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Bibliometric Analysis of Global Research Trends on the Use of Artificial Intelligence Techniques in Circular Economy Applications Using Databases scopus

تحليل ببليومتري لاتجاهات البحث العالمي حول استخدام تقنيات الذكاء الاصطناعي في تطبيقات الاقتصاد الدائري باستخدام قواعد بيانات *Scopus*

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Abstract :

The relationship between artificial intelligence (AI) and the circular economy is an emerging academic field that is rapidly evolving. This paper aims to focus on the current trajectory and future trends of research that integrates both domains. The study employed a bibliometric analysis using the Scopus database, covering the period from 2016 to 2024. The findings indicate that India is leading global research, followed by China, the United Kingdom, and Italy. Most of the leading journals publishing on the topic are of Dutch origin. A keyword analysis was conducted using the VOSviewer software, revealing that the current research trajectory focuses on integrating advanced AI applications in waste management, with particular attention to studying the economic and environmental impacts.

Keywords : Bibliometric analysis, Artificial Intelligence, Circular Economy.

الملخص:

تعتبر العلاقة بين الذكاء الاصطناعي والاقتصاد الدائري مجال أكاديمي ناشئ لكنه يتطور بسرعة، يهدف هذه المقال إلى التركيز على المسار الحالي والاتجاهات المستقبلية للبحث الذي يدمج كلا المجالين، اعتمدت الدراسة على تحليل ببليومتري في قاعدة بيانات Scopus بنطاق زمني يمتد بين 2016 - 2024توصلنا إلى أن الهند تقود البحث عالميا، تليها الصين، المملكة المتحدة وايطاليا، أغلب المجلات الرائدة التي تنشر في الموضوع هولندية الجنسية، تم اجراء تحليل الكلمات الرئيسية باستخدام برنامج VOS Viewer، وقد بينت الدراسة أن المسار البحثي الحالي يركز على دمج تطبيقات الذكاء الاصطناعي المتطورة في مجال إدارة النفايات مع اهتمام خاص بدراسة الآثار الاقتصادية والبيئية المترتبة، باستخدام تقنيات متقدمة مثل تحليل البيانات الضخمة، blockchain، إنترنت الأشياء.

الكلمات المفتاحية: التحليل الببليومتري، الذكاء الاصطناعي، الاقتصاد الدائري.

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1. Introduction

Specialists suggest that artificial intelligence (AI) techniques can help speed up the shift to a circular economy. AI can improve how resources are allocated and help achieve the goals of a circular economy. In addition to resource allocation, AI can analyze consumption and production patterns in real-time. This helps prevent overproduction and excessive waste generation, allowing production to match actual demand and move towards a circular production model.
Machine learning algorithms can also help predict resource needs more accurately, leading to more effective use of materials. Overall, AI can play a key role in changing production methods and reducing the environmental impact of industries.
The relationship between AI and the circular economy is an emerging but rapidly evolving academic field. This paper aims to focus on the current trajectory and future trends of research integrating both domains. In this regard, addressing the topic is of significant importance to industrialists and policymakers seeking to adopt a circular development model. Our study provides a bibliometric analysis due to its ability to offer a clear view of a specific academic field, enabling researchers to identify major trends and dominant themes, and thus provide important insights into the dynamics of knowledge production and dissemination. Moreover, this methodology is adept at identifying key influencers and thought leaders in a field, guiding researchers towards major contributions and ensuring applicability across a broad range of research topics.

2. Background

1.2. The Circular Economy

Organizations have recognized that the cost of resources has been increasing and becoming less predictable, leading to greater risks in business operations. The Ellen MacArthur Foundation estimates that 21 billion tons of materials used in manufacturing products do not end up in the final product, as these materials are lost during the manufacturing process. Eurostat data from 2011 showed that material inputs for the European economy amounted to 65 billion tons in 2010, with 2.7 billion tons of waste generated during manufacturing processes, and approximately 40% of discarded materials were not reused (Jaakkola, 2019). As a result, society has been set on an unsustainable path, leading to severe consequences that threaten the ecological system. The Earth's system is now at risk of losing its original function and being compromised.[1]

In 2002, the publication of the book *Cradle to Cradle: Remaking the Way We Make Things* by Michael Braungart and William McDonough sparked a new wave of interest in change. The book proposed the idea of environmental effectiveness over environmental efficiency—doing more good rather than just reducing harm. It argued that the principle of "reduce, reuse, and recycle" was inadequate because it did not change the impact of the old systems. Instead, the book suggested that poor design, rather than consumption and economic activity, was the problem, proposing a new philosophy of design where waste equals food and resources either safely enter the environment or circulate in a closed loop [2]

Principles of the 3 Rs (Reduce, Reuse, Recycle) have been expanded by some researchers to include the 4 Rs and 6 Rs (Redesign, Reduce, Reuse, Remanufacture, Recycle, Recover), and further to the 9 Rs, which include more specific strategies for enhancing circularity. The ten strategies for

[1] Abuhassna, H., Awae, F., Bayoumi, K., Alzitawi, D. U., Alsharif, A. H., & Yahaya, N. (2022). Understanding Online Learning Readiness among University Students: A Bibliometric Analysis. Int. J. Interact. Mob. Technol., 16(13), 81-94.
[2] Persson, O. (2015). What is ciruclar economy?-The discourse of circular economy in the Swedish public sector. In. p 22.

increasing circularity (9+1) are: Reject, Rethink, Reduce Consumption, Reuse, Repair, Renew, Remanufacture, Re-purpose, Recycle, and Resource Recovery[3].

2.2. Artificial Intelligence

John McCarthy is known as the father of artificial intelligence. In 1990, he defined artificial intelligence as follows: "Artificial intelligence is the science and engineering of making intelligent machines, especially intelligent computer programs.[4] His theory defines AI as a set of computer functions or automated systems managed by computers that perform tasks typically accomplished by intelligent programs. Recently, AI has been integrated into various fields such as engineering, economics, education, science, medicine, marketing, finance, accounting, law, and the stock market. The scope of AI has expanded as machines have become more computationally powerful over the past decade. AI's contribution has proven significant in paving the way for sustainable development, leading to a continued trend of integrating AI with all aspects of the circular economy

3. How AI Supports the Circular Economy

Artificial Intelligence (AI) can play a crucial role in facilitating the transition to a circular economy through a subset of modern technologies that handle models and systems performing tasks generally associated with human intelligence, such as thinking and learning, more effectively. AI enhances the understanding of big data, creating new opportunities to address some of the world's most significant challenges (MacArthur, 2019, p. 4). For example, in waste management, AI systems use robotic sensors to identify and sort different types of waste products for recycling, leading to better analytical data for systems .[5]

4. Methodology

To study the evolution of the topic in academic publications, a bibliometric analysis was conducted following these steps: (Brereton et al., 2007):

1. Define Search Criteria, Keywords, and Publication Timeframe: Establish the research criteria, including keywords and the time period for the publications.

2. Select Scopus Database: Choose Scopus as the database for the analysis.

3. Refine Search Criteria: Adjust and refine the search parameters.

4. Export Full Results: Export the complete results from the database.

5. Analyze Information and Discuss Results: Analyze the data and discuss the findings. (See Figure 1)

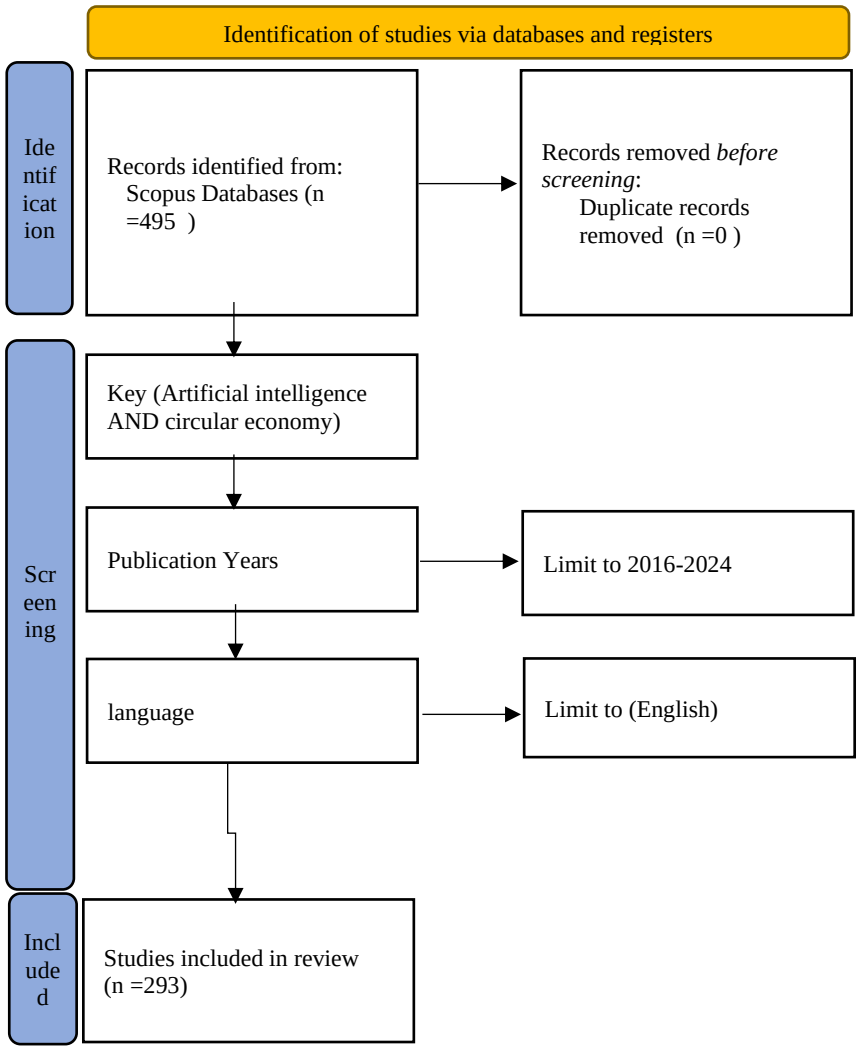
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[3] Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. Resources, conservation and recycling, p 127, 224.

[4] McCarthy, J., Minsky, M. L., Rochester, N., & Shannon, C. E. (2006). A proposal for the dartmouth summer research project on artificial intelligence, august 31, 1955. AI magazine, 27(4), 12-12. P 12.

[5] Stephen, J. (2023). How AI Technologies Can Benefit a Circular Economy to be Real, Relevant and Revenue Generator. https://www.circulareconomyclub.com/listings/how-ai-technologies-can-benefit-a-circular-economy-to-be-real-relevant-and-revenue-generator/

Figure 1: Analytical Framework of the Study



We relied on Scopus because it is a high-quality and reliable database and is widely used for academic research. The search was conducted on 28/06/2024 using the "Subject (keywords or title or abstract)" option with the search terms: "Circular Economy" and "Artificial Intelligence". The initial search results, without applying any exclusions, yielded a total of 495 documents. After refining these results according to the specified search criteria, which did not align with the study's objectives, we excluded conferences, books, and other non-peer-reviewed papers, retaining only articles published in English. To ensure the relative significance of these publications, a manual review was conducted to exclude publications based on the criteria outlined in Table 1. After a preliminary review of titles and abstracts, we identified 293 documents that matched the study's objectives.

Table 1: Inclusion and Exclusion Criteria

inclusion criteria	keywords+ any related keywords(Artificial intelligence" AND "circular economy'
Exinclusion criteria	Conference paper, Book chapter, Book

SMACOF Algorithm

The SMACOF (Scaling by MAjorizing a COnvex Function) algorithm is utilized to extract information from the collected documents. The algorithm initially implements a strategy for optimizing multidimensional data as follows: [6]

\[\sigma(x) = \sum_{i} \sum_{j} \omega_{ij} (\delta_{ij} - f(x))^2 \]

where:

- \(\sigma(x) \) is the stress function to be minimized.

- \(\omega_{ij} \) represents the weights associated with the dissimilarities.

- \(\delta_{ij} \) is the observed dissimilarity between items \(i\) and \(j\).

- \(f(x) \) is the model's predicted dissimilarity between items \(i\) and \(j\).

The goal of the algorithm is to minimize the discrepancy between observed dissimilarities and the model's predictions.

In the equation above (Equation 1), σ(x) is a distance measuring loss function that maps the distance between two points from a multidimensional data space X. A weight matrix ωij multiplied by the difference between the Euclidean distance dij and ideal distance δij squared yields the loss function σ(x) from n-dimensional data space [41]. An iterative approach of this loss function suggested by De Leeuw [41] is called the SMACOF algorithm, which is popularly used for bibliometric analysis[7]

This methodology was employed by examining the most frequently used keywords, the most cited journals, the journals with the highest number of publications, and the countries conducting the most studies on the subject. The VOSViewer software was utilized, which is widely used for visualizing bibliometric networks to uncover network visualizations in the analysis.

4. Results

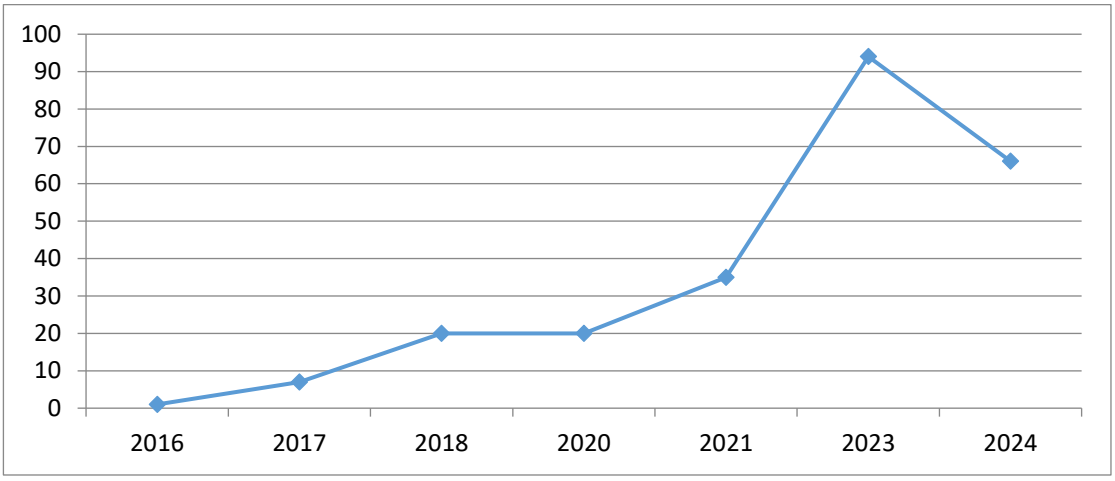
1.4 Distribution of Articles on Circular Economy and Artificial Intelligence

[6] Habiba Akter, U., Hasan Pranto, T., & Bahalul Haque, A. (2022). Machine Learning and Artificial Intelligence in Circular Economy: A Bibliometric Analysis and Systematic Literature Review. arXiv e-prints, arXiv: 2205.01042. p 17

[7] de Leeuw, J. (1988). Convergence of the majorization method for multidimensional scaling. Journal of Classification, 5(2), 163-180. https://doi.org/10.1007/BF01897162.

The number of articles related to the topics of circular economy and artificial intelligence has significantly increased during the study period (2016-2024), particularly after 2020. As shown in Figure 2, the number of articles reached 20 in 2020, compared to just one article in 2016. In 2021, the number of published articles rose to 35. The peak was observed in 2023, with a total of 94 articles, indicating substantial interest in applying artificial intelligence techniques within the circular economy. For the current year, 2024, which is still ongoing, there has already been significant publication activity with 66 articles. This suggests a potential for a considerable increase by the end of the year.

Figure 2: Distribution of Scientific Publications from 2016 to 2024



2.4. Most Relevant Journals and Researchers in Circular Economy and Artificial Intelligence Research

Numerous journals have published articles on the subject, indicating its academic significance, especially in recent years. To measure this aspect, we analyzed the content of the total 293 articles obtained from our search. We considered the following criteria for analysis: "Journal", "Number of Published Articles", "Total Citations", "Journal Impact Factor", "Most Cited Article Title on the Subject from the Journal", "Number of Citations", and "Publisher", as detailed in Table 2.

Tableau 1top 10 journals in Artificial intelligence and circular economy

Journal	Tp	Tc	Cite Score(2023)	The Most Cited Article	Citation	Publisher
Sustainability (Switzerland)	55991	381357	6.8	Circular digital built environment: An emerging framework	116	Multidisciplinary Digital Publishing Institute (MDPI)
Journal of Cleaner Production	19382	394597	16.2	Exploring the influenc of industry 4.0 technologies on the circular economy	95	Elsevier
Journal of Environmental Management	8751	120010	12.2	Decarbonization in waste recycling industry using	51	Academic Press

				digitalization to promote net-zero emissions and its implications on sustainability		
Business Strategy and the Environment	1065	23959	22.5	Application of digital technologies for sustainable product management in a circular economy: A review	101	John Wiley & Son
Environmental Science and Pollution Research	22908	199035	8.7	Concepts of circular economy for sustainable management of electronic wastes: challenges and management options	26	Springer
Science of the Total Environment	30644	540202	17.6	Macro-nutrients recovery from liquid waste as a sustainable resource for productio of recovered mineral fertilizer: Uncovering alternative options to sustain global food security cost-effectively	61	Elsevier
Technological Forecasting and Social Change	2602	55382	21.3	Role of institutional pressures and resource in the adoption of big data analytics powered artificial intelligence, sustainable manufacturing practices and circular economy capabilities	391	Elsevier
Bioresource Technology	6602	137044	20.8	Recent trends and advances in compostin and vermicomposting technologies: A reviev	55	Elsevier
Environmental Research	7640	96370	12.6	Innovation designs of industry 4.0 based soli waste management: Machinery and digital circular economy	42	Academic Press In

International Journal of Production Research	1574	30264	19.2	Industry 4.0 technologies as enablers of collaboration in circul supply chains: a systematic literature review	69	Taylor & Francis

tp= total publications, tc= total citations,

2.4. Journals and Researchers Most Relevant to Circular Economy and Artificial Intelligence Research

The most productive journal in the field of circular economy and artificial intelligence is **"Sustainability (Switzerland)"** with a total of 55,991 publications, including 27 related to our research topic, and 381,357 citations. This is followed by the **"Journal of Cleaner Production"** with 19,382 publications, including 22 related to our research, and 394,597 citations. The journal **"Resources, Conservation and Recycling"** ranks last among the top ten, with 2,166 total publications, including 27 related to our research, and 49,661 citations.

The most-cited article in the first journal is **"Circular digital built environment: An emerging framework"**, which has received 116 citations and is published by **MDPI**. Additionally, the article titled **"Role of institutional pressures and resources in the adoption of big data analytics powered artificial intelligence, sustainable manufacturing practices and circular economy capabilities"**, published in **"Technological Forecasting and Social Change"** (ranked 7th in the table), has received 391 citations. This highlights that the value and impact of scientific research are not only measured by the number of publications but also by the quality and significance of the content for the scientific community. High-quality articles may receive more attention regardless of the journal in which they are published, making it crucial to conduct qualitative analysis alongside quantitative bibliometric studies.

India leads in the number of publications on the topic during the study years with 50 articles, followed by China, the United Kingdom, Italy, the United States, and Spain. Iran is at the end of the top ten list. The global ranking changes when considering total citations; here, the United Kingdom holds the top position globally with 391 citations from 39 articles, followed by India, then Australia and Malaysia. The remaining countries are significantly behind this top trio. The affiliation of the authors to academic institutions is shown in the table below.

Tableau 2 top 10 countries and educational institutions

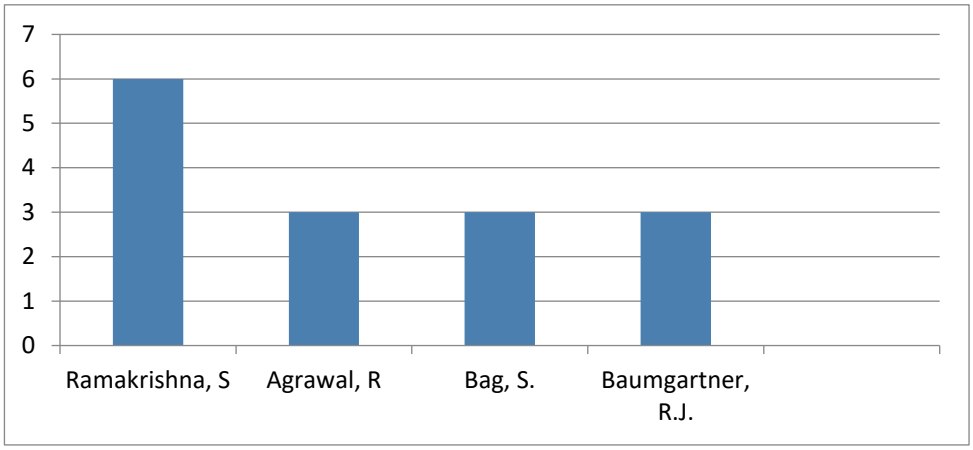
country	educational institutions	Tp	Tc
India	Department of Management Studies, Indian Institute of Technology Delhi, India	50	371
China	Institute of New Energy and Low-Carbon Technology, Sichuan University, Sichuan, China	44	120
United Kingdom	School of Management, Swansea University, Swansea, United Kingdom	39	391
Italy	Department of Environment, Land and Infrastructure Engineering, Turin, Italy	26	120

United States	Georgia Institute of Technology, Atlanta, United States	24	120
Spain	Universidade da Coruña, A Coruña, Spain	18	142
Australia	Department of Infrastructure Engineering, The Universit of Melbourne, Melbourne, Australia	17	240
Germany	Helmholtz-Institute Freiberg for Resource Technology, Freiberg, Germany	16	103
Malaysia	Faculty of Economic and Management, University Kebangsaan Malaysia, Bangi, Malaysia	16	205
Iran	Department of Industrial Management, University of Tehran, Iran	14	80

In addition to the data presented in the previous tables, the names of the most prolific authors in the field and their number of publications were examined.

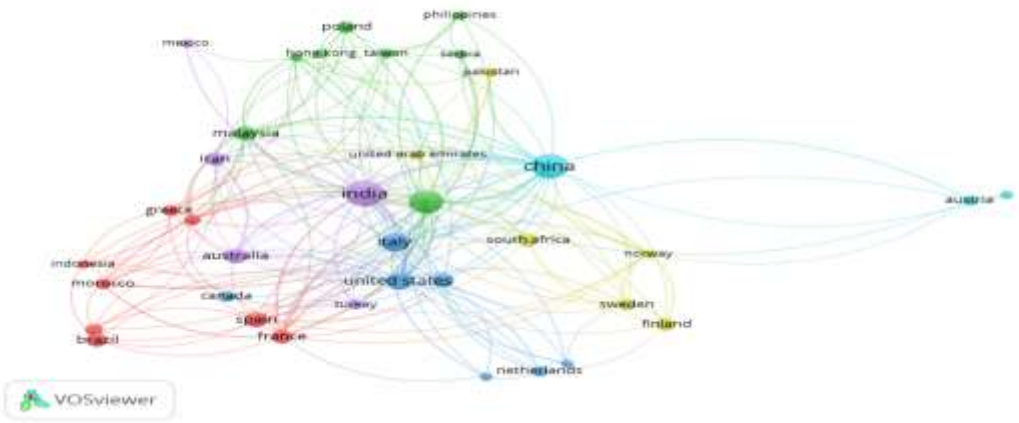
Ramakrishna Seeramis identified as the most prolific author on the topic between 2016 and 2024, with a total of 6 articles. This is followed by Agrawal RohitBag Surajitand Baumgartner Ruperteach with three articles. (See Figure 3)

Figure 3: Most Prolific Authors between 2016 and 2024



The research networks created by VOSviewer revealed collaboration among 37 countries in research on the circular economy supported by artificial intelligence, highlighting the importance of joint efforts in this field to achieve better results, as illustrated in the figure below.

Figure 5: Collaboration Among Countries in Publishing on Circular Economy and Artificial Intelligence



Countries cannot individually implement the circular economy or artificial intelligence on their own, as these are global phenomena requiring the collective effort of all nations. Therefore, international collaboration among researchers is crucial. India, China, Italy, and the United Kingdom are central to the research topic, with India collaborating with 24 countries, China with 28 countries, and Australia and Mexico needing to expand their international cooperation efforts

3.4. Different Research Trends

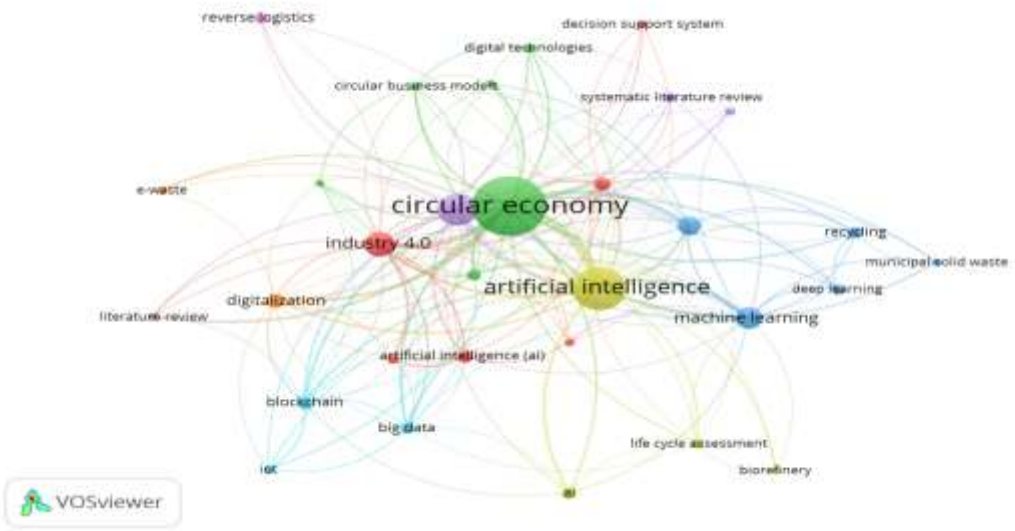
Keywords are fundamental terms in research. Using VOSviewer, we identified a total of 983 keywords from 293 articles. We set the minimum threshold for keyword occurrence at 5 times, meaning that keywords mentioned at least five times across all documents are considered, resulting in 31 keywords. Table 3 shows the frequency of these keywords. As expected, "artificial intelligence" and "circular economy" were the most frequent, mentioned 176 and 163 times, respectively. Following them were "sustainable development," "waste management," and "machine learning" in subsequent ranks.

Table 3: Frequency of Keywords

Keywords	Occurrences
Circular economy	176
Artificial intelligence	163
Sustainable development	82
Waste management	50
Machine learning	46
Industry 4.0	46
Recycling	43
Internet of things	38
Life cycle	24
Blockchain	18

The image below represents a bibliometric map created using VOSviewer, displaying the keywords related to our research topic. This map helps us understand the overall research trends embedded in the titles. At the center of the map, the main nodes, "Circular Economy" and "Artificial Intelligence," are prominently featured, showing their close association with other related research topics.

Figure 5: Co-occurrence Map of Keywords



The map reveals a wide range of research into various applications of Artificial Intelligence (AI) for Industry 4.0, machine learning, big data, the Internet of Things (IoT), blockchain, and digitalization applied to different concepts of the circular economy. This includes circular business models, reverse logistics, recycling, electronic waste, municipal solid waste, and life cycle assessment, without overlooking analytical tools and techniques such as decision support systems, machine learning, and deep learning.

5. Discussion

Analyzing 293 scientific documents on circular economy and artificial intelligence over the past nine years has shown significant progress in research. There has been a rapid growth trend between 2022 and 2023, indicating an increasing awareness of the subject over time, which confirms the growing integration of various smart technologies **into the circular economy.** Regarding journals with the highest number of publications, it is notable that the journal "Sustainability (Switzerland)" plays a significant role. Furthermore, the highest citation rate on the subject was achieved by the journal "Technological Forecasting and Social Change," which ranks 7th among the top publishing journals, surpassing "Sustainability (Switzerland)." This highlights the importance of looking beyond just the number of publications when evaluating research impact and focusing on publishing in specialized, high-impact journals, even if they publish fewer papers.

Regarding the nationality of the journals, it is clear that most of them are from the Netherlands (6 out of the top 10). There is also a noticeable global dominance of Indian research due to several reasons, including the evolving landscape driven by various government initiatives across sectors such as Digital India, Make in India, and the Smart Cities Mission. Additionally, the recently launched National Artificial Intelligence Portal and the National AI Strategy in India aim to advance research and development and promote AI across the country. Indian research institutions and academic organizations are also actively involved in AI research and development, with

institutes like the Indian Institutes of Technology (IITs), the Indian Statistical Institute (ISI), and the Indian Institute of Science (IISc) conducting advanced research in AI , However, the global ranking changes when considering the total number of citations, with the United Kingdom ranking first globally due to the reliability and quality of its research. In terms of individual scientific output, the author Ramakrishna Seeram is the most published. He is a Professor of Materials Engineering in the Department of Mechanical Engineering at the National University of Singapore (Singapore, 2024). In the field of international collaboration among researchers from 37 countries on the research topic, there is strong coordination among them, and Australia and Mexico need to enhance their coordination with other countries.

All of the above are some of the reasons why we consider it important to understand the current and future trends in publications related to the topic. Initially, the circular economy focused on production aspects . Today, the focus has expanded to include broader and more comprehensive areas with overlaps in several subfields, such as the use of modern technologies to support circular practices. The current subfields of research identified through the VOSViewer program can be categorized into four main groups:

• The first group focuses on digital technologies and Industry 4.0, including concepts such as artificial intelligence, big data, blockchain, and the Internet of Things. In this regard, Ertz et al. (2022) identified four core technologies constituting Industry 4.0 (i.e., additive manufacturing, artificial intelligence, the Internet of Things, and big data) that may contribute to improving product design, accessibility, maintenance, redistribution, and recovery. Ronaghi (2023) concluded that artificial intelligence technology could be a solution to transform production processes and reduce the harmful environmental impacts of industry by using machine learning capabilities, intelligence, and neural networks to manage resources and enhance product output. Ertz et al. (2022) focused on extending product life through advanced technological production systems within the Industry 4.0 concept by identifying four foundational technologies (additive manufacturing, artificial intelligence, the Internet of Things, and big data) that may enhance product design, accessibility, maintenance, redistribution, and recovery. Bin Abu Sofian et al. (2024) addressed the topic of bio-plastic derived from algae as an eco-friendly alternative, emphasizing the role of the Internet of Things and machine learning in improving production processes. The Internet of Things monitors agricultural conditions, collects data, and controls processes, thereby increasing the availability of raw materials for bio-plastic and enhancing its efficiency and productivity.

Pinheiro et al. (2022) investigated how Industry 4.0 technologies and stakeholder pressures affect circular product design and consequently company performance. Their findings suggest that applying Industry 4.0 technologies, particularly artificial intelligence and big data analytics, enhances circular product design, and stakeholder pressure can encourage the adoption of circular strategies, especially from suppliers responsible for developing and delivering smart components.

The second group focuses on waste management (such as e-waste, municipal solid waste, and recycling). In this context, Dodampegama et al. (2024) review advancements in the use of artificial intelligence and robotics to automate the sorting of construction and demolition waste, noting a gap in AI-supported robotics applications in this field. Singh et al. (2024) discuss the role of AI in improving waste management strategies by predicting waste composition and optimizing collection pathways, advocating for the adoption of circular economy principles with an emphasis on comprehensive risk assessment and the potential of AI in transforming waste into energy, while also highlighting challenges faced by developing countries.

• The third group focuses on the economic and environmental impacts of sustainability, including research on topics such as carbon footprint, greenhouse gases, decision-making, decision support systems, and life cycle assessment. In this regard, Kumar et al. (2024) aimed to explore carbon neutrality through algae-based wastewater treatment methods and examined the performance and cost of such treatments using an AI and machine learning-based methodology for algae-based wastewater systems. Garg et al. (2022) aimed to develop a simple model using artificial neural networks to predict soil erosion from biochar-amended soils under different conditions. Based on this, a model was developed to estimate total erosion rates and runoff. The results showed that soils amended with 5% biochar provided the best results in reducing soil erosion. Sobotka & Sagan (2021) present a decision support system for managing concrete waste during building demolition, based on a mathematical simulation model that evaluates different technological and organizational systems for waste management, considering multiple factors such as costs, environmental impact, and community disruption, using an artificial ranking index that provides a ranked list of options for decision-makers.

• The fourth group focuses on a specialized research direction applying AI techniques in specific sectors, including deep learning and machine learning in the construction and demolition industry. Sobotka & Sagan (2021) proposed a mathematical simulation model that generates technological and organizational indicators to assess concrete waste management systems, offering a ranked list of options based on an evaluation index analyzing factors like construction site area and waste management time. identified how 10 digital technologies could enhance design phase processes, leading to improved circularity in the construction sector, including AI technologies that support circular design concepts that improve material recycling rates and reduce unnecessary construction waste. Astorayme et al. (2024) focused on using machine learning and deep learning to detect and classify large plastics in aquatic environments to manage plastic pollution in water.

6. Conclusions

The bibliometric analysis of the 293 publications allowed us to determine that there has been a rising research trend over the past nine years in the fields of artificial intelligence and the circular economy. The year 2023 was the most representative with the highest number of publications, and it is expected that 2024 will surpass its predecessors. The most productive journal on the subject is "Sustainability (Switzerland)." We found that the value and impact of scientific research are not only measured by the quantity of publications but also by the quality of content and its relevance to the scientific community. High-quality articles with innovative ideas may receive greater attention regardless of the journal in which they were published. Therefore, it is crucial to conduct qualitative analysis alongside quantitative analysis in bibliometric studies.

India is considered a global leader in the field, followed by China, the United Kingdom, Italy, the United States, and Spain. When considering total citations, the United Kingdom ranks first globally, followed by India, Australia, and Malaysia. Among the 37 countries contributing to research on the topic, India collaborates with 24 countries, while China collaborates with 28 countries. Based on keyword analysis, the research trend in our study focuses on integrating advanced AI technologies in waste management, with particular attention to studying the economic and environmental impacts of this integration. This area includes the use of advanced technologies such as big data analytics, blockchain, IoT, and machine and deep learning, as well as an in-depth study of environmental impacts, including carbon footprint assessment and greenhouse gas emissions. It also involves developing decision support systems and conducting comprehensive life cycle assessments of products. Overall, the current research trend aims to find modern solutions that integrate technological efficiency and environmental awareness to contribute to achieving circular economy goals and promoting global sustainable development.

Finally, this study was conducted in the Scopus database, considering only nine years of publication (2016-2024). Therefore, we recommend analyzing other databases (such as Web of Science or Google Scholar). For future research, it could be directed towards different areas, including analyzing more specialized documents. For reference, the analysis conducted in this study was retrospective; we recommend conducting forward-looking studies with projections for developing countries.

References:

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Astorayme, M. A., Vázquez, I., & Kahhat, R. (2024). The use of artificial intelligence algorithms to detect macroplastics in aquatic environments: A critical review. *Science of The Total Environment*, 173843 .

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