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Bridging the gap: a systematic analysis of circular economy, supply chain management, and digitization for sustainability and resilience

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Abstract
The primary objective of this research paper is to conduct a comprehensive and systematic literature review (SLR) focusing on Sustainable Supply Chain Management (SSCM) practices that promote Circular Economy (CE), sustainability, and resilience through adopting emerging digital technologies. A SLR of 130 research articles published between 1991 and 2023 was used to analyze emerging trends in CE, supply chain management (SCM), and digitalization. This study meticulously examined research publication patterns, the intricate themes explored, influential scholars, leading countries, and substantial scientific contributions that have shaped this multifaceted domain. This paper contributed to the collective understanding of how SSCM practices, driven by the principles of CE and empowered by the adoption of digital technologies, foster sustainability, resilience, and innovation within contemporary SCs. The research findings presented herein are primarily based on an analysis of the current literature from only Scopus and Web of Science (WoS) databases, which may restrict the generalizability of implementing these results. Based on this study, organizations and practitioners can assess the maturity of their SCM practices, gauge the resilience and digitalization levels of their SCs, and align them with academic literature trends. This enables practitioners to bridge the gap between scholarly advancements and real-world SCM implementation. Through its systematic review, the study provides a structured literature review that offers a collective understanding of SSCM practices driven by CE principles and empowered by digital technologies. This understanding enables sustainability, resilience, and innovation within contemporary SCs, benefiting academicians and practitioners.

Keywords Sustainable supply chain management · Circular economy · Supply chain sustainability · Supply chain digitalization · Research trends

1 Introduction

In recent decades, sustainable supply chain management (SSCM) has emerged as a major area that has garnered substantial global interest. This increased focus on sustainability is driven by various external factors, including institutional regulations, market competition, and stakeholder demands (Lu et al. 2018; Morali and Searcy 2013). Sustainability is no longer restricted to a company's internal operations; it is now integrated into critical business activities in supply chain management (SCM) (Pagell and Wu 2009). Most importantly, the increased frequency of low-probability and high-impact risks over the past decade (Wildfires, flooding, etc.) has also brought supply chain (SC) sustainability and resilience under the spotlight. The timely identification of these risks by leveraging digital technologies can lead to resilient and sustainable SC that can effectively respond to disruptions and maintain uninterrupted operations. Carter and Rogers (2008) introduced the concept of SSCM, which involves transparently integrating and attaining an organization's social, environmental and economic objectives through coordinated management of internal and external business processes, with primary objective as to enhance

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an organization's long-run economic performance and its network of suppliers (Carter and Rogers 2008). Applying SSCM principles can have several advantages, such as reducing waste, promoting sustainability, improving financial performance etc. (Golicic and Smith 2013; Kähkönen et al. 2018).

The CE introduces a fresh perspective on producing and consuming goods systematically, emphasizing the principles of recycling, reuse, and remanufacturing (Ellen MacArthur Foundation 2013). The transition to a CE model for SCs has become a strategic goal for companies all over the globe. It encourages a comprehensive integration of sustainability into organizational strategies, generating shared benefits for society. This contrasts with the prevailing linear economic model of "take-make-dispose," which poses significant challenges to sustainable development. CE advocates for sustainable production and consumption practices, emphasizing the reuse of materials and products along with the adoption of renewable resources (Alamelu et al. 2023; Cerqueira-Streit et al. 2021). Scholars argue that achieving a successful CE transformation requires the integration of advanced emerging digital technologies to revamp SCs through data-driven decision-making (Chauhan and Singh 2019; Ingemarsdotter et al. 2019).

By combining technologies, such as harnessing artificial intelligence (AI), machine learning (ML), cloud computing, big-data, and real-time information from Internet of Things (IoT) devices, organizations can gain deeper insights into product lifecycles, consumer behavior, and market trends. This helps them to make informed and sustainable choices, supporting the smooth adoption of CE practices across the SC (Fisher et al. 2018; Ingemarsdotter et al. 2019; Karmaker et al. 2023). This information enables more accurate demand forecasting, efficient inventory management, and better product design for recyclability. SC digitalization catalyzes CE and sustainable SC initiatives (Luthra and Mangla 2018). Emerging digital technologies enable the optimization of logistics routes, tracking and tracing of products, improved inventory management, and facilitates data-driven decision making along with Industry 4.0, owing to the implementation of emerging digital technologies (Tortorella et al. 2022). In practice, digital technologies are expected to result in improvements in industrial and supply chain processes processes ranging from product design and manufacture to distribution, culminating in the growth of smart factories. For example, Sheep Inc. uses blockchain to track organic wool's entire SC. Each product has a unique digital identifier for customers to scan and access details on material sources, production processes, and sustainability certifications, fostering customers' trust and informed choices.

In the domain of SCM, the significance of digitization is crucial, particularly in shaping planning, production, control, and logistics functions. Industry 4.0's characteristic scenario revolves around self-organizing factories, where products navigate autonomously through the production process, sharing information with machinery depending on client needs (Branke et al. 2016). This allows the manufacturing system to make more informed decisions and promotes collaboration throughout the SC (Alamelu et al. 2023; Branke et al. 2016). Industry 4.0 facilitates instantaneous consumption data analysis, empowers demand-driven and adaptable product retrieval and distribution, and optimizes logistical processes (Hofmann and Rüsch 2017). Furthermore, Lopes de Sousa Jabbour et al. (2018) and Stock and Seliger (2016), emphasize for Industry 4.0 has the potential to result in more effective resource usage, reduced resource consumption, and increased output. In practice, notable manufacturing entities like Caterpillar and Renault have already embraced the tenets of Industry 4.0, effectively amplified their SC efficacy while concurrently mitigated superfluous wastage. This embracement of technological innovation by industry exemplifies tangible advantages, compellingly demonstrating the pragmatic gains attainable through such progressive adoptions.

Existing literature has explored the individual connections between CE and SCM (Ghisellini et al. 2016; Govindan and Hasanagic 2018), CE and Industry 4.0 (Lopes de Sousa Jabbour et al. 2018) alongside research on integrating Industry 4.0 with CE (Ellen MacArthur Foundation 2017). Despite this exploration, there is still a lack of comprehensive studies examining the interconnection and integration of all four themes within the broader SCM field, i.e., CE, SSCM, and SC Digitalization. Recognizing this research gap, the current study emphasizes the need for additional studies exploring the interrelationships among these components. This study calls for increased awareness of the advantages of CE, encouraging scholars focusing on SCM issues and the wider research community to contribute to addressing this research gap. Studying the interconnections between CE, SCM, and SSCM is crucial for achieving sustainable development goals, reducing environmental impact, ensuring economic viability, and meeting the growing expectations of socially responsible business practices. Thus, this research paper contributed to knowledge by.

(i) Innovatively combining these four constructs—CE, Sustainable SCs, SC Resilience, and Digitalization—to analyze their connections.
(ii) Substantially contributing to the academic literature by addressing three primary research objectives related to CE, SCM, and SC digitalization. Firstly, it examines annual publication trends and identifies influential journals, providing insights into the dynamic development of research in these fields. Secondly, it spotlights leading nations in research output, offering a global perspective on their influence in shaping research agendas. Lastly, it reveals

current and emerging research themes, establishing connections to industry needs and challenges, thus guiding future directions.

Researchers used the following assumptions to guide their research:

Assumption 1 - The annual publication trends in CE, SCM, and SC digitization indicate the research emphasis and evolving interests within these domains.
Assumption 2 - The current and emerging research themes and trends in CE, SCM, and SC Digitalization reflect evolving industry needs and challenges.
Assumption 3 - Mapping the bibliometric profile of the theme through yearly publication trends and productive journals provides a comprehensive understanding of the research landscape in CE, SCM, and SC Digitalization.

The further paper is structured as follows. Section 2 explores the connection between CE, SCs sustainability, digitization, and SC resilience. In Section 3, we outline the systematic literature review (SLR) methodology. Section 4 provides a comprehensive overview of the results, including insights on emerging countries, keyword analysis, geographical distribution, and thematic trends. Section 5 discusses the findings and conclusions addressing the research questions and objectives. Finally, in Sect. 6, we highlight the key implications of our study and suggest directions for future research.

2 Literature review

2.1 Circular economy (CE)

The CE emerges as both an economic model and a conceptual framework, aspiring to promote sustainability and combat waste by dismantling the traditional linear "take, make, dispose" approach pervasive in conventional economies (Alamelu et al. 2023). Within the CE paradigm, resources are meticulously preserved in extended usage cycles, and the inherent value of products, materials, and resources is not merely conserved but revitalized upon reaching the culmination of their life spans. Recent times have witnessed a notable surge in academic fascination encompassing the CE. This amplified attention can be largely attributed to the mounting emphasis placed on sustainable consumption and production practices, which have seeped into both commercial ventures and the fabric of everyday existence (Merli et al. 2018). This evolution has prompted a considerable influx of scholarly inquiries and contributions dedicated to comprehending and enacting strategies for the responsible stewardship of resources (Obeidat et al. 2023). The diverse motivations propelling these scholars to advocate for the CE paradigm span a wide spectrum. Their pursuits traverse the intricate realms of unraveling intricate economic and social processes, as well as evaluating the reverberations of their endeavors on the consumer landscape (Ferasso et al. 2020).

However, transitioning to a CE presents its own set of challenges, particularly in ensuring sufficient capacity for the reuse and recycling of unwanted goods. Industries must critically evaluate their existing practices and resource management approaches to facilitate this transition (Ferasso et al. 2020). For instance, the fashion industry faces significant waste accumulation due to the prevalence of fast fashion. To address this issue, companies are re-evaluating their operations, focusing on waste reduction and strategies to extend product lifespans. Initiatives like take-back schemes, where consumers can return worn clothing for recycling or reuse, have emerged as potential solutions (Talla and McIlwaine 2022). In the electronics sector, rapid technological advancements have contributed to a surge in electronic waste. In response to the growing importance of sustainable practices, businesses are proactively developing disassembly and recycling strategies while also implementing collection initiatives for electronics recycling (Merli et al. 2018). The transition to a CE demands a fundamental shift in the way production and resource consumption are understood across various industries (Ferasso et al. 2020). It requires integrating waste reduction, resource efficiency, and material recovery as integral elements of standard operating practices, thereby challenging the linear approach of prevailing consumption and disposal models. This paradigm shift calls for reorganizing businesses and natural resources to minimize waste, optimize resource utilization, and normalize material recovery. Achieving a shared vision of the CE is essential to unite these stakeholders in developing effective transformation strategies.

2.2 Circular economy (CE) and supply chain management (SCM)

"Sustainable Supply Chain" involves integrating eco-friendly and socially conscious principles and practices across all phases of SC process, spanning from raw material procurement to the final delivery of the end product or service to the end user (Kähkönen et al. 2018; Morali and Searcy 2013). The exploration of CE within SCM presents a complex landscape beyond manufacturing and extends to various business sectors, including financial, information technology, and service industries (Schmidt et al. 2021). The CE and SC are interconnected on multiple fronts. Firstly, raw materials sourcing, processing, and consumption must transform to align with CE principles (Ren et al. 2023). To facilitate this transition, it becomes imperative to adopt sustainable practices, including utilizing renewable resources

as raw materials and minimizing waste generation. Another crucial aspect involves designing products with future recycling and reuse in mind, necessitating collaboration between product design and SC teams (Bag et al. 2020). Distribution and delivery methods must also transform, adopting electric vehicles, optimizing routes, and reducing packaging waste to align with the CE (Bag and Pretorius 2022). By integrating CE principles across the SC, organizations enhance sustainability, curb resource depletion, and foster responsible practices in the broader economic ecosystem. SSCM can positively influence both micro and meso levels of the CE. However, it is important for firms to realize the role of human resources in adopting and implementing circular practices within or across firms. Cerqueira-Streit et al. (2021) validated that integrating CE principles into SC tends to reduce risks and increase resilience. The study by Alamelu et al. (2023) affirms that businesses incorporating SSCM to benefit the environment, society, and economy experience positive outcomes from the CE concept. CE practices serve as a source of value addition, particularly for small businesses. SSCM acts as a mediator between ethical business practices and corporate value, while the CE minimizes the impact of ethics on SSCM. Leveraging Industry 4.0 can streamline collaboration, modular processes, and ongoing monitoring of SC cost and performance through big data and analytics but critical insights for deeper understanding of risks in shifting from a linear to a CE is needed.

2.3 Circular economy (CE) and digitalization

Digitalization catalyze and enhances resource efficiency through real-time monitoring, data analytics, and enhanced customer engagement, yielding notable environmental advantages to achieve the notion of CE (Singh et al. 2023; Talla and McIlwaine 2022). The convergence of digitalization, CE principles, and sustainable business approaches generates a favorable environmental footprint and helps in making supply chains more resilient, when discussing CE (Birkel et al. 2023). It encompasses the exchange of expertise in product development, resource recovery, recycling, and waste management. Research has illustrated that integrating AI/ML and harnessing big data analytics can exert a substantial influence, effectively elongating the operational lifespan of machinery and products by means of judicious maintenance interventions (Yadav et al. 2020). Furthermore, according to Edwin Cheng et al. (2022), big data can tackle uncertainty within SCs by adjusting flexibility levels and responsiveness. This, in turn, leads to an enhancement in CE practices. Adopting CE practices and reducing environmental impact through technology transfer offers significant benefits for companies and governments. Collaborative efforts within global and local SCs have facilitated sustainability improvements, increased profitability, and reduced waste production (Tavera Romero et al. 2021).

Enterprises are now experimenting with blockchain technology in the context of SC applications. This technology promises to intensify transparency, traceability, and operational efficiency across SCs, thereby fostering sustainable practices and overarching enhancements in SCM. Blockchain and IoT as pivotal instruments that propel the CE's progress by adeptly confronting challenges and facilitating the seamless execution of CE practices. Essentially, they emerge as indispensable catalysts, steering the transformation toward a CE paradigm (Chauhan and Singh 2019). Cutting-edge Industry 4.0 and blockchain technologies (Esmaeilian et al. 2020) have the potential to bolster circularity within the construction sector by minimizing waste and streamlining material recycling (Talla and McIlwaine 2022). Moreover, these technologies can contribute to improving SC resilience (Nandi et al. 2021) via deploying specialized tokens. These tokens serve to amplify the visibility of product life cycles, engendering transparency within the SC. By upholding the integrity of data pertaining to upstream and downstream physical flow, blockchain technology effectively mitigates errors, slashes costs, truncates time delays, and facilitates agile responses (Gaur and Gaiha 2020). Moreover, cloud manufacturing presents avenues to cultivate collaboration, facilitate the exchange of knowledge and data, and foster interaction across diverse stakeholders within the SC. This, in turn, engenders flexibility and elevated resource efficiency (Fisher et al. 2018). These cloud-based solutions open doors for effective cooperation and streamlined operations throughout the SC ecosystem. Simultaneously, these advancements enable the creation of machines to replace labor-intensive previously required large workforces. Karmaker et al. (2023) validate that integrating Industry 4.0 technologies significantly and positively influences sustainability performance. Moreover, the effects of Industry 4.0 technologies are moderated by the implementation of green SCM and CE practices, improving sustainable SC performance. The profound significance lies in the seamless amalgamation of CE practices with digital technological solutions, a confluence that promises enduring advantages in fiscal gains and environmental conservation (Edwin Cheng et al. 2022).

2.4 Circular economy (CE) and supply chain resilience

To effectively address disruptions, SCs must proactively cultivate distinct resilience capabilities that complement conventional risk management strategies (Nandi et al. 2021; Pettit et al. 2010). Resilience furnishes SCs with essential capacities to maneuver through disruptions, mitigate vulnerability, and secure long-term viability (Pettit et al. 2010). SC resilience refers to the innate capacity of a SC system to predict and

absorb changes, restoring its previous performance standards after encountering a disruptive event (Hendry et al. 2019). These explanations are rooted in the overarching concept of resilience, which is pervasive in diverse realms such as engineering, ecology, and adaptation (Chari et al. 2022).

The combination of sustainability and resilience principles is shaping the future of SC management, particularly under uncertainty, as researchers strive to strike careful trade-offs between these concepts (El Baz et al. 2022; Jabbarzadeh et al. 2018). This merging of principles holds the potential to create more robust and environmentally responsible SC systems in the face of dynamic and uncertain business environments. SCs are facing growing challenges due to excess inventories and the associated financial burdens, prompting a re-evaluation of strategies and a push for more sustainable practices, such as the CE (Bag et al. 2020). Adopting circular business models within SCs hinges on their ability to cultivate resilience, allowing them to adeptly navigate and respond to the ever-evolving and demanding landscapes (Nandi et al. 2021). Key capabilities, including flexibility, agility, efficiency, visibility, and collaboration (Shin and Park 2021), are instrumental for SC resilience. They empower SCs to respond promptly to market uncertainties, changing customer demands, and disruptive events, ensuring they maintain their adaptability and competitive edge. By enhancing these capabilities, SCs can reduce excess inventories and associated costs and foster a more sustainable and circular approach to their operations. Singh et al. (2023) affirmed that integrating digital twins (DT) directly improves the sustainability of manufacturing operations in the SC. SC resilience and performance play a significant and positive role in enhancing sustainability. Implementing DT technologies significantly reduces inefficiencies, lowers costs, and enhances overall efficiency in the manufacturing SC. Additionally, it enables businesses to understand better and manage the interconnectedness of their processes and SCs.

3 Research methodology

In this study, we have chosen SLR as our research method. This approach entails the comprehensive identification, evaluation, and interpretation of pertinent research materials about a specific research question, subject area, or phenomenon under investigation (Govindan and Hasanagic 2018; Merli et al. 2018). Our principal objective in this study revolves around applying bibliometric and systematic analysis methodology to scrutinize the predominant subjects and themes within the realm encompassing CE, SC resilience, SCM, and digitalization. This method is characterized by its meticulous and transparent techniques, allowing us to conduct an exhaustive and all-encompassing exploration of pertinent studies, thereby diminishing potential biases and errors. Through the SLR with bibliometric analysis, our study aims to offer a comprehensive overview of the existing literature in this domain, providing valuable insights for future research and decision-making within CE and SC-related subjects. This broader perspective aims to maintain economic prosperity while safeguarding ecosystem resilience and life-supporting foundations amidst challenges like climate change and sustainable development (Dentoni et al. 2021). Understanding how CE practices affect corporate, industry, and social-ecological resilience is critical for avoiding suboptimal outcomes and vulnerabilities. Investigating these connections aims to promote sustainable practices that effectively address complex environmental challenges and support long-term resilience in the face of uncertainties.

The initial step in conducting a thorough SLR involves formulating research objectives and questions to provide a clear focus for the study (Govindan and Hasanagic 2018). The following are the research objectives (RO) for this study, formulated based on the assumptions discussed earlier:

- RO1. Mapping the bibliometric profile of the theme by analyzing yearly publication trends and identifying the most productive journals.
- RO2. Uncovering the top nations that hold a prominent role within this research domain.
- RO3. Determining the emergent themes in the research related to CE, SCM, and SC digitalization.

Research objectives (ROs) along with three aligned research questions (RQs):

- RQ1-RO1: What are the annual publication trends in the field of CE, SCM, and SC digitalization, and how have they evolved?
- RQ2-RO1: Which journals have contributed the most to research in CE, SCM, and SC digitalization, and what are the key characteristics of these publications?
- RQ3-RO2: Which countries are leading in terms of research output and influence in CE, SCM, and SC digitalization, and what factors contribute to their prominence?
- RQ4-RO3: What are the current and emerging research themes and trends in CE, SCM, and SC digitalization, and how do they reflect evolving industry needs and challenges?

The second step involves defining the criteria for paper inclusion and exclusion (Table 2; Fig. 1). We performed thorough searches across pertinent databases to ensure the appropriateness and mitigate the inclusion of extraneous literature. For data analysis, we conducted bibliometric analysis and SLR techniques, utilizing data gathered from the

Table 1 The search queries used for extracting articles

Database	Search string
Scopus And WoS	*("circular economy" OR "Sustainable circular economy" OR "Circular economy capability" OR "Circular design" OR "Circular model" OR "Sustainable business model" OR "Triple bottom line") AND TITLE-ABS-KEY ("Supply chain sustainability" OR "Green Supply Chain Management" OR "Digital supply chain" OR "Sustainable Supply Chain" OR "Supply Chain Resilience" OR "circular supply chain" OR "circular supply chain management" OR "Sustainable supply chain management" OR "closed-loop supply chain") AND TITLE-ABS-KEY ("machine learning" OR "Digital technology" OR "Blockchain" OR "big data" OR "Digitalisation" OR "digital technologies" OR "Big data analytics" OR "Blockchain technology" OR "Industry 4.0"))*

Scopus and WoS databases. Bibliometric analysis is a valuable tool for establishing connections and gaining insights within a specific field, finding widespread applications in business and management disciplines to summarize articles, conduct analysis, and stimulate the development of research ideas (Donthu et al. 2020). This approach permits the examination of associations among diverse objectives, such as countries and keywords, enabling the detection of prevalent research themes within the domain (Centobelli et al. 2021). Scopus and WOS databases were selected due to their multidisciplinary coverage and inclusion of high-impact journals on the subject (Chadegani et al. 2013).

Following the database selection, we chose the keywords for conducting the searches. We opted for four distinct sets of keywords: "Circular Economy," "Supply Chain Resilience," "Sustainable Supply Chain," and "Digitization," using the Boolean operator "AND"- "OR" to execute the searches (Table 1). Concerning document classification, our exclusive selection comprised full papers published in English-language journals. This led to excluding review/qualitative papers, chapters, books, editorial materials, letters, and conference proceeding papers (Table 2). These searches were executed and continuously updated until June 2023, encompassing all pertinent articles that had been published. The initial inquiry yielded a cumulative count of 160 articles from Scopus and 125 articles from WoS. Following the removal of 63 duplicates, the total number of records available for screening equaled 222. Then, 80 articles were removed automatically, consisting of 4 from books, 12 from book chapters, one from editorial material, 44 review papers, 18 conference proceedings, and 1 note. After this, 142 articles underwent eligibility assessment, excluding 12 articles, i.e., 10 were considered irrelevant, while 2 lacked a clear methodology. The ultimate count of articles subjected to manuscript review was 130 (Fig. 1). Figure 1 briefly presents the methodological path using the PRISMA flow diagram.

4 4. Results and analysis

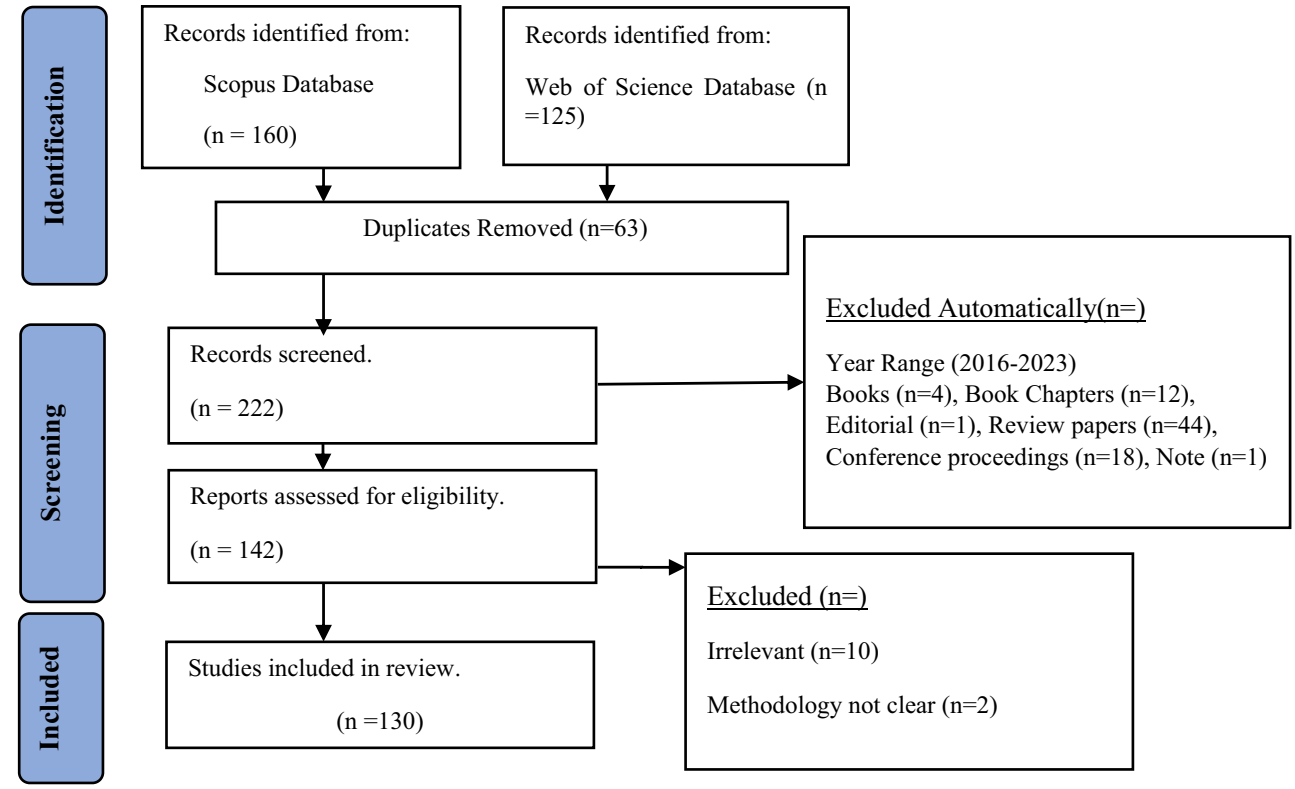
This section presents an extensive examination of the literature concerning CE in relation to SC resilience, SSCM, and digitalization, offering insights into the temporal distribution of publications, the journals, the geographic origins of authors, and the employed research methodologies. This comprehensive analysis aims to provide a comprehensive portrayal of the present status and research trajectories within these domains.

4.1 Keyword analysis

We used the word cloud tool to show the most recent concepts in the article titles and keywords. We employed the Bibliometrix R package to analyze Keyword Plus and selected 130 sources from 2016 to 2023 for investigation. Keyword Plus refers to words or phrases frequently

Table 2 Inclusion-Exclusion criteria

Article selection method	PRISMA guidelines
	1. Year range: 1991–2023
	2. Subject area: All
	3. Language of article: English
	4. Keywords: Only papers focusing on CE, supply chain resilience, supply chain sustainability, big data, and Industry 4.0 in the context of SSCM were selected.
	5. Source type: Journals
	6. Type of Study: Empirical
	7. Methodological quality: Articles that followed the quantitative methodology
Analysis Method	SLR and Bibliometrix



Source: authors' creation (2022)

Fig. 1 PRISMA flow diagram

appearing within the articles. Figure 2; Table 3 present the word cloud growth across the sources during the specified time frame. Significantly, during the period spanning from 2017 to 2021, the investigation of Keyword Plus data unveiled that among the 130 sources, SCM emerged as the dominant theme, succeeded by CE, industry 4.0, sustainable development, and subsequently, SCs.

Figure 3 illustrates the growing trends of CE studies in conjunction with Industry 4.0 and sustainability. The trend topic analysis conducted using the bibliophily R package reveals intriguing insights into the research landscape about CE, sustainability, and SCM. The analysis indicates a notable growth trajectory in CE studies, specifically in conjunction with Industry 4.0

Fig. 2 Word cloud

Table 3 Keyword frequency

Terms	Frequency
supply chain management	42
circular economy	38
industry 4 0	35
sustainable development	31
supply chains	25
sustainability	22
decision making	21
sustainable supply chains	21
big data	19
blockchain	18
data analytics	12
circular supply chain	6
triple bottom line	6
big data analytics	5
digitalization	5

and sustainability between 2021 and 2022. This suggests an increasing emphasis on integrating CE principles with the advancements associated with Industry 4.0 to enhance sustainability across various industries. Furthermore, sustainability emerges as a noteworthy research subject in its standalone capacity and within the framework of SC studies, spanning 2019 to 2021. This underscores the sustained attention to incorporating sustainable practices throughout SC operations. Scholars have likely delved into strategies and models to implement sustainability endeavours and evaluate their effects on SC performance.

In recent years, particularly from 2023 onwards, the research landscape has shifted towards digitalization and the digital SC. This indicates a growing interest in harnessing digital technologies and data-driven approaches to optimize SC processes and improve overall performance. Integrating digitalization into the SC domain is expected to facilitate greater transparency, agility, and efficiency, aligning with the overarching objectives of CE and sustainability. It underscores the increasing recognition of the synergies between Industry 4.0, sustainability, and CE practices.

Furthermore, the rising significance of digitalization in driving SC optimization and resilience to support sustainable development is evident.

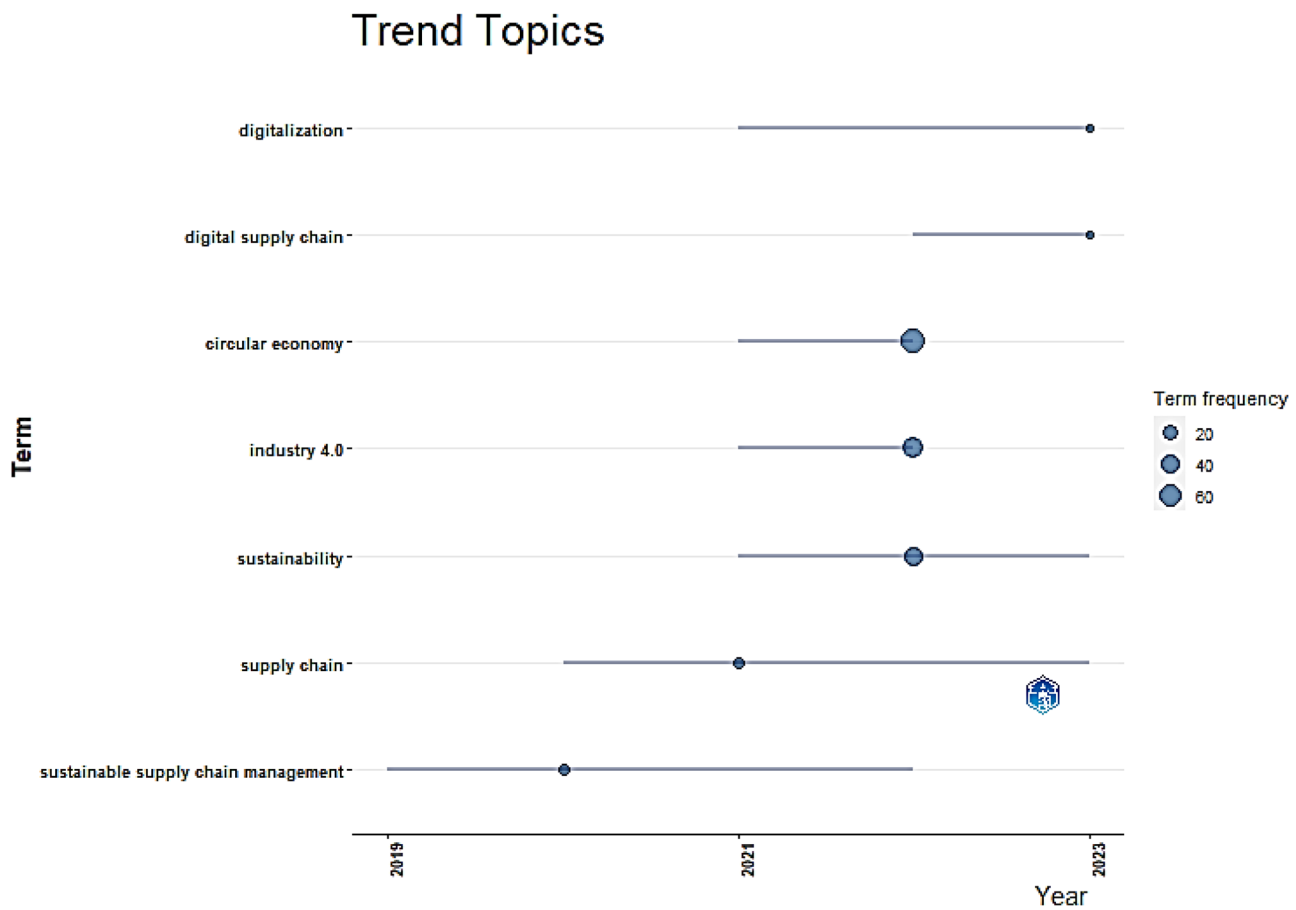


Fig. 3 Trending research topics

4.2 Keyword co-occurrence

The analysis of keyword co-occurrences provides a comprehensive approach to visualizing and understanding the underlying knowledge structure within a specific domain (Fig. 4). This study constructed a three-dimensional network based on the co-occurrence of keywords, resulting in a detailed knowledge map that enables a multi-dimensional visualization of the knowledge structure derived from a diverse set of journal papers. The analysis revealed that among 939 keywords, 74 met the minimum threshold of appearing at least four times in each article. These 74 keywords were analyzed for their co-occurrence patterns and the strength of their connections with other sources. The resulting visualization, presented in Fig. 4, provides insights into the relationships between keywords, with more prominent words indicating higher occurrence density. Furthermore, the proximity of keywords in the visualization represents their robust clustering based on keyword references and the strength of the links observed in Scopus and WoS. The figure below marks the presence of four distinct thematic clusters, each characterized by a specific group of keywords from the identified 74 keywords.

The first theme, represented by the red clusters, centers around the concept of CE, encompassing circular SC, triple bottom line, closed-loop SC, SCM, SC resilience, green SC, environmental management, small and medium-sized enterprises, and SC resilience. These keywords strongly emphasize sustainable practices and circularity within the SC context. The second theme, denoted by the green clusters, highlights the significance of data analytics and technological advancements. This cluster is centred around keywords such as artificial intelligence, technology development, digital SC, machine learning, Industry 4.0, IoT, economic aspects, and digitalization. These keywords suggest leveraging advanced technologies for optimizing SC processes and decision-making.

The purple-colored cluster, constituting the third theme, emphasizes sustainability-related aspects. It includes keywords such as environmental management, energy, performance, blockchain, blockchain technology, and digitalization. These keywords indicate a strong connection between sustainability, environmental considerations, and adopting innovative technologies in SC practices. The fourth theme, represented by the yellow cluster, revolves around keywords related to the broader field of SCM. This cluster includes

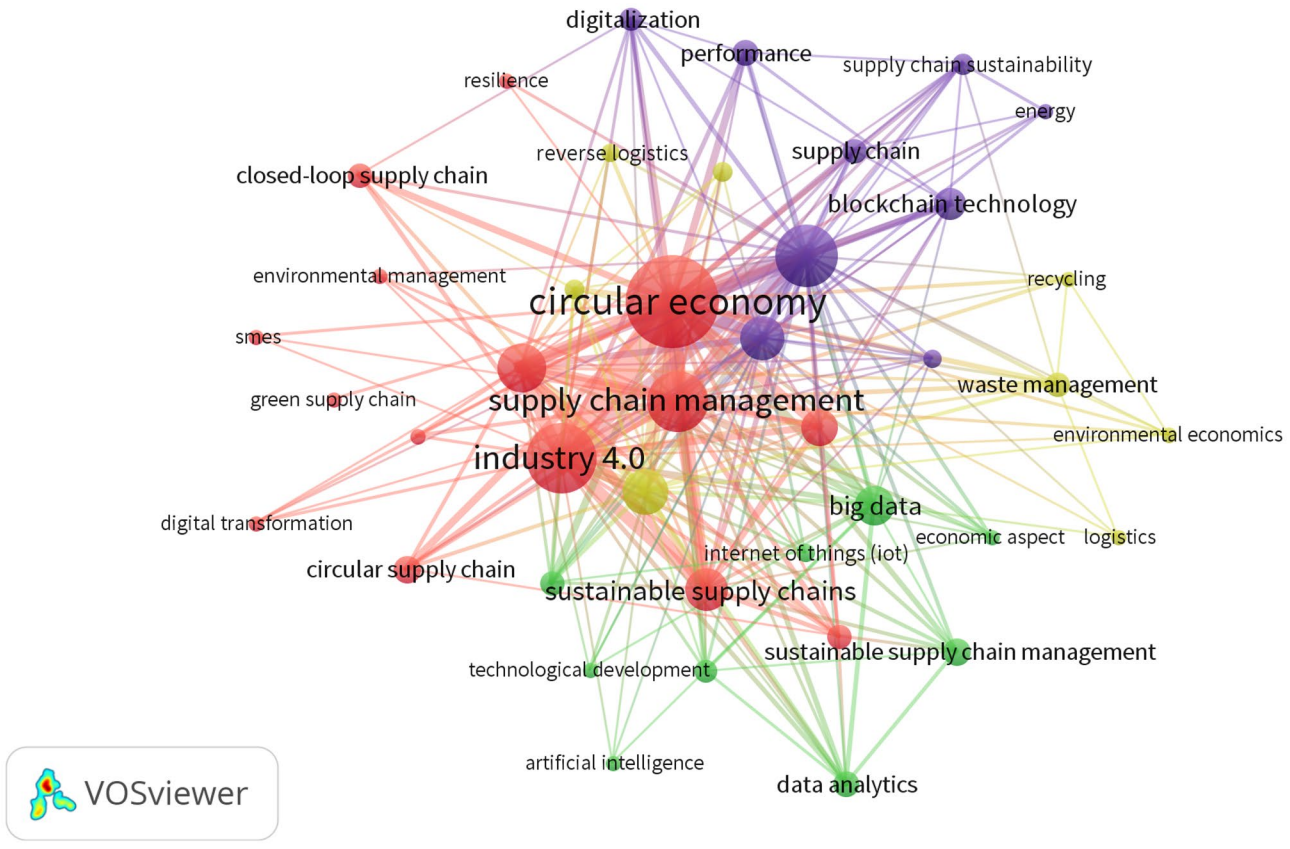
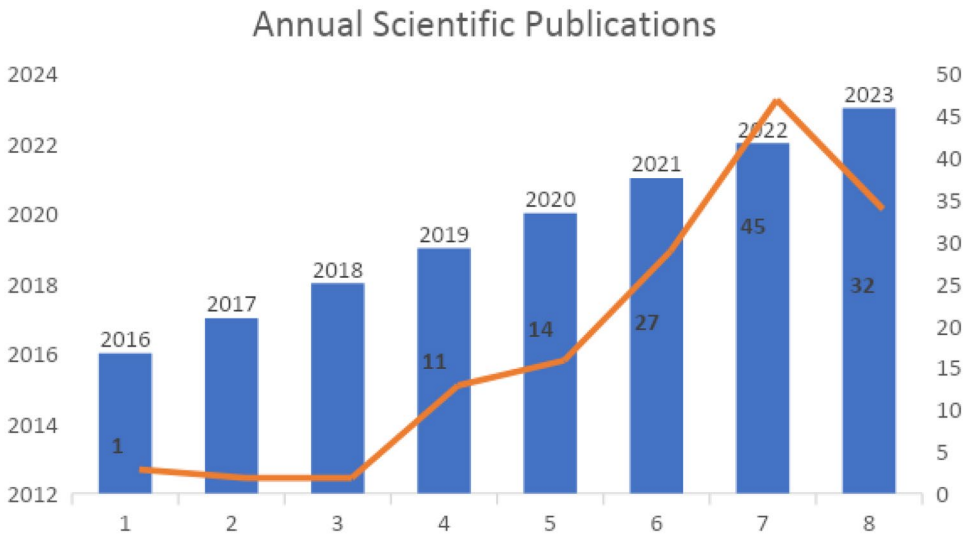


Fig. 4 Keyword Co-occurrence

Fig. 5 Evolution of publications



keywords such as circular SC, life cycle, logistics, reverse logistics, recycling, waste management, and environmental economics. These keywords highlight the importance of holistic SC approaches, including managing resource flows, optimizing logistics operations, and minimizing environmental impacts.

4.3 Evolution of the number of publications

Figure 5 shows no evidence of conceptual/construct-based collaborative research on CE, SCM, or big data discovered between 2016 and 2018. The first assumption is supported by Fig. 5 analysis, which shows a significant rise in publications on this topic since 2019, which might be attributed to the faster evolution of emerging digital technologies and the adoption rate. Technologies like IoT, RFIDs, sensor networks, etc., promote inter and intra-organizational connectivity, creating a need to rethink SC models to incorporate data-driven decision-making through big data analytics and non-linear SCM models based on CE (Graham and Hardaker 2000). Based on the analysis of publication distribution over the years, Fig. 5 indicates small variations until 2018. However, since 2019, there has been a considerable increase in publications on CE and big data/digitalization themes for SSCM. It is anticipated that the number of publications in 2021 surpassed those of 2019 and 2020 for several reasons.

However, starting in 2019, a significant upsurge in the volume of publications focused on the themes of CE and the convergence of big data and digitalization within the realm of SSCM has been evident. It is foreseen that the quantity of published works in 2021 is poised to surpass those of 2019 and 2020, driven by multiple underlying factors. Primarily, the global outbreak of the COVID-19 pandemic has precipitated a widespread adoption of various Industry 4.0 technologies across diverse sectors. The imperative to curtail COVID-19 transmission compelled individuals to work remotely, prompting companies to seek technological solutions to uphold productivity and bolster SC resilience. Secondly, research endeavors in sustainable SCM are predicted to expand in response to numerous governments' commitments towards achieving carbon dioxide (CO2) emission peaks by 2030 and attaining CO2 neutrality by 2060. The ambitious climate targets have catalyzed heightened interest and investigation into sustainable practices, encompassing CE principles and the digitization of SC processes.

4.4 Articles by journal

In 2023, the research on CE, SCM, and SC digitalization was published in 62 journals. Among these journals, sixteen have contributed significantly, publishing more than three articles on our research theme. Notably, the "Journal of Cleaner Production" has published the highest number of articles (11). Following closely are "Computers and Industrial Engineering" (7 articles), "Operations Management Research" (6 articles), "Production Planning and Control" (6 articles), "Business Strategy and the Environment" (5 articles), and the "International Journal of Production Research" (5 articles) (Table 4).

4.5 Country co-citation

Our analysis of the geographical distribution of research based on authors' affiliations reveals the involvement of 123 countries across 130 research documents. By examining the countries to which authors are affiliated, we can identify the key contributors to the field. The United Kingdom (UK) is the most prominent country, with 31 articles authored by researchers affiliated with UK institutions. Following closely are India with 22 articles and China with 20 articles,

Table 4 Top ten contributing journals

Sources	Articles
Journal of Cleaner Production	11
Computers and Industrial Engineering	7
Operations Management Research	6
Production Planning and Control	6
Business Strategy and the Environment	5
International Journal of Production Research	5
Journal of Enterprise Information Management	5
Resources, Conservation, and Recycling	5
Sustainability (Switzerland)	5
Technological Forecasting and Social Change	5

indicating significant research activity in these regions. Italy and France also make noteworthy contributions with 14 and 13 documents, respectively, while the United States (US) closely follows with 10 documents (Table 5).

In terms of collaborative efforts between countries, the UK demonstrates the highest level of engagement, particularly in partnerships with India, Turkey, China, and France. Collaboration between the UK and India is the most prevalent, highlighting a strong research relationship between these two nations. Additionally, collaborations between the UK and Turkey, the UK and China, and the UK and France signify active knowledge-sharing and joint research endeavors. Moreover, we observe an emerging collaboration between India and France, indicating a growing research partnership. This suggests a mutual interest in fostering international collaboration and exchanging expertise to address research topics within this field. The observed collaborations between nations underscore the importance of cross-border cooperation in advancing research and promoting knowledge dissemination on a global scale (Fig. 6).

Table 5 Top ten countries/ Geographical distribution

Country	Documents	Citations	Total Link Strength
United Kingdom	31	906	6693
India	22	842	4569
China	20	474	2954
Italy	14	395	1306
France	13	364	3221
United States	10	644	1254
Turkey	9	83	2066
Australia	8	278	1723
Brazil	6	225	975
Morocco	6	153	1349

4.6 Thematic evolution

Figure 7 shows the thematic evolution of research areas from 2016 to 2023, reflecting SCM's dynamic and progressive nature and its intersection with emerging technologies and sustainability practices. From 2016 to 2019, based on publications included in this analysis, three main themes were big data, sustainability, and SCM. This era shows a growing recognition of the potential of big data in revolutionizing SC operations. Researchers primarily explored how data-driven insights could enhance decision-making processes, optimize inventory management, improve demand forecasting, and streamline logistics operations. The sustainability aspect delved into incorporating environmental and social considerations into SC practices, aiming to minimize carbon emissions, reduce waste, and enhance social responsibility across the SC network.

Moving into 2020 to 2022, the research areas expanded to encompass SCM, the internet, big data analytics, CE, and logistics. As digital technologies have progressed swiftly, the emphasis has transitioned to utilizing the internet and tapping into the potential of big data analytics. Researchers explored how integrating these technologies could enhance SC visibility, enable real-time monitoring of inventory and assets, optimize transportation routes, and improve customer responsiveness. The CE gained significant attention as a sustainable business model, aiming to minimize resource consumption and waste generation by promoting the reuse, remanufacturing, and recycling of products and materials. The logistics aspect emphasized efficiently managing transportation and warehousing operations to ensure seamless SC flows. Examining concepts such as closed-loop SCs (CLSC) and reverse logistics associated with the CE has constituted a significant area of scholarly investigation (Centobelli et al. 2021).

Further, in 2023, the research areas continued to evolve, incorporating big data analytics, industry 4.0, circular SCM, innovation, SCM, economy, and impact. Big data analytics have become increasingly sophisticated, focusing on advanced algorithms, ML, and AI techniques to derive valuable insights from vast data. Industry 4.0 emerged as a prominent research area, integrating cyber-physical systems, cloud computing, IoT, and automation technologies within processes. Circular SCM has garnered increased attention, striving to establish closed-loop systems where products, components, and materials undergo perpetual reuse, repair, or recycling processes to mitigate waste and reduce environmental repercussions. Innovation became crucial, exploring novel approaches such as digital platforms, blockchain, and smart contracts to enhance SC collaboration, traceability, and efficiency. The research also delved into these evolving practices' economic and societal impact, examining the implications for businesses, stakeholders, and the overall

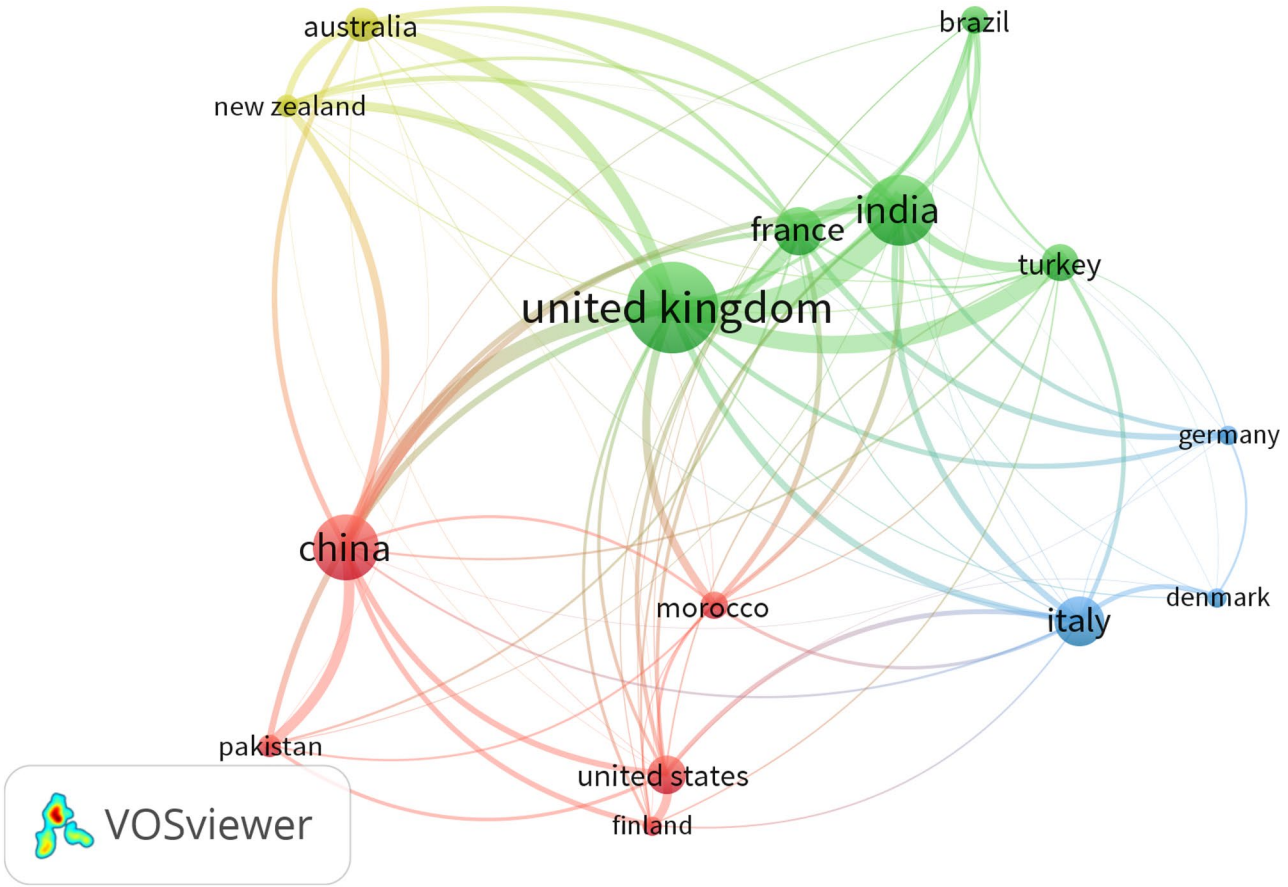


Fig. 6 Country co-occurrences

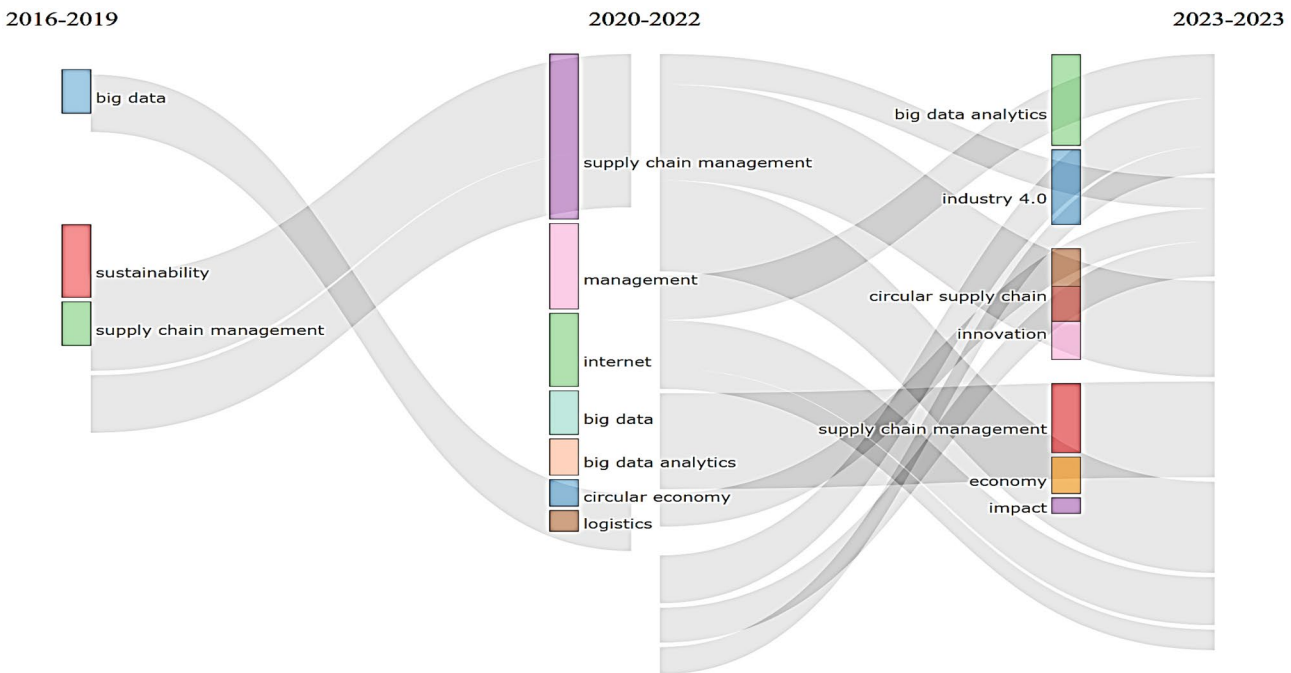


Fig. 7 Thematic evolution

economy regarding productivity, competitive positioning, and enduring sustainability.

Figure 8 illustrates the alignment of development and relevance within the Keyword Plus framework, categorizing the pertinent studies into four distinct quadrants, each contextualized with the others. The top left quadrant marks the presence of a niche theme, which signifies the existence of specialized research areas that have garnered attention but have yet to gain widespread recognition. It indicates that while similar research is being conducted, they are not yet significant enough to establish a niche. This theme reflects the pursuit of understanding the triple bottom line: digitalization, dynamic capabilities, sustainable SC, and artificial intelligence. It suggests that certain researchers are exploring unique aspects and pushing the boundaries of knowledge in these specific domains. Identifying a niche theme highlights the importance of fostering these specialized research areas and promoting interdisciplinary collaboration to enhance their growth and impact.

Themes in the upper right quadrant are classified as well-developed and significant to the research areas. The emergence of a motor theme indicates a powerful and influential area of research shaping the field's discourse and direction. Within the motor theme, the focus lies on digital SC, agility, and SC resilience. The motor theme reflects the momentum and dynamism within these research areas, showcasing ongoing advancements, innovative practices, and a drive toward excellence. Researchers should closely monitor and actively contribute to the motor theme to stay at the forefront of knowledge and contribute to the continuous progress of the field. Identifying basic themes in the bottom right quadrant highlights the enduring foundations and pillars of the research field. These themes encompass CE, blockchain technology, SCM, sustainability, SCs, industry 4.0, and closed loop SCs. They represent fundamental concepts and areas of study that have stood the test of time and continue to shape the understanding and development of the field. Basic themes reflect the core principles and established practices that serve as guiding principles. It is essential to strongly emphasize these basic themes while exploring innovative avenues to ensure a balanced and holistic approach to research and practice.

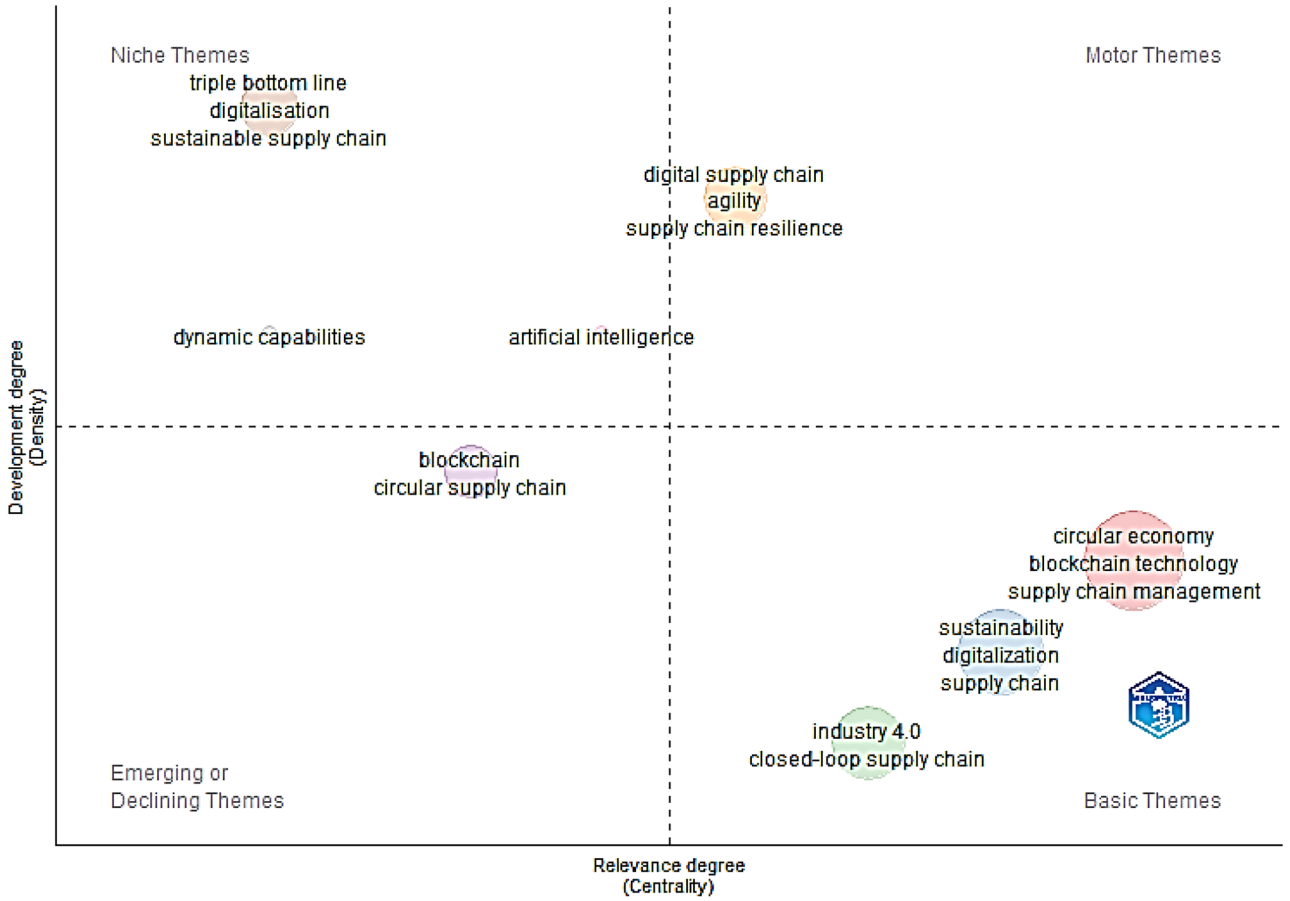


Fig. 8 Results from analysis of the degree of development v/s degree of relevance quadrant

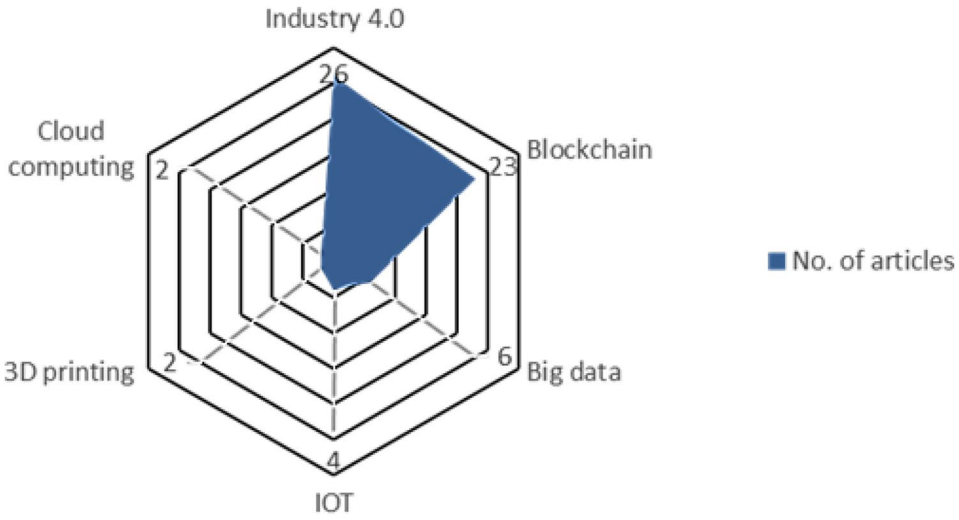


Fig. 9 Prominent digitalization technologies

The bottom left quadrant signifies the presence of an emerging theme that explains the exploration of novel and cutting-edge research directions within the field. In this case, the emerging theme focuses on the intersection of blockchain and the circular SC. This theme reflects the growing recognition of the potential of blockchain technology in enabling circularity within SCs. It suggests that researchers are exploring innovative solutions and conceptual frameworks to address the challenges and opportunities presented by this emerging trend. Identifying an emerging theme emphasizes the need for continuous monitoring and proactive engagement with nascent research areas to foster their development and capitalize on their transformative potential.

4.7 Digital technologies distribution

The diagram below illustrates the prominent digitalization technologies discussed in relation to CE and SSCM throughout the article. The selected articles were categorized into three distinct groups for analysis: (a) papers that delve into multiple technologies (15 papers), indicating the simultaneous use of several digital technologies within circular SCs; (b) papers that do not specifically address any technology (21 papers). These articles discuss digital technologies without delving into the technical aspects; finally, (c) papers focusing on specific Industry 4.0 tools (50 papers). As depicted in Fig. 6, the technology that received the most attention in the literature is Industry 4.0 (26 papers), closely followed by blockchain (23 papers), Big Data Analytics (BDA) (6 papers), and IoT (4 papers). This finding underscores the interest in exploring and utilizing various emerging technologies to advance CE and sustainable SC practices Fig. 9.

The study of the identified articles highlighted themes relating to how SSCM contributes to the CE's goals. Some authors also discussed the concept of a circular SC and the need to redesign SCs to align with CE principles. The table below highlights the authors' focus on digitalization and Industry 4.0, particularly concerning big data, the IoT, and blockchain.

5 Discussion

Considering the emergent nature of digitalization concepts in academic exploration, our objective resides in augmenting the prevailing body of knowledge. Our research presents a deeper theoretical understanding of evolving themes on both micro and macro levels and fosters the development of dynamic capabilities that integrate CE, digital technologies, and Industry 4.0. Moreover, it highlights the interaction of SSCM practices and digitization and encourages continuous improvement. The essence of sustainability and its integration into SSCM hinges significantly upon the presence and accessibility of resources (Dentoni et al. 2021; El Baz et al. 2022). The increasing adoption of data analytics and IoT emerge as quintessential catalysts, substantially enhancing a company's knowledge competency. This transformation paves the way for exhaustive analysis and a heightened comprehension of the intellectualization of extant systems. Based on the detailed review of major latest articles in Table 7 (Appendix), it can be concluded that no single study carried out research that considers all these themes.

Adopting a CE model presents a major challenge as it necessitates a fundamental change in how resources are produced and used across industries. Industries with waste buildup problems require waste reduction and strategic reevaluation. To successfully implement the CE, collaborative attempts are needed to promote a common understanding of the CE and integrate waste reduction, resource efficiency, and material recovery across many sectors.

Table 6 From a detailed literature review, the following managerial implications are presented

Theme	Focus	Managerial Implications
CE	Organizational Strategy	Aligning organizations' strategies with CE principles. This involves transitioning from the linear "take, make, dispose" approach to designing products and processes that prioritize extended usage cycles, waste reduction, and material recovery.
	Process (Operations) Focus	Critical evaluation of current processes, practices, and resource management approaches can identify areas where waste can be minimized, resources can be optimized, and CE practices can be integrated into operations.
	Innovation and Digitization	Organizations can leverage innovation and collaboration across product design, operations optimization, SC network design and optimization, and research teams. This might involve exploring new materials, technologies, and partnerships to enable circular practices.
	Consumer Engagement	Developing strategies to engage consumers in circular practices, such as take-back schemes or product leasing, requires effective communication and marketing.
CE and SSC	End-to-End SC Integration	Integrating CE principles throughout the SC, from raw material sourcing to end product delivery, by collaborating with various departments, suppliers, and partners to ensure all stages align with circular practices.
	Collaboration and Communication	Promoting collaboration between product design, SC, and other relevant teams is crucial to ensuring products are designed for recycling and reuse. Effective communication and coordination are essential to implement sustainable practices across the SC network.
	Technology Adoption	Adopting technologies that support circular practices, such as electric vehicles for distribution, data analytics for route optimization, and blockchain for transparency and traceability. This requires strategic decision-making and investment.
CE and Digitalization	SC digitization	Assessing how digitalization can enhance CE practices, such as real-time monitoring, data analytics, and customer engagement. Identifying opportunities to apply technology in waste reduction, resource efficiency, and material recovery is crucial.
	Technology Transfer	Facilitating the transfer of technological knowledge related to circular practices across the organization, i.e., disseminating expertise in waste reduction, recycling, and material reuse to various departments and teams.
	Emerging Technologies	Exploring the potential of blockchain and IoT technologies to enhance transparency, traceability, and efficiency in circular SCs. This may involve collaborating with technology experts to implement these solutions effectively.
CE and SC Resilience	Resilience Strategies	Building resilience capabilities within SCs to effectively navigate disruptions. Identifying vulnerabilities and developing strategies for flexibility, agility, efficiency, visibility, and collaboration by leveraging digital technologies.
	Balancing Act	Striking a balance between sustainability and resilience principles. They must find ways to align circular practices with resilient strategies, enabling SCs to withstand uncertainties while remaining environmentally responsible.
	Measure and Promote	Continuous monitoring and evaluation of the performance of SC resilience initiatives through IoT devices and emerging technologies. This also involves measuring the effectiveness of implemented strategies and adjusting as needed to ensure both sustainability and operational robustness.

Positively, by encouraging ethical actions and reducing resource depletion, CE principles in SCM improve sustainability. SSCM crucially mediates corporate values and moral business conduct. Leveraging Industry 4.0 may also improve SC cost and performance monitoring, expedite cooperation, and expose associated challenges. The study's findings confirmed our three assumptions. The examination of yearly publishing patterns in the fields of CE, SCM, and SC digitalization revealed that these patterns reflect shifting research interests. Similarly, it was confirmed that the subjects of contemporary research correspond with industry requirements, confirming a close relationship between academic research and real-world applications. The mapping of bibliometric profiles confirmed the validity of the argument through annual publishing trends and prolific journals, which offered a thorough grasp of the research landscape. These validations strengthen the findings by establishing a field of research that recognizes shifts in the industry and strategically builds contributions while keeping an in-depth knowledge of the emerging domains. In the future, we shall

build a sustainable SC resilience framework, considering all the critical factors highlighted in this study, including CE, Closed-loop SC, SCM, and IoT. Blockchain, Industry 4.0, Big Data Analytics and Digitalization Table 6.

6 Conclusion and future research directions

A paradigm change in research focus is reflected in the rapidly evolving fields of CE and SSCM and the integration of big data and digitization. The shifting thematic research landscape illustrates a shift from conventional SCM approaches to an integrated framework with a focus on sustainability and digital resilience. The increasing number of publications since 2019 highlights the growing importance of these related subjects, driven by the rapid advancement of digital technologies like Industry 4.0, RFIDs, sensor networks, and IoTs. This study presents several future research directions. The research findings presented herein are primarily based on an analysis of the current literature, which may restrict the generalizability of the implementation of these results. To make a significant contribution to the growing corpus of knowledge in these transformational areas, it is imperative to delve deeper into the investigation of emergent events and underlying processes in this dynamic environment. The current study findings show that techniques for strengthening SC resilience in the face of continuous disruptions via digital transformation must be investigated. Subsequent studies may focus on industry-specific strategies, leveraging Industry 4.0 technology to enhance operational effectiveness and decision-making procedures in SSCM operations. Future researchers could delve deeper into the co-evolving and reconceptualized process of integrating CE and Industry 4.0 to expand the body of knowledge further. Such investigations can explore emerging contexts and elucidate the underlying mechanisms at play. Further, only Scopus and WoS databases were used to extract relevant articles. Future researchers can explore other relevant databases. It is worth noting that dynamic changes within various regions, industries, and systems may exhibit distinct characteristics and conditions. Further research can explore the applicability of the provided framework in diverse regions, investigating the extent to which it can be implemented or adapted. Additionally, exploring strategies to enhance SC resilience through digital transformation within industries to manage ongoing disruptions in SSCM practice effectively would be a valuable avenue for future research.

Appendix

Table 7 Literature review synthesis: circular economy, SCM, SCM Digitalization

Year	Authors	CE	Closed-loop supply chain	SCM	Internet of Things (IoT)	Blockchain	Industry 4.0	SMES	Big data	Digitalization
2020	Yadav G	✓		✓			✓			
2020	Esmaeilian B	✓		✓		✓	✓			
2020	Sarkis	✓		✓						✓
2020	Kumar S	✓		✓			✓			
2020	Chiappetta Jabbour Cj			✓		✓				
2020	Ozkan-Ozen Yd	✓						✓		
2020	Centobelli P	✓					✓			
2020	Nandi S		✓	✓						
2020	Garrido-Hidalgo		✓						✓	
2021	Mastos Td	✓	✓	✓						
2021	Lu J	✓		✓		✓				
2021	Ivanov D	✓					✓			
2021	Alavi	✓		✓					✓	
2021	Edwin Cheng Tc	✓	✓	✓		✓				
2021	Tsai	✓		✓						✓
2021	Bag S			✓					✓	
2021	Rejeb A			✓						✓
2021	Cwiklicki M			✓					✓	
2021	Taddei E	✓		✓						

Table 7 (continued)

Year	Authors	CE	Closed-loop supply chain	SCM	Internet of Things (IoT)	Blockchain	Industry 4.0	SMES	Big data	Digitalization
2021	Belhadi A	✓		✓		✓	✓			
2021	Ivascu	✓								✓
2021	Choi T-M	✓		✓			✓			
2021	Sun L			✓					✓	✓
2021	Luthra S	✓		✓			✓			
2021	Kusi-Sarpong S	✓		✓						
2021	De Souza	✓		✓						
2021	Kayikci Y	✓					✓			
2022	Gong Y,	✓		✓			✓			✓
2022	Akbari M,	✓							✓	
2022	De Giovanni P	✓		✓						
2022	Tseng M-L	✓		✓				✓		
2022	Zhang A	✓					✓			
2022	Dwivedi,			✓			✓			✓
2022	Sharma R			✓						
2022	Mahroof K	✓	✓				✓			
2022	Anastasiadis,			✓		✓				
2022	Tsolakis N	✓		✓						
2022	Prajapati D			✓		✓				
2022	Elghaish F	✓		✓		✓				
2022	Morella	✓		✓	✓					
2022	Kayikci	✓	✓			✓				
2022	Shang C	✓		✓						✓
2022	Franchina L	✓		✓						✓
2022	Hennemann Hilario Da Silva T	✓				✓	✓			
2022	Cerqueira-Streit	✓			✓	✓				
2022	Munir Ma	✓		✓						
2022	Zhang F	✓		✓			✓			
2022	Liu J	✓		✓						
2022	Mastrocinque E			✓		✓	✓			
2022	Pishdar M			✓		✓				
2022	Azevedo	✓		✓			✓			
2022	Cherrafi A	✓					✓			
2022	Filho Mg,	✓		✓						
2022	Zhou, B.; Siddik, A.B.;	✓	✓				✓	✓		
2022	Zheng, G. W.; Masukujjaman, M.	✓		✓						
2022	Yu Ren, Ran Li, Kuo-Jui Wu, Ming-Lang Tseng			✓		✓				
2022	Arunmozhi M,	✓		✓		✓				
2022	Xie Z,	✓			✓	✓				
2023	Yu Ren, Ran Li, Kuo-Jui Wu, Ming-Lang Tseng	✓		✓			✓			✓

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Data availability Data can be provided upon request.

Declarations

Conflict of interest There are no relevant financial or non-financial competing interests to report.

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