

TRENDS AND INSIGHTS IN THE APPLICATION OF AI FOR CIRCULAR ECONOMY AND SUSTAINABLE MANUFACTURING

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Abstract: This study presents a comprehensive bibliometric analysis to investigate the role of artificial intelligence (AI) in advancing circular economy practices, sustainability, and manufacturing innovation. The analysis identifies key contributors, dominant research streams, and emerging trends within this multidisciplinary domain. By systematically reviewing academic literature, the study maps the intellectual landscape, showcasing influential authors and publications that have shaped the field. The findings provide critical insights into the evolution of research on AI applications in sustainable manufacturing and circular economy strategies, highlighting the transformative potential of AI in optimizing resource efficiency and minimizing environmental impacts. This analysis offers valuable guidance for academics and industry professionals, providing a foundation for understanding recent advancements and pinpointing research gaps. Moreover, the study underscores the importance of AI in driving sustainable innovation, paving the way for more efficient and environmentally responsible manufacturing systems.

Key words: circular economy, artificial intelligence, sustainability, data analytics, manufacturing, industry 4.0

1. INTRODUCTION

In response to the growing challenges of resource depletion, environmental degradation, and unsustainable production practices, the concept of a circular economy has emerged as a transformative approach to economic and environmental sustainability [1]. Unlike the traditional linear economy, which follows a "take-make-dispose" model, the circular economy emphasizes resource efficiency, waste reduction, and the continual reuse, recycling, and regeneration of materials [2]. This paradigm shift is particularly critical in the manufacturing sector, where significant environmental impacts arise from resource-intensive processes and waste generation. By adopting circular economy principles, manufacturing industries can transition towards more sustainable practices that balance economic growth with environmental stewardship [3].

Sustainability lies at the core of the circular economy, addressing the need to meet current demands without compromising the ability of future generations to meet their own. This involves minimizing the ecological footprint of manufacturing activities while promoting economic viability and social well-being [4]. The transition to sustainable manufacturing requires innovative solutions to optimize resource use, reduce energy consumption, and integrate environmental considerations into product design and production processes [5].

Artificial Intelligence (AI) has emerged as a powerful enabler in achieving the goals of the circular economy within the manufacturing sector. By leveraging advanced algorithms and machine learning models, AI facilitates data-driven decision-making and process optimization [6]. Applications of AI in circular manufacturing include predictive maintenance, resource optimization, and the design of intelligent systems for waste management and material recovery. AI-driven tools can analyze complex datasets to identify inefficiencies, predict equipment failures, and optimize supply chain operations, enabling manufacturers to reduce waste and improve resource efficiency [7]. Moreover, AI supports the creation of closed-loop systems, where materials and products are continually recycled or reused. For instance, AI can enhance product lifecycle analysis by providing detailed insights into material flows and environmental impacts, guiding manufacturers in designing products that are easier to disassemble, recycle, or repurpose [8]. Additionally, AI-powered platforms can enable the development of circular business models, such as product-as-a-service (PaaS), where ownership is replaced by access, promoting the reuse of products and materials [9].

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The convergence of the circular economy, sustainability, and AI offers immense potential to reshape the manufacturing landscape. By integrating these principles and technologies, manufacturers can not only reduce their environmental impact but also enhance operational efficiency, foster innovation, and create competitive advantages in a rapidly evolving market. This alignment of sustainability goals with technological advancements is essential for addressing the pressing environmental challenges while driving long-term economic growth [10].

This study aims to facilitate the development and implementation of AI models to support circular economy practices, sustainability, and advancements in manufacturing. By conducting a comprehensive bibliometric analysis, it identifies key contributors and major research streams shaping the field. The findings will serve as a valuable resource for scholars seeking insights into the latest developments in sustainable manufacturing and circular economy strategies. Additionally, the study highlights opportunities for further research on leveraging AI to improve resource efficiency, minimize waste, and optimize manufacturing processes, fostering innovation and promoting more sustainable industrial practices.

2. METHODS

The Scopus database, renowned for its comprehensive collection of high-quality scholarly journals and research articles, was selected as the primary source for obtaining scientific studies relevant to this topic. To identify pertinent research, the keywords "Circular Economy," "Sustainability," "Manufacturing," and "AI" were used during the search process. An overview of the data used in the analysis is presented in Table 1.

Table 1 – Data used in the analysis

Timespan	2018:2025
Documents	107
Annual Growth Rate %	10.41
Document Average Age	1.14
Average citations per doc	28.61
Keywords Plus (ID)	639
Author's Keywords (DE)	324
Authors	404
Article	55
Book	21
Conference paper	31

To facilitate the collection and organization of the database, the Biblioshiny application, available through the RStudio cloud, was used. This software delivers comprehensive insights into key scientific metrics, such as leading countries, institutions, researchers, topics, journals, and frequently used keywords. It also offers valuable bibliometric indicators, including h-indexes, impact factors, citation counts, and more. This open-source tool is particularly well-suited for conducting in-depth analyses and mapping the landscape of scientific research.

3. RESULTS AND DISCUSSION

This section presents the primary bibliometric analysis focused on the role of AI to support circular economy practices, sustainability, and advancements in manufacturing.

Details about the ten leading sources of articles addressing the application of AI in promoting circular economy practices, sustainability, and advancement in manufacturing are provided in Figure 1. The information presented in Figure 2 includes the most prominent affiliations contributing to advancements in AI for sustainability and circular economy practices within the manufacturing sector. Information about sources and affiliations is critical in bibliometric analysis because it provides insights into the research landscape, highlighting the key contributors and trends within a particular field. By analysing sources and affiliations, researchers can pinpoint which entities are at the forefront of research in a specific domain, such as AI applications in sustainability or circular economy practices, with the focus on manufacturing sector. Additionally, it is interesting to highlight the most productive researchers in the field (e.g., J. Liu, S. Bag, R. J. Baumgartner, N. Bocken, C. De Wolf, J.A Garza-Reyes) to help researchers in the literature search.

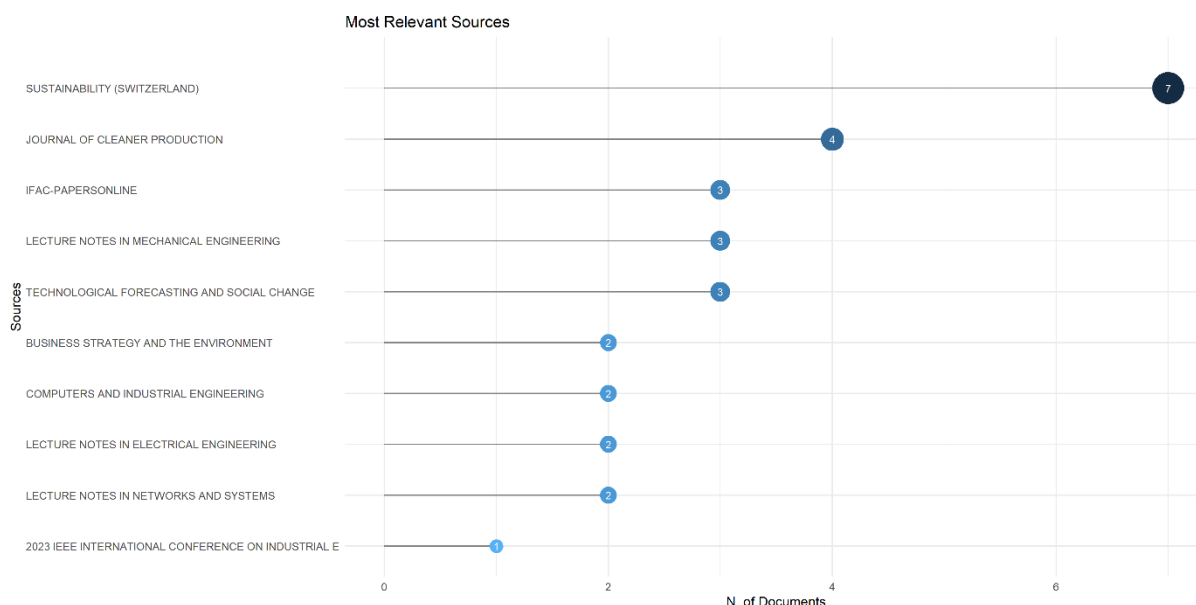


Figure 1 – Leading sources of articles

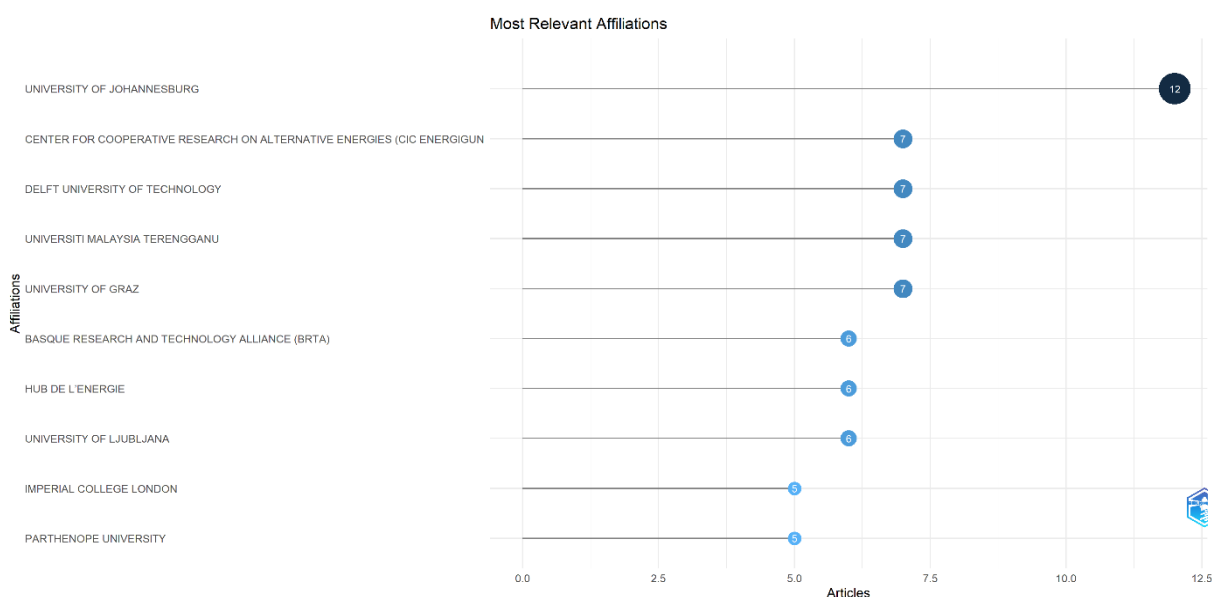


Figure 2 – Most relevant affiliations

Figure 3 illustrates the countries of origin of authors contributing to research on the application of AI in promoting circular economy practices, sustainability, and advancement in manufacturing. The largest volume of publications originates from authors based in India (70), UK (47), Italy (29), and China (24).

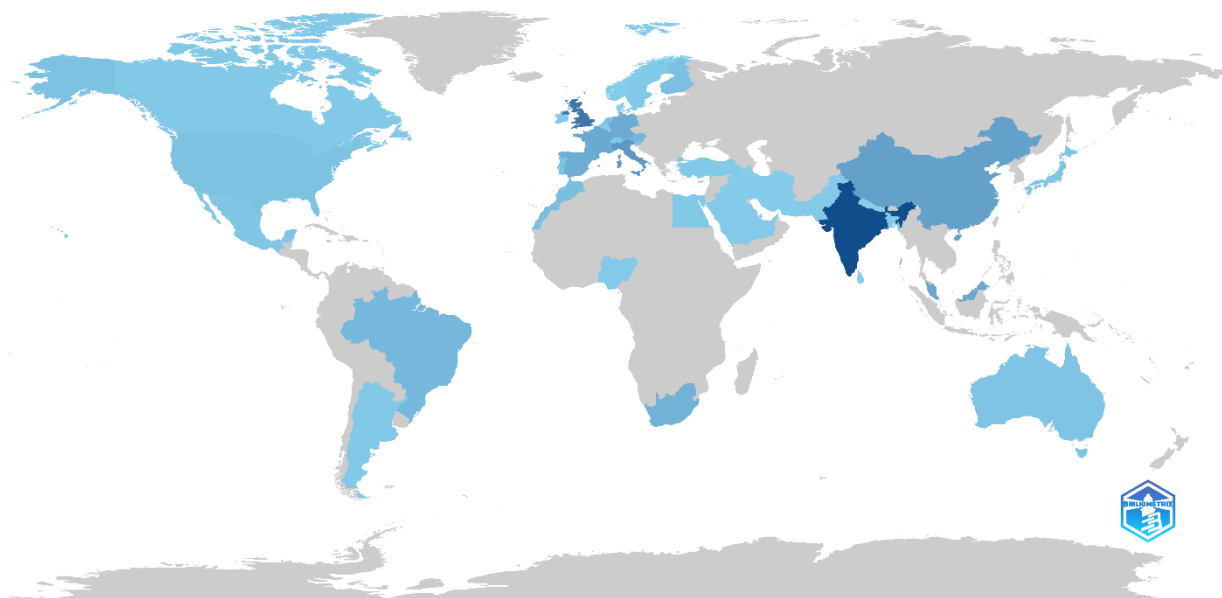


Figure 3 – Contribution by countries

Co-word analysis is a highly effective method for understanding the conceptual structure of research within a specific field. This approach identifies the most frequently used terms and phrases from the titles and keywords of papers, as depicted in Figure 4. The results of the co-word analysis indicate that "Circular economy", "Artificial intelligence", "Sustainable development", "Data analytics", "Manufacturing", and "Industry 4.0" are the most often used keywords in the paper titles and abstract. The word cloud presented in Figure 5 highlights the most important keywords.



Figure 4 – The most frequently used terms and phrases



Figure 5 – Word cloud

Finally, Figure 6 presents a thematic map categorizing key research themes into basic themes (e.g., economic system, innovation, business model), niche themes (e.g., green manufacturing, industrial economics, accident prevention), motor themes (e.g., circular economy, sustainability, manufacturing), and emerging or declining themes (e.g., design, application of AI, robotics).

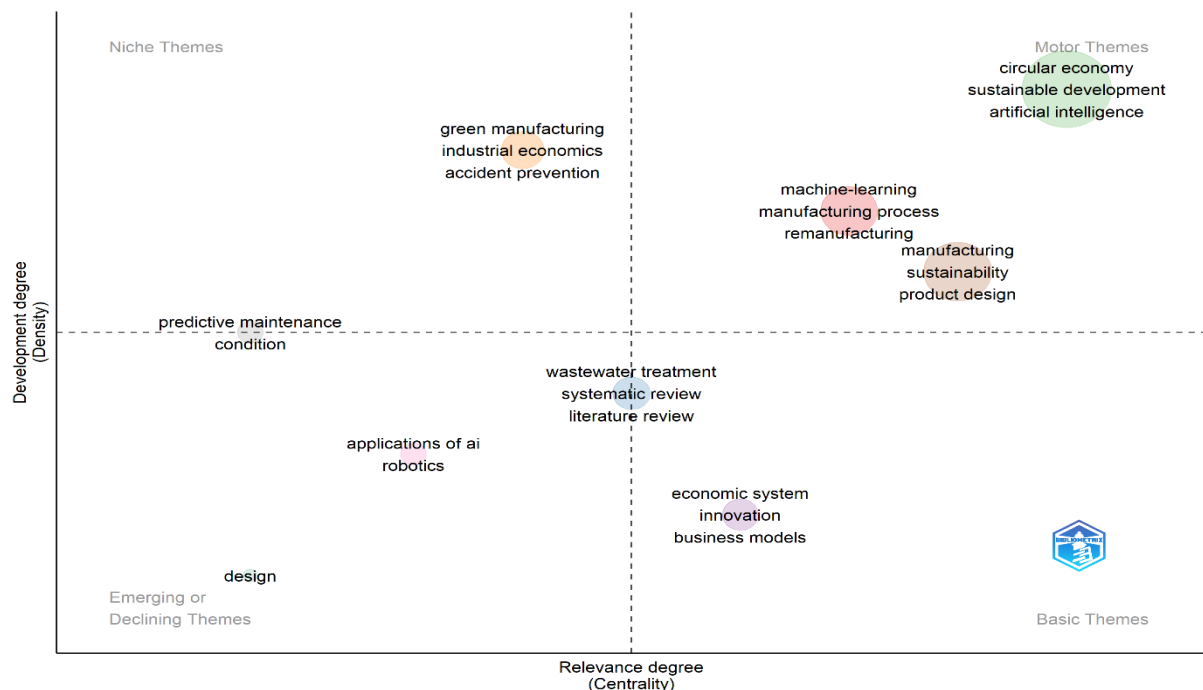


Figure 6 – Thematic map

4. CONCLUSION

This study aimed to explore the relationship between AI, circular economy practices, sustainability, and advancements in manufacturing, emphasizing their potential as transformative elements in reshaping industrial processes and resource management. By integrating AI into circular economy frameworks, manufacturers can access advanced tools to optimize resource efficiency, minimize waste, and promote sustainable production methods.

Through a bibliometric analysis, the authors identified the key contributors and major research trends driving the integration of AI in sustainable manufacturing and circular economy practices. The

primary objective was to provide a comprehensive overview that serves as a resource for academics and practitioners interested in the latest developments within this multidisciplinary field.

The analysis was conducted using the Scopus database, recognized for its extensive collection of high-quality academic publications. However, acknowledging the limitations of relying on a single data source, the authors recommend incorporating additional databases, such as Web of Science, for future studies to enhance the scope and depth of analysis. As AI technologies continue to evolve and the principles of the circular economy gain momentum, the manufacturing sector is poised for significant transformation. This bibliometric study not only captures the current state of research but also lays the foundation for further exploration, fostering a deeper understanding of how AI can drive innovation and sustainability in manufacturing.

5. REFERENCES

- [1] Korhonen J., Honkasalo A., Seppälä, J.: Circular Economy: The Concept and its Limitations, *Ecological Economics*, vol. 143, pp. 37–46, Jan. 2018, doi: 10.1016/j.ecolecon.2017.06.041.
- [2] Geissdoerfer M., Savaget P., Bocken N. M. P., Hultink E. J.: The Circular Economy – A new sustainability paradigm?, *Journal of Cleaner Production*, vol. 143, pp. 757–768, Feb. 2017, doi: 10.1016/j.jclepro.2016.12.048.
- [3] Bag S., Pretorius J. H. C.: Relationships between industry 4.0, sustainable manufacturing and circular economy: proposal of a research framework, *International Journal of Organizational Analysis*, vol. 30, no. 4, pp. 864–898, Jun. 2022, doi: 10.1108/IJOA-04-2020-2120.
- [4] Tseng M.-L., Tran T. P. T., Ha H. M., Bui T.-D., Lim M. K.: Sustainable industrial and operation engineering trends and challenges Toward Industry 4.0: a data driven analysis, *Journal of Industrial and Production Engineering*, vol. 38, no. 8, pp. 581–598, Nov. 2021, doi: 10.1080/21681015.2021.1950227.
- [5] Rosário A., Dias J.: Sustainability and the Digital Transition: A Literature Review, *Sustainability*, vol. 14, no. 7, p. 4072, Mar. 2022, doi: 10.3390/su14074072.
- [6] Kar A. K., Choudhary S. K., Singh V. K.: How can artificial intelligence impact sustainability: A systematic literature review, *Journal of Cleaner Production*, vol. 376, p. 134120, Nov. 2022, doi: 10.1016/j.jclepro.2022.134120.
- [7] Nayal K., Kumar S., Raut R. D., Queiroz M. M., Priyadarshinee P., Narkhede B. E.: Supply chain firm performance in circular economy and digital era to achieve sustainable development goals, *Bussines Strategy Environment*, vol. 31, no. 3, pp. 1058–1073, Mar. 2022, doi: 10.1002/bse.2935.
- [8] Turner C., Oyekan J., Garn W., Duggan C., Abdou K.: Industry 5.0 and the Circular Economy: Utilizing LCA with Intelligent Products, *Sustainability*, vol. 14, no. 22, p. 14847, Nov. 2022, doi: 10.3390/su142214847.
- [9] Sjödin D., Parida V., Kohtamäki M.: Artificial intelligence enabling circular business model innovation in digital servitization: Conceptualizing dynamic capabilities, AI capacities, business models and effects, *Technological Forecasting and Social Change*, vol. 197, p. 122903, Dec. 2023, doi: 10.1016/j.techfore.2023.122903.
- [10] Cioffi R., Travaglioni M., Piscitelli G., Petrillo A., Parmentola A.: Smart Manufacturing Systems and Applied Industrial Technologies for a Sustainable Industry: A Systematic Literature Review, *Applied Sciences*, vol. 10, no. 8, p. 2897, Apr. 2020, doi: 10.3390/app10082897.