

THE DIGITAL–CIRCULAR ECONOMY NEXUS IN SUPPLY CHAINS: TRENDS, THEMES, AND INSIGHTS FROM A SCIENTOMETRIC PERSPECTIVE

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The growing urgency for sustainability in global supply chains, spurred by increasing demand, environmental degradation, and resource scarcity, has intensified academic and industrial focus on adopting circular economy (CE) principles. Recently, digital technologies have become key enablers of this shift, facilitating improved supply chain resilience, efficiency, and environmental outcomes. This study addresses a critical gap in the literature by systematically exploring the convergence of digitalization, supply chain management, and the circular economy. A scientometric analysis of 628 peer-reviewed articles published between 2010 and 2025 offers a comprehensive mapping of the intellectual structure and evolution of knowledge in this field. The findings reveal a marked acceleration in publication volume in 2025 compared with previous years, particularly in journals focusing on environmental sustainability and technological innovation. Citation and network analyzes indicate that China dominates research output, whereas the United Kingdom and India exhibit higher citation impact, reflecting their intellectual prominence in the field. Content analysis reveals four core thematic clusters: the technological influence of digital tools such as blockchain, the Internet of Things, artificial intelligence, digital twins, and machine learning; strategic approaches to strengthening supply chain resilience; emerging opportunities and innovation potential; and real-world industrial deployment across various sectors. These themes collectively underscore a growing scholarly consensus on the integrative role of digital technologies in advancing circular economy goals within supply chain systems. By tracing the evolution of research and highlighting key authors, journals, and thematic trends, this study offers critical insights for both academia and industry. This study is grounded in Dynamic Capabilities Theory (DCT), which explains how organizations purposefully identify opportunities, seize them, and reconfigure resources to sustain competitive advantage. It provides a strategic foundation for practitioners to evaluate digital maturity and align technological adoption with circular-economy objectives. Ultimately, this study highlights the transformative role of digitalization in integrating circular principles into global supply chains, offering deeper insights into sustainable value creation in the digital era.

Keywords: Digitalization, Circular Economy, Sustainable Supply chain management, Scientometric approach, Thematic analysis.

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1. INTRODUCTION

Unsustainable production and consumption are significant environmental challenges threatening developed and developing nations. The prevailing linear economic model has become increasingly unsustainable, leading to evident social and ecological consequences such as deforestation, soil erosion, overflowing landfills, ecosystem degradation, and the rapid depletion of vital natural resources (Khan *et al.*, 2021). Manufactured goods become toxic or hazardous at the end of their lifecycle, particularly when disposed of improperly. Combined with the overexploitation of natural resources and the limited capacity of ecosystems to absorb waste, such practices have heightened societal awareness of the urgent need for robust environmental management strategies. Contemporary ecological challenges have prompted governments to introduce regulatory frameworks that incentivize raw material reuse and extend product lifespans. As a result, businesses are increasingly required to implement reverse logistics and product recovery systems to comply with these standards, thereby reducing environmental impact and enhancing economic value (Gebhardt *et al.*, 2022). This has

intensified pressure on supply chains to adopt circular economy principles, driven by the pursuit of competitive advantage, brand value, economic efficiency, and sustainability. The circular supply chain (CSc) represents more than just an alternative to traditional linear models; it signifies a transformative approach to addressing complex 21st-century challenges. CSc is defined as an integrated supply chain designed to embed CE principles throughout the entire product lifecycle, including product design, sourcing, manufacturing, distribution, use, recovery, remanufacturing, reuse, and recycling. Unlike the linear model, which ends in disposal, the CE promotes a holistic strategy to reduce waste and pollution, enhance resilience, and support human and ecological well-being. Establishing closed-loop systems enables the recovery, recycling, and extended use of resources, thereby minimizing environmental impact (Davim 2015). In contrast, a supply chain supporting CE practices refers to a traditional supply chain that adopts selected circular principles without primarily reforming its processes or goals around circularity.

Adopting digitalization is essential for organizations seeking to enhance their strategic and operational capabilities. As firms transition toward circularity and environmental sustainability, innovation, particularly through modern technologies, becomes critical for optimizing product flows, supporting job creation in redesign and recycling, and improving resource efficiency. Recent technological advancements have profoundly impacted the adoption of circular practices across economic, business, and social domains (Di Maria *et al.*, 2022). Innovations in digitalization by leveraging tools like the Internet of Things (IoT), artificial intelligence (AI), blockchain (BC), digital twins (DT), and automation have transformed CSc, enabling organizations to optimize operations, enhance transparency, and respond more rapidly to consumer demands (Shoaib *et al.*, 2025a).

Innovative digital tracking technologies have enhanced enterprises' ability to monitor inventory, shipments, and manufacturing processes more effectively. Increased transparency supports evidence-based decision-making, enables proactive interventions, and improves supply chain efficiency. Digitalization thus fosters CSc that are more efficient, collaborative, integrated, and environmentally sustainable. Digital technologies enable organizations to collaborate more effectively with suppliers, producers, distributors, and consumers (Ali *et al.*, 2023; Shoaib *et al.*, 2020). Enhanced coordination strengthens interorganizational relationships, facilitates seamless communication and information exchange, improves supply chain efficiency, reduces lead times, and increases responsiveness to changing market demands.

Integrating digital technologies into CSc enables data-driven decision-making and predictive analytics, enhancing operational precision and strategic planning (Taddei *et al.*, 2022). With vast volumes of data generated across supply chain interfaces, firms can leverage advanced analytical tools to uncover patterns, generate actionable insights, and improve forecasting accuracy. These capabilities facilitate optimized inventory management, more accurate demand forecasting, and efficient resource allocation. As a result, organizations benefit from reduced operational costs, improved customer service, and enhanced key supply chain performance metrics, aligning technological advancement with the goals of circularity and efficiency.

The ability of digital technologies to capture and analyze large datasets supports predictive modeling, particularly in waste management, where AI can forecast waste generation trends and ensure traceability of recycled materials. The integrated application of AI, IoT, and BC technologies also facilitates real-time supply-demand alignment and secure, transparent peer-to-peer transactions, reducing reliance on intermediaries and improving resource efficiency (Birkel and Müller, 2021). For governments, such integration provides policymakers with dynamic, real-time tools to design and enforce circular-economy policies, enabling accurate tracking of resource flows and immutable compliance records. Consequently, regulatory activities can evolve consistently with the changing dynamics of the circular economy, ensuring transparency and verification.

CE is a key driver of sustainable competitive advantage, with digitalization identified as a critical enabler. Numerous studies have broadly explored emerging technologies to elucidate their role in facilitating digital transformation, including IoT frameworks for circular supply chains (Jum'a *et al.*, 2024), Industry 4.0 integration technologies (Gebhardt *et al.*, 2022), BC for organizational performance (Rehman Khan *et al.*, 2022), DT for logistics efficiency (Shoaib *et al.*, 2025a), food supply chains through digital technologies (Ada *et al.*, 2023), linkages between big data analytics and CE (Edwin Cheng *et al.*, 2022), and production using IoT and big data (Tavana *et al.*, 2024). While these works provide valuable insights into specific technologies and sectors, there remains a lack of comprehensive, integrated research addressing the full spectrum of technology-enabled circular economies. Existing literature reviews like Bressanelli *et al.* (2021) on CE in the electrical and electronic equipment supply chain and Agrawal *et al.* (2022) integrate CE and sustainable business performance, whereas Bhawna *et al.* (2024), including 130 research articles from the time span of 1991-2023, have contributed to understanding CE and digital supply chains. In 2025, literature reviews by Polimetta *et al.* (2025) and Ali *et al.* (2025) recognized Digital Twins as a critical enabler of Circular Supply Chain Management, demonstrating their potential to improve resource efficiency and sustainability performance by strengthening lifecycle visibility and reverse logistics. Similarly, Ventura *et al.* (2025) demonstrated that blockchain strengthens transparency, traceability, and stakeholder trust in sustainable supply chains; however, issues concerning standardization and interoperability continue to impede its widespread adoption. Majiwala *et al.* (2025) developed a hybrid fuzzy-based framework to evaluate the influence of Industry 5.0 on circular supply chains, with a particular focus on identifying and prioritizing critical implementation challenges.

In conclusion, the existing literature primarily examines the application of one or two digital technologies within circular supply chains, with a particular emphasis on improving performance and operational efficiency across specific sectors, such as the food, manufacturing and electronics industries. Furthermore, most studies rely on qualitative methods or systematic literature reviews, resulting in limited use of quantitative, structured analytical approaches (e.g., scientometric reviews) to map the evolving knowledge landscape comprehensively. Moreover, while existing studies extensively discuss the CE, they often provide only limited coverage of circularity principles within the context of circular supply chain Management. This limitation highlights the need for more systematic investigations into the multifaceted role of digitalization in advancing circular supply chains, particularly its effects on circular economy efficiency, sustainability, innovation, and competitiveness, offering deeper insights into the intellectual structure, emerging research trends, and future directions in this rapidly evolving field.

To address the gap, this study employs a scientometric approach, using tools such as Bibliometrix and VOSviewer, to systematically examine research on technology-enabled CE. The objective is to provide researchers and practitioners with a comprehensive understanding of the field's evolutionary trends, prevailing paradigms, and thematic foci. The study identifies key contributors and dominant research patterns by analyzing influential publications, authors, journals, institutions, and countries. Recognizing these trends facilitates the identification of existing research gaps, thereby guiding future investigations. Ultimately, this approach provides valuable insights that advance theoretical knowledge and practical applications within digitalized circular economies.

The current study aims to explain the following questions:

- (i) What does digitalization imply for the circular economy?
- (ii) What research trends have been prevalent in the area?
- (iii) What principal thematic Clusters are observed in research studies?
- (iv) What emerging research opportunities exist for advancing CSc from an industrial engineering perspective?
- (v) What is the evolutionary trajectory of digitalization in CSc through the lens of Dynamic Capabilities Theory?

The current article contributes uniquely to academic literature as follows:

- (i) This article integrates digitalization, the circular economy, and supply chain management to analyze their linkage based on previous literature.
- (ii) This study advances research by examining publication growth, identifying relevant search terms, prominent journals, and leading contributor countries, thereby providing a global research outlook. It also highlights emerging thematic areas that reflect industry demands and inform future scholarly inquiry.
- (iii) The study investigates prior research to identify dominant focus areas, examines the impact of various digital technologies, and reviews the industries and methodologies involved. This analysis supports the identification of research gaps, highlighting underexplored technologies and sectors requiring further investigation.
- (iv) The study provides meaningful guidance for academic scholars to outline future directions by identifying research gaps and overlooked topics, and for industry professionals to adopt a strategic approach to evaluate digital readiness and align technological implementation with circular economy objectives.

The rest of the manuscript is organized as follows: Section 2 presents the methodology for searching and analyzing publications on digitalization in the circular supply chain. It also lists the analysis-related potential terms, subject categories, leading journals, authors, countries, institutions, and organizations. Section 3 offers a discussion of the research. The research implications are provided in Section 4. Section 5 concludes the paper and discusses the study's limitations and potential avenues for future research.

2. LITERATURE REVIEW

The global sustainability agenda underscores the need to balance economic growth with environmental and social considerations. In this context, CSc integrates CE principles across the entire product lifecycle, encompassing product design, sourcing, manufacturing, distribution, use, recovery, remanufacturing, reuse, and recycling. By promoting resource efficiency, minimizing waste, and maximizing material value, CSc facilitates the transition from a linear to a circular economic model, thereby reducing environmental pressures associated with increased resource consumption (Kusumawardhani *et al.* 2025).

CE aims to optimize resource use by minimizing waste, emissions, and consumption while promoting renewable energy adoption. Digital technologies accelerate this transition by enhancing operational efficiency, reducing waste, and enabling smart manufacturing and sustainable supply chain practices. Integrating these concepts provides a comprehensive framework for understanding recent trends in digitalization within CSc and its role in advancing CE practices and supply chain performance.

Although recent studies have increasingly examined the digitalization–CE nexus, most have relied on systematic literature reviews. In contrast, only a limited number of studies have employed bibliometric approaches to systematically map the intellectual structure and research evolution of the field (e.g., Agrawal *et al.*, 2022; Ren *et al.*, 2023; Gou *et al.*, 2024; Lin *et al.*, 2024; Polimetla *et al.*, 2025). Addressing this research domain requires integrating diverse datasets and managing complex relationships, uncertainties, and dynamic interactions. Furthermore, prior review studies have

predominantly focused on individual digital technologies rather than adopting a comprehensive perspective. For example, Rejeb *et al.* (2022) examined the IoT; Rejeb and Zailani (2023), Lin *et al.* (2024), Abid *et al.* (2024), and Samadhiya *et al.* (2025) focused on blockchain technology; Farshadfar *et al.* (2024) reviewed machine learning applications, whereas Ali *et al.* (2025) investigated Digital Twin technology. Consequently, a holistic understanding of how multiple digital technologies collectively enable Circular Supply Chain Management remains limited.

Table 1 critically summarises previous review studies by comparing their review periods, methodologies, digital technologies, major findings, and limitations. Specifically, it identifies whether each study addresses the CE, Supply Chain Management (SCM), CSc, and Closed-Loop Supply Chains (CLSc). The analysis reveals several important research gaps. These limitations highlight the need for a comprehensive assessment capable of synthesizing large volumes of research and identifying emerging knowledge structures. To address these gaps, the present study adopts a scientometric approach by integrating Bibliometrix and VOSviewer to conduct comprehensive performance, network, and content analyzes. Unlike previous review studies, this research simultaneously investigates the roles of Big Data Analytics, Artificial Intelligence, Digital Twins, the Internet of Things, Blockchain, and Industry 4.0 in advancing Circular Economy implementation within Circular and Closed-Loop Supply Chains. Furthermore, the study maps the intellectual structure, collaboration patterns, thematic evolution, and emerging research trends, and proposes a comprehensive future research agenda for digitalization-driven circular supply chain management.

This study is interpreted through the lens of Dynamic Capabilities Theory (DCT), which describes how organizations continually sense environmental changes, seize emerging opportunities, and reconfigure their resources to sustain competitive advantage. In the context of CSc, digital technologies such as AI, BC, IoT, DT, and Big Data Analytics enhance companies' capabilities to monitor supply chain flows, enhance decision-making, optimize operational processes, and support circularity principles. Accordingly, DCT provides a theoretical foundation for interpreting the progression of digitalization research within CSc and for understanding how digital technologies support organizational adaptation and sustainable value creation.

Table 1. Research gap in previous studies

Sources	Time Domain Covered	Adopted Methodology	Adopted Technologies	CE	SCM	CSc	CLSc	Major Findings	Limitations
Rosa <i>et al.</i> (2020)	2008–2018	SLR	Industry 4.0, IoT, CPS, Big Data, Cloud, Additive Manufacturing	✓	★	★	✓	Conceptual relationship between Industry 4.0 and CE for circular manufacturing.	Manufacturing-focused; limited supply chain perspective.
Awan <i>et al.</i> (2021)	2015–2020	SLR	AI, IoT, Blockchain, Big Data, CPS	✓	★	★	★	Identified Industry 4.0 as a catalyst for CE	Focused mainly on CE rather than Circular Supply Chains.
Abideen <i>et al.</i> (2021)	2009–2020	PRISMA-based SLR	Blockchain, IoT, Cloud, AI, Big Data	✓	✓	✓	✓	Digital technologies facilitate circular business models through CSc	Limited quantitative synthesis; lacks bibliometric mapping.
Agrawal <i>et al.</i> (2022)	2011–2020	SLR + Bibliometric study	AI, IoT, Blockchain, Additive Manufacturing, Cloud, Big Data	✓	★	★	★	Identified major research themes integrating Industry 4.0 with CE	Manufacturing emphasis; limited Circular Supply Chain analysis.
Taddei <i>et al.</i> (2022)	2008–2021	PRISMA-based SLR	Industry 4.0, IoT, Blockchain, AI, CPS	✓	✓	✓	✓	Industry 4.0 technologies significantly improve collaboration, traceability, and reverse logistics in CScs such as Digital Twins.	Lack of empirical validation and integration of emerging technologies.
Rejeb <i>et al.</i> (2022)	2010–2021	SLR	IoT	✓	✓	★	✓	IoT supports resource optimization, product tracking, and circular business models.	Focuses exclusively on IoT.
Chauhan <i>et al.</i> (2022)	2010–2021	SLR	AI, Blockchain, IoT, Big Data, Industry 4.0	✓	★	★	★	How digitalization technologies accelerate CE adoption	Broad CE focus; limited emphasis on Circular Supply Chains.
Gebhardt <i>et al.</i> (2022)	2008–2021	SLR	IoT, Blockchain, AI, Digital Twin	✓	✓	✓	★	Demonstrated that Industry 4.0 technologies enhance collaboration, information sharing, transparency, and decision-making in Circular Supply Chains.	Limited empirical evidence and sector-specific validation.
Rusch <i>et al.</i> (2023)	2000–2022	SLR	AI, IoT, Blockchain, Digital Technologies	✓	★	★	★	Digital technologies improve sustainable product lifecycle management and circular business models.	Product-management focus rather than end-to-end CSc.
Rejeb and Zailani (2023)	2019–2022 (79 articles)	SLR	Blockchain	✓	✓	★	✓	Demonstrated that blockchain improves traceability, transparency, product lifecycle	Technology-specific review; excludes AI, IoT, and Digital Twins.

Sources	Time Domain Covered	Adopted Methodology	Adopted Technologies	CE	SCM	CSc	CLSc	Major Findings	Limitations
Ren <i>et al.</i> (2023)	2000–2022	Bibliometric Analysis	Industry 4.0, Technology Transfer, Digitalization	✓	✓	✓	★	management, and reverse logistics for CE implementation. Identified intellectual structure linking CE, Industry 4.0, supply chains, and technology transfer.	Limited analysis of individual digital technologies.
Bhawna <i>et al.</i> (2024)	1991–2023	PRISMA-based SLR	AI, Blockchain, IoT, Big Data, Cloud Computing	✓	✓	★	★	Digitalization improves resilience, sustainability, and resource efficiency across supply chains.	Lacks bibliometric/scientometric mapping and quantitative synthesis.
Das (2024)	91 publications	SLR	Industry 4.0, IoT, Blockchain	✓	✓	✓	✓	Proposed a conceptual framework for CSc	Conceptual review without bibliometric evidence.
Abid <i>et al.</i> (2024)	41 publications	SLR	Blockchain	✓	✓	★	✓	BC significantly enhances traceability, transparency, and reverse logistics for CE implementation.	Focused solely on blockchain technology.
Farshadfar <i>et al.</i> (2024)	2013–2023 (66 publications)	PRISMA-based SLR	Machine Learning	✓	✓	✓	✓	Machine learning enhances demand forecasting, reverse logistics, recycling optimization, and decision support.	Focuses only on machine learning; excludes broader Industry 4.0 technologies.
Gou <i>et al.</i> (2024)	2006–2023	Bibliometric Analysis + Systematic Literature Review	Industry 4.0, AI, Fuzzy Set Theory	✓	★	★	★	Mapped the evolution of research linking fuzzy decision-making, Industry 4.0, and CE, identifying emerging research themes.	Focuses on fuzzy methods rather than integrated digital supply chains.
Sánchez-García <i>et al.</i> (2024)	2013–2022 (890 publications)	LR	AI, IoT, Blockchain, Digital Twins, Big Data	✓	★	★	★	Contribution of emerging digital technologies to accelerating CE implementation and sustainable industrial transformation.	Broad Circular Economy focus; limited emphasis on Circular Supply Chain Management.
Lin <i>et al.</i> (2024)	2008–2023	Bibliometric Analysis + LR	Blockchain	✓	★	★	★	Revealed rapid growth in BC-enabled CE research and identified future thematic directions.	Limited to blockchain literature.
Polimetla <i>et al.</i> (2025)	2000–2024 (109 articles)	PRISMA + Bibliographic Coupling	Digital Twin, AI, Big Data, Industry 4.0	✓	✓	✓	✓	Identified six major research clusters and demonstrated that Digital Twins significantly enhance lifecycle visibility, predictive decision-making, reverse logistics, and CSc resilience.	Focuses only on Digital Twin-enabled CSc; limited empirical implementation across industries.
Morshedi <i>et al.</i> (2025)	157 publications	LR + Multi-layer Network Analysis	Blockchain, IoT, Big Data, AI/ML, Digital Twin, Cloud Computing, CPS, Additive Manufacturing, AR	✓	✓	✓	✓	Mapped the evolution of Industry 4.0 technologies in CSc and found blockchain, IoT and Big Data to be the most mature technologies, while AI and Digital Twins are rapidly emerging.	Network-based review; lacks empirical validation of technology adoption.
Zardo <i>et al.</i> (2025)	2017–2024 (28 articles)	SLR	Industry 4.0, AI, IoT, Blockchain, Digital Technologies	✓	✓	✓	★	Industry 4.0 technologies improve circular practices through waste identification, material reuse, traceability, demand prediction, and operational transparency.	Small review dataset; limited quantitative analysis.
Ali <i>et al.</i> (2025)	2019–2024	SLR	Digital Twin	✓	★	★	★	DT supports sustainability, lifecycle optimization, predictive maintenance, and resource efficiency in CE systems.	Mainly conceptual; limited industrial validation.
Samadhiya <i>et al.</i> (2025)	2015–2022	Comprehensive Literature Review	Blockchain, Smart Contracts	★	✓	★	✓	Blockchain as a critical technology for enhancing reverse logistics, waste recovery, recycling efficiency, and supply chain transparency.	Focuses primarily on reverse logistics and blockchain, with limited consideration of other Industry 4.0 technologies.

Includes (✓), Not Includes (✗), Partial (★), CE (Circular Economy), SCM (Supply Chain Management), CSc (Circular supply chain), CLSc (Closed loop supply chain)

3. RESEARCH METHODOLOGY

This study employs a systematic literature review (SLR) underpinned by scientometric methods to comprehensively analyze existing research on CSc and digitalization. The methodology integrates analytic tools, including Bibliometrix and VOSviewer for network and content analysis, to systematically identify, evaluate, and interpret relevant scholarly works. Following the structured review protocol shown in Figure 1, the data acquisition involved systematic searches of academic databases, followed by rigorous screening and processing to extract pertinent information. The analysis involved interconnected modules: network analysis, keyword density evaluation, co-authorship, bibliographic coupling, co-citation, and citation analysis. These methods helped identify core research areas, emerging themes, and directions for future study (Shoaib *et al.*, 2023). As an iterative process, the SLR allowed for the continuous refinement of research questions and the inclusion of new sources of evidence. The study comprehensively mapped existing literature by adhering to a structured analytical protocol, enhancing transparency, reducing bias, and ensuring methodological rigor. This study is a foundation for future research and supports evidence-based decision-making in CSc contexts. The insights gained offer an expanded, objective understanding of the current knowledge base and highlight key directions for further investigation.

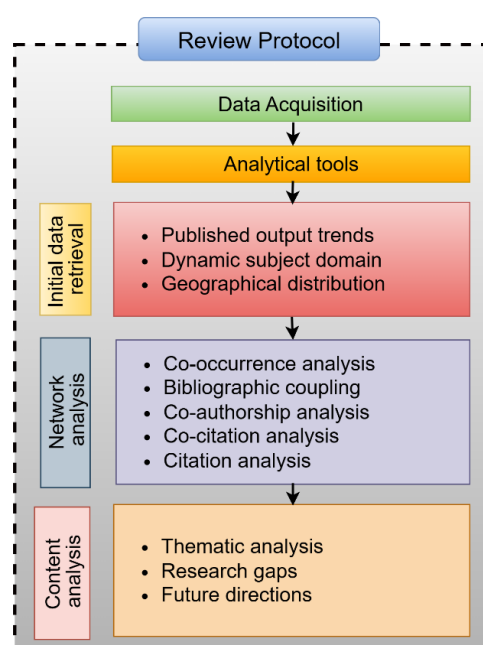


Figure 1. Research Review Protocol

3.1. Data acquisition

Data were collected from two leading academic databases, Scopus and Web of Science (WOS), known for their extensive coverage and high-quality publications. These databases include works from reputable publishers such as Elsevier, ScienceDirect, Taylor & Francis, Wiley, Emerald Insight, and Springer, ensuring the reliability and credibility of the sourced literature. To provide comprehensive coverage, Scopus data were supplemented with WOS records, which serve as the primary source due to their lower duplication rate and advanced query capabilities. Its credibility, particularly through indices such as SSCI, ESCI, and SCI-E, further supports its use for acquiring high-quality manuscripts. WOS is particularly valued for its extensive coverage of research in social sciences, business, and economics (Bhawna *et al.*, 2024). Additionally, supplementary data were gathered from Microsoft Academic, Google Scholar, CrossRef, and PubMed to maximize coverage and minimize the risk of omitting relevant studies.

3.2. Keyword identification

In this SLR, keyword selection was guided by practical relevance and a strategic theoretical approach to capture the most influential literature at the intersection of digitalization and CSc. Aligned with best practices for systematic reviews, the keywords were refined through extensive literature analysis to ensure consistency with core research themes and emerging scholarly and practical trends. A key strength of this study lies in the coherent integration of keyword identification with its findings, effectively offering a roadmap for future research. The selected keywords highlight gaps in the existing literature and suggest new avenues for exploring digitalization in CSc, particularly its role in regulatory

compliance within sustainable supply chain management (Hammouti *et al.*, 2025). Additionally, Boolean operators such as “AND” and “OR” enabled a focused yet thorough literature search on the intersection of digitalization and CSc principles.

A structured search string was developed to design a systematic search strategy by combining relevant keywords with Boolean operators. This approach ensured a comprehensive and targeted retrieval of pertinent literature. The search terms encompassed (“Digitalization” OR “Technology” OR “Big Data” OR “Artificial Intelligence” OR “Digital Twin” OR “Internet of Things” OR “Blockchain” OR “Industry 4.0”) AND (“Circular Economy” OR “Circularity” OR “Reverse” OR “Closed Loop” OR “Sustainability” OR “Environment” OR “Green” OR “Ecology” OR “Recycling” OR “Remanufacturing” OR “Waste management” OR “Reuse” OR “Recovery” OR “Disposal”) AND (“Supply chain” OR “Value Chain” OR “Logistics”). This search was conducted across two leading academic databases and included publications up to June 30, 2025.

3.3. Inclusion-Exclusion criteria

The process for applying the Inclusion-Exclusion criteria is shown in Figure 2. The search term analysis focused on abstracts, titles, and keywords, initially identifying 1,365 records from Scopus, 931 from WOS, and 63 from additional sources.

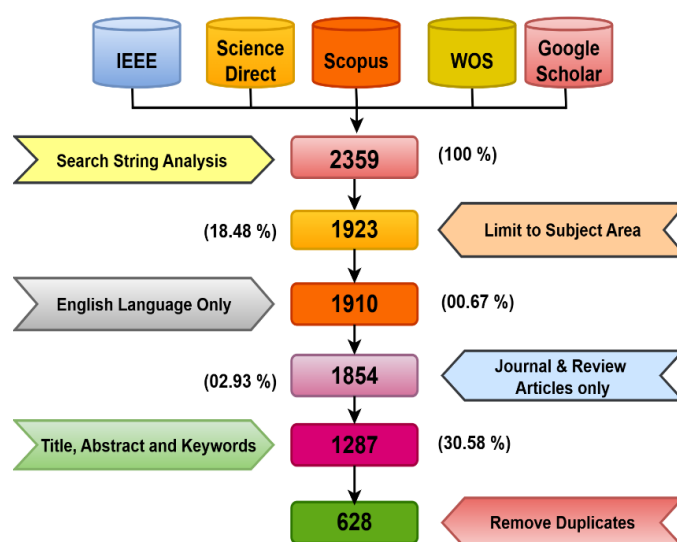


Figure 2. The Inclusion-Exclusion Criteria

Applying a defined inclusion–exclusion criterion, the scope was narrowed to environmental science, engineering, business management, decision sciences, operations, and social sciences. Only peer-reviewed journal articles and reviews published in English were retained, while grey literature, including editorials, conference proceedings, and book chapters, was excluded to maintain academic rigor. After carefully screening titles and abstracts, 851 relevant articles were selected from Scopus and 436 from WOS. Duplicate records were removed, and bibliographic files were merged and cleaned in R-Studio, resulting in a final dataset of 628 high-quality articles, exported in .csv format for subsequent scientometric analysis. Scopus and Web of Science (WoS) served as the primary data sources due to their extensive coverage and recognition in scientometric research. Google Scholar, IEEE Xplore, and ScienceDirect were used only to verify dataset completeness and identify any additional relevant publications. Duplicate records were removed based on title, DOI, authors, publication year, and source, while unique studies absent from the dataset were manually included to ensure that no relevant study was overlooked while maintaining a high-quality dataset.

Two reviewers independently participated in the data collection and screening process to finalize the bibliographic dataset. The inclusion and exclusion criteria were applied independently by both reviewers. Any discrepancies in study selection were resolved through discussion until a mutual consensus was reached, ensuring the consistency and reliability of the final dataset.

3.4. Analytical tool

This study systematically examines the literature on digitalization-based CSc from 2010 to June 30, 2025, ensuring a comprehensive and up-to-date analysis. It focuses exclusively on peer-reviewed academic publications that define digitalization-based CSc and present relevant quantitative or analytical models. A range of scientometric tools, such as Bibliometrix (Büyükkıdık, 2022), Gephi (Roy and DeRoche, 2025), CiteSpace (Nan *et al.*, 2025), Pajek (Wang *et al.*,

2023), VOSviewer (Hammouti *et al.*, 2025), HistCite (Thakuria *et al.*, 2024), and Bibexcel (Nair *et al.*, 2022), were employed to enhance the analytical depth and visualization of findings.

This study employed Bibliometrix for bibliometric analysis and VOSviewer for network visualization. The Bibliometrix tool extracted key bibliographic data, including annual publication counts, leading journals, keywords, citation metrics, top authors, institutions, and countries. To identify prominent and emerging research themes, VOSviewer was employed to visualize and analyze bibliometric data, generating maps of combined, co-citation, and co-occurrence networks that reveal patterns and dynamics within the research field (Wang *et al.*, 2023). VOSviewer facilitates the identification of clusters and the graphical visualization of nodes to interpret knowledge from prior publications. Node proximity reflects thematic similarity through an iterative process, where the distance between nodes reflects their weighted density and position, facilitating a clearer understanding of prevailing patterns and research dynamics.

3.5. Initial information retrieval

Using the Bibliometrix tool, essential bibliographic data were systematically extracted and analyzed to enhance study quality and minimize personal bias. The findings reveal that 628 research articles, including 97 review papers, were published between 2010 and 2025. These articles had an average citation rate of 61.22 per article and an annual growth rate of 16.84%. A total of 2,232 authors contributed, including 29 single-author papers, and the average number of co-authors per paper was 4.12, indicating a strong trend towards collaborative research.

3.5.1. Publication output trends

Figure 3 presents a longitudinal analysis of the 628 retrieved articles, showing a continuous upward trend in publication volume since 2010. Although early contributions were limited, a notable inflection point occurred in 2017, marked by the publication of 10 articles. From 2018 onward, publication rates exhibit exponential growth, reflecting heightened scholarly interest. This surge aligns with the accelerated development and adoption of advanced digital technologies, particularly since 2019, a pivotal year for introducing new technologies. This trend reflects the rapid evolution and adoption of digital technologies such as the IoT, RFID, and sensor networks. These innovations enhance inter- and intra-organizational connectivity, prompting firms to redesign supply chains toward nonlinear, data-driven models powered by big data analytics, thereby closely aligning with CE principles (Shoaib *et al.*, 2024).

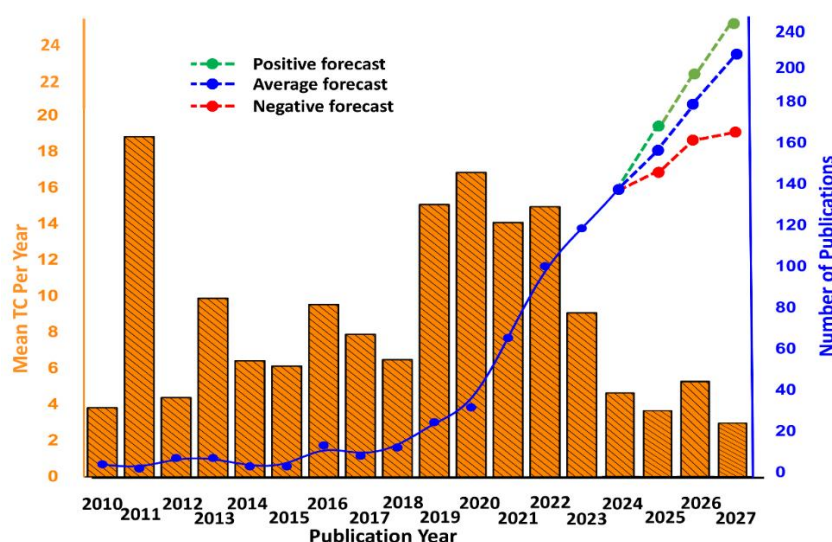


Figure 3. Publication output trends

The growing focus on the intersection of technology and the CE has continued to gain momentum. In 2021, 66 articles were published, reflecting a doubling from the previous year, followed by 100 in 2022, 118 in 2023, and 136 in 2024, indicating a sustained and increasing scholarly interest in the field. Publication output increased substantially after 2019. This trend coincided with the accelerated adoption of Industry 4.0 technologies during the COVID-19 period, as reported in previous studies. The pandemic-induced shift to remote work compelled organizations to implement digital solutions to maintain operational continuity and supply chain resilience (Kayikci *et al.*, 2022b). However, the present scientometric analysis does not examine whether the pandemic directly motivated the reviewed publications and therefore does not infer a causal relationship. As of June 30, 2025, 89 publications had been recorded, with projections indicating that this number could exceed 159 by year-end if the current 14% growth rate continues. To analyze future publication trends, an Autoregressive Integrated Moving Average (ARIMA) model was implemented in SPSS to forecast scholarly

output over the next three years. Model performance was evaluated using the Root Mean Square Error (RMSE) as a goodness-of-fit statistic, providing an assessment of forecasting accuracy and enhancing the transparency and reliability of the forecasting analysis. While the model provides optimistic and pessimistic scenarios, the trajectory of future growth remains uncertain, highlighting the dynamic and evolving nature of digitalization and CSc.

Moreover, the figure illustrates that the annual average total citations (TC) in 2011 and from 2019 to 2022 were notably higher than in other years, indicating sustained academic attention to the convergence of digital technologies and the CE. From a DC perspective, the evolution of research drives the progressive development of organizational detection, capture, and renewal capabilities. Early studies focused on sensing capabilities enabled by blockchain-enabled traceability and IoT-based data collection, whereas recent studies increasingly emphasize AI, Digital Twins, and Big Data Analytics to support predictive decision-making, process optimization, and organizational transformation toward CSc. This trend highlights the field's multidisciplinary relevance and growing recognition within scholarly discourse. The elevated citation rates underscore the growing recognition of emerging technologies as transformative tools for advancing sustainability and shaping a more resilient, circular future.

3.5.2. Dynamic Subject domain

The disciplinary distribution of publications shown in Figure 4 reveals that 203 (31%) of the literature falls within environmental sciences, followed by engineering (93, 14%), business management (81, 13%), and energy (71, 11%). Additional contributions include social sciences 59(9%), economics and econometrics 53(8%), decision sciences 47(7%), and operations 38(6%). While digitalization within the CE is gaining traction, it remains underrepresented in several key domains, underscoring the need for broader interdisciplinary engagement to fully capture its potential and implications.

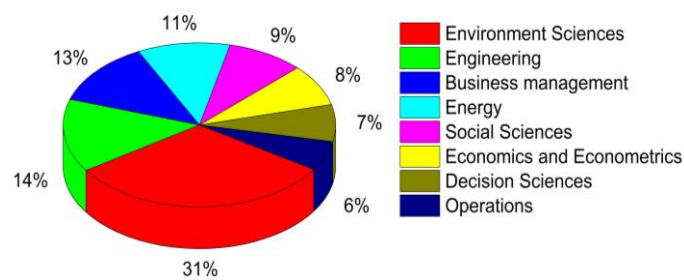


Figure 4. Dynamic Subject domain

3.5.3. Geographical distribution

Figure 5 shows the distribution of articles by country of origin. The top twelve countries, i.e., China (134), the UK (106), India (89), and the USA (68), account for about 61 percent of the top 10 countries.

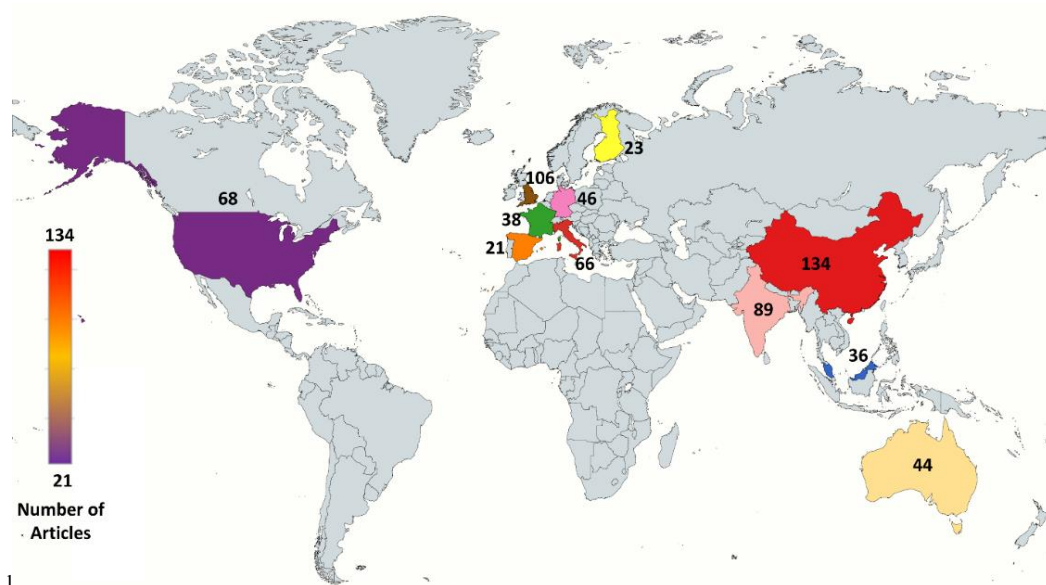


Figure 5. Geographical distribution

3.6. Network analysis

This study employed VOSviewer to visually map the scholarly landscape of the research domain using network analysis techniques such as co-occurrence, bibliographic coupling, co-authorship, citation, and co-citation. Following the methodological guidelines of Wang *et al.* (2023) and Hammouti *et al.* (2025), data were extracted, analyzed, and presented across multiple categories, including authors, publications, keywords, countries, and institutions. In these visualizations, each map highlights only one category at a time—for instance, keywords and countries are not shown together. Moreover, the node size in the network reflects the quantitative significance of an entity, with larger nodes indicating higher relevance or frequency within the dataset.

In network analysis, nodes represent entities with numerical values indicating key metrics such as citation counts or reference frequency. Connections between nodes, known as edges or links, reflect relational ties, each of which is assigned a weight. The total link strength (TLS) quantifies the overall connectedness between nodes. A high TLS indicates a strong relationship between two nodes representing citation or reference frequencies, where edges illustrate reciprocal connections among articles (Shoaib *et al.*, 2023). Node size and TLS are positively correlated; larger nodes with higher TLS signify greater inter-article influence.

Additionally, node color and spatial positioning convey further contextual information. In VOSviewer, spatial proximity reflects bibliographic similarity, as closely positioned articles often share common citations. Similar color schemes indicate thematic associations. The software offers three main visualization modes, e.g., network, overlay, and density, each providing distinct insights into the structural patterns of the publication network.

3.6.1. Keyword co-occurrence analysis

A co-occurrence analysis was performed to identify key scholarly terms across multiple publications, focusing on “keywords” that appear in at least 2 articles within the defined timeframe. This method facilitated the clustering of related concepts, offering a comprehensive view of research themes within the domain. During the VOSviewer analysis, the minimum occurrence threshold was set to two. This relatively low threshold was selected because research on digitalization in Circular Supply Chains is still an emerging field. Adopting a higher threshold could exclude recently published but relevant studies and emerging research themes, thereby limiting the comprehensiveness of the network analysis. A total of 1,916 author keywords and 4,539 index keywords were initially extracted and subsequently standardized to ensure consistency throughout the analysis. The co-occurrence of two keywords in a publication indicates a conceptual link between the topics. The TLS values of the 10 most popular authors and index keywords are given in Table 2. The network visualization in Figure 6 shows the keywords, with prominent nodes highlighting central themes. Notably, “circular economy,” “sustainability,” and “supply chain” emerged as the most influential keywords according to TLS, aligning with the study's core focus and confirming the relevance of digitalization in CSc management.

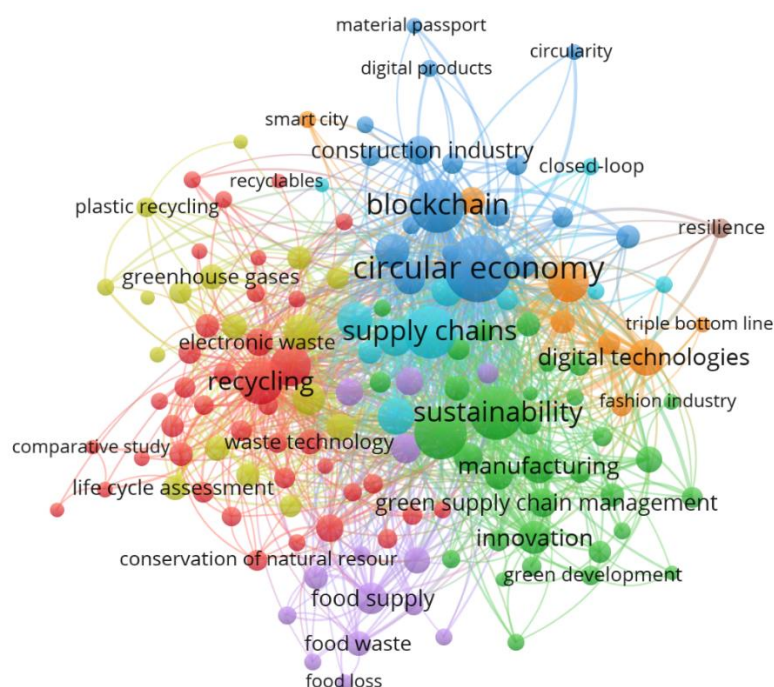


Figure 6. Visualization of potential keywords

A temporal analysis of emerging keywords was conducted to capture the evolution of thematic focus. Figure 7 illustrates an overlay visualization of all keywords, revealing distinct shifts in research emphasis over time. In 2024, dominant keywords included sustainability, waste management, Industry 4.0, life cycle assessment, and resource management, indicating a broader environmental and operational focus in earlier phases of research. In contrast, the 2025 literature emphasized themes such as digital technologies, blockchain, circularity, closed-loop systems, recyclables, and resilience—reflecting growing interest in integrating technology into circular practices (for more detail, see the discussion section).

Table 2. Authors and Index Keywords

Author keyword	TLS	Index keyword	TLS
Circular Economy	252	Circular Economy	189
Blockchain	123	Supply chain	169
Sustainability	117	Sustainable development	162
Industry 4.0	72	Recycling	111
Supply chain	55	Blockchain	106
Digitalization	37	Sustainability	88
Artificial intelligence	26	Waste management	79
Digital Twin	25	Environmental technology	59
Recycling	25	Decision making	55
Traceability	21	Life Cycle	53

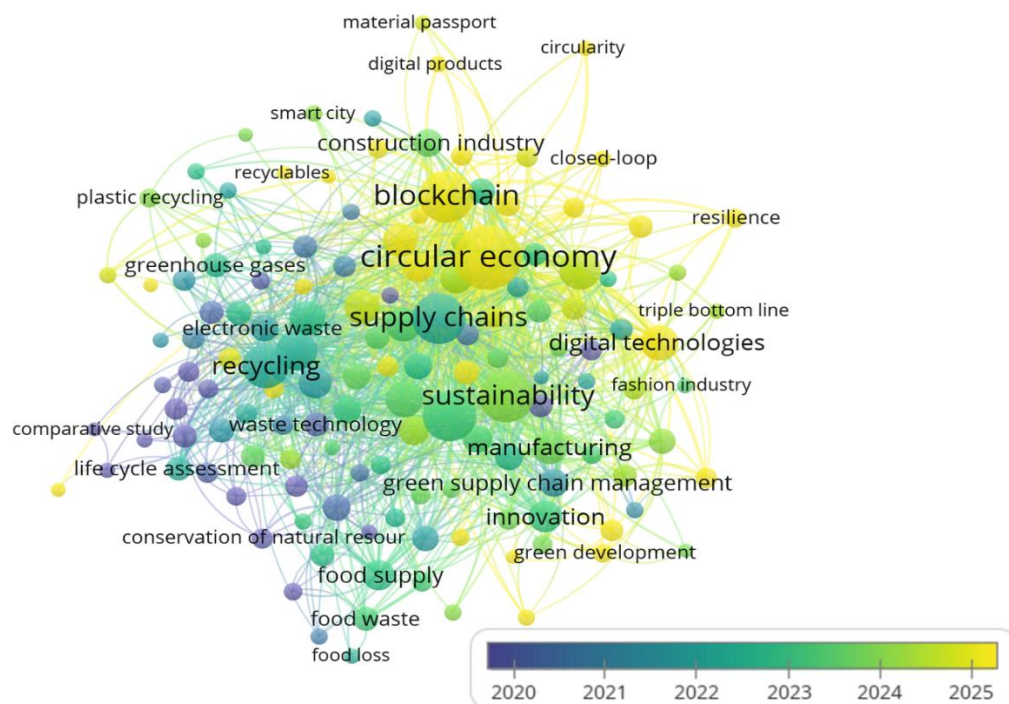


Figure 7. Temporal Visualization of keywords

3.7. Bibliographic coupling

Table 3 highlights the bibliographic coupling among the top 10 journals based on TLS, revealing a broad, interdisciplinary publication landscape in CSc research. Rather than being confined to a limited set of sources, researchers publish across diverse domains such as strategy, engineering management, computer science, conservation, recycling, and environmental management. Leading journals include *Journal of Cleaner Production*, *Sustainability*, *Business Strategy and the Environment*, and *Computers and Industrial Engineering*. Figure 8 illustrates these connections, focusing on journals with at least six articles and a minimum of six citations per article, and emphasizing their role in disseminating research on advanced technologies, waste management, pollution control, and circularity strategies.

Table 3. Top Leading Journals.

Journal Name	Count	Citation	TLS
Journal of Cleaner Production	47	3787	846.93
Sustainability (Switzerland)	53	2014	773.29
Business Strategy and The Environment	23	1267	772.51
Computers and Industrial Engineering	21	868	425.29
International Journal of Production Research	10	3010	386.18
Sustainable production and consumption	13	1035	381.01
International Journal of Production Economics	12	818	378.58
Resources, Conservation, and Recycling	33	2623	347.48
Journal of Environmental Management	15	792	293.26
Resources, Conservation, and Recycling Advances	5	134	197.69

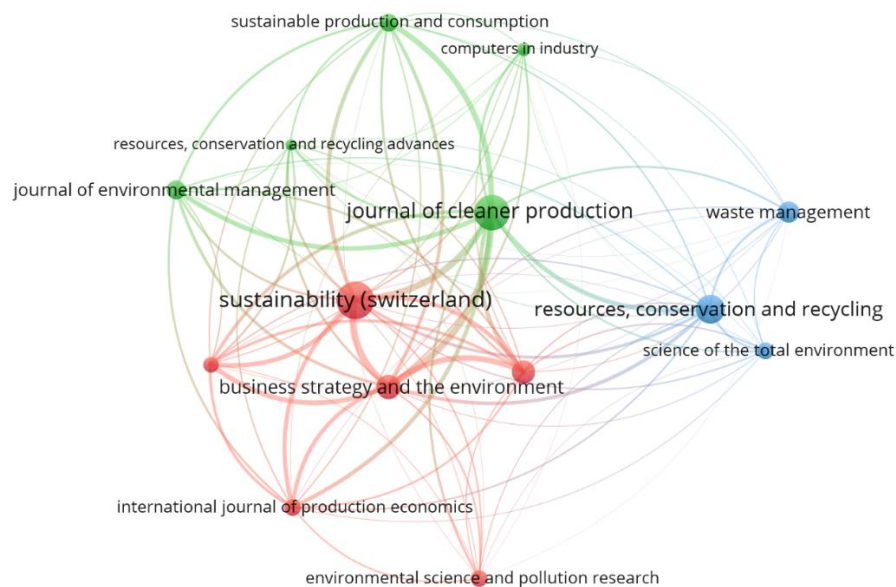


Figure 8. Leading Journals

Bibliographic coupling was employed to assess the influence of authors, institutions, and countries in this domain, using TLS as the primary metric. Table 4 identifies leading contributors, with Rejeb A., Zailani S., and Sarkis J. emerging as the most influential authors, followed by Goh H. H. and Kurniawan T. A. At the institutional level, London Metropolitan University (UK), OP Jindal Global University (India), and Guangxi University (China) were the most impactful organizations. Nationally, the United Kingdom, India, and China lead in scholarly influence, though China has the highest publication volume. Notably, the higher TLS values of the UK and India suggest a greater academic impact per publication. Emerging contributions from countries such as Malaysia and Pakistan indicate growing global interest in this research area.

Table 4. Top influencing authors, countries, and organizations.

Authors (TLS)	Organizations (TLS)	Countries (TLS)
Rejeb A. (622.32)	London Metropolitan University, London, UK (237.93)	UK (6878.27)
Zailani S. (575.89)	OP Jindal Global University, Sonipat, India (234)	India (5601.7)
Sarkis J. (542.26)	Guangxi University, Guangxi, China (228.53)	China (5411.35)
Goh H. H. (504.69)	Xiamen University, Xiamen, China (223.53)	USA (3153.2)
Kurniawan T. A. (504.69)	Qatar University, Doha, Qatar (146)	Australia (2929.49)
Kouhizadeh M. (473.51)	Cadi Ayyad University, Marrakech, Morocco (138.33)	France (2802.49)
Kumar A. (370.57)	Worcester Polytechnic Institute, Worcester, United States (60.51)	Malaysia (2754.7)
Garza-Reyes J. A. (330.52)	Ilma University, Karachi, Pakistan (43)	Italy (2270.23)
Bag S. (79.03)	University of Derby, Derby, United Kingdom (38.48)	Germany (1420.87)
Ramakrishna S. (16)	Linköping University, Linköping, Sweden (21.6)	Pakistan (1323.42)

3.7.1. Three-field plot analysis

Figure 9 uses a bibliometric tool to construct a three-field plot linking authors (left), keywords (center), and countries (right) by frequency. The analysis reveals that several leading authors contribute to multiple thematic areas, rather than focusing on a single technology. For example, authors such as Kumar, Li, Bag, Zhang and Gupta are connected with multiple keywords, including CE, I4.0, BC, digital transformation, and SCM.

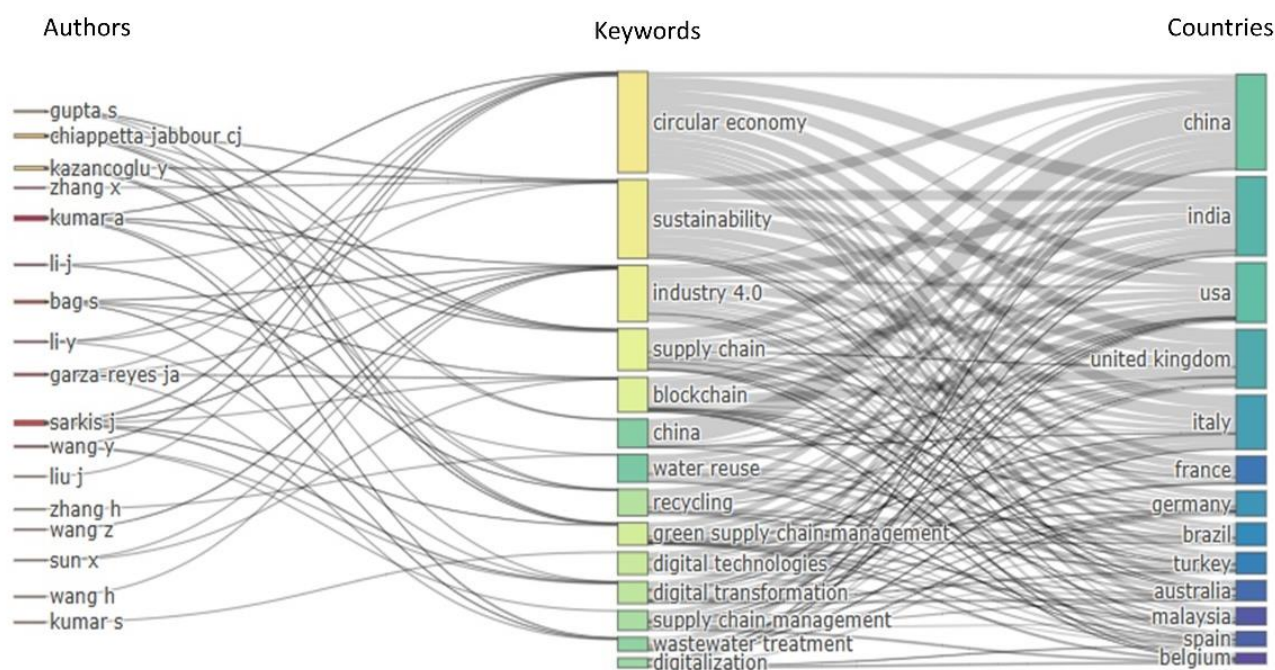


Figure 9. Triple field plot of authors, keywords, and countries.

This shows that influential researchers widely adopt multidisciplinary domains to address CSc issues through integrated technologies rather than standalone technological solutions. Moreover, the figure shows that "circular economy," "sustainability," "Industry 4.0," "supply chain," and "blockchain" are the most frequently used and interconnected keywords, indicating that recent studies primarily focus on adopting digital technologies to boost circular supply chain sustainability. In addition, CE and sustainability are identified as prime themes, drawing contributions from a diverse range of scholars and countries and representing a hot topic. The strong connections between the top countries and the leading keywords show that research interests are geographically focused. These topics are particularly emphasized in research outputs from China and India, highlighting their leading roles in advancing scholarship at the intersection of digitalization and circular economy practices.

Regardless of these strong connections, the three-field plot also reveals several research gaps. Digital technologies such as AI, DT, ML, Data Analytics, and cloud computing are underrepresented compared with I4.0 and BC, suggesting that their integration into CSc research is still developing. Future studies should therefore encourage cooperative research involving various technologies to develop broad solutions for CSc rather than focusing on separate technological applications.

3.7.2. Co-authorship

A co-authorship analysis was conducted to evaluate collaborative patterns among researchers. Despite the fragmented nature of author connections, only 14 authors formed meaningful linkages, as illustrated in Figure 10. Four major author clusters were identified based on a minimum threshold of five citations per article, as mentioned in Table 5. The red cluster had the greatest impact, featuring key contributors such as Garza-Reyes J. A., Kumar A., and Luthra S., each with more than 4 collaborative links. Other clusters include Belhadi A. and Gunasekaran A. in the green group, Upadhyay A. in the blue group, and Gupta S. and Mangla S.K., who exhibit notable coordination within the yellow cluster.

Table 6 presents the co-authorship analysis at the organizational level, identifying 83 institutions engaged in collaborative research on digitalization and CSc. However, only 13 organizations formed meaningful connections, grouped into four distinct clusters. Five universities collectively contributed the most co-authored publications in the red cluster. The green cluster includes institutions that co-authored four publications, with an average of two collaborative

links. The analysis also reveals cross-institutional and cross-national collaboration, indicating a growing global research network in this emerging field.

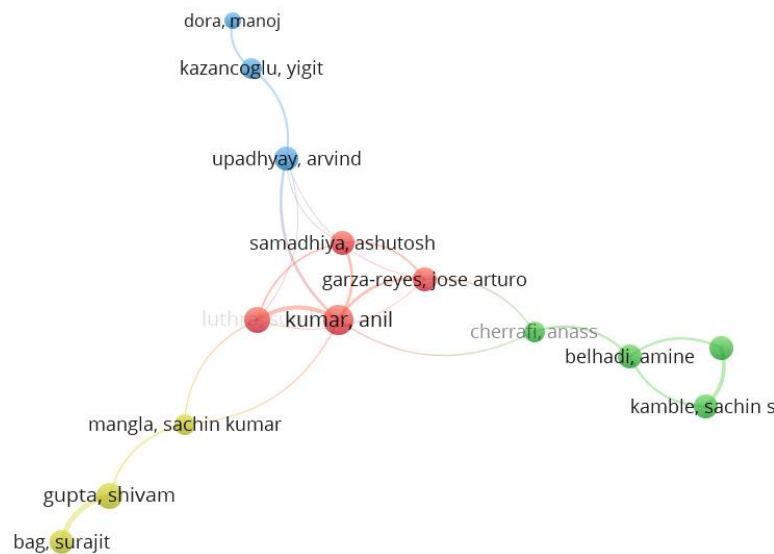


Figure 10. Top 4 clusters for author linkage

Table 5. Links and TLS for author connections.

Cluster red	Links	TLS	Cluster green	Links	TLS	Cluster blue	Links	TLS	Cluster yellow	Links	TLS
Garza-Reyes J. A.	5	3	Belhadi A.	3	3	Dora M.	1	1	Bag S.	1	3
Kumar A.	6	7	Gunasekaran A.	2	3	Kazancoglu Y.	2	2	Gupta S.	2	4
Luthra S.	5	4	Kamal S. S.	2	3	Upadhyay A.	5	3	Mangla S. K.	3	2
Samadhiya A.	4	3	Cherrafi A.	3	2						

Table 6. Links and TLS for an organization level

Cluster red			Links	TLS	Cluster green			Links	TLS
University of Southern Denmark, Denmark			4	2	The University of Derby, Derby, UK			2	4
Shanghai Maritime University, Shanghai, China			4	2	London Metropolitan University, London, UK			2	5
Graphic Era (Deemed to be University), Uttarakhand, India			5	2	Graphic Era (Deemed to be University), Uttarakhand, India			2	3
Woxsen University, Sadasivpet, India			4	2	OP Jindal Global University, Sonipat, India			2	4
Yonsei University, Seoul, South Korea			4	2					
Cluster blue			Links	TLS	Cluster yellow			Links	TLS
Bangladesh university of engineering and technology, Dhaka, Bangladesh			3	1	Turkish-German University, Istanbul, Turkey			4	2
Indian Institute of Technology, New Delhi, India			3	2	Yasar University, Izmir, Turkey			4	1

Moreover, there is a notable lack of consistency in how organizations are identified as co-authors in the literature, which complicates systematic analysis. Organizational attribution involves the quantity of publications and the citations those publications receive, but meeting both criteria simultaneously is challenging. Additionally, variations in naming conventions—including those for departments, universities, cities, or nationalities—create a heterogeneous, fragmented dataset. Consequently, constructing accurate co-authorship profiles for academic affiliations remains a complex and unresolved task, as illustrated in Figure 11.

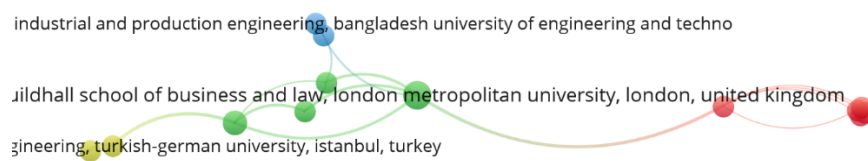


Figure 11. Co-authorship analysis for an academic affiliation

The co-authorship analysis of 25 countries is outlined in Table 7 and visualized in Figure 12. The top four clusters for countries reveal four distinct patterns of international collaboration. Notable bilateral collaborations include those with China, Pakistan, and Malaysia, which exhibit high levels of co-authored research. The red cluster represents the strongest network, with countries like Finland, Sweden, Spain, Norway, and the United States, and active partnerships among India, Italy, Brazil, the UK, and France, indicating dynamic knowledge exchange. Emerging collaborations are evident in the blue cluster, which includes Australia, Austria, Germany, and Singapore. These patterns underscore the growing importance of cross-national cooperation in advancing global research on digitalization and circular supply chains.

Table 7. Links and TLS for co-authorship analysis for countries.

Cluster red	Links	TLS	Cluster green	Links	TLS	Cluster blue	Links	TLS	Cluster yellow	Links	TLS
Denmark	16	11	Brazil	8	8	Australia	18	33	China	23	59
Finland	9	11	France	17	31	Austria	11	10	Malaysia	16	25
Norway	15	10	India	22	51	Germany	17	18	Pakistan	13	14
Portugal	12	8	Italy	17	21	Netherlands	10	12	South Korea	16	9
Spain	11	13	Morocco	11	12	Singapore	14	9	Thailand	11	8
Sweden	13	13	Turkey	7	9	Switzerland	12	9			
USA	19	32	UK	22	77						

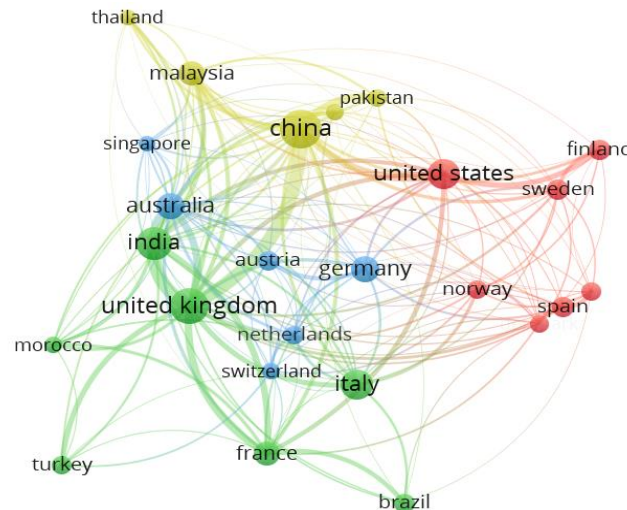


Figure 12. Top four clusters for countries

3.7.3. Citation analysis

Citation analysis offers valuable insights into the scholarly influence of authors, countries, and organizations. Table 8 identifies Sarkis J. and Kouhizadeh M. as the most cited authors, followed by Garza-Reyes J. A. and Goh H. H. The United States, the United Kingdom, and China lead in citation counts at the national level, emphasizing key thematic areas in digitalization and CSc research. Worcester Polytechnic Institute (USA) and Guangxi University (China) emerge as major contributors. Compared to other bibliographic coupling tools, citation analysis provides a more unambiguous indication of impactful work, highlighting entities whose research is widely acknowledged and referenced.

Moreover, citation analysis often involves ranking journal articles to assess their academic value. Table 9 presents the most cited articles among the 628 reviewed, with Saberi *et al.* (2019) leading significantly with 2,621 citations, followed by Nascimento *et al.* (2019) with 698 citations and Rissman *et al.* (2020) with 674 citations. Saberi *et al.* (2019) work is particularly influential for its comprehensive exploration of digital technologies in sustainable supply chains,

addressing potential applications and practical challenges. Nascimento *et al.* (2019) focus on circular practices within the manufacturing sector. The high citation counts of articles published between 2019 and 2021 underscore the rapid rise in scholarly attention to digitalization and its integration into CE research.

Table 8. TLS and citation values for the top 10 authors, countries, and organizations.

Authors	Citation	Countries	Citation	Organisations	Citation
Sarkis, J	4153	USA	8224	Worcester Polytechnic Institute, Worcester, USA	728
Kouhizadeh M.	3388	UK	6988	Guangxi University, Guangxi, China	457
Garza-Reyes J. A.	848	China	6824	Ilma University, Karachi, Pakistan	414
Goh H. H.	572	India	3873	Linköping University, Linköping, Sweden	356
Kurniawan T. A.	572	Germany	3395	Cadi Ayyad University, Marrakech, Morocco	275
Rejeb A.	369	Italy	3066	OP Jindal Global University, Sonipat, India	269
Kumar A.	290	France	2498	Xiamen University, Xiamen, China	255
Ramakrishna S.	251	Australia	2287	London Metropolitan University, London, UK	144
Zailani S.	227	Finland	1904	Qatar University, Doha, Qatar	129
Bag S.	14	Norway	1854	The University of Derby, Derby, UK	80

Table 9. Top-ranked articles

Sources	Article titles	Published Journals	Citations
Saberi <i>et al.</i> (2019)	“Blockchain technology and its relationships to sustainable supply chain management.”	International journal of production research	2621
Nascimento <i>et al.</i> (2019)	“Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context: A business model proposal.”	Journal of Manufacturing Technology Management	698
Rissman <i>et al.</i> (2020)	“Technologies and policies to decarbonize global industry: Review and assessment of mitigation drivers through 2070.”	Applied Energy	674
Esmailian <i>et al.</i> (2020)	“Blockchain for the future of sustainable supply chain management in Industry 4.0.”	Resources, Conservation, and Recycling	635
Centobelli <i>et al.</i> (2022)	“Blockchain technology for bridging trust, traceability, and transparency in circular supply chain.”	Information and Management	511
Upadhyay <i>et al.</i> (2021)	“Blockchain technology and the circular economy: Implications for sustainability and social responsibility.”	Journal of Cleaner Production	479
Cohen <i>et al.</i> (2016)	“The impact of demand uncertainty on consumer subsidies for green technology adoption.”	Management Science	428
Nandi <i>et al.</i> (2021)	“Redesigning Supply Chains using Blockchain-Enabled Circular Economy and COVID-19 Experiences.”	Sustainable Production and Consumption	385
Kouhizadeh <i>et al.</i> (2020)	“Blockchain and the circular economy: potential tensions and critical reflections from practice.”	Production Planning and Control	379
Camacho-Otero <i>et al.</i> (2018)	“Consumption in the circular economy: A literature review.”	Sustainability (Switzerland)	342

3.7.4. Co-citation analysis

Co-citation analysis examines how frequently two articles are cited in a third publication, indicating their conceptual relatedness. In graphical representations, nodes represent articles, and links denote citation relationships; greater link density reflects stronger co-citation. High co-citation values typically suggest thematic alignment within a research field. Due to the extensive volume of articles, a threshold of at least five citations per article was set for inclusion. Co-citation analysis of references is shown in Figure 13. The resulting co-citation network revealed five clusters comprising 7,527 connections and a TLS of 10,823, highlighting strong interrelatedness among the articles and suggesting a high Degree of thematic cohesion in the literature.

Figure 14 presents the results of a journal co-citation analysis, which identifies journals that are frequently cited together, thereby indicating a shared research focus. The analysis produced 16,148 co-citation links across five clusters. The blue cluster primarily comprises journals related to sustainability studies. Among them, *Sustainability* emerges as the most influential, with 272 links, 55,573 TLS, and 1,318 citations. It is followed by the *Journal of Cleaner Production*, which holds 89 links and a TLS of 15,783. This confirms its prominence in publishing work related to circular economy and digital supply chain topics.

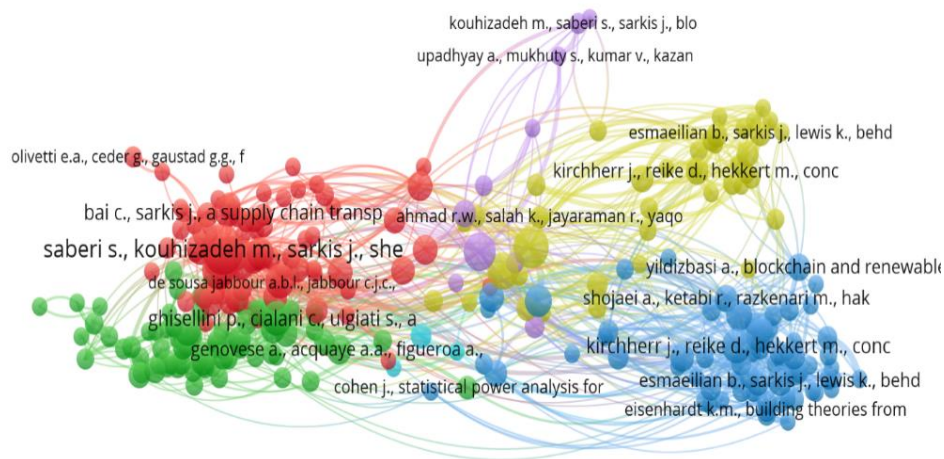


Figure 13. Co-citation analysis for references

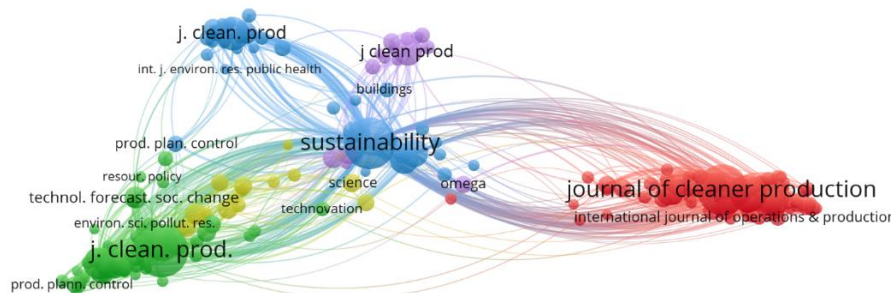


Figure 14. Co-citation analysis for journals.

3.8. Thematic Analysis

The rapid growth of digitalization-related applications has created challenges in analyzing an expanding body of literature. To address this, a thematic analysis was conducted to organize existing studies into a coherent framework based on semantic proximity. Studies such as Bhawna *et al.* (2024) and Lin *et al.* (2025) outline the conceptual basis of thematic analysis. This method enhances the examination of knowledge structures by enabling within-cluster comparisons, thereby supporting content analysis by classifying distinct topic areas. This study employed VOSviewer to identify four thematic clusters within a dataset of 16,664 links and 36,707 TLS. Each cluster is distinguished by specific color codes. Figure 15 and Table 10 list the four TLS-ranked articles per cluster.

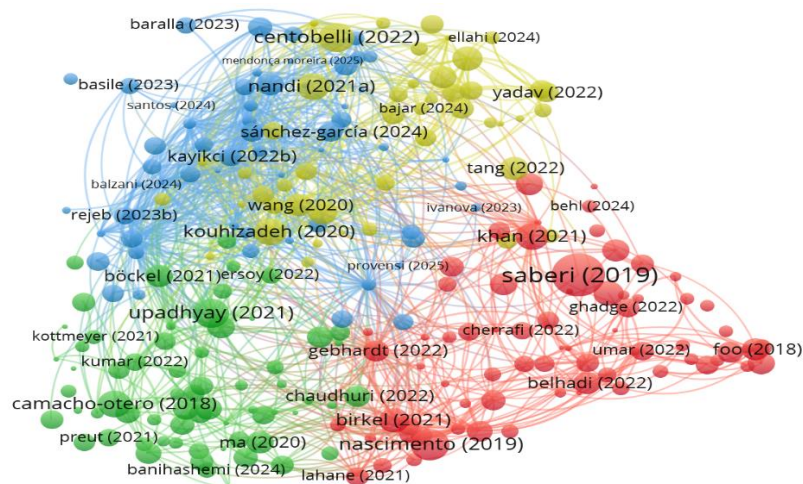


Figure 15. Thematic cluster visualization

Table 10. Top extracted thematic Clusters

Clusters	Sources	Links	TLS	Citations
Cluster red Technological impact	Akbari and Hopkins (2022)	49	41	114
	Birkel and Müller (2021)	45	44	261
	Khan <i>et al.</i> (2021)	50	52	338
	Kamble and Gunasekaran (2023)	46	52	61
	Junaid <i>et al.</i> (2024)	44	52	12
Cluster green Strategies and Framework	Kumar and Chopra (2022)	48	65	69
	Kayikci <i>et al.</i> (2021)	46	67	77
	Ma <i>et al.</i> (2020)	45	52	165
	Joshi <i>et al.</i> (2023)	41	33	35
	Kouhizadeh <i>et al.</i> (2019)	33	44	181
Cluster blue Potentials and opportunities	Kayikci <i>et al.</i> (2022a)	44	33	92
	Jiang <i>et al.</i> (2023)	47	38	79
	Massari <i>et al.</i> (2023)	41	36	14
	Quayson <i>et al.</i> (2023)	39	32	51
	Dwivedi and Paul (2022)	45	43	74
Cluster yellow Industrial deployment	Giganti <i>et al.</i> (2024)	32	44	24
	Gong <i>et al.</i> (2022)	45	56	62
	Pakseresht <i>et al.</i> (2023)	42	47	69
	Rejeb <i>et al.</i> (2021)	26	31	83
	Sharma <i>et al.</i> (2025)	49	60	37

3.8.1. Technological impact

The largest thematic cluster, accounting for approximately 30% of the dataset and marked in red, centers on the intersection of digital technologies and supply chain sustainability. This cluster primarily explores how IoT, BC, big data analytics, and other Industry 4.0 tools transform CSc, particularly in enhancing visibility, optimizing logistics, and improving environmental performance. Significant scholarly attention has been given to real-time inventory tracking, transportation optimization, and customer responsiveness. Research by Khan *et al.* (2021), Birkel and Müller (2021), and Karmaker *et al.* (2023) examined the impact of Industry 4.0 on the sustainable supply chain. Concurrently, the CE has emerged as a vital business model, emphasizing waste reduction and resource efficiency through reuse, remanufacturing, and recycling. The cluster also highlights the growing relevance of logistics in maintaining continuous, sustainable product flows, as well as the integration of CE principles into closed-loop supply chains and reverse logistics. Scholars such as Saberi *et al.* (2019), Di Maria *et al.* (2022), and Taddei *et al.* (2022) integrate the circularity concept with Industry 4.0, whereas Trujillo-Gallego *et al.* (2022) and Belhadi *et al.* (2022) also focused on sustainable supply chain performance.

3.8.2. Strategies and Resilience

Cluster Green, comprising approximately 26% of the reviewed articles, centers on strategies and resilience in digitalization-enabled CSc. Supply-chain resilience refers to a circular network's capacity to withstand threats and recover rapidly from disruptions. Modern supply chains enhance this capability by addressing vulnerabilities and adopting comprehensive strategies that promote flexibility, agility, efficiency, visibility, and collaboration, leveraging digital technologies when needed. Implementing such strategies requires a balanced integration of sustainability and resilience to support CE practices, align with resilient architectures, and uphold environmental responsibility. Key contributions include Kayikci *et al.* (2021), who examined barriers to innovative, sustainable CE, and Kumar and Chopra (2022), who employed smart contract technologies to address implementation challenges. Other studies in this cluster explored strategic frameworks for sustainable intelligent manufacturing (Ma *et al.*, 2020), evaluation of waste electronic products (Tozanlı *et al.*, 2020), product life cycle decision-making (Jensen *et al.*, 2023), and circular business models in the fashion industry (Huynh, 2022), among others. This theme centers on the triple bottom line, digitalization, dynamic capabilities, and sustainable supply chain management, with research increasingly addressing discrete and integrated aspects of these domains. The focus on niche areas underscores the need for specialized inquiry and interdisciplinary collaboration to enhance growth and impact (Kouhizadeh *et al.*, 2019).

Researchers are developing innovative approaches and theories to address the challenges of this emerging phenomenon. Recognizing this evolving theme highlights the importance of vigilance and a proactive stance in emerging research areas to foster their growth and harness their transformative potential (Tozanlı *et al.*, 2020).

3.8.3. Potentials and opportunities

This cluster, representing 24% of the total corpus, focuses on the potential of digital technologies in CSc, highlighting how Industry 4.0 technologies, such as BC and big data, can transform these systems. Most studies explore how data-driven technologies contribute to environmental sustainability (Dwivedi and Paul, 2022), waste management (Jiang *et al.*, 2023), agri-food supply chain management (Yontar, 2023), and related domains. Simultaneously, sustainability has become a central focus, with research exploring how to integrate environmental and social concerns into CSc practices to reduce carbon footprints, minimize waste, and promote social responsibility across the entire network.

Additionally, research in this area addresses technology-driven dynamic capabilities for developing CSc (Quayson *et al.*, 2023), resource loop redesign (Massari *et al.*, 2023), potential enablers (Rejeb *et al.*, 2022), and the prioritization of requirements for technology implementation (Sadeghi *et al.*, 2023). Digitalization is valuable for enhancing green supply chain transparency, supporting eco-design, and guiding strategic initiatives toward environmental sustainability. The literature suggests that integrating technology enables the incorporation of green incentives within industrial CSc networks.

3.8.4. Industrial deployment

The yellow thematic cluster, encompassing 19% of the reviewed articles, centers on the sector-specific implementation of digital technologies across various industries. Significant attention has been given to the integration of Industry 4.0 in sectors such as agriculture and food (Giganti *et al.*, 2024; Kayikci *et al.*, 2022b; Pakseresht *et al.*, 2023; Zhang and Zhai, 2025), marine plastics (Gong *et al.*, 2022), dairy supply chains (Varavallo *et al.*, 2022), pharmaceuticals (Bamakan *et al.*, 2021), and many others. The literature emphasizes that digitalization fosters automation and transparency, particularly in engineering sectors, by reducing transaction costs and enhancing real-time information and material flows. Agrawal *et al.* (2022) further propose digital frameworks to optimize data and goods movement in extended value chains. However, a gap remains, as numerous other industries remain underexplored, highlighting a need for future research to broaden the scope of digital technology applications for more comprehensive sectoral integration.

4. DISCUSSION

Digital technologies have emerged as pivotal in managing CSc, with a noticeable surge in scholarly publications after 2019. This trend coincided with the accelerated adoption of Industry 4.0 technologies during the COVID-19 period, as organizations increasingly implemented digital solutions to maintain operational continuity and supply chain resilience (Kayikci *et al.*, 2022b). However, the present scientometric analysis does not establish a direct causal relationship between the pandemic and publication growth; rather, the observed increase reflects the growing research interest in leveraging digitalization to enhance CSc. As remote working became necessary, organizations increasingly adopted Industry 4.0 technologies to sustain productivity and strengthen supply chain resilience (Basit *et al.*, 2025). The study critically assesses current knowledge and identifies persistent gaps, emphasizing the need to explore further the strategic role of digital solutions in advancing sustainable, circular supply chain practices. The temporal evolution identified in this scientometric analysis reflects the maturation of DC within CSc. Early research primarily focused on enhancing detection capabilities by improving transparency, traceability, and information visibility through BC and IoT. Further recent research increasingly investigates AI, DT, and ML to strengthen grasping capabilities through predictive analytics and operational optimization, while collective digital platforms and Industry 4.0 technologies enable transformative capabilities by enabling smart, circular, and resilient supply chain systems.

The findings reveal that most studies intersect with environmental sciences, engineering, and business management, with digitalization in supply chains emerging as a key focus within the circularity domain. However, a significant need remains to explore digital circular supply chains in underrepresented areas such as social sciences, decision-making, operations, economics, and econometrics. Geographically, China leads in research output, followed closely by the United Kingdom, India, and the United States, indicating strong international interest and opportunities for broader global participation and interdisciplinary engagement.

The keywords used by authors in the reviewed literature largely reflect core concepts central to digitalization-based circular supply chains, with author keywords more specific and index keywords broader. The analysis in Figure 16 shows that approximately 27% of the articles focused on integrated technologies using overarching terms such as “Industry 4.0,” “Logistics 4.0,” and “Digital technologies,” which encompass tools like the IoT, BC, big data, DT, AI, and ML. These general terms are commonly employed to explore the overall potential, strategic implementation, and operational impacts of digital technologies within CSc. While some studies offer comprehensive discussions of multiple technologies, others are more narrowly focused, examining specific tools in detail by analyzing their design structures, enablers, barriers, and applications across various industries, including food, pharmaceuticals, steel, chemicals, electronics, and textiles, within the CE framework. Statistical analysis reveals that blockchain technology has received the most scholarly attention in the context of digitalization in CSc, appearing in approximately 19% of the reviewed studies. This is followed by the IoT at 17%, big data at 15%, AI at 10%, DT at 7%, and ML at 5%. While 27% of articles discussed these technologies in general

terms, BC stood out for its early emergence in 2008 and subsequent evolution into a decentralized, distributed ledger system.

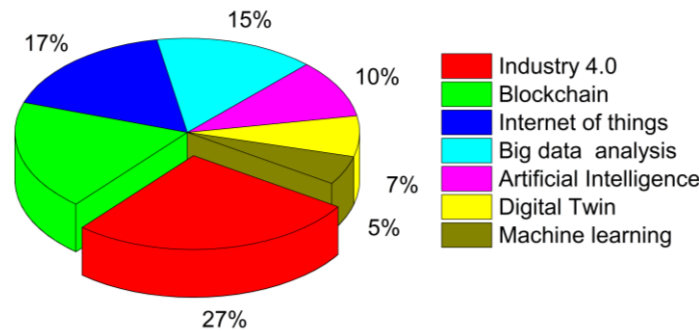


Figure 16. Digital technologies distribution.

Its popularity in CSc stems from its capacity to address critical issues such as transparency, secure data sharing, operational efficiency, traceability, and enhanced collaboration across supply-chain networks. Moreover, BC is increasingly recognized as a foundational technology for improving resilience in CSc, as it promotes data coherence, decentralization, stakeholder trust-building, and collaborative learning (Shoaib *et al.*, 2024). However, its effectiveness depends on integrating supporting technologies, such as IoT and big data systems, that leverage RFID and sensors to enhance transparency and accountability. While substantial research exists on applying IoT and big data in general supply chain and logistics contexts, their role within CE frameworks remains underexplored. Furthermore, emerging technologies such as DT, AI, and ML remain underexplored in Circular Supply Chains, underscoring the need for future research to leverage these technologies for systems optimization, performance measurement, predictive analytics, and operational decision-making within Industrial Engineering. The trend reflects growing interest in testing and deploying these advanced tools to support the transition toward more sustainable, adaptive CSc systems.

Keyword evolution further illustrates the progression of research over time. During 2010–2015, the literature represented the early phase of digital transformation, focusing primarily on BC, linear supply chains, reverse logistics, waste management, resource efficiency, and the foundational concepts of the CE. Between 2016 and 2019, as the Industry 4.0 paradigm emerged rapidly, research expanded substantially into big data analytics, blockchain, sustainability, resilience, circularity, and green supply chain management. This shift reflects the growing adoption of intelligent digital technologies to support systems integration, process optimization, operational efficiency, and data-driven decision-making within CSc, consistent with core Industrial Engineering objectives (Kouhizadeh *et al.*, 2019; Saberi *et al.*, 2019). This period's literature reflects increasing recognition of the transformative impact of digital technologies on supply chain practices. Concurrently, the sustainability discourse focused on embedding environmental and social standards into daily CSc operations, thereby reducing carbon emissions and waste and enhancing overall social responsibility across the supply chain.

From 2020 to 2022, scholarly interest intensified around themes such as platform-based reuse systems, predictive maintenance technology, technology-based CE readiness, life cycle assessment (LCA), and challenges for implementing technologies. The rapid advancement of digital technologies reinvigorated academic interest, particularly in leveraging IoT and big data to enhance supply chain visibility, enable real-time tracking of materials and assets, optimize transportation routes, and improve customer responsiveness (Akbari and Hopkins, 2022). Simultaneously, CE emerged as a sustainable business model by reducing resource consumption and waste through increased reuse, remanufacturing, and recycling. In logistics, attention shifted to optimizing transportation and warehousing to ensure efficient supply chain flows (Gong *et al.*, 2022). Concepts such as closed-loop supply chains, reverse logistics, and their connections to the CE have attracted significant research interest. Recent research (2023–2025) highlights emerging themes such as BC, smart contracts, Industry 4.0, CSc management, green technologies, lithium-ion battery supply chains, smart manufacturing, digital product passports, collaborative ecosystems, standardized CE digital protocols, and scalable digital platforms. These developments reflect a growing emphasis on integrating advanced digital technologies to enhance systems integration, process optimization, performance measurement, operational efficiency, and data-driven decision-making in CSc (Jiang 2024). Furthermore, recent studies increasingly leverage AI, ML, and advanced algorithms to support predictive analytics and intelligent operational management, although their adoption and industrial implementation remain at an early stage (Jensen *et al.*, 2023). Concurrently, CSc has placed greater emphasis on establishing closed-loop systems that promote the continuous reuse, repair, and recycling of products and materials, thereby minimizing waste and environmental impact (Machado and Davim, 2020).

In this domain, most journal articles focus on environmental protection and sustainability, with China contributing the most publications. However, researchers from the UK and India lead in terms of authorship and citation impact. These trends align with findings from citation analyzes, underscoring that Industry 4.0 and digitalization in CSc have become

prominent research priorities. The reviewed literature is categorized into four thematic clusters: Technological Impact, Strategies and Frameworks, Potentials and Opportunities, and Industrial Deployment. Substantial work has been conducted on the first two themes, examining the influence of digital technologies on CSc operations, reverse logistics, and TBL dimensions. Moreover, there remains a notable gap in research addressing the broader potential and domain-specific opportunities of emerging technologies such as DT, ML, and AI within CSc contexts. In addition, the literature indicates that research on digitalization in CSc has primarily focused on a limited number of industries. Figure 17. indicates that most studies have focused on manufacturing (18%), electrical and electronics (13%), automotive (11%), and the textiles industry (10%). Other sectors, such as construction (10%), the food industry (9%), electric vehicle batteries (including lithium-ion, 8%), steel (7%), and plastics (6%), have received moderate attention. In contrast, industries like chemicals (5%) and pharmaceuticals (3%) remain significantly underrepresented. Additionally, several other sectors are only minimally explored, suggesting the need for future research to broaden industrial coverage and fully realize the potential of digital technologies in CSc.

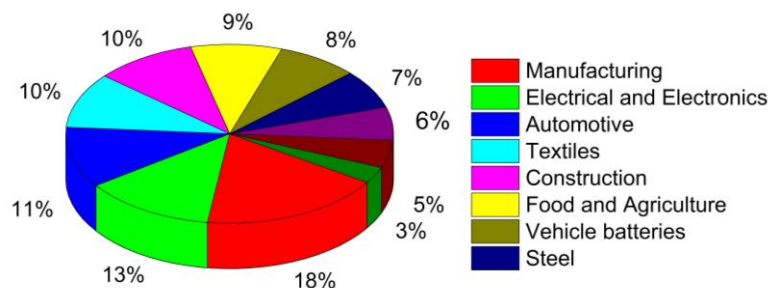


Figure 17. Employed Industries

Regarding research methodologies, qualitative approaches (case study, theory building, and conceptual framework) dominate, accounting for 40% of studies. At the same time, quantitative methods (surveys, statistical models, simulation, LCA, and big data analysis) account for 32%, and mixed or grounded methodologies comprise 28%. This prevalence of qualitative research is mainly due to limited access to proprietary data, as companies adopting digital technologies often withhold information to maintain a competitive advantage (Sadeghi *et al.*, 2023). It is observed that reliance on a single methodology may limit the research findings. Given the complexity of the topic, integrating quantitative and mixed methods would provide a more thorough understanding by investigating the research problem from multiple perspectives. To enhance operational improvements and facilitate more robust quantitative analyzes, it is recommended that organizations share their technology-related CSc data more openly.

5. STUDY IMPLICATIONS

This paper presents a scientometric analysis that combines theoretical and visual literature surveys on digitalization in circular supply chain management. It is a valuable resource for researchers and industry practitioners as it enhances domain knowledge and identifies research gaps. Specifically, the study offers crucial insights for scholars, practitioners, and policymakers seeking to understand the evolving landscape of digitalization within the CSc literature.

5.1. Theoretical Implications

This research reviews the current state of digitalization in CSc to establish the scope, limitations, trends, and advancements related to digital technologies in this context. The study identifies key subject areas, influential publications, leading scholars, geographic hotspots, organizations, and journals using approaches such as keyword analysis, bibliographic coupling, citation analysis, co-authorship, and co-citation. This study assesses the potential of digitalization to advance CE practices through real-time monitoring, data analytics, and customer engagement.

Moreover, this study also covers Dynamic Capabilities Theory by explaining how the digital technology evolution starts with the introduction of BC and IoT for traceability, transparency, and real-time monitoring, and is progressively followed by more advanced, smart and data-driven technologies, including AI, ML and DT, by following the detection, grasping, and converting capabilities in CSc.

It also highlights key opportunities to apply technology to reduce waste, improve resource efficiency, and increase material recycling. Subsequently, companies improve their ability to modify and transform operations, thereby increasing resilience, operational efficiency, and circular value creation within industrial engineering systems. The findings offer supply chain researchers guidance on addressing challenges related to digital technology adoption. The thematic analysis synthesizes existing literature and highlights opportunities for further contributions within industrial engineering systems.

Additionally, widespread knowledge sharing within organizations is essential to promote circular practices, such as waste reduction, recycling, and material recovery, across departments and teams. The study highlights the need to explore greater adoption of digital technologies in CSc, given their potential to enhance transparency, traceability, and efficiency. Industry managers and practitioners can leverage these insights to mitigate risks associated with integrating technological capabilities in CSc, thereby advancing sustainable development goals. The study outlines key methodologies employed in the field, facilitating a comparative analysis between past and current research approaches. This aids decision-makers in selecting the most effective future methodology techniques. Industry-specific discussions enable practitioners and managers to adopt digital technologies more effectively within their respective sectors.

5.2. Practical Implications

Digital technologies enable industrial managers to align CE principles with organizational strategies by shifting from a linear model to product and process designs that promote extended use, waste reduction, and material recovery. Process analysis plays a critical role in this transition, enabling managers to assess existing processes, procedures, and resource management to identify opportunities for waste reduction, resource optimization, and the integration of other CE practices into operations. This study also provides practical guidance for industrial engineering practitioners by identifying innovation and digitalization as key enablers for advancing CE practices through process optimization, resource efficiency, and data-driven operational improvements across diverse industrial sectors. Collaboration among design teams, functional departments, supply chain researchers, engineers, and research centers is essential to identify novel materials, technologies, and partnerships required to implement circular practices. Fostering interdisciplinary collaboration among product circular design, supply chain management, and other stakeholders is crucial for developing goods inherently aligned with circularity. Effective networking and coordination underpin the integration of sustainable practices across CSc. Strategic adoption of technological enablers, such as electric vehicles for distribution, data analytics for route optimization, and digital tools to enhance traceability and transparency, requires organized decision-making and investment. This study also has practical implications in industry-based applications of digital technologies in CSc. For example, Mezquita *et al.* (2023) implemented BC, IoT, and DT in the pharmaceutical supply chain and reported that these technologies can improve traceability, regulatory compliance, and operational visibility. In the waste management sector, Castiglione *et al.* (2023) illustrated that integrating BC, AI, and IoT can improve waste sorting, recycling, and resource recovery through smart, data-driven decision-making. Similarly, Shoaib *et al.* (2025b) examined the potential of BC to facilitate circular practices in the toxic-material supply chain. These industry-specific examples demonstrate that digital technologies have moved beyond conceptual discussions. These applications provide valuable insights for industrial engineering practitioners on adopting these technologies to optimize processes, improve resource efficiency, strengthen circularity principles, and enhance decision-making across diverse industrial contexts. Additionally, consumer engagement plays a vital role; fostering new sustainable behaviors requires targeted communication and marketing strategies to educate stakeholders about emerging eco-friendly options.

6. CONCLUSION AND FUTURE RECOMMENDATIONS

Scientometric research in technological CSc has shifted toward a multifaceted paradigm emphasizing sustainability and digital resilience. This paper presents a comprehensive review of 628 articles published from 2010 to 2025, integrating digitalization, the circular economy, and supply chain management, and employing scientometric methods to analyze academic output, including publication trends, subject domains, influential authors, key documents, journals, and leading countries. The results showed that the gradual rise in publications indicates that researchers are primarily focusing on implementing digitalization in the supply chain in line with the circularity principle. The thematic analysis results indicate that much work has been done in four main clusters: technological influence, strategic and resilience; opportunities and innovation potential; and industrial deployment, offering valuable insights for both scholars and practitioners. The study also applied the Dynamic Capabilities Theory by demonstrating the evolution of digital technologies in CSc from BC and IoT for traceability and transparency to AI, ML, and DT for smart and efficient data-driven decision-making. The study has implications for the pharmaceutical, chemical, waste supply chain, and other manufacturing industries.

To our knowledge, this study represents the most extensive literature review in the field, combining theoretical, bibliometric, visual, and thematic analyzes to identify critical research gaps and guide future investigations. However, the study acknowledges limitations related to database selection, article inclusion criteria, data screening and visualization techniques, and the scope of industries and themes covered.

This paper critically evaluates the current research landscape surrounding digitalization in CSc and identifies key research gaps to guide future inquiry.

1. Subject areas such as environmental sciences, engineering, and business management dominate the discourse; there is a need to explore the role of digital technologies in decision-making and operational contexts under circularity principles.

2. A marked surge in scholarly output is linked to the accelerated adoption of Industry 4.0 technologies such as BC, IoT, AI, ML, and DT; however, the literature remains heavily skewed toward BC and IoT, warranting further investigation of underexplored technologies.
3. Industry-specific research has primarily focused on manufacturing, electronics, automobiles, and food sectors, leaving gaps in areas such as plastics, steel, pharmaceuticals, and the chemical industry.
4. Additionally, financial constraints limit digital adoption in CSc, underscoring the need for research into cost-effective, scalable solutions tailored to diverse industrial contexts. Future research may explore industry-specific actions to leverage Industry 4.0 platforms and improve operational effectiveness and decision-making within a circular model.
5. Although IoT and cloud technologies are recognized as integral to CSc performance, a deeper analysis of their integration with CE principles and the co-evolution of CE and Industry 4.0 is necessary to refine conceptual models for future research.
6. Furthermore, performance evaluation frameworks remain underdeveloped, and 40% of current studies rely on qualitative methods; there is a pressing need for more rigorous quantitative research approaches in this domain.

Collectively, this study's findings and proposed research directions are expected to catalyze advancing scholarly exploration of digitalization-enabled circular supply chains. Moreover, the study offers practical guidance to reverse logistics practitioners and industrial engineers by promoting operational strategies that are more resilient and efficient, aligned with CE principles. Future research should empirically study how these digital technologies, when combined, contribute to DCT by focusing on detecting, grabbing, and transforming capabilities, and on the influence of dynamic capabilities on CSc performance.

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