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DIGITAL TECHNOLOGIES AND CIRCULAR ECONOMY: BIBLIOMETRIC EVIDENCE FROM INDUSTRY 4.0

A.N. Anna[1*], Zam Zuriyati Mohamad[2], Vikniswari Viji Kumaran[3]

[1] Faculty of Business & Management, Quest International University, Perak, Malaysia;
Teh Hong Piow Faculty of Business & Finance, Universiti Tunku Abdul Rahman, Perak, Malaysia
Email: anna.arokianathen@qiu.edu.my
[2] Teh Hong Piow Faculty of Business & Finance, Universiti Tunku Abdul Rahman, Perak, Malaysia
Email: zuriyati@utar.edu.my
[3] School of Social Sciences, Universiti Sains Malaysia, Penang, Malaysia
Email: vikniswarivk@usm.my
[*] Corresponding Author

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Abstract:

The accelerating convergence of Industry 4.0 (I4.0) digital technologies and circular-economy imperatives presents both a research opportunity and a coordination challenge. Although scholars increasingly examine how Artificial Intelligence (AI), Internet of Things (IoT), and other digital technologies act as enablers for resource-efficient business models and closed-loop systems, the literature remains scattered across disciplines, geographies, and methods. Here, this study seeks to fill that gap through a systematic bibliometric and network analysis of 689 Scopus-indexed records retrieved via an advanced Scopus query, cleaned and harmonized in OpenRefine. The data are profiled using Scopus Analyzer for descriptive statistics and visualized with VOSviewer to generate co-occurrence and co-authorship maps. Numerical findings reveal a concentrated production profile, with China leading with 251 documents, 6,406 citations, and a Total Link Strength (TLS) of 117, followed by the United Kingdom (UK) and the United States (US). Network analysis produced seven robust thematic clusters in the keyword co-occurrence map and nine stable country collaboration clusters, identifying core themes (technology enablers, circular business models, environmental performance) alongside policy and regional empirical strands. Collaboration topology is dominated by China, with the UK acting as a high-connectivity collaborator and several emergent regional hubs such as Malaysia and India. Collectively, these results synthesize the field's intellectual structure, reveal under connected yet promising topic bridges related to digital finance and circular business models, and indicate priority areas for causal empirical research and cross-cluster collaboration. We conclude by recommending a targeted research area integrating causal identification, multi-level datasets, and reproducible materials to accelerate

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theory consolidation and evidence-based policy in the digitally enabled transition to Circular Economies (CEs).

Keywords:

Digital Technologies, Circular Economy, Industry 4.0, Bibliometric Analysis

Introduction

The advent of Industry 4.0 (I4.0) has revolutionized various sectors by integrating advanced digital technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), Augmented Reality (AR), blockchain, big data analytics, and advanced robotics. These technologies have enhanced operational efficiencies and opened novel pathways towards sustainable practices, particularly in the context of the Circular Economy (CE). It seeks to reduce waste and optimize resource use by establishing closed-loop systems in which products and materials are reused, remanufactured, and recycled. The intersection of I4.0 and CE is gaining significant focus in academic, corporate, and policy-making circles due to its potential to foster sustainable development and resource efficiency (Elghaish et al., 2022; Singh et al., 2025; Hadi et al., 2025). This paper explores the emerging relationship between digital technologies and CE, focusing on how I4.0 can facilitate the transition from a linear to a circular economic model.

Literature Review

The integration of I4.0 technologies into CE practices is still in its nascent stages, with most research providing conceptual frameworks rather than practical applications. A critical review of 115 scientific papers indicates a significant increase in the adoption of digital technologies to support CE systems. The integration of IoT, blockchain, and AI is recommended to facilitate the tracking of building assets and components, optimizing their salvage value through reuse or recycling, and extending their operating lifetime (Elghaish et al., 2022). However, the relationship between I4.0 technologies and CE is not yet fully understood, and there is a need for advanced information systems to enhance the reporting and analysis processes of CE operations (Singh et al., 2025).

The role of circular open innovation is essential in ensuring that digital transformation promotes both productivity and sustainability. Organizations that adopt circular open innovation leverage open innovation platforms, blockchain-based supply chain transparency, and AI-powered circular analytics to develop scalable circular business models. Conversely, those that do not adopt these practices risk missing opportunities to establish genuinely regenerative systems (Hadi et al., 2025). Empirical studies also suggest that both I4.0 and non-I4.0 technologies can significantly impact CE practices, although no clear dominance is observed for I4.0 technologies over non-I4.0 technologies in terms of environmental impact (Akkad et al., 2022).

Despite the potential benefits, the implementation of I4.0 technologies in CE practices faces several challenges. The complexity involved in managing material, information, and human flows within circular manufacturing systems makes the use of digital technologies essential. However, the specific effects of these technologies on CE have not been widely explored. A critical analysis of the literature suggests that multidisciplinary research is needed to address these challenges and fill existing research gaps (Denu et al., 2024). Moreover, while IoT is the

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most widely implemented technology for collecting data from production processes, the use of AI, big data analytics, and blockchain in sustainability management is still limited and mainly in pilot phases (Schöggl et al., 2023).

The transition to CE demands a fundamental shift from conventional linear production models toward resource efficiency and closed-loop systems. Furthermore, I4.0 technologies have the potential to accelerate this transition by enabling smart and connected manufacturing. However, their impact on digital sustainability is neither automatic nor assured. Many organizations implement I4.0 technologies primarily to enhance operational efficiency and reduce costs, often without aligning them with CE strategies. Hence, integrating I4.0 with circular open innovation is essential to drive circular transformation and ensure that digital technologies contribute effectively to sustainable outcomes (Hadi et al., 2025). Additionally, empirical studies indicate a synergistic effect with respect to performance resulting from the joint adoption of CE and I4.0 technologies, particularly in terms of social performance (Lopes de Sousa Jabbour et al., 2022).

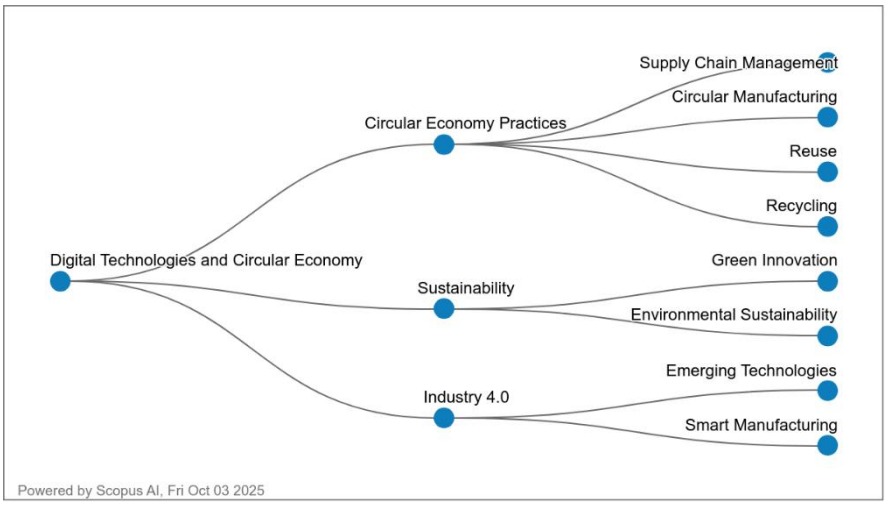

Figure 1: Concept Map

Source: Scopus AI. Elsevier.

The concept map in Figure 1 illustrates the interconnected themes shaping research on "Digital Technologies and Circular Economy" within the I4.0 framework. At its core, three major clusters emerge: CE practices, sustainability, and I4.0. CE practices encompass strategies such as supply chain management, circular manufacturing, reuse, and recycling, reflecting how digital tools enable closed-loop systems and resource efficiency. The sustainability dimension extends this by emphasizing environmental sustainability and green innovation, underscoring the alignment of digital technologies with ecological goals. Meanwhile, I4.0 contributes through emerging technologies and smart manufacturing, highlighting how automation, IoT, and data-driven processes enhance sustainable production. Collectively, these interrelated nodes suggest that digital technologies support and accelerate CE transitions by integrating sustainability objectives with advanced industrial innovations. This framework underscores the importance of synergy between technology, environmental responsibility, and industrial transformation, positioning I4.0 as both an enabler and driver of circular and sustainable economies.

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The integration of I4.0 technologies into CE practices holds substantial potential for sustainable transformation, yet current integration is still in its early stages. There is a need for further applied research to develop practical applications and advanced information systems that can streamline the process of reporting and analyzing the performance of CE operations. Therefore, multidisciplinary research and circular open innovation are essential to fully capitalize on the potential of I4.0 technologies for circular transitions and sustainable transformation. The integration of CE and I4.0 technologies can lead to significant enhancements in operational efficiency, resource management, and social performance, thereby contributing to the broader goals of sustainable development.

Hence, the study endeavors to answer the following Research Questions (RQs).

1. How have the trends in digital technologies and the CE in Industry 4.0 evolved?
2. What are the top lead articles that are most influential on digital technologies and the circular economy?
3. Where are the leading 10 countries that contribute to the publication of digital technologies and the CE?
4. What are the dominant and emerging author keyword themes of digital technologies and the CE?
5. What is co-authorship collaboration at the country level for digital technologies and the CE?

Through a rigorous bibliometric and network analysis, this study provides a robust understanding of the digital technologies integration and CE in I4.0. The comprehensive nature of this study will reveal the key clusters, thematic developments, and collaborative patterns within this field. Moreover, its findings are instrumental for informing policy and practice, supporting the development of agile, innovative, and environmentally responsible systems to meet future challenges. Overall, this study aims to map the complex landscape of digital technologies and the CE within the context of I4.0.

Methodology

Bibliometrics is a rigorous method that systematically gathers, organizes, and analyzes bibliographic data from scientific publications (Alves et al., 2021; Assyakur & Rosa, 2022; Verbeek et al., 2002). Rather than limiting itself to descriptive statistics, such as identifying prolific journals, publication trends, or leading authors (Wu & Wu, 2017), bibliometric analysis utilizes advanced techniques such as document co-citation and network mapping to uncover deeper intellectual structures within a field. A robust literature review, therefore, relies on an iterative process of defining precise keywords, conducting comprehensive searches, and applying critical analytical frameworks to ensure both breadth and depth of coverage. This methodological rigor enables the construction of a comprehensive body of literature and ensures reliable, replicable outcomes (Fahimnia et al., 2015). In line with this, the present study focuses on high-impact publications, since they provide significant theoretical and empirical contributions that shape ongoing discourse. To safeguard consistency and accuracy, Scopus was selected as the primary data source (Al-Khoury et al., 2022; Di Stefano et al., 2010; Khiste & Paithankar, 2017), given its extensive indexing of peer-reviewed scholarship. Furthermore, to maintain analytical quality, only journal articles were included, while books and lecture notes were deliberately excluded (Gu et al., 2019). The dataset comprised publications indexed

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in Elsevier's Scopus database between 2015 and 2025, ensuring both timeliness and relevance for bibliometric analysis.

Data Search Strategy

This study employed the Scopus database, widely recognized for its substantial multidisciplinary coverage and reliable indexing of peer-reviewed scholarly outputs. Table 1 shows the search string that was executed using the advanced search function. This string was carefully constructed to capture the intersection between digital transformation, I4.0, and sustainability-related economic frameworks, with a particular emphasis on the CE. The inclusion of the terms "Digital" and *"Technolog"** allowed the retrieval of records using multiple lexical variations, such as "technology," "technologies," and "technological," ensuring both breadth and inclusivity of relevant scholarship. Likewise, *"Industry 4.0"* * was included to accommodate variations in terminology, reflecting its association with automation, data-driven production, cyber-physical systems, and advanced manufacturing. To connect these technological dimensions to sustainability, the search integrated "Circular" and **"Econom*", which expanded coverage to works addressing the CE, sustainable economy, or broader economic implications of digital innovations. Importantly, the restriction to the Digital Technologies and the Circular Economy in I4.0 was a deliberate methodological choice, aimed at ensuring high thematic precision by including only those publications explicitly focused on these areas, rather than works that only mentioned the terms incidentally in abstracts or keywords.

Table 1: The Search String

Database	Search String
Scopus	TITLE ("Digital" AND "Technolog*" OR (Industr* 4.0) AND Circular OR Econom*) AND PUBYEAR > 2014 AND PUBYEAR < 2026 AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j") OR LIMIT-TO (SRCTYPE , "p"))

Source: Scopus. Elsevier.

To improve the relevance of the dataset, Table 2 represents the temporal filter that was applied in this research search. The publication years were restricted to 2015 and 2025 to reflect the decade when I4.0 and digital sustainability discourse gained significant global traction, influenced by international policy agendas, technological diffusion, and heightened awareness of sustainable development challenges. Additional refinement was introduced by limiting the dataset to English-language publications, ensuring linguistic consistency and accessibility for analysis, as English serves as the dominant medium for international academic exchange. Furthermore, the source type filter, which restricts results to journal articles, conference papers, or proceedings, guarantees the inclusion of peer-reviewed and high-quality contributions while excluding less formal sources such as editorials or book reviews. Following the application of these parameters, the final dataset comprised 689 documents, a corpus that is sufficiently comprehensive to enable meaningful bibliometric analysis while remaining thematically focused and methodologically robust. This dataset provides an empirical foundation for exploring research trends, intellectual structures, co-authorship networks, thematic clusters, and citation patterns within the field. Moreover, by specifying the access date of October 3, 2025, the study ensures reproducibility and transparency, enabling future scholars to replicate or extend the search for comparative or longitudinal purposes.

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Table 2: The Selection Criterion for Searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Time Line	2015-2025	< 2015
Literature Type	Journal (Article)	Conference, Book, Review

Source: Scopus. Elsevier.

Overall, this carefully designed search strategy reflects a balance between inclusivity and precision, generating a dataset that effectively captures the scholarly discussion at the nexus of digital technologies, I4.0, and sustainable economic paradigms over the past decade.

Data Cleaning and Harmonization

Ensuring data accuracy and consistency is fundamental to the rigor and reliability of bibliometric analysis, as these attributes profoundly affect the study's validity and reproducibility. In this research, extensive data cleaning and harmonization were performed using OpenRefine (Ahmi, 2023), a standard tool that optimized for refining and standardizing complex bibliographic datasets. These platforms were crucial for resolving discrepancies and redundancies in author names, institutional affiliations, and keyword fields. Hence, employing data cleaning will enhance overall dataset coherence. The process began with the export of Scopus-indexed records in comma-separated value (.csv) format. Consequently, the data were imported into the cleaning environment, where specific columns, such as authors' keywords, were systematically reviewed and corrected using advanced clustering algorithms and transformation functions native to the tools. OpenRefine proved especially effective at identifying variations in spelling, merging duplicate entries, and unifying metadata structure. This rigorous process yielded a high-quality, standardized dataset, forming a reliable foundation for subsequent bibliometric and network analyses.

Data Analysis

VOSviewer, developed by Nees Jan Van Eck and Ludo Waltman at Leiden University, Netherlands (Van Eck & Waltman, 2010, 2017), stands as a leading bibliometric software widely recognized for its capacity to visualize and analyze scientific literature with clarity and precision. Its main strength lies in producing intuitive network visualizations, clustering related items, and generating density maps that allow researchers to identify hidden patterns within large datasets. The tool's adaptability extends across co-citation, co-authorship, and keyword co-occurrence analyses, providing comprehensive insights into the intellectual structure of research fields. With its interactive interface, robust metrics, customizable visualizations, and compatibility with manifold bibliometric data sources, VOSviewer has become crucial for researchers navigating increasingly complex scholarly landscapes. Continuous updates ensure its sustained relevance, making it equally valuable to both early-stage and advanced scholars seeking to interpret and map scientific knowledge.

A distinctive feature with respect to VOSviewer is its ability to transform detailed bibliometric data into visually interpretable maps and charts, thereby enhancing accessibility and interpretive depth. In this study, datasets containing publication year, title, author names, journal, citations, and keywords were retrieved in plain text format from the Scopus database, covering the period from 2015 to December 2025. The analysis was conducted using VOSviewer version 1.6.20, employing its advanced clustering and mapping techniques to

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generate knowledge structures. Unlike traditional Multidimensional Scaling (MDS), which depends mainly on similarity measures, for instance, cosine or Jaccard indices (Van Eck & Waltman, 2010), VOSviewer positions items in low-dimensional spaces based on association strength, ensuring that proximity reflects true relational intensity (Appio et al., 2014). The Association Strength (AS_{ij}) is defined as:

$$AS_{ij} = \frac{C_{ij}}{w_i w_j},$$

where C_{ij} represents the observed number of co-occurrences between items i and j, and $w_i w_j$ denote their expected co-occurrence under statistical independence. This measure provides a more accurate normalization of co-occurrence frequencies, refining the precision of bibliometric mapping and solidifying VOSviewer's role as a cornerstone in contemporary bibliometric research (Van Eck & Waltman, 2007).

Findings

The findings provide a comprehensive analysis of digital technologies and CE in I4.0 by addressing the RQs to deepen the understanding of the field. By delving into the RQs, the study offers a thorough and nuanced exploration that gives significant findings for academics, practitioners, as well as policymakers.

Publication Trends

To address the first RQ, which aims to explore the trends in Digital Technologies and CE within the context of I4.0, has evolved based on the number of documents published over the years. The publication trend from 2015 to 2025, shown in Figure 2, discussed a steady and remarkable rise in research on digital technologies and the CE within the context of I4.0. Starting from just three publications in 2015, the field saw incremental growth in the early years, with gradual increases until 2019. A more significant jump appears from 2020 onward, where publications grew rapidly from 42 in 2020 to 196 in 2024, followed by a slight dip to 124 in 2025. This sharp increase after 2020 indicates that I4.0 and sustainability-driven research gained considerable momentum, likely due to global shifts towards digital transformation, Sustainable Development Goals (SDGs), and the acceleration of technology adoption throughout the COVID-19 pandemic era. The peak in 2024 suggested that academic interest and funding priorities have strongly aligned with digital sustainability topics in recent years.

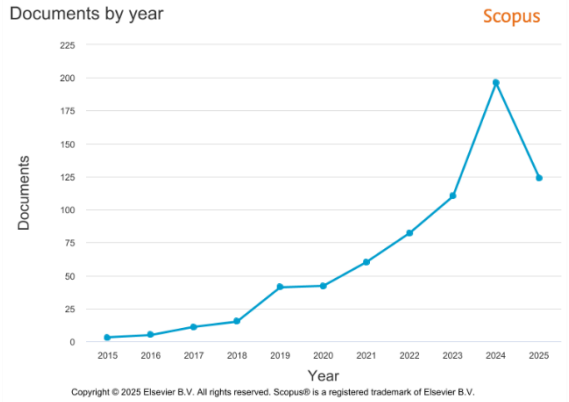

Figure 2: Number Of Documents Based on Year of Publication

Source: Scopus Analyzer. Elsevier.

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Several other factors can explain the observed trend. First, the increasing urgency of climate change and resource scarcity has driven global attention towards CE models, creating fertile ground for integrating digital technologies, for instance, AI, IoT, and big data into sustainability research. Second, governments, industries, and international organizations have pushed forward initiatives combining digital innovation with environmental and economic resilience, further fueling academic studies. The surge from 2020 to 2024 likely reflects both policy priorities and the rapid expansion of I4.0 applications across sectors, making it a dynamic research domain. The slight decline in 2025 may not indicate reduced importance but rather the natural stabilization of publication output after peak years or delays in indexing recent works. All in all, the data highlights a vibrant and evolving research landscape where digital transformation and the CE continue to converge as a central focus in the I4.0 scope.

Highly Cited Documents

Table 3 represents a concentrated citation profile in addressing the second RQ on the top lead articles that are most influential on digital technologies and the CE. These articles link I4.0 digital technologies, for instance, IoT, big data analytics, AI, AR, blockchain, advanced robotics, and digital finance, to CE outcomes, attaining predominant influence. The highest impact studies are predominantly conceptual syntheses and rigorously executed empirical studies published in interdisciplinary and prominent journals. These studies reflect as conceptual hubs by standardizing terminology, theoretical frameworks, and measurement approaches across management, engineering, and sustainability literatures. Other than that, the citation patterns reflect the temporal effects. Earlier, the foundational contributions from 2017 to 2019 accrued more citations due to their sustained academic influence. Nonetheless, recent publications addressed urgent policy and industry issues, particularly those leveraging large, cross-regional datasets that rapidly gained widespread attention and cross-disciplinary recognition.

The highly cited article was from Teece's 2018, which received 1241 citations, describing the digital technologies enablers in the Research Policy publication. The next highest citations were articles from Y. Li et al.'s 2020, Cao et al.'s 2021 and Bressanelli et al.'s 2018 with 699, 586, and 586 citations, respectively. These articles describe the impact of digital technologies on environmental performance, linking to I4.0 and CE. They were published in the International Journal of Production Economics, Journal of Cleaner Production, and Sustainability (Switzerland). On the other hand, the lowest citation received was 291 citations for an article published in the Sustainability (Switzerland) from Ding et al. (2022), which discusses digital technology and innovation for better digital economic development. Apart from that, an article published in the Sensors journal by Fraga-Lamas et al. (2021) received 301 citations, discussing digital technologies as enablers of a sustainable transition to CE.

As such, the top 10 most cited documents have several structural and substantive mechanisms that underpin the distribution of influential publications by the authors in this field. Note that high-impact papers integrate a clear theoretical framework that links digitalization to circular outcomes with robust causal identification, such as quasi-experimental designs, panel models, and valid instrumental variables. These studies often leverage multi-level or large-scale samples that enhance the external validity of the findings.

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Table 3: Most Cited Documents

Authors	Title	Year	Source title	Cited by
Teece (2018)	Profiting from innovation in the digital economy: Enabling technologies, standards, and licensing models in the wireless world	2018	Research Policy	1241
Y. Li et al. (2020)	The impact of digital technologies on economic and environmental performance in the context of Industry 4.0: A moderated mediation model	2020	International Journal of Production Economics	699
Cao et al. (2021)	Digital finance, green technological innovation and energy-environmental performance: Evidence from China's regional economies	2021	Journal of Cleaner Production	586
Bressanelli et al. (2018)	Exploring how usage-focused business models enable circular economy through digital technologies	2018	Sustainability (Switzerland)	507
Litvinenko (2020)	Digital Economy as a Factor in the Technological Development of the Mineral Sector	2020	Natural Resources Research	463
Pagoropoulos et al. (2017)	The Emergent Role of Digital Technologies in the Circular Economy: A Review	2017	Procedia CIRP	414
Ranta et al. (2021)	Digital technologies catalyzing business model innovation for circular economy—Multiple case study	2021	Resources, Conservation and Recycling	367
J. Li et al. (2022)	Digital economy, technological innovation, and green economic efficiency—Empirical evidence from 277 cities in China	2022	Managerial and Decision Economics	307
Fraga-Lamas et al. (2021)	Green IoT and edge AI as key technological enablers for a sustainable digital transition towards a smart circular economy: An Industry 5.0 use case	2021	Sensors	301

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Ding et al. (2022)	Digital economy, technological innovation, and high-quality economic development: Based on spatial effect and mediation effect	2022	Sustainability (Switzerland)	291

Source: Scopus Analyzer. Elsevier.

Moreover, they further articulate explicit policy and managerial implications, accompanied by reproducible materials that facilitate further research. For authors targeting Scopus-indexed journals, emphasis should be placed on demonstrating theoretical novelty and clearly defining boundary conditions. The authors employ transparent and rigorously justified empirical methodologies, incorporating robustness checks and mixed-method validation of causal mechanisms. Additionally, clear translational implications for policy and practice are crucial. Publishing in interdisciplinary journals and providing replication files will materially increase the research's visibility, reach, and citation impact.

Publications by Countries

Figure 3 revealed the contribution of the top 10 countries to the publication. China dominates and significantly leads in publications on digital technologies and CE within the context of I4.0. The following are the Russian Federation, the United Kingdom (UK), Italy, the United States (US), and the emerging Asian economies (India, Malaysia, and Indonesia). China contributed 251 publications, which is more than double the output of the second-highest contributor, the Russian Federation, with 99 publications. European countries, for instance, the UK and Italy, also feature prominently, with 53 and 31 publications respectively, while the US contributes 45 publications. Surprisingly, the emerging economies in Asia, including India, Malaysia, and Indonesia, are moderately contributing, ranging from 23 to 28 publications, and Saudi Arabia records 19 publications. This geographical distribution underscores a global interest in integrating I4.0 technologies with CE goals that have gained uneven research capacity and investment across regions.

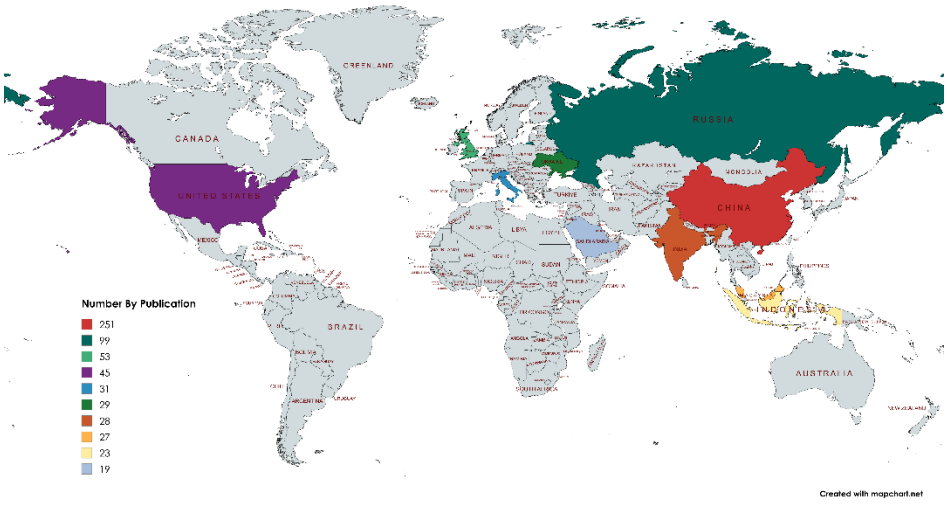

Figure 3: Country Mapping based on the Number of Publications

Source: Adopted from Scopus Analyzer. Elsevier and develop a map at https://www.mapchart.net/world.html

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The dominance of China can be due to heavy investment in I4.0 initiatives, smart manufacturing, and digital infrastructure, coupled with strong governmental support for research and innovation in sustainability and CE models. The substantial output from European countries and the US reflects their long-standing emphasis on research excellence, policy-driven sustainability programs, and well-established academic and industrial collaboration networks. On the other hand, notable activity from emerging economies indicates a broadening international engagement in sustainable manufacturing and resource-efficient transitions. Emerging economies, such as India, Malaysia, and Indonesia, are increasingly participating in this research area due to rising awareness of environmental issues, governmental incentives for technological innovation, and growing academic focus on sustainable industrial practices. Overall, the country-level distribution underscores the interplay of research capacity, policy priorities, and technological advancement as key drivers of publication output in this domain.

Co-occurrence Analysis

Co-occurrence analysis was conducted to provide a rigorous and quantitative mapping using the VOSviewer tool.

Author Keywords

The dominant and emerging author keyword themes for digital technologies and the CE are reflected in Figure 4. It represents the field's intellectual framework produced via co-occurrence analysis of author keywords. The co-occurrence measures how frequently two keywords appear together in the same article, so frequently co-occurring terms form strong links and cluster into coherent topical modules. In this analysis, the study applied the full counting method, where each co-occurrence is counted equally by setting a minimum occurrence threshold of 5 and a required minimum cluster size of 5. The result presented 2,255 unique keywords, where 261 met the threshold, and VOSviewer partitioned them into seven clusters. Node size reflects keyword prominence, which reflects the occurrences, link strength, and Total Link Strength (TLS), which quantify relational intensity. The seven clusters reveal which concepts are central and which operate as bridges, with core terms occupying the largest, most connected nodes. The map significantly advances the literature by transforming qualitative insights into a structured and testable framework.

The network visualization highlights "digital economy", "digital technologies", and "environmental technology" as the most impactful and central research themes that reflect their important roles in advancing contemporary collaboration. The prominence of these keywords indicates the research's focus on how digital innovations are transforming economic structures and environmental solutions, often intersecting with sustainability objectives such as the "circular economy." This suggests that high-impact articles in this domain emphasize integrated approaches leveraging digital tools to drive economic growth while addressing environmental challenges.

Additionally, clusters around the prominent topics such as "information systems," "China spillover," and "carbon emission" reveal specific areas of investigation within this expansive field. These specific areas underscore the importance of regional dynamics and the environmental consequences of technological advances. The connections between these terms suggest a comprehensive exploration of technological impacts on different scales, from global economic models to localized environmental effects. Thus, demonstrating the multifaceted nature of current research, which aims to balance development, innovation, and sustainability.

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The inclusion of terms such as "building information modeling" and "construction industry" further points to practical applications in infrastructure, marking the intersection of digital technologies with real-world industry sectors.

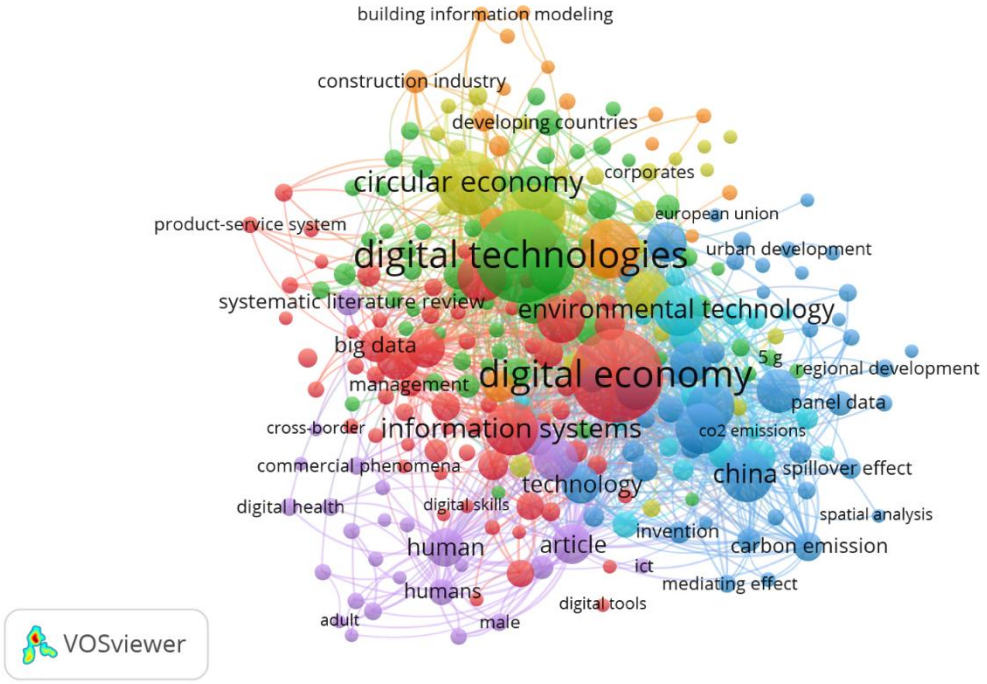

Figure 4: Network Visualization Map of Keywords' Co-Occurrence
Source: VOSviewer

For researchers, the visualization supports targeted literature reviews and encourages bridge studies that link less connected clusters, for example, CO_2 emissions with the CE or cross-country causal analyses. For journal editors and funders, the findings clarify where evidence is sufficiently robust to support translational research and where investment in rigorous empirical or experimental designs could address the critical knowledge gaps. This will accelerate both theory development and policy relevance within the evolving I4.0 to CE research agenda.

Co-authorship Collaboration

Co-authorship collaboration on digital technologies and CE captured the international collaboration research. Figure 5 illustrates the nodes that represent countries, and links to the shared authorship, and the weights of node links represent the intensity of collaboration. Utilizing full counting methodology, setting a minimum of five documents as the threshold, and a minimum cluster size of five, 42 of 84 countries met the inclusion threshold and were grouped into nine robust clusters. This approach filters out the sporadic partnerships and emphasizes more sustained and meaningful research collaborations in this field. The TLS metrics distinguish prolific producers such as China (251 publications, TLS=117), from highly cited but less voluminous contributors such as the US (42 documents, 2,205 citations, TLS=46), to a central connected collaborator, the UK (57 documents, TLS=89).

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The analysis reveals China's dominance as a production hub with extensive network reach, the UK's critical role as an intermediary connecting clusters, and the US's role as a high-impact contributor. Emerging regional players, including Malaysia, India, Saudi Arabia, and Pakistan, broaden the geographic diversity of the field. By quantifying where collaboration is dense versus peripheral engagement, the map highlights a few strategic opportunities. Bridge building, capacity development, and targeted funding are strategies to foster a more geographically inclusive and interconnected research landscape, accelerating knowledge exchange and advancing digital technologies for global digital CE transitions.

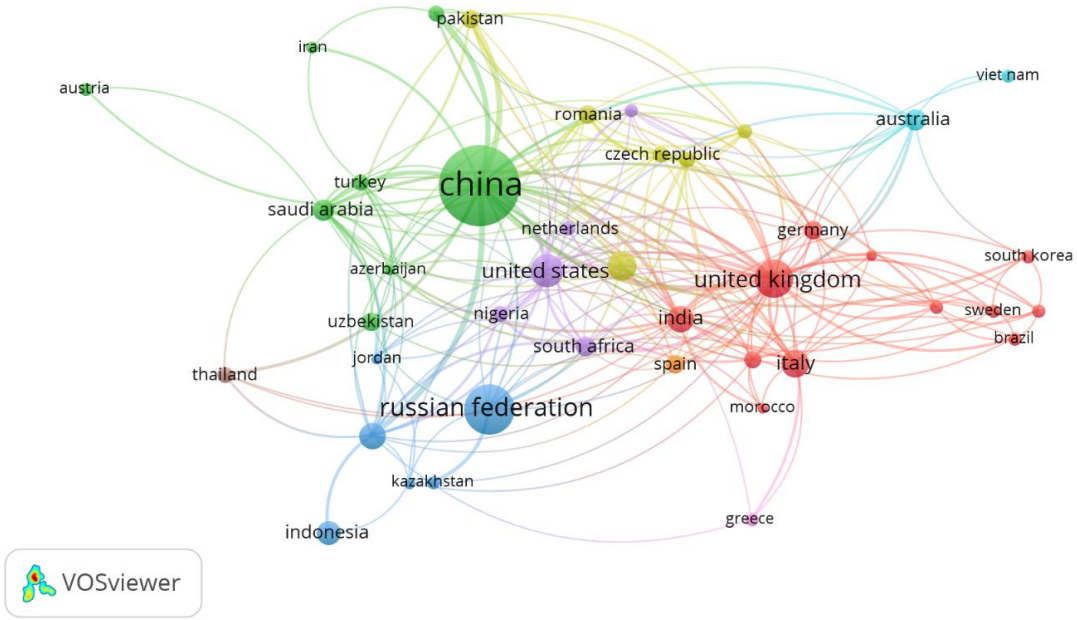

Figure 5. Network Visualization, Countries

Source: VOSviewer

Conclusions

This analysis aimed to systematically map the intellectual landscape of research connecting I4.0 digital technologies with CE objectives, guided by key questions on temporal trends, influential publications, national research output, keyword prominence, and patterns of international collaboration. Utilizing 689 Scopus-indexed publications, the dataset was cleaned, profiled, and visualized to generate descriptive statistics using Scopus Analyzer. Co-occurrence on author keywords and country-level co-authorship networks was generated using VOSviewer. The primary aim was to synthesize a fragmented scholarly literature into an evidence-based overview that supports the identification of research gaps and identifies opportunities for future research scope.

Findings reveal a rapidly growing interest in this research field, coupled with a marked concentration of publication volumes accelerated after 2018, anchored by a core set of highly cited seminal papers. Geographically, scholarly production is uneven, with a dominant country leading in volume and network connectivity, complemented by high-impact contributions and pivotal intermediate roles from several Western and emerging economies. Keyword analysis clustered seven thematic groupings that emphasize technology enablers, circular business

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models, environmental performance, and policy-driven as well as regional-specific empirical strands. Correspondingly, collaboration analysis identified nine robust country clusters, highlighting dense regional networks coexisting with global hubs and peripheral contributors. These patterns expose well-established translation for hotspots alongside underexplored intersections, such as links between CO_2 emission and digital finance to circular business models that represent promising avenues for integrative theoretical advancement and causal testing.

The contributions include an empirically grounded taxonomy of themes, a clarified visualization of collaborative topology, and a strategic identification of methodological and geographic gaps. These insights provide practical implications for funders and policymakers regarding areas primed for pilot implementation versus those requiring targeted capacity development to enhance knowledge diffusion. Limitations include reliance on a single bibliographic database, a methodological aspect that excludes several articles using different keyword terminology in the data search strategy, and the descriptive nature of bibliometrics, which cannot, by itself, establish causal relationships. Future research should broaden data sources and keyword terminology for data search, combine bibliometric mapping with systematic literature synthesis and meta-analysis, and pursue causal and field-experimental designs using multi-level data to validate mechanisms. Overall, this work provides a foundational framework for the I4.0 digital technologies and CE research frontier and advocates coordinated empirical efforts to translate scholarly knowledge into scalable, evidence-based circular transitions.

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References

Ahmi, A., 2023. BiblioMagika. Available from: https://aidi-ahmi.com/index.php/bibliomagika.

Akkad, M. Z., Šebo, J., & Bányai, T. (2022). Investigation of the Industry 4.0 Technologies Adoption Effect on Circular Economy. *Sustainability (Switzerland)*, *14*(19). https://doi.org/10.3390/su141912815

Al-Khoury, A., Hussein, S. A., Abdulwhab, M., Aljuboori, Z. M., Haddad, H., Ali, M. A., Abed, I. A., & Flayyih, H. H. (2022). Intellectual Capital History and Trends: A Bibliometric Analysis Using Scopus Database. *Sustainability (Switzerland)*, *14*(18). https://doi.org/10.3390/su141811615

Alves, J. L., Borges, I. B., & De Nadae, J. (2021). Sustainability in Complex Projects of Civil Construction: Bibliometric and Bibliographic Review. *Gestao e Producao*, *28*(4). https://doi.org/10.1590/1806-9649-2020v28e5389

Appio, F. P., Cesaroni, F., & Di Minin, A. (2014). Visualizing the Structure and Bridges of the Intellectual Property Management and Strategy Literature: A Document Co-citation Analysis. *Scientometrics*, *101*(1), 623–661. https://doi.org/10.1007/s11192-014-1329-0

Assyakur, D. S., & Rosa, E. M. (2022). Spiritual Leadership in Healthcare: A Bibliometric Analysis. *Jurnal Aisyah : Jurnal Ilmu Kesehatan*, *7*(2). https://doi.org/10.30604/jika.v7i2.914

Advanced International Journal of Business, Entrepreneurship and SME's
AIJBES
EISSN: 2682-8545
Volume 7 Issue 26 (December 2025) PP. 218-233
DOI 10.35631/AIJBES.726016

Bressanelli, G., Adrodegari, F., Perona, M., & Saccani, N. (2018). Exploring How Usage-focused Business Models Enable Circular Economy Through Digital Technologies. *Sustainability (Switzerland)*, *10*(3). https://doi.org/10.3390/su10030639

Cao, S., Nie, L., Sun, H., Sun, W., & Taghizadeh-Hesary, F. (2021). Digital Finance, Green Technological Innovation and Energy-Environmental Performance: Evidence from China's Regional Economies. *Journal of Cleaner Production*, *327*. https://doi.org/10.1016/j.jclepro.2021.129458

Denu, M., David, P., Landry, A., & Mangione, F. (2024). Managing Material, Information and Human Flows in Circular Manufacturing Systems with the Help of Emerging Digital Technologies. In L. Settineri & P. C. Priarone (Eds.), *Procedia CIRP* (Vol. 122, pp. 461–466). Elsevier B.V. https://doi.org/10.1016/j.procir.2024.01.067

Di Stefano, G., Peteraf, M., & Veronay, G. (2010). Dynamic Capabilities Deconstructed: A Bibliographic Investigation Into the Origins, Development, and Future Directions of the Research Domain. *Industrial and Corporate Change*, *19*(4), 1187–1204. https://doi.org/10.1093/icc/dtq027

Ding, C., Liu, C., Zheng, C., & Li, F. (2022). Digital economy, technological innovation and high-quality economic development: Based on spatial effect and mediation effect. *Sustainability (Switzerland)*, *14*(1). https://doi.org/10.3390/su14010216

Elghaish, F., Matarneh, S. T., Edwards, D. J., Pour Rahimian, F., El-Gohary, H., & Ejohwomu, O. (2022). Applications of Industry 4.0 Digital Technologies Towards A Construction Circular Economy: Gap Analysis and Conceptual Framework. *Construction Innovation*, *22*(3), 647–670. https://doi.org/10.1108/CI-03-2022-0062

Fahimnia, B., Sarkis, J., & Davarzani, H. (2015). Green Supply Chain Management: A Review and Bibliometric Analysis. In *International Journal of Production Economics* (Vol. 162, pp. 101–114). https://doi.org/10.1016/j.ijpe.2015.01.003

Fraga-Lamas, P., Lopes, S. I., & Fernández-Caramés, T. M. (2021). Green IoT and Edge AI as Key Technological Enablers for a Sustainable Digital Transition Towards a Smart Circular Economy: An Industry 5.0 Use Case. *Sensors*, *21*(17). https://doi.org/10.3390/s21175745

Gu, D., Li, T., Wang, X., Yang, X., & Yu, Z. (2019). Visualizing the Intellectual Structure and Evolution of Electronic Health and Telemedicine Research. *International Journal of Medical Informatics*, *130*. https://doi.org/10.1016/j.ijmedinf.2019.08.007

Hadi, N. U., Almessabi, B., & Imran Khan, M. (2025). Leveraging Industry 4.0 and Circular Open Innovation for Digital Sustainability: The role of circular ambidexterity. *Journal of Open Innovation: Technology, Market, and Complexity*, *11*(2). https://doi.org/10.1016/j.joitmc.2025.100545

Khiste, G. P., & Paithankar, R. R. (2017). Analysis of Bibliometric Term in Scopus. *International Research Journal*, *01*(32), 78–83.

Li, J., Chen, L., Chen, Y., & He, J. (2022). Digital Economy, Technological Innovation, and Green Economic Efficiency—Empirical evidence from 277 cities in China. *Managerial and Decision Economics*, *43*(3), 616–629. https://doi.org/10.1002/mde.3406

Li, Y., Dai, J., & Cui, L. (2020). The Impact of Digital Technologies on Economic and Environmental Performance in the Context of Industry 4.0: A Moderated Mediation Model. *International Journal of Production Economics*, *229*, 107777. https://doi.org/10.1016/j.ijpe.2020.107777

Litvinenko, V. S. (2020). Digital Economy as a Factor in the Technological Development of the Mineral Sector. *Natural Resources Research*, *29*(3), 1521–1541. https://doi.org/10.1007/s11053-019-09568-4

Advanced International Journal of Business, Entrepreneurship and SME's
AIJBES
EISSN: 2682-8545
Volume 7 Issue 26 (December 2025) PP. 218-233
DOI 10.35631/AIJBES.726016

Lopes de Sousa Jabbour, A. B., Chiappetta Jabbour, C. J., Choi, T.-M., & Latan, H. (2022). 'Better together': Evidence on the Joint Adoption of Circular Economy and Industry 4.0 Technologies. *International Journal of Production Economics*, *252*. https://doi.org/10.1016/j.ijpe.2022.108581

Pagoropoulos, A., Pigosso, D. C. A., & McAloone, T. C. (2017). The Emergent Role of Digital Technologies in the Circular Economy: A Review. *Procedia CIRP*, *64*, 19–24. https://doi.org/10.1016/j.procir.2017.02.047

Ranta, V., Aarikka-Stenroos, L., & Väisänen, J.-M. (2021). Digital Technologies Catalyzing Business model Innovation for Circular Economy—Multiple Case Study. *Resources, Conservation and Recycling*, *164*. https://doi.org/10.1016/j.resconrec.2020.105155

Schöggl, J.-P., Rusch, M., Stumpf, L., & Baumgartner, R. J. (2023). Implementation of Digital Technologies for a Circular Economy and Sustainability Management in the Manufacturing Sector. *Sustainable Production and Consumption*, *35*, 401–420. https://doi.org/10.1016/j.spc.2022.11.012

Singh, R., Rani, S., & Kandpal, V. (2025). Driving Environmental Resilience: Integrating Industry 4.0 for Circular Economy. In *Approaches to Global Sustainability, Markets, and Governance: Vol. Part F260* (pp. 23–40). Springer. https://doi.org/10.1007/978-981-96-0843-0_2

Teece, D. J. (2018). Profiting from Innovation in the Digital Economy: Enabling Technologies, Standards, and Licensing Models in the Wireless World. *Research Policy*, *47*(8), 1367–1387. https://doi.org/10.1016/j.respol.2017.01.015

Van Eck, N. J., & Waltman, L. (2010). Software Survey: VOSviewer, A Computer Program for Bibliometric Mapping. *Scientometrics*, *84*(2), 523–538. https://doi.org/10.1007/s11192-009-0146-3

Van Eck, N. J., & Waltman, L. (2017). Citation-based Clustering of Publications using CitNetExplorer and VOSviewer. *Scientometrics*, *111*(2), 1053–1070. https://doi.org/10.1007/s11192-017-2300-7

Van Eck, N. J., & Waltman, L. (2007). Bibliometric Mapping of the Computational Intelligence Field. *International Journal of Uncertainty, Fuzziness and Knowldege-Based Systems*, *15*(5), 625–645. https://doi.org/10.1142/S0218488507004911

Verbeek, A., Debackere, K., Luwel, M., & Zimmermann, E. (2002). Measuring Progress and Evolution in Science and Technology - I: The Multiple uses of Bibliometric Indicators. *International Journal of Management Reviews*, *4*(2), 179–211. https://doi.org/10.1111/1468-2370.00083

Wu, Y. C. J., & Wu, T. (2017). A Decade of Entrepreneurship Education in the Asia Pacific for Future Directions in Theory and Practice. In *Management Decision* (Vol. 55, Issue 7, pp. 1333–1350). https://doi.org/10.1108/MD-05-2017-0518