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Key players in renewable energy and artificial intelligence research

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Abstract

INTRODUCTION: As countries work on the transition towards renewable energies that comply with the 2030 Agenda and the sustainable development goals, Artificial Intelligence is presented as a tool that is being adopted to promote the generation of renewable energies such as solar or wind power. , given the support it offers to automation, assisted decisions, and production efficiency.
OBJECTIVES: To analyze the key players in renewable energy and artificial intelligence research.
METHODS: The Scopus database is used to obtain the scientific articles for the period 2013-2023, and the Visualization of Similarities program (VOSviewer 1.6.18) is used for data processing and analysis.
RESULTS: An analysis of 822 articles shows that the countries with the highest scientific production are China (148), India (136) and the United States (81). In this regard, it is clear that there is significant collaboration between countries. With regard to the analysis of Co-occurrence - Author Keywords, three clusters are generated. The first cluster, identified with the color red, is related to artificial intelligence management; the second cluster, identified with the color green, is related to artificial intelligence innovation; and the third cluster, identified with the color blue, is related to energy models.
CONCLUSION: Researchers are facing new challenges every day to respond to the irruption of the use of new algorithms in the generation of renewable energies, given the range of available tools such as deep learning or neural networks. Research results have revealed that in recent years, scientific production has understood that AI is not a trend but rather a challenge facing society, industry, countries, or education in order to achieve sustainable development.

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

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1. Introduction

The growth of energy demand worldwide and the dependence on fossil fuel-based energies is leading countries to seek Renewable Energy (RE) in order to meet Sustainable Development Goal 7 (SDG7) of the 2030 Agenda related to the generation of clean and sustainable energy. (1) (2) Solar and wind energy, among others, are presented as energy alternatives with great potential to produce safe and modern energy for society. (3) (4)

Energy is fundamental to life and affects employment, food production, and climate change. Energy is of vital importance to achieve Sustainable Development (SD). (5) (6) Hence, it becomes important for the emergence of initiatives that enable the modernization of current energy services in order to improve energy efficiency and inclusive communities. (7) (8)

RE and Artificial Intelligence (AI) play a key role in achieving the performance and performance of equipment. (9) (10) AI is currently facilitating energy efficiency with positive environmental impacts and enabling smart grid management by analyzing large amounts of data to predict energy demand

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or system failures, reducing downtime and production costs. [11] [12]

AI plays a crucial role in the resources needed, their efficiency, and risks. It also helps in the prediction and optimization of the data obtained, which helps to reduce costs in renewable energy production with positive impacts on the environment. [13] AI algorithms help to improve the performance of RE generation such as photovoltaic and wind; also, they allow to accurately predict failures in the operation of the systems, which prevents equipment downtime. [14] [15]

In view of the above, the objective of this research was to analyze the key players in RE and AI research. For this purpose, the Scopus database was used to obtain the scientific articles for the period 2013-2023, and the Visualization of Similarities program (VOSviewer 1.6.18) was used for data processing and analysis.

2. Methods

A bibliometric analysis was performed on RE and the use of AI. For this, they followed the steps for this type of study, ranging from searching for information in databases to knowing the current state of research. [16] The search equation was (TITLE-ABS-KEY ("renewable energy") AND TITLE-ABS-KEY ("artificial intelligence")) AND PUBYEAR > 2012 AND PUBYEAR < 2024 AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (PUBSTAGE , "final"))).

The articles published in the English language in the Scopus database in the period 2013-2023 were selected, excluding papers and books, among others; in this sense, 822 documents were found.

From the Scopus database, the CSV file was obtained, which was analyzed with the Visualization of Similarities program (VOSviewer 1.6.18) (www.vosviewer.com). [17] Among the analyses carried out were the collaboration between countries and authors and the co-occurrence of keywords. In order to refine the information obtained, the thesaurus file was used to join common words.

3. Results

Table 1 shows that 822 articles were produced in the period 2013-2023, with the highest scientific production concentrated in the years 2023 (245), 2022 (174) and 2021 (129).

Researchers in the last three years have shown interest in studying the use of AI with RD in order to promote SD and demonstrate compliance with the 2030 Agenda.

Table 1. This is a legend. Caption to go above table

YEAR	DOCUMENTS
2023	245
2022	174
2021	129
2020	73
2019	57
2018	29
2017	22
2016	38
2015	21
2014	24
2013	10
TOTAL	822

Table 2 shows the top 10 papers by the author, with Mosavi, A. (7), Mohammadzadeh, A. (6), and Zjavka, L. (6) occupying the first three places.

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

N°	AUTHOR NAME	DOCUMENTS
1	Mosavi, A.	7
2	Mohammadzadeh, A.	6
3	Zjavka, L.	6
4	Deo, R. C.	5
5	Rizwan, M.	5
6	Alaraj, M.	4
7	Almasoudi, F. M.	4
8	Guerrero, J. M.	4
9	Olabi, A. G.	4
10	Tavoosi, J.	4

Table 3 shows the top 10 documents by country. The first three places are occupied by China (148), India (136) and the United States (81). It is evident that countries with strong economies are leading in scientific production and are considering the possibility of linking RE with AI in order to promote SD.

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

N°	COUNTRY/TERRITORY	DOCUMENTS
1	China	148
2	India	136
3	United States	81
4	Saudi Arabia	71
5	United Kingdom	66
6	Iran	50
7	Spain	49
8	South Korea	41
9	Egypt	36
10	Germany	36

Table 4 shows the top 10 of the subject area. In this regard, the areas with the highest number of documents are Engineering (453), Energy (419) and Computer Science (234). It should be noted that these areas play a fundamental role in the study and development of affordable, efficient, and clean energy for all economic and social sectors.

Table 4. Top 10 subject area

SUBJECT AREA	DOCUMENTS
Engineering	453
Energy	419
Computer Science	234
Environmental Science	155
Mathematics	150
Materials Science	78
Social Sciences	62
Business, Management and Accounting	52
Physics and Astronomy	45
Chemical Engineering	39

For the analysis of Co-Authorship Author - Authors, a minimum number of documents of an author of 1 and a minimum number of citations of an author of 145 were considered; only 20 authors met the criterion.

Table 5 shows the top 10 Co-Authorship Author - Authors. The first three places are occupied by Chaouachi et al. (545), Tran K. et al. (480), and Kefayat et al. (307). The results showed that there is no collaboration among the authors; therefore, the papers are independent.

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

N°	AUTHOR	YEAR	CITATIONS
1	Chaouachi A.; Kamel R.M.; Andoulsi R.; Nagasaka K.	2013	545
2	Tran K.; Ulissi Z.W.	2018	480
3	Kefayat M.; Lashkar Ara A.; Nabavi Niaki S.A.	2015	307
4	Bhandari B.; Lee K.-T.; Lee G.-Y.; Cho Y.-M.; Ahn S.-H.	2015	269
5	Ahmad M.W.; Reynolds J.; Rezgui Y.	2018	267
6	Persson C.; Bacher P.; Shiga T.; Madsen H.	2017	259
7	Rahim S.; Javaid N.; Ahmad A.; Khan S.A.; Khan Z.A.; Alrajeh N.; Qasim U.	2016	247
8	Wei Y.; Yu F.R.; Song M.; Han Z.	2016	240
9	Liu Y.; Fan R.; Terzija V.	2016	229
10	Noorollahi Y.; Yousefi H.; Mohammadi M.	2016	223

As for the Co-Authorship Author - Countries analysis, considering a minimum number of documents of a country of 2 and a minimum number of citations of a country of 470, only 20 countries met the criterion.

Table 6 reveals the top 10 Co-Authorship Authors - Countries. The countries with the most documents are China (148), India (136), and the United States (81). As for the countries with the most citations, there is a slight change in the previous order, with China (3614) in first place, followed by the United States (3216) and India (2113).

Table 6. Top 10 Top 10 most cited documents by country

N°	Country	documents	Country	citations
1	China	148	China	3614
2	India	136	United States	3216
3	United States	81	India	2113
4	Saudi Arabia	71	United Kingdom	1951
5	United Kingdom	66	Iran	1828
6	Iran	50	Canada	1814
7	Spain	48	Saudi Arabia	1684
8	South Korea	41	Egypt	1214
9	Egypt	36	South Korea	1115
10	Italy	36	Italy	990

In this sense, there is an important collaboration between countries, given the formation of three clusters. The first cluster identified with the red color is made up of Australia, Egypt, India, Malaysia, Pakistan, Saudi Arabia, Taiwan, and Turkey. The second cluster identified with the color green is made up of Canada, China, Germany, Iran, South Korea, and the United States. The third and last cluster, identified with the color blue, is made up of Denmark, France, Italy, Japan, Spain, and the United Kingdom (Figure 1).

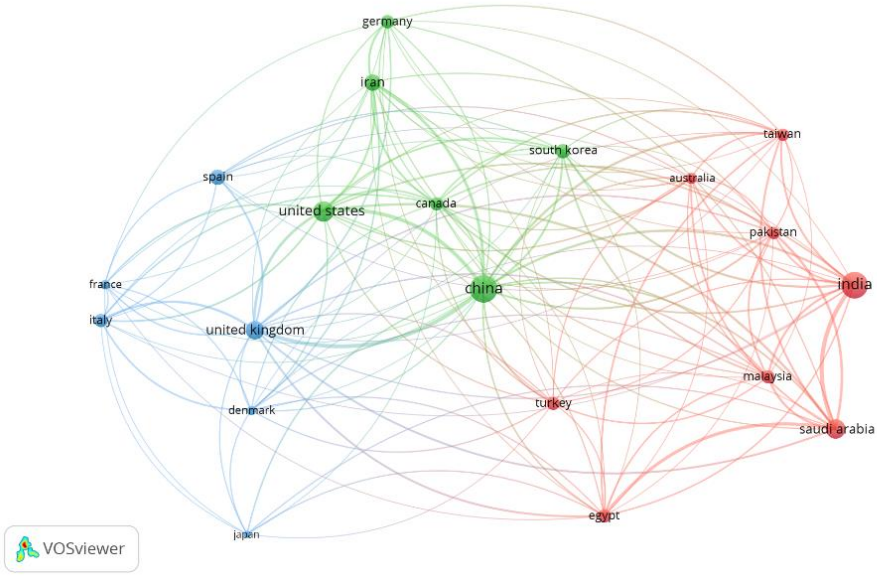

Figure 1. Co-Authorship Author - Countries

For the analysis of the Co-occurrence of All Keywords, a minimum number of occurrences of keywords of 54 was taken as a criterion. In this sense, out of 6927 keywords, only 19 words met the criterion. It should be noted that 4 common words were joined with thesaurus.

Three clusters were generated. The first cluster, identified with the color red, is composed of the words Alternative Energy, Artificial Intelligence, Decision Making, Decision Support Systems, Energy Efficiency, Energy Utilization, Optimization, Renewable Energy, and Sustainable Development.

The second cluster is identified with the color green. It is made up of the words Deep Learning, Forecasting, Learning Systems, Machine Learning, Machine Learning, Solar Energy, Solar Power Generation, and Wind Power.

The third and last cluster, identified with the color blue, is integrated by the words Electric Power Transmission Networks and Smart Grid (Figure 2).

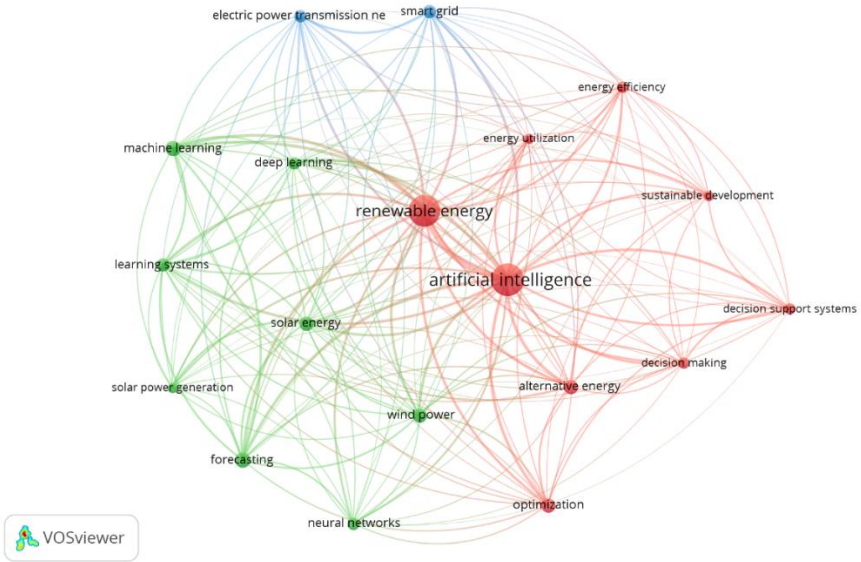

Figure 2. Co-ocurrence All Keywords

4. Discussion

For the analysis of Co-occurrence - Author Keywords, a minimum number of occurrences of keywords of 15 was considered. It was found that out of 2597 keywords, only 17 met the criterion. In this regard, 3 common words were joined with thesaurus (Figure 3).

Three clusters were formed. The first cluster, identified with the color red, is related to AI management. The cluster is integrated with the words Artificial Intelligence, Energy Efficiency, Energy Management, Microgrid, Optimization, Renewable Energy, and Smart Grid.

Currently, there are several proposals for the generation of RE that favor SD and the fulfillment of Agenda 2023; an example of this is the fourth and fifth-generation urban energy that seeks to replace the old energy generation based on boilers in order to provide systems that contribute to the reduction of greenhouse gas emissions [18] and the development of integrated energy systems that guarantee urban sustainability. [19] [20].

Also, work is being done on remediation with the support of AI-based Anaerobic digestion (AD) technology in order to recover RE. [21] In this regard, studies are showing that Microbial electrolysis cell-assisted anaerobic digestion (MEC-AD) with the use of an artificial neural network helps biomass waste management. [22]

The second cluster, identified with the color green, is related to AI innovation. This cluster is integrated by the words Decision Support System, Deep Learning, Forecasting, Machine Learning, Neural Networks, and Sustainability.

Researchers are in a constant search for clean energy production supported by AI. In this sense, several proposals seek to reduce the consequences of environmental deterioration due to the burning of fossil fuels, for example, hydrogen storage with the use of intelligent modeling techniques such as Adaptive Neuro-Fuzzy Inference System, Multilayer Perceptron optimized with Bayesian Regularization and Levenberg-Marquardt. [23]

From the above, it is evident that AI is forming part of the transition process towards RE with the development of innovative software that facilitates environmental monitoring. [24]

The third and last cluster identified with the blue color is related to energy models. This cluster is integrated by the words Artificial Neural Network, Genetic Algorithm, Solar Energy, and Wind Energy.

Solar and wind energy are the focus of attention due to their potential for sustainable energy generation and are key to achieving Goal 7 of the 2030 Agenda. For example, wind energy allows the generation of clean energy, and currently, there are AI methods that allow the prediction of wind energy production effectively; among these methods are support vector machines (SVMs), adaptive neuro-fuzzy inference systems (ANFIS), and artificial neural networks (ANNs). [25] [26]

Within solar energy, one of the most popular types of energy is photovoltaics, which, with the help of algorithms such as Fuzzy logic (FL), achieves optimal efficiency. [27] Also, photovoltaics can achieve minimization of habitat removal and negative impacts on biodiversity where the panels are located, with the study of geospatial covariates and solar development rate. [28] It should be noted that new optimization techniques use artificial intelligence algorithms in order to achieve greater convergence and accuracy in the calculations. [29]

The above shows the challenges faced by society to generate RE without carbon emissions, and therefore, flexible AI-based planning is needed to maximize the potential of RE sources. [30] Emerging countries with high dependence on traditional energy sources are developing strategies to promote RE using AI models to analyze complex data and make accurate predictions. [31] [32]

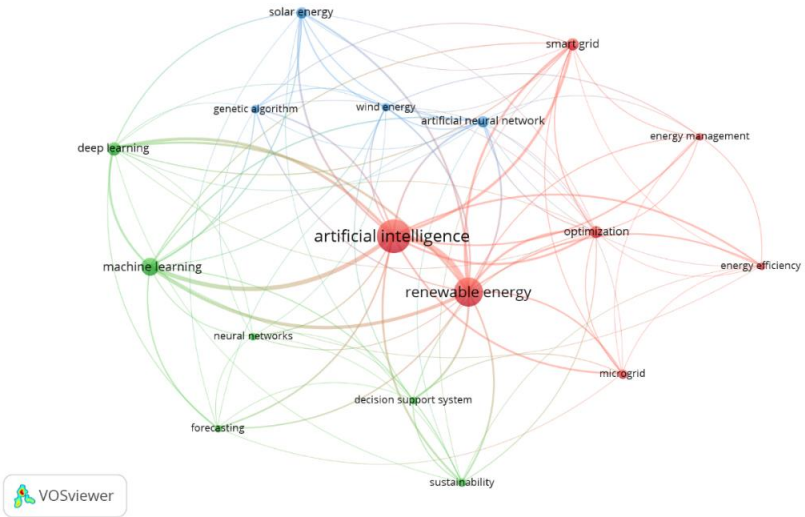

Figure 3. Co-ocurrence – Author Keywords

Figure 4 shows the trend in current research. It is evident how the topics of interest have been changing over time. Thus, there has been a shift from Genetic Algorithms and Artificial Neural Networks to a strong interest in Artificial Intelligence, Machine Learning, and Deep Learning.

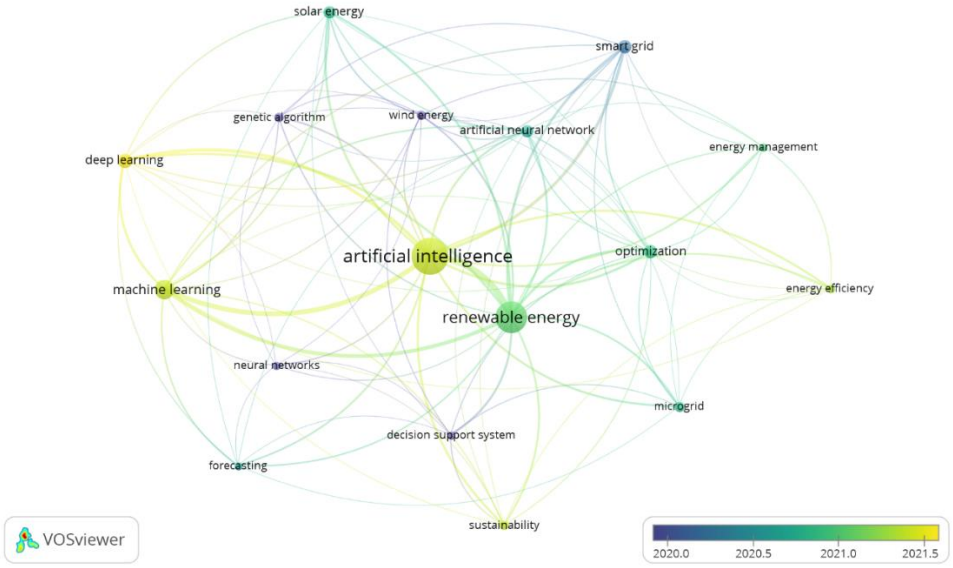

Figure 4. Overley of Co-ocurrence - Author Keywords

5. Conclusions

Countries have a great responsibility to provide sustainable energy that is accessible to society and minimizes environmental impacts. In order to comply with SDG 7, the development of RE sources, energy efficiency, and the adoption of innovative tools that favor access to clean energy in detriment to the use of polluting fuels must be expanded.

Clean energies make it possible to combat climate change and achieve sustainable communities with good levels of health, air quality, reduced CO_2 emissions, and the use of polluting fuels. In fact, the population is demanding affordable energy to meet their energy needs.

RE, hand in hand with AI, is making significant advances in energy efficiency and energy consumption. AI algorithms are facilitating machine learning, predicting equipment capacity levels and correcting equipment failures to avoid blockages in energy systems.

AI is a useful tool for energy systems and their safety since it allows for the detection of risks in order to take corrective measures. The future of RE is closely linked to AI, as it allows energy systems to become more efficient and intelligent.

Researchers are facing new challenges every day to respond to the irruption of the use of new algorithms in the generation of RE, given the range of available tools such as Deep learning or neural networks. Research results have revealed that in recent years, scientific production has understood that AI is not a trend but rather a challenge faced by society, industry, countries, or education to achieve SD. The processing of large amounts of data and the optimization of processes are opening opportunities for innovation and the development of significant and useful scientific contributions to achieve the development of an energy sector that is in community with SD.

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