countries are doing, such as China, which is implementing innovative strategies, for example, electric transportation, to achieve positive transformations in environmental protection (Burgos-Moncada, 2018; Ramírez et al., 2023).

The PE is generated through solar panels, which are non-polluting because they do not emit greenhouse gases; this ends up favoring Sustainable Development (SD) since the resources of future generations are not compromised (Alamelu & Mythili (2022); Vázquez-Vidal & Martínez-Prats (2023)). Since solar energy is available worldwide, there is a reduction in energy imports, allowing countries to achieve SD and generate wealth (Eslava-Zapata et al. (2022); Gómez-Ortiz & Durán (2023)).

Over the years, the PE has gone through stages of stagnation, growth, and regulatory changes, positioning itself today as a clean energy competitive with other types of energy (He et al. 2023). Therefore, the PE promotes the development of communities and countries' economies thanks to job creation and low electricity generation costs promoted by the circular economy (Ding et al. 2023).

The growth of solar energy and the costs for its production are becoming significant. In some countries, such as India, the cost of PE is lower than that of coal or gas (Barbón et al., 2023). In addition to costs, there is a reduction in prices due to the escalation of the market in the commercialization of solar panels; even the World Bank (WB), in collaboration with emerging countries such as Turkey and Morocco, is strengthening the legal frameworks to lay the foundations for the expansion of the PE. The support of the WB is provided throughout the value chain, from advice on regulations to partnerships with the public-private sector and the granting of financing (Yuan et al., 2023)

The social contributions of the PE are diverse, including the fact that this type of energy can be generated anywhere, favoring communities where it is challenging to have electricity grids as we know them (Shao et al., 2023) In this way, homes, businesses, industries, and hospitals, among others, can cover their energy needs at a low cost and more environmentally friendly way (Guatemala-Mariano & Martínez-Prats, 2023).

Therefore, this study aimed to analyze the implications of PE and the use of algorithms in ED. Based on bibliometric analysis, the production of scientific articles in the Scopus database for 2013-2023 was reviewed. In this sense, 135 articles met the criterion with the search filter used, and the data were analyzed with the VOSviewer program.

2. Methods

The study used the bibliometric method of articles dealing with PE and algorithms in the period 2013-2023 to know their implications on ED (Solarte-Solarte et al., 2023). The search filter was (TITLE-ABS-KEY (photovoltaic AND energy) AND TITLE-ABS-KEY (algorithms) AND TITLE-ABS-KEY (economic AND development)) AND PUBYEAR > 2012 AND PUBYEAR < 2024 AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (PUBSTAGE , "final"))).

The information was obtained from the Scopus database, and the analysis was done with the VOSviewer program, which allowed the creation of author maps through co-citation and keyword maps through co-occurrence (Del-Campo-Saltos et al., 2023).

3. Results

The total number of articles found in the study period was 135. Table 1 shows the trend in research. The results reveal that from 2013 to 2020, the publications remained between 1 and 15, while for the last three years, the production jumped significantly, as can be seen in the years 2021 (20), 2022 (35), and 2023 (41).

Research on PE and the use of algorithms to achieve ED has increased in recent years, mainly due to the interest in evidencing progress in meeting Sustainable Development Goal (SDG) 7, which is access to affordable and sustainable energy for poverty reduction (Niekurzak & Mikulik, 2023).

The PE makes essential contributions to health due to the non-generation of greenhouse gases, favoring the reduction of the greenhouse gas footprint; in addition, photovoltaic panels have a useful life of thirty years, their maintenance is low cost, and they generate little noise. It should be noted that PF is playing a fundamental role in achieving energy sovereignty in emerging countries by leaving fossil fuels aside (Li et al., 2023).

Table 1. Documents by year

YEAR	DOCUMENTS
2023	41
2022	35
2021	20
2020	8
2019	7
2018	15

2017	11
2016	7
2015	9
2014	1
2013	1

Table 2 shows the ten most productive authors. In this regard, the first four places are occupied by Liu, N. (4), Das, B.K. (3), Hassan, R. (3) and Senjyu, T. (3).

Table 2. Top 10 authors with the highest number of publications

N°	AUTHOR NAME	DOCUMENTS
1	Liu, N.	4
2	Das, B.K.	3
3	Hassan, R.	3
4	Senjyu, T.	3
5	Adewuyi, O.B.	2
6	Gabbar, H.A.	2
7	Hua, Q.	2
8	Jurado, F.	2
9	Kamel, S.	2
10	Khan, B.	2

Table 3 shows the ten most influential countries in PE research using algorithms. The first five places are occupied by China (46), India (19), Egypt (11), Iran (11) and Spain (11). The results demonstrate the interest of researchers in these countries in generating new lines of research.

Universities, together with governments, companies, and international agencies, have shown their concern for climate change and the need to take energy measures that support sustainability and the protection of the planet (Saxena et al., 2023).

The idea is not only the incorporation of the PE but also how to deal with photovoltaic waste in the future. Hence, researchers and environmentalists have suggested enacting standards and policies in favor of the circular economy to recover and reuse materials (Sengor et al., 2023).

The transition to the PE requires government intervention to ethically lead the transition to this energy model to improve people's quality of life and achieve SD (Sun L. et al., 2023).

Table 3. Top 10 countries with the highest number of publications

N°	COUNTRY/TERRITORY	DOCUMENTS
1	China	46
2	India	19
3	Egypt	11
4	Iran	11
5	Spain	11
6	Italy	10
7	Saudi Arabia	9
8	United Kingdom	9
9	Australia	7
10	United States	7

Table 4 shows that the five main areas of study are Energy (111), Engineering (95), Environmental Science (43), Mathematics (30) and Computer Science (24).

The PE using algorithms requires research in fundamental areas to generate component testing, review material technologies, and design algorithms that enable efficient PE production. Solar communities and agrovoltaic energy are gaining relevance in the academic field since, from a financial point of view, the investment can be recovered in the medium term, and from an environmental point of view, it contributes to mitigating global warming (Yin & Liu, 2023).

The partial or total implementation of the PE implies the connection of critical academic networks in the different areas of study that lead to the search for energy solutions for the countries and encourage the environmental culture in the social and organizational environment (Amoussou et al., 2023).

Table 4. Top 10 subject area

N°	SUBJECT AREA	DOCUMENTS
1	Energy	111
2	Engineering	95
3	Environmental Science	43
4	Mathematics	30
5	Computer Science	24
6	Materials Science	15
7	Business, Management and Accounting	13
8	Social Sciences	11
9	Physics and Astronomy	7
10	Chemical Engineering	4

One document per author and seventy-two citations were considered for the analysis of Co-Authorship Author-Authors. Out of 306 authors, only 20 authors met the criterion. The first three places in citation were occupied by Xu X. et al. (204), Belmili H. et al. (181), and Das M. et al. (173). The results reveal independent citation independence among the authors (Table 5).

Table 5. Top 10 of Co-Authorship Author - Authors

N°	AUTHOR	YEAR	CITATIONS
1	Xu X. et al.	2020	204
2	Belmili H. et al.	2014	181
3	Das M. et al.	2019	173
4	Wang J. et al.	2018	154
5	Azaza M. et al.	2017	148
6	Wang Y. et al.	2018	146
7	Wang R. et al.	2011	142
8	Obi M. et al.	2017	136
9	Bala B.K. et al.	2009	133
10	Schopfer S. et al.	2018	127

As for the Co-Authorship Author - Countries analysis, five documents, and sixty citations were used. Of 66 countries analyzed, only 20 met the criterion. Table 6 shows that the countries with the most documents published are China (113), India (29) and Iran (17). At the same time, the countries with the most citations per paper are China (1694), the United Kingdom (613), and Denmark (416).

The results in Table 6 reveal that China is leading in research output and has the most citations to its credit. The transformation of China's economy has been closely linked to generating renewable energies, which is conducive to reducing carbon emissions. China's economic growth in 2023 has been closely associated with the energy transition, given ambitious decarbonization targets and the production of technologies that drive the commercialization of PE across continents. (Zeng et al., 2023).

India is also among the countries generating the most research on PE. Notably, India is one of the fastest-growing economies in the world and is pursuing expansion strategies in the energy market, considering its natural wealth. (Bawazir et al., 2023) In addition, the country's technological potential is fostering economic growth and job creation. It provides a likely opportunity to generate knowledge that will support India in achieving sustainable goals with a less polluted landscape (Mohapatra et al., 2023).

Table 6. Top 10 most cited documents by country

N°	COUNTRY	DOCUMENTS	COUNTRY	CITATIONS
1	China	113	China	1694
2	India	29	United Kingdom	613
3	Iran	17	Denmark	416
4	Egypt	16	India	398
5	Saudi Arabia	16	Algeria	383
6	Spain	16	Iran	327
7	United Kingdom	16	Italy	299
8	United States	16	Australia	288
9	Italy	15	United States	275
10	Algeria	10	France	222

The bibliographic coupling of the countries highlights the formation of three clusters (Figure 1). The first cluster identified with red is China, Denmark, Germany, Iran, South Korea, the United Kingdom, and the United States. The second cluster, identified with green, comprises Australia, Bangladesh, Canada, Egypt, India, Japan, and Nigeria. The third cluster, identified with blue, comprises Algeria, France, Italy, Saudi Arabia, Spain, and Sweden.

There are more and more scientific cooperation projects between countries to modernize the energy matrix and advance in global challenges and the energy sector (Cheraghi & Hossein-Jahangir, 2023). Although China leads in photovoltaic installed capacity, other countries are building robust photovoltaic parks that will allow them to catch up with the rest of the world, including the United States, India, Japan, Brazil, Germany, and Spain (Mazzeo et al., 2023).

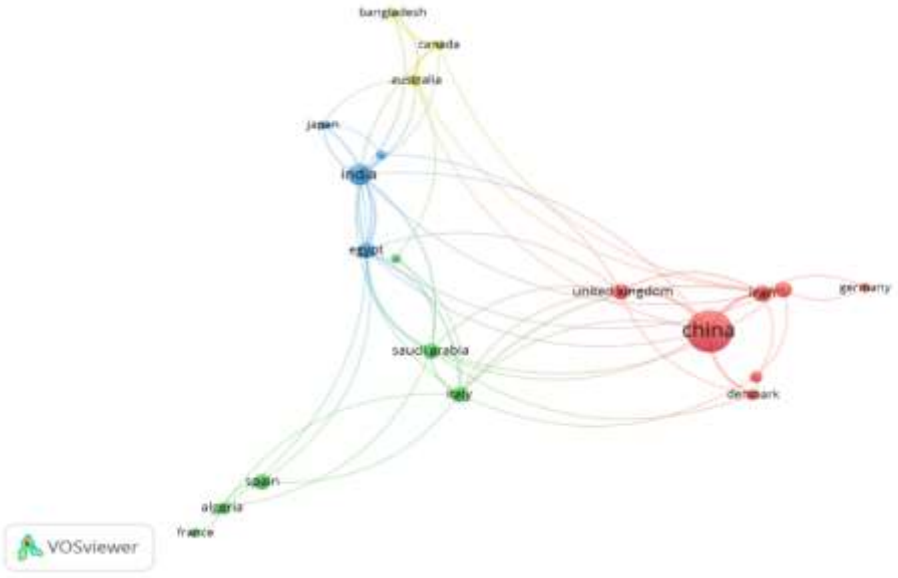

Figure 1. Co-Authorship Author - Countries

A minimum occurrence of thirty-six was used to analyze the Co-occurrence of All Keywords. The results showed that 14 words met the criterion. Six common words were joined with the thesaurus file.

Two distinct clusters were formed (Figure 2). The first cluster identified with the red color is made up of the words Economic and Social Effects, Electric Power Transmission Networks, Genetic Algorithms, Multiobjective Optimization, Particle Swarm Optimization (PSO), Photovoltaic System, Solar Energy, and Wind Power.

The second cluster, identified with green, comprises Economic Analysis, Energy Efficiency, Energy Storage, Investments, Renewable Energy, and Sustainable Development.

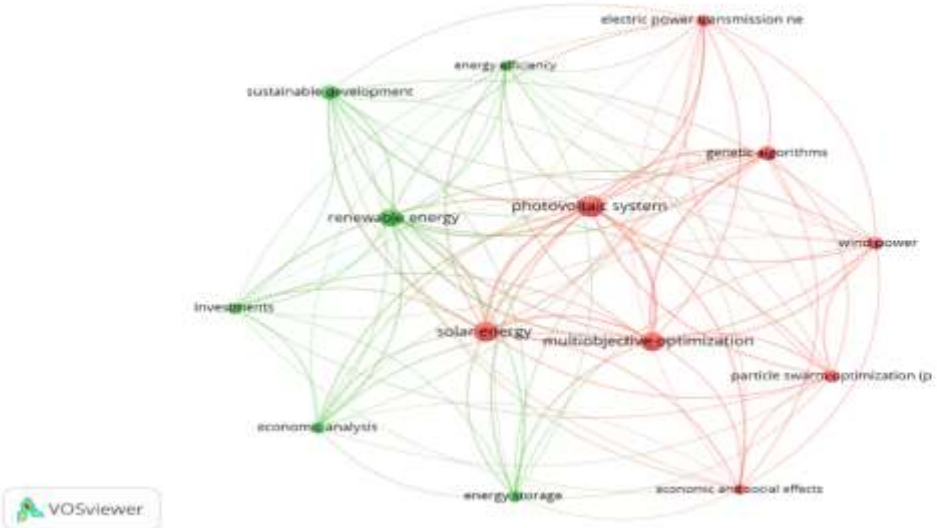

Figure 2. Co-ocurrence All Keywords

4. Discussion

For the analysis of Co-occurrence - Author Keywords, the criterion of a minimum keyword occurrence of six was used. The results show that 15 words met the criterion. Nine common words were joined with the thesaurus file.

The results revealed the formation of two clusters (Figure 3). The first cluster identified with the red color is composed of the words Demand Response, Energy Management, Genetic Algorithm, Hybrid Energy System, Machine Learning, Multiobjective Optimization, Particle Swarm Optimization, Photovoltaic System, and Solar Energy. This cluster is related to photovoltaic efficiency. Algorithms enable the development of higher-quality panels, facilitating electricity generation with the solar energy received (Afzali et al., 2022). Therefore, the efficiency of the panel will be determined by the effectiveness of the cell, heat accumulation, and clouds, among other factors (Sun Y. et al., 2023).

Here also comes into play the performance, which is the ability of the solar panel to convert solar energy into electrical energy (Chen et al., 2023). Also, algorithms become essential, considering the potential to predict climate changes to optimize energy systems (Coronado-Espinoza et al., 2023). There is a diversity of algorithms in the market that allow predicting the production of PE, for example, r SVR, Dual Descent by Coordinates, or Pegasos, among others, which allow users to know in advance the production of PE and manage resources (Wang et al., 2023).

The second cluster, identified with green, comprises the words Distributed Generation, Electric Vehicle, Energy Storage, Microgrid, and Renewable Energy. This cluster is related to sustainable development (Kishore-Veparala & Kalpana, 2023). The PE allows using solar energy to generate electricity to improve people's quality of life and the planet's conditions (Afanador-Cubillos, 2023).

Countries' economies are gradually decarbonizing with unprecedented PE installed capacity. However, the PE also requires sustainable management beyond the procurement and commissioning of energy parks (Alshammari et al., 2023). It is also necessary to think about good practices that generate benefits for ecosystems and human beings to comply with the SDG (Rodríguez-Torres et al., 2022). Also, countries must assume criteria framed in the circular economy to ensure the recycling of PE equipment at the end of its life cycle to contribute to reducing toxic and solid waste (Flórez-Márquez, et al., 2023).

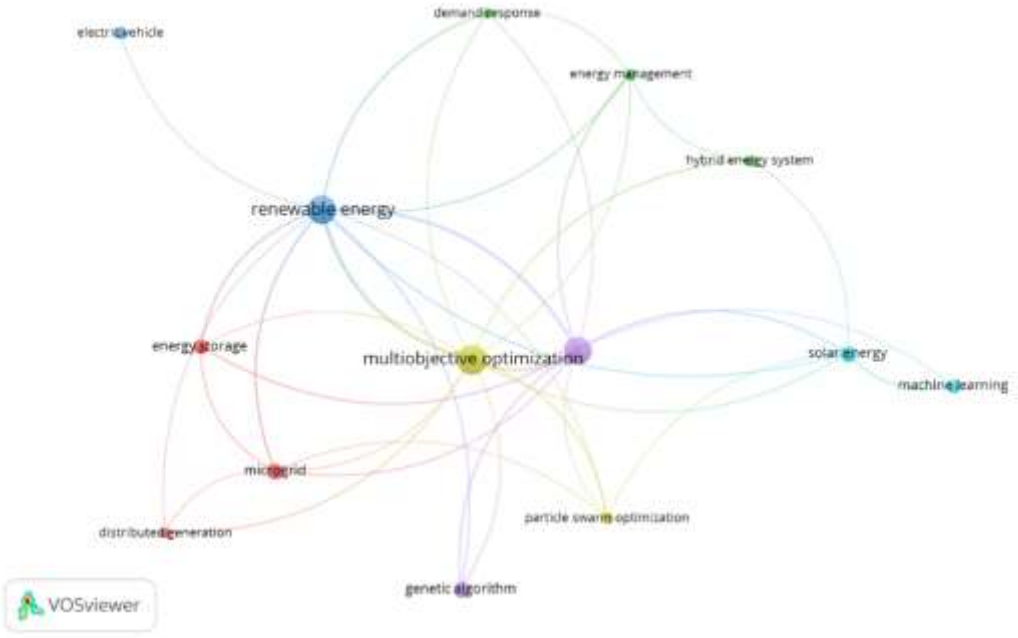

Figure 3. Co-ocurrence – Author Keywords

Figure 4 shows the trend in research. The data show that by 2021, there was an interest in Renewable Energy, Multiobjective Optimization, and Energy Storage research. By 2023, the interest has turned to studies on Electric vehicles and Machine Learning, which requires multidisciplinary studies that enable the generation of knowledge on this subject of study applied to PE and ED.

Machine learning allows computers to autonomously learn autonomously and handle large amounts of information (Madkar et al., 2022). It will undoubtedly mark the research in the study of PE and its effects on ED (Sanabria-Martínez, 2022).

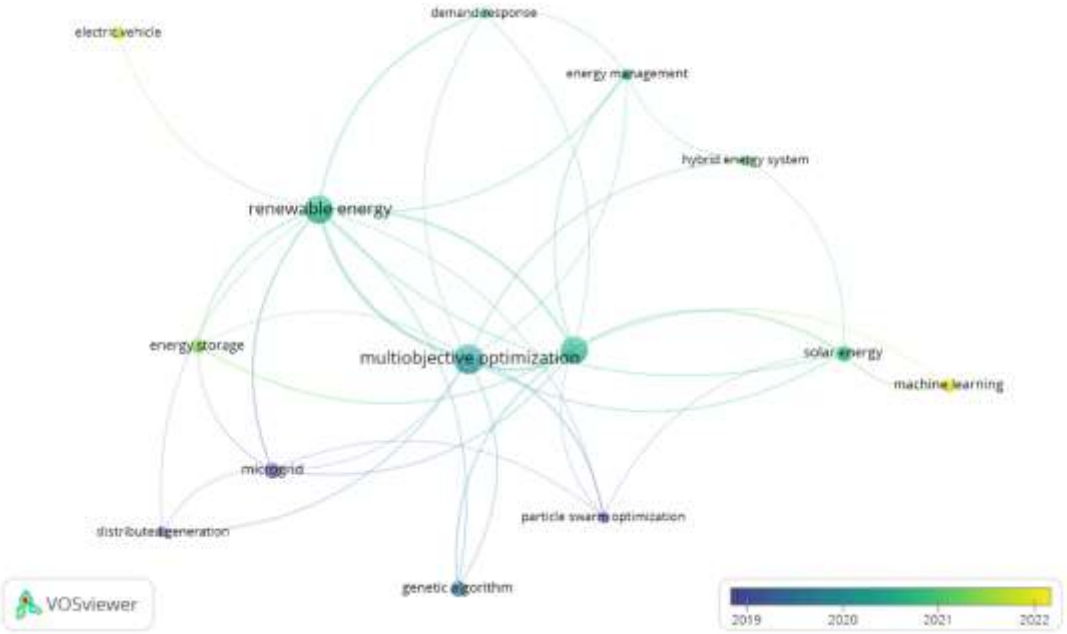

Figure 4. Overley of Co-ocurrence - Author Keywords

5. Conclusions

This research provides a holistic view of the scientific production of PE and the use of algorithms to understand their implications for ED in the last ten years. The search term demonstrates that globalization and the development of algorithms have posed new challenges for countries to adopt new technologies to achieve ED. As the years have gone by, scientific production has been increasing, evidenced by the notorious increase of articles in the years 2021, 2022, and 2023. It is noted that the Asian continent is leading the research, with China at the forefront, followed by India and Iran. However, Egypt also leads an influence in Africa, and in Europe, Spain is the most active country.

A line of research has been generated on machine learning, which requires multidisciplinary studies that enable the generation of knowledge on this topic applied to PE and ED. This work will guide academics and researchers in emerging fields of study aimed at generating knowledge in their educational institutions.

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